IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

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BEFORE THE PATENT TRIAL AND APPEAL BOARD

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PASCAL TECHNOLOGIES,
Petitioner

v.

CAMBRIDGE ENTERPRISE LIMITED, UNIVERSITAT DE BARCELONA, AND UNIVERSITAT POLITÈCNICA DE CATALUNYA,
Patent Owner

_____

Case No. IPR2024-01235
U.S. Patent No. 11,230,656

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PETITIONER'S MOTION TO SUBMIT SUPPLEMENTAL INFORMATION PURSUANT TO 37 C.F.R. § 42.123(a)

Pursuant to 37 C.F.R. § 42.123(a), Petitioner Pascal Technologies hereby moves to submit proposed exhibit 1025, the attached supplemental declaration by Petitioner's expert, Sylvia Hall-Ellis, Ph.D., as supplemental information.

I. STATEMENT OF MATERIAL FACTS.

1. On August 26, 2024, Petitioner filed a petition for *inter partes* review requesting review of claims 1-3, 6-11, and 14-16 of U.S. Patent No. 11,230,656 (the "'656 Patent"). Paper 1. Petitioner's petition relied on several non-patent prior art references from established technical journals. (Exs. 1006 ("Xie"), 1007 ("Mañosa"), 1009 ("Patel"), 1021 ("Tamarit"), (collectively, the "NPL References)).

2. On December 30, 2024, Patent Owner filed its preliminary response arguing that the petition "fails to present any evidence that the cited [NPL References] constitute printed publications." Paper 6 at 1, 13-19.

3. On March 24, 2025, the Board instituted trial on claims 1-3, 6-11, and 14-16 based in part on the petition establishing a reasonable likelihood that Mañosa, Patel, and Tamarit are printed publications. Paper 8 at 21-24, 35. Specifically, the Board noted that "indicia on the face of a reference, such as printed dates and stamps, are considered as part of the totality of the evidence" and identified numerous indicia evidencing the public availability of Mañosa, Patel, and Tamarit. Paper 8 at 21-24 (citing *Hulu, LLC v. Sound View Innovations, LLC*, IPR2018-01039, Paper 29 at 17-18 (PTAB Dec. 20, 2019) (precedential). The Board also noted the public

availability record of Xie "can be more fully developed" during trial and "Petitioner may move to submit [] evidence through the supplemental information process (37 C.F.R. § 42.23)." Paper 8 at 20-21, n.5.

4. On April 7, 2025, Patent Owner filed a Request for Director Review and objections to the NPL references on the basis of public availability. *See* Paper 10 at 5-10; Paper 11 at 2.

5. On April 21, 2025, Petitioner served on Patent Owner supplemental evidence in the form of the Supplemental Declaration of Sylvia Hall-Ellis, Ph.D. in Support of Petition for Inter Partes Review of U.S. Patent No. 11,230,656 (the "Supplemental Declaration"), which is relevant to claims 1-3, 6-11, and 14-16 of the '656 Patent and addresses public availability of the NPL References.

6. On April 24, 2025, within one month of the date the trial was instituted, Petitioner requested authorization to file this motion.

7. On April 29, 2025, the parties presented their positions during a conference call, where Patent Owner only opposed introduction of the supplemental information prior to resolution of its request for Director review.

8. On May 6, 2025, the Board authorized Petitioner to file this motion.

II. ARGUMENT

Petitioner's motion to submit supplemental information should be granted

because it satisfies the requirements of 37 C.F.R. § 42.123(a),[1] does not change the basis for unpatentability, and will help "secure the just, speedy, and inexpensive resolution" of this proceeding per 37 C.F.R. § 42.1(b).

A party may file a motion to submit supplemental information pursuant to 37 C.F.R. § 42.123(a) if (1) its request for authorization to file the motion was made within one month of the date the trial was instituted and (2) the supplemental information is relevant to a claim for which trial has been instituted.

Here, Petitioner requested authorization to file this motion on April 24, 2025—within one month of the trial institution date on March 24, 2025. *See* ¶¶ 3, 6. And the Supplemental Declaration Petitioner seeks to submit as supplemental information is relevant to claims 1-3, 6-11, and 14-16 of the '656 Patent, on which trial has been instituted, and addresses only the public accessibility of the NPL References. *See* ¶¶ 3, 5; 37 C.F.R. § 42.123(a).

The Board has granted similar motions where the supplemental information,

[1] The Board's order provided authorization under 37 C.F.R. § 42.123(b), but Petitioner's request on April 24 was "within one month of the date the trial is instituted" on March 24, satisfying 37 C.F.R. § 42.123(a). ¶ 3, 6. Section 42.123(a) does not require an explanation of "why the supplemental information reasonably could not have been obtained earlier." 37 C.F.R. § 42.123(a), (b); *see also Inergy Tech., Inc. v. Force Mos Technology Co., Ltd.*, IPR2024-00094, Paper 14 at 5 (PTAB July 19, 2024) ("We further note that § 42.123(a) does not articulate any requirement for a petitioner to explain why information was not provided at the time of its petition."); *Palo Alto Networks, Inc. v. Juniper Networks, Inc.*, IPR2013-00369, Paper 37 at 4 (Feb. 5, 2014) (comparing the requirements under 42.123(a) with those under 42.123(b) and (c)).

as here, addresses the public accessibility of prior art without disturbing the schedule and without changing the grounds of patentability or the evidence relied upon in the petition. *See, e.g.*, *Inergy Tech.*, IPR2024-00094, Paper 14 at 3-6; *Palo Alto*, IPR2013-00369, Paper 37 at 3; *Pac. Mktg. Int'l, LLC v. Ignite USA, LLC*, IPR2014-00561, Paper 23 at 4 (PTAB Dec. 2, 2014). Petitioner carried its initial burden by establishing a reasonable likelihood that Mañosa, Patel, and Tamarit are printed publications, Paper 8 at 21-24, and the Supplemental Declaration corroborates the same for all four NPL references without altering the invalidity analysis.

The Supplemental Declaration is also consistent with existing evidence of record. *See, e.g.*, Paper 8 at 21-24; Paper 1 at 27 (citing Exs. 1007 and 1008), 30 (citing Ex. 1009), 36 (citing Ex. 1021). Petitioner did not submit the supplemental information earlier because it did not foresee Patent Owner's unreasonable arguments and objections regarding public availability. Patent Owner identified both Xie and Patel during prosecution and the '656 Patent *itself* discusses both references as prior art within the knowledge of a person of ordinary skill in the art. Paper 1 at 15-16, 19-20, 24-25; Ex. 1001 at 5:38-42, 5:52-6:3. The other two NPL references, Mañosa and Tamarit, were authored by two of the '656 Patent's inventors and available upon publication. *See, e.g.*, Ex. 1002. Permitting submission is in the interest of justice because it would address Patent Owner's efforts to avoid the inventors' own prior art and its prior admissions as to public availability. *See* 37

C.F.R. § 42.123(b). There is no doubt the NPL references were printed publications; the Supplemental Declaration merely lays to rest Patent Owner's arguments and objections and narrows the issues for trial.

Moreover, because "Patent Owner already has possession of the supplemental information, there is little, if any, prejudice to Patent Owner if the information is allowed into the record." *Inergy Tech*, IPR2024-00094, Paper 14 at 6; *see also Palo Alto*, IPR2013-00369, Paper 37 at 5. Patent Owner's only objection to the supplemental information was to the timing of its introduction, i.e., before its request for Director review is addressed. ¶ 7. However, a request for Director review "does not stay the time for the parties to take action in the underlying proceeding." 37 C.F.R. § 42.75(e)(1). Patent Owner has until June 17, 2025 to respond to the petition and this supplemental information, and has not yet cross-examined Petitioner's expert, Dr. Dincă, which will take place on June 5, 2025. Admitting this supplemental information, before Patent Owner's response, will thereby further the interests of justice, advance efficiency, and "secure the just, speedy, and inexpensive resolution" of this trial. 37 C.F.R. § 42.1(b). Petitioner's motion should be granted.

III. CONCLUSION

Petitioner respectfully requests that the supplemental information found in the Supplemental Declaration be admitted into the record. Petitioner also requests authorization to reply to Patent Owner's response to this motion.

May 13, 2025

Respectfully submitted,

/Jeffrey Johnson/
Jeffrey Johnson (Reg. No. 53,078)

CERTIFICATE OF SERVICE

The undersigned hereby certifies on this 13th day of May, 2025, that true and correct copies of the foregoing Petitioner's Motion to Submit Supplemental Information Pursuant to 37 C.F.R. § 42.123(a) were served in their entirety on the following parties via email on Counsel for Patent Owner at the email addresses as indicated in their Mandatory Notices under 37 C.F.R. § 42.8:

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UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

PASCAL TECHNOLOGIES,

Petitioners

v.

CAMBRIDGE ENTERPRISE LIMITED, UNIVERSIAT POLITECNICA DE CATALUNYA AND UNIVERSITAT DE BARCELONA,

Patent Owner

Case No. IPR2024-01235

U.S. Patent No. 11,230,656

SUPPLEMENTAL DECLARATION OF SYLVIA HALL-ELLIS, PH.D. IN SUPPORT OF PETITION FOR *INTER PARTES* REVIEW OF U.S. PATENT NO. 11,230,656

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DECLARATION OF SYLVIA HALL-ELLIS, PH.D.

I. INTRODUCTION

1. My name is Sylvia D. Hall-Ellis. I have been retained as an expert on behalf of Pascal Technologies ("Petitioner").

2. I have written this Declaration on behalf of Petitioner to provide my expert opinion regarding the authenticity and public availability of several publications. My Declaration sets forth my opinions in detail and provides the basis for my opinions regarding the public availability of these publications.

3. I have personal knowledge of the facts contained in this Declaration, am of legal age, and am otherwise competent to testify.

4. Unless otherwise stated, the matters contained in this Declaration are of my own personal knowledge and, if called as a witness, I could and would testify completely and truthfully with regard to the matters set forth herein.

5. I reserve the right to supplement or amend my opinions, and basis for them, in response to any additional evidence, testimony, discovery, argument, and/or other additional information that may be provided to me after the date of this Declaration.

6. I am being compensated for my time spent working on this matter at my normal consulting rate, plus reimbursement for any additional reasonable expenses. My compensation is not in any way tied to the content of this Declaration,

the substance of my opinions, or the outcome of this litigation. I have no other interests in this proceeding or with any of the parties.

7. All of the materials that I considered are discussed explicitly in this Declaration.[1]

II. QUALIFICATIONS

8. I am qualified by education and experience to testify as an expert in the field of library science. Attached as Appendix A to this Declaration is a copy of my curriculum vitae detailing my education and experience. Additionally, the following overview of my background pertains to my qualifications for providing expert testimony in this matter.

9. I am currently an Adjunct Professor in the School of Information at San José State University. I obtained a Master of Library Science from the University of North Texas in 1972 and a Ph.D. in Library Science from the University of Pittsburgh in 1985. Over the last 50-plus years, I have held various positions in the field of library and information resources. I was first employed as a librarian in 1966 and have been involved in the field of library sciences since, holding numerous positions.

[1] Where appropriate, I refer to exhibits that I understand were submitted with the petition for *inter partes* review of the '656 Patent and continue attachment numbering from my prior declaration, Exhibit 1024.

10. I am a member of the American Library Association (ALA) and its Association for Library Collections & Technical Services (ALCTS) Division, and I served on the Committee on Cataloging: Resource and Description (which wrote the new cataloging rules) and as the chair of the Committee for Education and Training of Catalogers and the Competencies and Education for a Career in Cataloging Interest Group. I also served as the Chair of the ALCTS Division's Task Force on Competencies and Education for a Career in Cataloging. Additionally, I have served as the Chair for the ALA Office of Diversity's Committee on Diversity, as a member of the REFORMA National Board of Directors, as a member of the Editorial Board for the ALCTS premier cataloging journal, *Library Resources and Technical Services,* as a Co-Chair of the Membership Committee for the Library Research Round Table (LRRT) for the American Library Association, and as a member of the LRRT Nominating Committee. Currently, I serve as a member of the CORE Margaret Mann Citation Committee.

11. I have also given over one hundred presentations in the field, including several on library cataloging systems and Machine-Readable Cataloging ("MARC") standards. My current research interests include library cataloging systems, metadata, and organization of electronic resources.

III. LEGAL STANDARDS

12. *Scope of this Declaration.* I am not an attorney and will not offer

opinions on the law. I am, however, rendering my expert opinion on the authenticity of the documents referenced herein and on when and how each of these documents was disseminated or otherwise made available to the extent that persons interested and ordinarily skilled in the subject matter or art, exercising reasonable diligence, could have located the documents before on or around the listed dates of their respective publications below.

13. I am informed by counsel that a publication in printed or electronic or other version qualifies as publicly accessible as of the date it was disseminated or otherwise made available such that a person interested in and ordinarily skilled in the relevant subject matter could locate it through the exercise of ordinary diligence. I am further informed by counsel that the following factors are considered to determine whether a work is publicly available: (a) the breadth of dissemination of the work; (b) whether the material is addressed to or of interest to a POSITA; (c) how widely the work was disseminated; (d) for how long the reference was disseminated or available; and, (e) whether the information was disseminated publicly with no expectation of confidentiality.

14. While I understand that the determination of public accessibility under the foregoing standard rests on a case-by-case analysis of the facts particular to an individual publication, I also understand that a publication is rendered "publicly accessible" if it is cataloged and indexed by a library such that a person interested in

the relevant subject matter could locate it (*i.e.*, I understand that cataloging and indexing by a library is sufficient, though there are other ways that a printed publication may qualify as publicly accessible). One manner of sufficient indexing is indexing according to subject matter category. I understand that the cataloging and indexing by a single library of a single instance of a particular publication is sufficient, even if the single library is in a foreign country. I understand that, even if access to a library is restricted, a publication that has been cataloged and indexed therein is publicly accessible so long as a presumption is raised that the portion of the public concerned with the relevant subject matter would know of the publication. I also understand that the cataloging and indexing of information that would guide a person interested in the relevant subject matter to the publication, such as the cataloging and indexing of an abstract, is sufficient to render the publication publicly accessible.

15. *Persons of ordinary skill in the art*. I am told by counsel that the subject matter of this proceeding generally relates to the identification and use of organic caloric materials, specifically organic barocaloric materials, in refrigeration methods and apparatus.

16. I have been informed by counsel that a "person of ordinary skill in the art at the time of the invention" is a hypothetical person who is presumed to be familiar with the relevant field and its literature at the time of the invention(s). This

hypothetical person is also a person of ordinary creativity, capable of understanding the scientific principles applicable to the pertinent field.

17. I am told by counsel that persons of ordinary skill in this subject matter or art would have had at least a Bachelor's degree in chemical engineering, chemistry, materials science engineering (or a related or equivalent field), and two or more years of experience identifying, researching, developing, designing and/or evaluating (or supervising the same) caloric materials, including the effects and use thereof as well as systems supporting and exploring the effects and use of caloric materials. A person with less or different education but more relevant practical experience, or vice versa, may also meet this standard. Each of these POSITAs may be part of an interdisciplinary team with others having the relevant experience set forth above.

18. It is my opinion that such a person would have been engaged in research, learning through study and practice in the field and possibly through formal instruction the bibliographic resources relevant to his or her research. Before October 14, 2016, such a person would have had access to an array of long-established print resources in the identification and use of caloric materials, including both inorganic and organic barocaloric materials, and systems and methods involving the use of inorganic and organic barocaloric materials in heating and cooling applications.

19. Based on my experience working in research libraries with researchers having the qualifications described above, or even lesser qualifications, it is my opinion that such researchers would have been able to locate the material discussed herein on their own or with the assistance of a research librarian with relative ease using the tools and resources described herein.

IV. LIBRARY CATALOGING PRACTICES

20. In preparing this declaration, I used authoritative databases, such as the OCLC bibliographic database, the Library of Congress Online Catalog, and the Library of Congress Subject Authorities, to confirm citation details of the various publications discussed. Unless I note otherwise below in reference to a specific serial publication, it is my expert opinion that this standard protocol was followed for the serial publication discussed below.

21. Based on my experience working in research libraries with researchers having the qualifications described above, or even lesser qualifications, it is my opinion that such researchers would have been able to locate the material discussed herein on their own or with the assistance of a research librarian with relative ease using the tools and resources described herein.

A. INDEXING

22. A researcher may discover material relevant to his or her topic in a variety of ways. One common means of discovery is to search for relevant

information in an index of periodical and other publications. Having found relevant material, the researcher will then normally obtain it online, look for it in libraries, or purchase it from the publisher, a bookstore, a document delivery service, or other provider. Sometimes, the date of a document's public accessibility will involve both indexing and library date information. However, date information for indexing entries is often unavailable. This is especially true for online indices.

23. Indexing services use a wide variety of controlled vocabularies to provide subject access and other means of discovering the content of documents. The formats in which these access terms are presented vary from service to service.

24. Online indexing services commonly provide bibliographic information, abstracts, and full-text copies of the indexed publications, along with a list of the documents cited in the indexed publication. These services also often provide lists of publications that cite a given document. A citation of a document is evidence that the document was publicly available and in use by researchers no later than the publication date of the citing document.

25. Before the widespread development of online databases to index articles in journals, magazines, conference papers, and technical reports, libraries purchased printed volumes of indices. Graduate library school education mandated that students learn about the bibliographic control of disciplines, the prominent indexing volumes, and searching strategies required to use them effectively and

efficiently. Half of the courses that I studied in library school were focused on bibliography and resources in academic disciplines.

26. Librarians consulted with information seekers to verify citations, check availability in union catalogs, printed books catalogs, the OCLC database, and make formal requests for materials (e.g., books, conference proceedings, journal articles). Requests were transmitted using Telex machines, rudimentary email systems, and the United States Postal Service. During my career, I have performed and supervised staff who handled these resource sharing tasks.

27. A major firm known for the breadth of subjects and comprehensive treatment in the preparation of index volumes, the H. W. Wilson Company offered these reference resources since the firm was founded in 1898. The *Reader's Guide to Periodical Literature* is one of the best-known titles available from H. W. Wilson. Each volume includes a comprehensive index for 300 of the most popular and important periodicals published in the United States and Canada. Information seekers have subject access expressed in plain language terminology, author access, and cross references to find the desired results from their searches. The family of index titles included *Science & Technology Index*, *Business Periodicals*, *Applied Science & Technology Index, Humanities Index, Biological & Agricultural Index*, and *Industrial Arts Index*. These printed indices have been superseded by digital database offerings available to information seekers through Ebsco.

28. A citation of a document by another is evidence that the document was publicly available and in use no later than the publication date of the citing document.

29. Online indexing services such as Google Scholar[2] or ScienceDirect[3] commonly provide bibliographic information, abstracts, and full-text copies of the indexed publications, along with a list of the documents cited in the indexed publication. These services also often provide lists of publications that cite a given document.

30. A researcher may discover material relevant to his or her topic in a variety of ways. A citation of a document by another is evidence that the document was publicly available and in use no later than the publication date of the citing document. One common means of discovery is to search for relevant information in an index of periodicals and other publications. Having found relevant material, the researcher will then normally obtain it online, look for it in libraries, or purchase it from a publisher, a bookstore, a document delivery service, or other provider. Sometimes, the date of a document's public accessibility will involve both indexing and library date information. However, date information for indexing entries is often unavailable. This is especially true for online indices.

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[2] Exhibit 1024, Attachment 2, https://scholar.google.com/.

[3] Exhibit 1024, Attachment 3, https://www.sciencedirect.com/.

31. Indexing services use a wide variety of controlled vocabularies to provide subject access and other means of discovering the content of documents. The Library of Congress Subject Authorities includes standard forms of terms and cross references that are included in bibliographic records. Subject headings are terms that an individual seeking a document regardless of format can enter in the search bar of the online catalog. Subjects also connect an authenticated term (one included in the Library of Congress subject headings list) with related, broader, and narrower terms. The formats in which these access terms are presented vary from service to service.

32. Online indexing services commonly provide bibliographic information, abstracts, and full-text copies of the indexed publications, along with a list of the documents cited in the indexed publication. These services also often provide lists of publications that cite a given document. A citation of a document is evidence that the document was publicly available and in use by researchers no later than the publication date of the citing document. Prominent indexing services include *Scopus,* the *IEEE Xplore* database, the *ACM Digital Library, Google Scholar,* and the *Internet Archive*.

B. MARC RECORDS AND THE ONLINE LIBRARY CATALOG

33. I am fully familiar with the library cataloging standard known as the MARC standard, which is an industry-wide standard method of storing and

organizing library catalog information.[4] MARC was first developed in the 1960s by the Library of Congress. A MARC-compatible library is one that has a catalog consisting of individual MARC records for each of its items. Today, MARC is the primary communications protocol for the transfer and storage of bibliographic metadata in libraries.[5]

34. Since at least the early 1970s and continuing to the present day, MARC has been the primary communications protocol for the transfer and storage of bibliographic metadata in libraries.[6] As explained by the Library of Congress:

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[4] The full text of the standard is available from the Library of Congress at http://www.loc.gov/marc/bibliographic/ (Attachment 11).

[5] Almost every major library in the world is MARC-compatible. *See, e.g.*, *MARC Frequently Asked Questions (FAQ)*, Library of Congress, https://www.loc.gov/marc/faq.html (Attachment 12) (last visited April 19, 2025) ("MARC is the acronym for MAchine-Readable Cataloging. It defines a data format that emerged from a Library of Congress-led initiative that began nearly fifty years ago. It provides the mechanism by which computers exchange, use, and interpret bibliographic information, and its data elements make up the foundation of most library catalogs used today."). MARC is the ANSI/NISO Z39.2-1994 (reaffirmed 2016) standard for Information Interchange Format.

[6] A complete history of the development of MARC can be found in *MARC: Its History and Implications* by Henrietta D. Avram (Washington, DC: Library of Congress, 1975) and available online from the Hathi Trust

> You could devise your own method of organizing the bibliographic information, but you would be isolating your library, limiting its options, and creating much more work for yourself. Using the MARC standard prevents duplication of work and allows libraries to better share bibliographic resources. Choosing to use MARC enables libraries to acquire cataloging data that is predictable and reliable. If a library were to develop a "home-grown" system that did not use MARC records, it would not be taking advantage of an industry-wide standard whose primary purpose is to foster communication of information.
>
> Using the MARC standard also enables libraries to make use of commercially available library automation systems to manage library operations. Many systems are available for libraries of all sizes and are designed to work with the MARC format. Systems are maintained and improved by the vendor so that libraries can benefit from the latest advances in computer technology. The MARC standard also allows libraries to replace one system with another with the assurance that their data will still be compatible.

Why Is a MARC Record Necessary? LIBRARY OF CONGRESS.[7]

35. Thus, almost every major library in the world is MARC-compatible. *See, e.g.*, *MARC Frequently Asked Questions (FAQ)*, LIBRARY OF CONGRESS.[8]

(https://babel.hathitrust.org/cgi/pt?id=mdp.39015034388556;view=1up;seq=1 (Attachment 13); last visited April 19, 2025).

[7] Attachment 14, http://www.loc.gov/marc/umb/um01to06.html#part2.

[8] Attachment 12, https://www.loc.gov/marc/faq.html.

("MARC is the acronym for MAchine-Readable Cataloging. It defines a data format that emerged from a Library of Congress-led initiative that began fifty years ago. It provides the mechanism by which computers exchange, use, and interpret bibliographic information, and its data elements make up the foundation of most library catalogs used today."). MARC is the ANSI/NISO Z39.2-1994 standard (reaffirmed in 2016) for Information Interchange Format. The full text of the standard is available from the Library of Congress.[9]

36. A MARC record comprises several fields, each of which contains specific data about the work. Each field is identified by a standardized, unique, three-digit code corresponding to the type of data that follow. For example, a work's title is recorded in Field 245; the primary author of the work is transcribed in Field 100; an item's International Standard Book Number ("ISBN") consisting of ten or thirteen digits is transcribed in Field 020; an item's International Standard Serial Number ("ISSN") is transcribed in Field 022; the Library of Congress classification notation is recorded in Field 050; and the publication date is recorded in Field 260 under the subfield "c." If a work is a periodical, then its publication frequency is recorded in Field 310, and the publication dates (e.g., the first and last publication) are recorded in Field 362, which is also referred to as the enumeration/chronology

[9] Attachment 11, http://www.loc.gov/marc/bibliographic/.

field.[10]

37. The library that created the record is recorded in Field 040 in subfield "a" with a unique library code. When viewing the MARC record online via Online Computer Library Center's ("OCLC") bibliographic database, hovering over this code with the mouse reveals the full name of the library. I used this method of "mousing over" the library codes in the OCLC database to identify the originating library for the MARC records discussed in this declaration. Where this "mouse over" option was not available, I consulted the Directory of OCLC Libraries to identify the institution that created the MARC record.[11]

38. MARC records also include several fields that include subject matter classification information. An overview of MARC record fields is available through the Library of Congress.[12] For example, 6XX fields are termed "Subject Access Fields."[13] Among these, for example, is the 650 field; this is the "Subject Added Entry – Topical Term" field.[14] The 650 field is a "[s]ubject added entry in which the entry element is a topical term." These entries "are assigned to a bibliographic record

[10] Attachment 15, http://www.loc.gov/marc/bibliographic/bd3xx.html.

[11] Attachment 16, https://www.oclc.org/en/contacts/libraries.html.

[12] Attachment 11, http://www.loc.gov/marc/bibliographic/.

[13] Attachment 17, http://www.loc.gov/marc/bibliographic/bd6xx.html.

[14] Attachment 18, http://www.loc.gov/marc/bibliographic/bd650.html.

to provide access according to generally accepted thesaurus-building rules (e.g., *Library of Congress Subject Headings* (LCSH), *Medical Subject Headings* (MeSH))." *Id.* Further, MARC records include call numbers, which themselves include a classification number. For example, the 050 field is the "Library of Congress Call Number."[15] A defined portion of the Library of Congress Call (LCC) Number is the classification number, and "source of the classification number is *Library of Congress Classification* and the *LC Classification-Additions and Changes*." Thus, included in the 050 field is a subject matter classification. Further, the 082 field is the "Dewey Decimal Call Number."[16] A defined portion of the Dewey Decimal Call (DDC) Number is the classification number, and "source of the classification number is the *Dewey Decimal Classification and Relative Index*." Thus, included in the 082 field is a subject matter classification. Each item in a library has a single classification number. A library selects a classification scheme (*e.g.*, the Library of Congress classification scheme just described or a similar scheme such as the Dewey Decimal classification scheme) and uses it consistently. When the Library of Congress assigns the LCC classification number, it appears as part of the 050 field. When the Library of Congress assigns the DDC classification number, it appears as part of the 082 field. If a local library assigns the classification

[15] Attachment 19, http://www.loc.gov/marc/bibliographic/bd050.html.

[16] Attachment 20, http://www.loc.gov/marc/bibliographic/bd082.html.

number, it appears in a 090 field. In either scenario, the MARC record includes a classification number that represents a subject matter classification.

C. OCLC

39. The OCLC was created "to establish, maintain and operate a computerized library network and to promote the evolution of library use, of libraries themselves, and of librarianship, and to provide processes and products for the benefit of library users and libraries, including such objectives as increasing availability of library resources to individual library patrons and reducing the rate of rise of library per-unit costs, all for the fundamental public purpose of furthering ease of access to and use of the ever-expanding body of worldwide scientific, literary and educational knowledge and information."[17] Among other services, OCLC and its members are responsible for maintaining the WorldCat database,[18] used by independent and institutional libraries throughout the world.

40. OCLC also provides its members online access to MARC records through its OCLC bibliographic database. When an OCLC member institution acquires a work, it creates a MARC record for this work in its computer catalog

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[17] Third Article, Amended Articles of Incorporation of OCLC Online Computer Library Center, Incorporated (available at https://www.oclc.org/content/dam/oclc/membership/articles-of-incorporation.pdf) (Attachment 21).

[18] Attachment 22, http://www.worldcat.org/.

system in the ordinary course of its business. MARC records created at the Library of Congress are directly uploaded or may be tape-loaded into the OCLC database through a subscription to MARC Distribution Services daily or weekly. Once the MARC record is created by a cataloger at an OCLC member institution or is tape-loaded from a participating institution, the MARC record is then made available to any other OCLC members online, and therefore made available to the public. Accordingly, once the MARC record is created by a cataloger at an OCLC member institution or is tape-loaded from the Library of Congress or another library anywhere in the world, any publication corresponding to the MARC record has been cataloged and indexed according to its subject matter such that a person interested in that subject matter could, with reasonable diligence, locate and access the publication through any library with access to the OCLC bibliographic database or through the Library of Congress.

41. When an OCLC member institution creates a new MARC record, OCLC automatically supplies the date of creation for that record. The date of creation for the MARC record appears in the fixed field (008), characters 00 through 05. The MARC record creation date reflects the date on which, or shortly after which, the item was first acquired or cataloged. Initially, field 005 of the MARC record is automatically populated with the date the MARC record was created in year, month, day format (YYYYMMDD) (some of the newer library catalog systems

also include hour, minute, second (HHMMSS)). Thereafter, the library's computer system may automatically update the date in field 005 every time the library updates the MARC record (*e.g.*, to reflect that an item has been moved to a different shelving location within the library). Field 005 is visible when viewing a MARC record via an appropriate computerized interface. The date upon which the most recent update to field 005. Thus, when an item's MARC record has been printed to hardcopy—as is the case with the exhibits to this report—the date reflected in field 008 is necessarily on or after the date the library first cataloged and indexed the underlying item.

42. Once one library has cataloged and indexed a publication by creating a MARC record for that publication, other libraries that receive the publication do not create additional MARC records—the other libraries instead rely on the original MARC record. They may update or revise the MARC record to ensure accuracy, but they do not replace or duplicate it. This practice does more than save libraries from duplicating labor. It also enhances the accuracy of MARC records. Further, it allows librarians around the world to know that a particular MARC record is authoritative (in contrast, a hypothetical system wherein duplicative records were created would result in confusion as to which record is authoritative).

43. The date of creation of the MARC record by a cataloger at an OCLC member institution reflects when the underlying item is accessible to the public.

Upwards of two-thirds to three-quarters of book sales to libraries come from a jobber or wholesaler for online and print resources. These resellers make it their business to provide books to their customers as fast as possible, often providing turnaround times of only a single day after publication. Libraries purchase a significant portion of the balance of their books directly from publishers themselves, which provide delivery on a similarly expedited schedule. In general, libraries make these purchases throughout the year as the books are published and shelve the books as soon thereafter as possible in order to make the books available to their patrons. Thus, books are generally available at libraries across the country within just a few days of publication.

V. PUBLICATIONS

A. Document 1: Exhibit 1006 ("Xie")

44. Exhibit 1006 is a technical report titled *Demonstration of Liquid Crystal for Barocaloric Cooling Application* prepared by Zhongjian Xie and Yao Zhu (hereafter "Xie"), identified as document 1609.07939 (the arXiv identifier shown on the arXiv.org website) and originally submitted on September 26, 2016. I obtained a copy of the Xie technical report from the arXiv digital repository hosted by Cornell University (Ithaca, New York).[19] I have compared the copy I obtained

[19] Attachment 43, Xie technical report, https://arxiv.org/pdf/1609.07939; Attachment 26, https://arxiv.org/abs/1609.07939.

with Exhibit 1006. In my opinion, Exhibit 1006 is a true and correct copy of the Xie technical article. The arXiv digital open access research-sharing platform hosts more than two million scholarly articles in the fields of physics, mathematics, computer science, quantitative biology, quantitative finance, statistics, electrical engineering and systems science, and economics.[20] Submissions to the arXiv digital repository are given an identifier when the submission is publicly announced. [21] The arXiv digital repository follows a scheduled announcement process, where submissions to the arXiv.org digital repository are publicly announced Sunday through Thursday at a set time (8 pm Eastern Standard Time).[22] Per the Announcement Schedule, articles submitted between Friday at 2 pm ET and Monday at 2 pm ET are publicly announced on Monday at 8 pm ET and mailed to subscribers on Monday night/Tuesday morning. Because the Xie technical report was submitted on September 26, 2016 at 12:03 UTC (8:03 am ET),[23] a Monday, it would have been publicly announced on Monday at 8 pm ET and mailed to subscribers on Monday night/Tuesday morning. As described above, the Xie technical report's identifier is 1609.07939, and its prefix ("1609") indicates its announcement and public

[20] Attachment 23, https://info.arxiv.org/about/index.html.

[21] Attachment 24, https://info.arxiv.org/help/arxiv_identifier.html.

[22] Attachment 25, https://info.arxiv.org/help/availability.html.

[23] Attachment 26, https://arxiv.org/abs/1609.07939.

availability in September 2016. Specifically, the text of Attachment 43 is complete; no pages are missing, and the text on each page appears to flow seamlessly from one page to the next; further, there are no visible alterations to the document.

45. Further, Attachment 43 was found within the custody of the issuing higher education institution (i.e., the arXiv digital repository hosted by Cornell University), a place where, if authentic, a copy of this technical report would likely be. Exhibit 1006 is a true and correct copy in a condition that creates no suspicion about its authenticity.

46. The Xie technical report is also available through the digital repository *ResearchGate*, which also shows a publication date of "September 2016."[24] A technical report exhibits the following characteristics: the technical report is attributed to one or more creators or authors (in this case Zhongjian Xie and Yao Zhu) who affix a date of creation (in this case September 2016), recognize one or more outside funding agencies (in this case the arXiv digital repository), a list of scholarly references (in this case 18 references), and publishes the document through a sponsoring institution or organization (in this case the arXiv digital repository at Cornell University).

[24] Attachment 27, https://www.researchgate.net/publication/308646552_Demonstration_of_liquid_crystal_for_barocaloric_cooling_application.

47. Based on the above information provided by the arXiv digital repository and about the Xie technical report, it is my opinion that the technical report titled *Demonstration of Liquid Crystal for Barocaloric Cooling Application* was available to the public by or shortly after September 27, 2016, as indicated on the arXiv website. It is also my opinion that there is no reason to doubt the authenticity of Exhibit 1006 given its appearance, contents, and the web address from which it was obtained.

B. Document 2: Exhibit 1007 ("Mañosa")

48. Exhibit 1007 is a copy of the journal article titled "Advanced Materials for Solid-State Refrigeration" by Lluís Mañosa, Antoni Planes, and Mehmet Acet (hereafter "Mañosa"). The Mañosa article was published in Volume 1, Issue 16 of the *Journal of Materials Chemistry A* and was found in the Linda Hall Library of Science, Engineering & Technology (Kansas City, Missouri). The Mañosa article appears beginning on page 4925 of this issue dated April 28, 2013. I received a true and correct copy of the Mañosa article (pages 4925-4936) from the Linda Hall Library of Science, Engineering & Technology.[25] I have compared the copy I obtained with Exhibit 1007. In my opinion, Exhibit 1007 is a true and correct copy of the Mañosa article. Specifically, the text of the article is complete; no pages are missing, and the text on each page appears to flow seamlessly from one page to the

[25] Attachment 44, Mañosa article.

next; further, there are no visible alterations to the document. Attachment 44 was found within the custody of a library – a place where an authentic copy of this journal would likely be. Attachment 44 is a true and correct copy in a condition that creates no suspicion about its authenticity.

49. The Mañosa article is available from the publisher, the Royal Society of Chemistry,[26] and the digital repositories *ResearchGate*[27] and *Semantic Scholar*.[28]

50. Attached hereto as Attachment 31A is a true and correct copy of the MARC record for the *Journal of Materials Chemistry A* from the Linda Hall Library of Science, Engineering & Technology online catalog. Library ownership is indicated by the presence of the library's code ("LHL") in field 049. The library continues to update and enhance this MARC record to meet current cataloging rules. The most recent enhancement to Attachment 31A occurred on October 7, 2022, as shown in field 005 ("20221007"). I personally identified and retrieved the MARC

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[26] Attachment 28, https://pubs.rsc.org/en/content/articlelanding/2013/ta/c3ta01289a.

[27] Attachment 29, https://www.researchgate.net/publication/255773535_Advanced_materials_for_solid-state_refrigeration.

[28] Attachment 30, https://www.semanticscholar.org/paper/Advanced-materials-for-solid-state-refrigeration-Ma%C3%B1osa-Planes/6150e5b6fd43746569f1b090d12753b897521966.

record that is Attachment 31A.

51. Based on finding a copy of Exhibit 1007 in the Linda Hall Library of Science, Engineering & Technology and MARC record in its online library catalog attached as Attachment 31A, it is my opinion that the Mañosa article was published in the *Journal of Materials Chemistry A* and was publicly available on April 23, 2013, as shown by the stamp on the cover (Attachment 44, page 1). This date stamp has the general appearance of date stamps that libraries have long affixed to periodicals to show when an issue was received, verified, and checked.

52. Attachment 31A includes an entry in field 050 ("TA404.2 $b.J674"), a subject matter consistent with the Library of Congress classification system (analogous to the Dewey Decimal classification system) and an entry in field 082 ("543.0284"), a subject matter consistent with the Dewey Decimal classification system. Attachment 31A also shows that Exhibit 1007 was catalogued with three descriptor terms reading "Materials $x Research $v Periodicals" (see Attachment 31B, Library of Congress subject heading sh85082082 and Attachment 31C, Library of Congress subject heading sh85099890), "Chemistry, Analytic $v Periodicals" (see Attachment 31D, Library of Congress subject heading sh85023011 and Attachment 31C, Library of Congress subject heading sh85099890), and "Environmental sciences $x Research $v Periodicals" (see Attachment 31E, National Library of Medicine subject heading sh92004048, Attachment 31F, Library

of Congress subject heading sh85113021, and Attachment 31C, Library of Congress subject heading sh85099890) in the 650 fields.

53. As noted in the holdings information (362 field), the Linda Hall Library of Science, Engineering & Technology has received the *Journal of Materials Chemistry A* since January 2013 and continues to receive the publication. In view of the MARC record for Exhibit 1007, the Mañosa article was publicly available on April 23, 2013, because the serial title had been received, cataloged, and indexed in the Linda Hall Library of Science, Engineering & Technology and made part of its online catalog database.

54. Attached hereto as Attachment 31G is a true and correct copy of the MARC record for the *Journal of Materials Chemistry A* obtained from the OCLC bibliographic database. As previously noted, the library that created the record is recorded in field 040 with a unique library code. For Attachment 31G, that library code is "ERD," which means that the MARC record for this serial was cataloged at the Trinity College Dublin Library (Dublin, Ireland). As can be seen in field 008 for this exhibit ("Date entered on file"), a cataloger at the Trinity College Dublin Library created OCLC record number 830991078 on July 5, 2012, as shown in field 008 ("120705"). The library continues to update and enhance this MARC record to meet current cataloging rules. The most recent enhancement to Attachment 31G occurred on December 30, 2020, as shown in field 005 ("20201230"). I personally identified

and retrieved the MARC record that is Attachment 31G. The "BLvl" entry in Attachment 31G is "s," which indicates that the *Journal of Materials Chemistry A* is a serial publication. Field 310 of Attachment 31G reads "Forty-eight no. a year." Accordingly, the MARC record for Exhibit 1007 corresponds to the *Journal of Materials Chemistry A* from the time the serial title began and includes the date of the Mañosa article.

55. Attachment 31G includes an entry in field 050 ("TA404.2 $b .J674")—as described above, a subject matter classification number consistent with the Library of Congress classification system(analogous to the Dewey Decimal classification system) and an entry in field 082 ("543.0284"), a subject matter consistent with the Dewey Decimal classification system. Attachment 31G also shows that Exhibit 1007 was catalogued with three descriptor terms reading "Materials $x Research $v Periodicals" (see Attachment 31B, Library of Congress subject heading sh85082082 and Attachment 31C, Library of Congress subject heading sh85099890), "Chemistry, Analytic $v Periodicals" (see Attachment 31D, Library of Congress subject heading sh85023011 and Attachment 31C, Library of Congress subject heading sh85099890), and "Environmental sciences $x Research $v Periodicals" (see Attachment 31E, National Library of Medicine subject heading sh92004048, Attachment 31F, Library of Congress subject heading sh85113021, and Attachment 31C, Library of Congress subject heading sh85099890) in the 650

fields. Thus, as of its cataloging, the publication corresponding to the MARC record attached hereto as Attachment 31G was indexed according to its subject matter by virtue of at least three independently sufficient classifications: the field 050 entry, the field 082 entry, and the field 650 entries. As of July 5, 2012, the MARC record attached hereto as Attachment 31G was accessible through any library with access to the OCLC bibliographic database or the online catalog at a library that subscribed to the serial, which means that the corresponding publication was publicly available on or before that same date through any library with access to the OCLC bibliographic database or through an individual library.

56. WorldCat indicates that the *Journal of Materials Chemistry A* as cataloged at the Trinity College Dublin Library is currently available from 349 libraries.[29] In view of the above, this issue of the *Journal of Materials Chemistry A* was publicly available on April 23, 2013, because by that date it had been cataloged and indexed at the Trinity College Dublin Library, made part of the OCLC bibliographic database, and received in the Linda Hall Library of Science, Engineering & Technology. Two other Exhibits confirm the public availability of the Mañosa article by citing to it – Ex. 1015 (Lloveras), received on July 17, 2015, published on November 26, 2015, and listing the Mañosa article as reference 2); and

[29] Attachment 32, https://search.worldcat.org/title/830991078.

Ex. 1010 (Stern), received on June 17, 2016, published September 19, 2016, and listing the Mañosa article as reference 25. For these reasons, it is my opinion that Exhibit 1007 was published and accessible to the public on April 23, 2013.

C. Document 3: Exhibit 1009 ("Patel")

57. Exhibit 1009 is a copy of the journal article titled "Elastocaloric and Barocaloric Effects in Polyvinylidene Di-Fluoride-Based Polymers" by Satyanarayan Patel, Aditya Chauhan, Rahul Vaish, and Paramanandam Thomas (hereafter "Patel"). The Patel article was published in Volume 108, Number 7 of the journal *Applied Physics Letters* and was found in the Linda Hall Library of Science, Engineering & Technology (Kansas City, Missouri). The Patel article appears beginning on page 072903-1 of this issue dated February 15, 2016. I received a copy of the Patel article (pages 072903-1—072903-5) from the Linda Hall Library of Science, Engineering & Technology.[30] I have compared the copy I obtained with Exhibit 1009. In my opinion, Exhibit 1009 is a true and correct copy of the Patel article. Specifically, the text of the article is complete; no pages are missing, and the text on each page appears to flow seamlessly from one page to the next; further, there are no visible alterations to the document. Attachment 45 was found within the custody of a library – a place where an authentic copy of this journal would likely be. Attachment 45 is a true and correct copy in a condition that creates no suspicion

[30] Attachment 45, Patel article.

about its authenticity.

58. The Patel article is available from the publisher, AIP Publishing,[31] and the digital repository *ResearchGate.*[32]

59. Attached hereto as Attachment 35A is a true and correct copy of the MARC record for the journal *Applied Physics Letters* from the Linda Hall Library of Science, Engineering & Technology online catalog. Library ownership is indicated by the presence of the library's code ("LHL") in field 049. The library continues to update and enhance this MARC record to meet current cataloging rules. The most recent enhancement to Attachment 35A occurred on September 6, 2023, as shown in field 005 ("20230906"). I personally identified and retrieved the MARC record that is Attachment 35A.

60. Based on finding a copy of Exhibit 1009 in the Linda Hall Library of Science, Engineering & Technology and MARC record in its online library catalog attached as Attachment 35A, it is my opinion that the Patel article published in the journal *Applied Physics Letters* and was publicly available on March 9, 2016, as

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[31] Attachment 33, https://pubs.aip.org/aip/apl/article-abstract/108/7/072903/31142/Elastocaloric-and-barocaloric-effects-in?redirectedFrom=fulltext.

[32] Attachment 34, https://www.researchgate.net/publication/294799590_Elastocaloric_and_barocaloric_effects_in_polyvinylidene_di-fluoride-based_polymers.

shown by the stamp on page 2 (Attachment 45, page 2). This date stamp has the general appearance of date stamps that libraries have long affixed to periodicals to show when an issue was received, verified, and checked.

61. Attachment 35A includes an entry in field 050 ("QC1 $b.A74"), a subject matter consistent with the Library of Congress classification system (analogous to the Dewey Decimal classification system). Attachment 35A also shows that Exhibit 1009 was catalogued with a descriptor term reading "Physics $v Periodicals" (see Attachment 35B, Library of Congress subject heading sh2008109342) in the 650 field.

62. As noted in the holdings information (362 field), the Linda Hall Library of Science, Engineering & Technology has received the journal *Applied Physics Letters* since September 1962 and continues to receive the publication. In view of the MARC record for Exhibit 1009, the Patel article was publicly available on March 9, 2016, because the serial title had been received, cataloged, and indexed in the Linda Hall Library of Science, Engineering & Technology and made part of its online catalog database.

63. Attached hereto as Attachment 35C is a true and correct copy of the MARC record for the journal *Applied Physics Letters* obtained from the OCLC bibliographic database. As previously noted, the library that created the record is recorded in field 040 with a unique library code. For Attachment 35C, that library

code is "DLC," which means that the MARC record for this serial was cataloged at the Library of Congress. As can be seen in field 008 for this exhibit ("Date entered on file"), a cataloger at the Library of Congress created OCLC record number 1580952 on August 29, 1975, as shown in field 008 ("750829"). The library continues to update and enhance this MARC record to meet current cataloging rules. The most recent enhancement to Attachment 35C occurred on February 26, 2025, as shown in field 005 ("20250226"). I personally identified and retrieved the MARC record that is Attachment 35C. The "BLvl" entry in Attachment 35C is "s," which indicates that the journal *Applied Physics Letters* is a serial publication. Field 310 of Attachment 35C reads "Weekly, $b 1986-." Accordingly, the MARC record for Exhibit 1009 corresponds to the journal *Applied Physics Letters* from the time the serial title began and includes the date of the Patel article.

64. Attachment 35C includes an entry in field 050 ("QC1 $b .A74")—as described above, a subject matter classification number consistent with the Library of Congress classification system (analogous to the Dewey Decimal classification system) and an entry in field 082 ("530"), a subject matter consistent with the Dewey Decimal classification system. Attachment 35C also shows that Exhibit 1009 was catalogued with a descriptor term reading "Physics $v Periodicals" (see Attachment 35B, Library of Congress subject heading sh85082082) in the 650 field. Thus, as of its cataloging, the publication corresponding to the MARC record attached hereto as

Attachment 35C was indexed according to its subject matter by virtue of at least three independently sufficient classifications: the field 050 entry, the field 082 entry, and the field 650 entry. As of August 29, 1975, the MARC record attached hereto as Attachment 35C was accessible through any library with access to the OCLC bibliographic database or the online catalog at a library that subscribed to the serial, which means that the corresponding publication was publicly available on or before that same date through any library with access to the OCLC bibliographic database or through an individual library.

65. WorldCat indicates that the journal *Applied Physics Letters* as cataloged at the Library of Congress is currently available from 1,071 libraries.[33] Another printed publication, submitted on May 19, 2016 and published July 18, 2016, cites to and confirms the public availability of the Patel article.[34] In view of the above, this issue of the journal *Applied Physics Letters* was publicly available on March 9, 2016, because by that date it had been cataloged and indexed at the Library of Congress, made part of the OCLC bibliographic database, and received in the

[33] Attachment 36, https://search.worldcat.org/title/1580952.

[34] Attachment 42, F. Wang, et al., "Giant room temperature elastocaloric effect of PbTiO3 ferroelectric materials with 90° domain structure," available at https://pubs.rsc.org/en/content/articlelanding/2016/ra/c6ra13030e/unauth (citing the Patel Article as reference 9).

Linda Hall Library of Science, Engineering & Technology. For these reasons, it is my opinion that Exhibit 1009 was published and accessible to the public on March 9, 2016.

D. Document 4: Exhibit 1021 ("Tamarit")

66. Exhibit 1021 is a copy of the journal article titled "Thermodynamic Study of Some Neopentane Derivated by Thermobarometric Analysis" by J. Li Tamarit, B. Legendre, and J. M. Buisine (hereafter "Tamarit"). The Tamarit article was published in Volume 250, Number 1 of the journal *Science and Technology. Section A. Molecular Crystals and Liquid Crystals* and was found in the Library of Congress. The Tamarit article appears beginning on page 347 of this issue dated July 1994. I received a true and correct copy of the Tamarit article (pages 347-358) from the Library of Congress.[35] I have compared the copy I obtained with Exhibit 1021. In my opinion, Exhibit 1021 is a true and correct copy of the Tamarit article. Specifically, the text of the article is complete; no pages are missing, and the text on each page appears to flow seamlessly from one page to the next; further, there are no visible alterations to the document. Attachment 46 was found within the custody of a library – a place where an authentic copy of this journal would likely be. Attachment 46 is a true and correct copy in a condition that creates no suspicion about its authenticity.

[35] Attachment 46, Tamarit article.

67. The Tamarit article is available from the publisher, Taylor & Francis,[36] and the digital repository *Semantic Scholar.*[37] The publisher indicates that the Tamarit article was accepted for publication on July 9, 1993. The publisher also indicates the Tamarit article was viewed more than 60 times, including 10 times between October 2012 and October 2016, and cited at least 7 times before October 2016,[38]

68. Attached hereto as Attachment 40A is a true and correct copy of the MARC record for the journal *Science and Technology. Section A. Molecular Crystals and Liquid Crystals* from the Library of Congress online catalog. Library ownership is indicated by the presence of the library's name at the top of each page. The library continues to update and enhance this MARC record to meet current cataloging rules. The most recent enhancement to Attachment 40A occurred on May 3, 2024, as shown in field 005 ("20240503"). I personally identified and retrieved

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[36] Attachment 37, https://www.tandfonline.com/doi/abs/10.1080/10587259408028219.

[37] Attachment 38, https://www.semanticscholar.org/paper/Thermodynamic-study-of-some-neopentane-derivated-by-Tamarit-Legendre/0e028e599dad9d487453940cbfbf6965a0f0c7e6.

[38] Attachment 39, https://www.tandfonline.com/doi/metrics/10.1080/10587259408028219?scroll=top .

the MARC record that is Attachment 40A.

69. Based on finding a copy of Exhibit 1021 in the Library of Congress and MARC record in its online library catalog attached as Attachment 40A, it is my opinion that the Tamarit article published in the journal *Science and Technology. Section A. Molecular Crystals and Liquid Crystals* and was publicly available by July 31, 1994.[39]

70. Attachment 40A includes an entry in field 050 ("QD901 |b .M64"), a subject matter consistent with the Library of Congress classification system (analogous to the Dewey Decimal classification system) and an entry in field 082 ("548/.08"), a subject matter consistent with the Dewey Decimal classification system. Attachment 40A also shows that Exhibit 1021 was catalogued with two descriptor terms reading "Molecular crystals |v Periodicals" (see Attachment 40B, Library of Congress subject heading sh85086581 and Attachment 31C, Library of Congress subject heading sh85099890) and "Liquid crystals |v Periodicals" (see Attachment 40C, Library of Congress subject heading sh85077357 and Attachment

[39] The journal *Science and Technology. Section A. Molecular Crystals and Liquid Crystals* was published monthly and, therefore, new issues were available approximately every 30 days. Based on the frequency of publication (see Attachment 40A, field 310) and my years of experience working with serials, it is my opinion that issues would be published by the end of the month. Therefore, a public availability date of July 31, 1994, is reasonable.

31C, Library of Congress subject heading sh85099890) in the 650 fields.

71. As noted in the holdings information (362 field), the Library of Congress received the journal *Science and Technology. Section A. Molecular Crystals and Liquid Crystals* from January 1992 until the publication ceased operations in October 2001. In view of the MARC record for Exhibit 1021, the Tamarit article was publicly available by July 31, 1994, because the serial title had been received, cataloged, and indexed in the Library of Congress and made part of its online catalog database.

72. Attached hereto as Attachment 40D is a true and correct copy of the MARC record for the journal *Science and Technology. Section A. Molecular Crystals and Liquid Crystals* obtained from the OCLC bibliographic database. As previously noted, the library that created the record is recorded in field 040 with a unique library code. For Attachment 40D, that library code is "NSD," which means that the MARC record for this serial was cataloged as part of the National Serials Data Program at the Library of Congress. As can be seen in field 008 for this exhibit ("Date entered on file"), a cataloger at the Library of Congress created OCLC record number 24363825 on September 12, 1991, as shown in field 008 ("910912"). The library continues to update and enhance this MARC record to meet current cataloging rules. The most recent enhancement to Attachment 40D occurred on May 1, 2024, as shown in field 005 ("20240501"). I personally identified and retrieved

the MARC record that is Attachment 40D. The "BLvl" entry in Attachment 40D is "s," which indicates that the journal *Science and Technology. Section A. Molecular Crystals and Liquid Crystals* is a serial publication. Field 310 of Attachment 40D reads "Monthly (irregular)." Accordingly, the MARC record for Exhibit 1021 corresponds to the journal *Science and Technology. Section A. Molecular Crystals and Liquid Crystals* from the time the serial title began and includes the date of the Tamarit article.

73. Attachment 40D includes an entry in field 050 ("QD901 $b .M64")—as described above, a subject matter classification number consistent with the Library of Congress classification system (analogous to the Dewey Decimal classification system) and an entry in field 082 ("548/.08"), a subject matter consistent with the Dewey Decimal classification system. Attachment 40D also shows that Exhibit 1021 was catalogued with two descriptor terms reading "Molecular crystals $v Periodicals" (see Attachment 40B, Library of Congress subject heading sh85086581 and Attachment 31C, Library of Congress subject heading sh85099890) and "Liquid crystals $v Periodicals" (see Attachment 40C, Library of Congress subject heading sh85077357 and Attachment 31C, Library of Congress subject heading sh85099890) in the 650 fields. Thus, as of its cataloging, the publication corresponding to the MARC record attached hereto as Attachment 40D was indexed according to its subject matter by virtue of at least three

independently sufficient classifications: the field 050 entry, the field 082 entry, and the field 650 entry. As of September 12, 1991, the MARC record attached hereto as Attachment 40D was accessible through any library with access to the OCLC bibliographic database or the online catalog at a library that subscribed to the serial, which means that the corresponding publication was publicly available on or before that same date through any library with access to the OCLC bibliographic database or through an individual library.

74. WorldCat indicates that the journal *Science and Technology. Section A. Molecular Crystals and Liquid Crystals* as cataloged at the Library of Congress is currently available from 1,031 libraries.[40] In view of the above, this issue of the journal *Science and Technology. Section A. Molecular Crystals and Liquid Crystals* was publicly available by July 31, 1994, because by that date it had been cataloged, indexed, and received at the Library of Congress and made part of the OCLC bibliographic database. For these reasons, it is my opinion that Exhibit 1021 was published and accessible to the public by July 31, 1994.

VI. SUMMARY OF OPINIONS

75. In view of the foregoing, it is my opinion that the publications described above were publicly available no later than the corresponding date listed in the table below:

[40] Attachment 41, https://search.worldcat.org/title/24363825.

Exhibit	Publication	Publicly Available No Later Than
1006	Xie, Zhongjian, and Yao Zhu. *Demonstration of Liquid Crystal for Barocaloric Cooling Application*. Paper 1609.07939. Ithaca, NY: Cornell University, 2016.	September 27, 2016
1007	Mañosa, Lluís, Antoni Planesa, and Mehmet Acet. "Advanced Materials for Solid-State Refrigeration." *Journal of Materials Chemistry A*, vol. 1, issue 16 (28 April 2013): 4925-4936.	April 23, 2013
1009	Patel, Satyanarayan, Aditya Chauhan, Rahul Vaish, and Paramanandam Thomas. "Elastocaloric and Barocaloric Effects in Polyvinylidene Di-Fluoride-Based Polymers." *Applied Physics Letters*, vol. 108, no. 7 (15 February 2016): 072903-1--072903-5.	March 9, 2016
1021	Tamarit, J. Li, B. Legendre, and J. M. Buisine. "Thermodynamic Study of Some Neopentane Derivated by Thermobarometric Analysis." *Science and Technology. Section A. Molecular Crystals and Liquid Crystals*, vol. 250 no. 1 (July 1994): 347-358.	July 31, 1994

76. In signing this Declaration, I recognize that the Declaration will be filed as evidence in a case before the Patent Trial and Appeal Board of the United States Patent and Trademark Office. I also recognize that I may be subject to cross-examination in the case and that cross-examination will take place within the United States. If cross-examination is required of me, I will appear for cross-examination within the United States during the time allotted for cross-examination.

77. I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true, and further that these statements were made with the knowledge that willful

false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code.

DATED: April 21, 2025

By: Sylvia D. Hall-Ellis
Sylvia D. Hall-Ellis, Ph.D.

ATTACHMENT A

CURRICULUM VITAE SYLVIA D. HALL-ELLIS

EDUCATION

Ph.D., University of Pittsburgh, Pittsburgh, Pennsylvania, 1985
M.P.S., University of Denver, Denver, Colorado, 2014
Post Graduate Studies, University of Texas – San Antonio, Texas, 1975-1976
M.L.S., University of North Texas, Denton, Texas, 1972
B.A., Rockford University, Rockford, Illinois, 1971

PROFESSIONAL EXPERIENCE

1981- **Consultant for higher education, non-profit organizations, and corporations.**

2002- **Adjunct Professor, School of Information, San José State University, San José, California.** Serve as part-time faculty member teaching graduate students in technical services (cataloging, bibliographic control, classification), "core courses," and special topics.

2014-2016 **Director, Grants and Resource Development, Colorado Community College System.** Provided leadership and vision to foster the continued growth of rigorous scholarship, innovative projects, and creative work for statewide system, 13 campuses, and 50 teaching sites serving 155,000 students. Responsible for leadership and ensured efficient functioning of contract and grants in compliance with state & federal requirements and successful implementation and management. Served as a subject matter expert and liaison for college Grant Directors for all issues relating to grants and subcontracts.

2010-2014 **Senior Grant Administrator, Morgridge College of Education, University of Denver (Colorado).** Provided leadership and vision to foster continued growth of rigorous scholarship, innovative research, and creative work in the Morgridge College of Education. Ensure that contract and grants processes function effectively and efficiently for 60 faculty and researchers with a focus on the successful progression and efficient management of grants totaling $13M. Worked effectively and collegially with Department Chairs and Program Coordinators on operational grant-related management activities and with a broad range of internal and external constituencies. Supported the dissemination and promotion of faculty research and scholarship to outside constituents at conferences and through publications. Assisted Principal Investigators and grant project teams by coaching, mentoring, and financial management.

2011-2013 **Interim Director & Assistant Dean, Westminster Law Library, Sturm College of Law, University of Denver.** Planned, organized, and directed all administrative activities for the library serving students, faculty, and alumni; oversaw the employment, retention, promotion, transfer and termination of library personnel; represented the library at professional conferences and public meetings; created and promoted a climate and culture of acceptance for new programs and services, a positive high-quality image of the law library, and that reflect the organization's values, encourage excellent performance, and reward high productivity and innovation; provided leadership and set strategic direction of the organization; ensured that the library provided excellent customer service through solution-oriented staff response to patron needs and by responsiveness and continuous improvement of the organization; promoted, developed, and maintained positive working relationships with colleagues and customers including key stakeholders and groups, higher education institutions, the legal community, other regional libraries and districts statewide, and national library organizations.

2007-2014 **Associate Professor, Library & Information Science, Morgridge College of Education, University of Denver (Colorado).** Served in leadership role and worked collaboratively in program, college, campus and community environments. Advised and supervised students, taught core and specialized courses at the graduate level in an integrative, student-centered learning environment. Served on LIS, College, and University committees, and maintained working relationships with colleagues in other academic units and information professionals in the Rocky Mountain region and beyond. Served on and chair doctoral student dissertation committees. Oversaw and facilitated the College and LIS graduate student association.

2002-2007 **Assistant Professor, Library & Information Science, College of Education, University of Denver (Colorado).** Served as tenure-track faculty member teaching graduate students in "core courses," resource description and access, service learning, and independent studies. Advised graduate students, participate on LIS and College committees, and serve on doctoral student dissertation committees. Oversaw and facilitated the LIS graduate student association and alumni association.

2000-2002 **Affiliate Faculty, Library & Information Science, College of Education, University of Denver (Colorado).** Served as part-time faculty member teaching graduate students in technical services (cataloging, bibliographic control, classification), "core courses," and special topics. Oversaw and facilitated the LIS graduate student association and alumni association.

2000-2001 **Special Assistant to the Secretary's Regional Representative, U.S. Department of Education, Region VIII, Denver, Colorado.** Served as the principal advisor and representative of the U. S. Secretary of Education's Regional Representative (SRR). Ensured the implementation of major goals of the SRR and the Secretary. Provided leadership on behalf of the SRR in contacts with high-level officials in Region VIII requiring sensitive policy interpretation in communication with senior Department officials to solve problems and resolve issues raised by State and local education officials. Served as the primary contact for School-to-Work/Career, Children's Health Insurance Program, and Safe and Drug-Free Schools. Delivered technical assistance to local education agencies and institutions of higher education in technology, professional development, and school construction.

1999-2000 **Catalog Librarian, Jefferson County Public Library, Lakewood, Colorado.** Performed original, copy cataloging and classification of library materials (English and Spanish) using standard library protocols; completed original descriptive cataloging and subject analysis; enhanced brief catalog and authority records in III.

1997-1999 **Development Officer, McREL International, Aurora, Colorado.** Served as senior member of corporate management team in strategic planning, development of proposals and contracts, implementation, and evaluation of new services, products, and programs for educational agencies. Provided creative leadership to corporate committees to solicit ideas, identify goals and objectives, plan, develop, present, and evaluate professional development opportunities.

1995-1997 **Education Specialist, Education Service Center, Region One, Edinburg, Texas.** Served as member of Administrative Cabinet team in strategic planning, development of proposals and contracts, implementation, and evaluation of telecommunications capabilities, services, products, and programs for 40 school districts serving 283,000 students in 7 counties. Provided creative leadership to regional and state committees to solicit ideas, identify strategic goals and objectives, plan, develop, present, and evaluate funding opportunities and professional development for 400 librarians.

1993-1996 **Assistant Professor of Library Science, Sam Houston State University, Huntsville, Texas.** Served a faculty member teaching 400 graduate students in technical services (cataloging, bibliographic control, classification), automation, and networking. Participated in distance education program and coordinated annual conference. Conducted university and Texas Library Association-funded field research focused on library collection development and academic achievement.

1992-1993 **Head Librarian, Rocky Mountain College of Art & Design, Denver, Colorado.** Responsible for the daily operation, selection and acquisition of materials, formulation of policies for library operations, media center, and photography/slides archives. Designed and implemented library automation and delivery of electronic resources to college community.

1981-1985 **Development Officer, PRLC, Inc., Pittsburgh, Pennsylvania.** Served as senior member of corporate management team in strategic planning, development of proposals and contracts, implementation, and evaluation of new services, products, and programs for 100 institutional member organizations. Coordinated the development of proposals and contracts totaling $4,000,000 annually. Provided creative leadership to corporate committees to solicit ideas, identify goals and objectives, plan, develop, present, and evaluate professional development opportunities.

1981 **Director of Library Development, Pennsylvania Department of Education, Harrisburg, Pennsylvania.** Responsible for statewide development, technical assistance, professional development, resource sharing, children's services, institutional library services, networking, and state aid program for all libraries throughout the Commonwealth. Functioned as liaison to Governor's Advisory Council, LSCA Advisory Council, District Administrators, private colleges, universities, consortia managers, and network directors. Supervised $14,000,000 formula-based state aid program and $3,000,000 grant awards to individual libraries, consortia, and networks.

1978-1981 **Assistant Director, Southern Tier Library System, Corning, New York.** Coordinated operation of system-wide programs (technical assistance, professional development, resource sharing, technical services, outreach) to 40 public libraries in 5 counties serving 500,000 residents. Solicited ideas, identified goals, sponsored, and evaluated professional development opportunities and technical assistance sessions.

1976-1978 **Division Librarian for Technical Services, Corpus Christi Public Libraries, Corpus Christi, Texas.** Provided leadership in acquisitions, cataloging, serials control, and processing for main library and 4 branches serving 250,000 residents. Participated as senior member of library management team. Compiled and prepared technical evaluations, reports, and statistical analyses of Division operations to measure the achievement and cost of annual goals, objectives, and staff performance.

1975-1976 **System Coordinator, San Antonio Major Resource Center, San Antonio, Texas.** Served as senior member of the management team for District X Office, charged to provide technical assistance, resource sharing, media services, and professional development to librarians and staff representing 30 public library jurisdictions in 21 counties serving 1,500,000 residents. Functioned as liaison to System Director, staff, and members of governing bodies with the System Board of Directors and the Texas State Library and Historical Commission. Prepared LSCA grant applications and monitored awards totaling $1,100,000 annually.

1973-1975 **Bilingual Branch Librarian, San Antonio Public Library, San Antonio, Texas.** Worked as librarian providing reference, information, and readers' advisory services in branch serving 50,000 Spanish-speaking residents in southwest San Antonio. Participated in collection development and resource acquisition activities, specializing in children's work, Spanish language resources, and multicultural studies.

1972-1973 **Librarian, Holding Institute, Laredo, Texas.** Worked as high school librarian serving 500 boarding students in Spanish-speaking environment of private school. Provided reference, research assistance, and library instruction to students and 35 faculty members.

1966-1971 **Rockford Public Library, Rockford, Illinois.** Worked in branches as part-time as a Library Assistant, Clerk, and Page in city library serving 150,000 residents.

PUBLICATIONS

Editor-reviewed Monographs (Completed and in Progress)

Hall-Ellis, Sylvia D., and Mary Bolin. *Contemporary Cataloging in an RDA Environment: A Handbook for Students and Practitioners.* Chicago, IL: American Library Association. Under contract & In development.

RDA Testing: Lessons Learned and Challenges Revealed. Sylvia D. Hall-Ellis and Robert O. Ellett, Jr., eds. Binghamton, N.Y.: Haworth, 2012. 128 p.

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Hall-Ellis, Sylvia D., ed. "Standard III: The Faculty." In the *Library and Information Science Program Self-Study Document for Accreditation by the American Library Association.* Denver, Colo.: University of Denver, Morgridge College of Education, 2010. 22 p.

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Hall-Ellis-Sylvia D. "Job Design for Cataloging and Metadata Librarians." Submitted to *Journal of Library Administration.* In progress.

Hall-Ellis, Sylvia D. "The Relationship of Situational Leadership and the Dreyfus Model of Skill Acquisition for Supervisors in Cataloging and Metadata Services." To be submitted to *Library Resources and Technical Services.* In progress.

Hall-Ellis, Sylvia D. *The Relationship of Core Competencies on Learning Outcomes and Employers' Expectations for Catalog Librarians and Metadata Specialists.* To be submitted to the *Journal of Education for Library and Information Science.* In progress.

Hall-Ellis, Sylvia D. "Building Cataloger Competencies: The Dreyfus Model as a Prototype for the Education and Professional Development of Catalog Librarians and Metadata Specialists in Bibliographic Control." To be submitted to the *Cataloging & Classification Quarterly.* In progress.

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Hall-Ellis, Sylvia D. "Investment in Staff Development for Seeking External Grant Funds." *The Bottom Line 27*, no. 1 (January 2014): 22-25.

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Hall-Ellis, Sylvia D. *Grant Writing Tips and Resources.* Denver, Colo.: University of Denver, 2008-2014. http://portfolio.du.edu/grants

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Hall-Ellis, Sylvia D., guest editor, with Deborah S. Grealy, Clara L. Sitter, and Tassos Petrou. *Library Students' Voices in Colorado: An Issue of Colorado Libraries* 31:1 (Spring 2005).

Hall-Ellis, Sylvia D., ed. *Library and Information Science Program Self-Study Document for Accreditation by the American Library Association.* Denver, Colo.: University of Denver, College of Education, 2003. 125 p. with CD-ROM.

Hall-Ellis, Sylvia D. and Deborah S. Grealy, guest editors. *Library Education in Colorado: An Issue of Colorado Libraries* 29, no. 2 (Summer 2003).

Hall-Ellis, Sylvia D., ed. *Library and Information Science Program Self-Study Document for Accreditation by the American Library Association.* Denver, Colo.: University of Denver, College of Education, 2003.

Hall-Ellis, Sylvia D. "Adaptive Furniture for the ADA-Qualified: An Investigative Study." 2001. Unpublished manuscript.

Hall-Ellis, Sylvia D. "Cataloging Electronic Serials: A Study in User Access and Article Delivery." 2001. Unpublished manuscript.

Hall-Ellis, Sylvia D. "E-books: Acquisition and Circulation Issues in Public Libraries." 2001. Unpublished manuscript.

Hall-Ellis, Sylvia D. "Authority Control and Its Importance in School Library Media Online Catalogs." 1999. Unpublished manuscript.

Hall, Sylvia D. "Cooperation Improving Service in San Antonio System." *Texas Libraries* XXXVII (Spring 1976): 27-29.

Hall, Sylvia D. "Summer is Sea Monstrously Fun!" *Texas Library Journal* L (December 1974): 224-226.

Hall, Sylvia D. "A Brief Annotated Bibliography of Non-book Materials on the Mexican American." *Texas Library Journal* XLVIII (October 1972): 213-232.

Book Reviews

ALA Book of Library Grant Money. Ann Kepler, ed. 8th ed. Chicago, IL: American Library Association, 2011. 978-0-8389-1058-0, $175.00 [*Colorado Libraries,* June 2012]

Developing a Compensation Plan for Your Library. Paula M. Singer and Laura L. Francisco, comps. 2nd ed. Chicago, IL: American Library Association, 2009. 978-0-8389-0985-0, $57.00 [*Colorado Libraries,* March 2012]

Frugal Librarian. Carol Smallwood, ed. Chicago, IL: American Library Association, 2011. 978-0-83891-075-7, $42.00 [*Colorado Libraries,* February 2012]

Dowlin, Ken. *Getting the Money: How to Succeed in Fundraising for Public and Nonprofit Libraries.* Westport, Conn.: Libraries Unlimited, 2008. 978-1-59158-597-X, $50.00 [*Colorado Libraries,* February 2009]

Lundahl, Mats. *Bebo de Cuba; Bebo Valdés y Su Mundo*, by Mats Lundahl. Traducción de Linda Oakeshott Dragó. Barcelona: RBA Libros, 2008. 978-849-86-7259-6, $33.99 [*Críticas*, November 2008]

Bonelli, Florencia. *Marlene*, by Florencia Bonelli. Buenos Aires: Aguilar, Altea, Taurus, Alfaguara, 2008. 978-987-04-0995-3, $24.95 [*Críticas*, October 2008]

Keret, Etgar. Traducción de Ana María Bejarano. *Pizzería Kamikaze y Otras Relatos.* México, D.F.: Editorial Sexto Piso, 2008. 968-5679-29-0, no price given [*Críticas*, September 2008]

Littauer, Marita, and Florence Littauer. *Enriquece tu Comunicación. Miami, Fla.: Editorial Unilit, 2008.* 978-0-7899-1521-4, $11.99 [*Críticas*, August 2008]

Martínez, Guillermo. *La Muerte Lenta de Luciana B.* New York: Rayo Planeta, 2008. 978-0-06-156551-9, $14.95 [*Críticas*, May 2008]

Matthews, Joseph R. *The Evaluation and Measurement of Library Services.* Westport, Conn.: Libraries Unlimited, 2007. 978-1-59158-532-9, $50.00 [*Colorado Libraries,* April 2008]

Gómez-Jurado, Juan. *A Masacre de Virginia Tech: Anatomía de una Mente Torturada.* Barcelona: Ediciones El Andén, 2007. 978-84-935789-4-7, €16.50 [*Críticas*, February, 2008]

Matthews, Joseph R. *Library Assessment in Higher Education.* Westport, Conn.: Libraries Unlimited, 2007. 978-1-59158-531-2, $45.00 [*Colorado Libraries,* February 2008]

Chacón, Inma. *La Princesa India: Cuando el Viento Azul.* México: Alfaguara, 2006. 970-770398-9, $19.95 [*Críticas*, June 2006]

Vargas Llosa, Mario. *Israel/Palestina: Paz o Guerra Santa.* fotogs. by Morgana Vargas Llosa. Spain/U.S.: Aguilar: Santillana, 2006. 84-03-09691-7, paper, $19.95 [*Críticas*, May 2006]

Findlay, Diane. *Digging into Dewey.* Fort Atkinson, Wisc.: Upstart Books, 2005. 978-1-932146-18-9, $16.95 [*Colorado Libraries,* May 2006]

Pequeñas Resistencias 4: Antología del Nuevo Cuento Norteamericano y Caribeño. Menéndez, Ronaldo, Ignacio Padilla & Enrique del Risco, eds. Madrid**:** Páginas de Espuma, 2005. 84-95642-59-X, paper, $36.95 [*Críticas*, April 2006]

Rueda, André. *Vengo a Salvar a España: Biografía de Un Franco Desconocido.* Madrid**:** Nowtilus (Investigación Abierta), 2005. photogs., bibliog. 84-9763-202-8, paper, $23.95 [*Críticas*, March 2006]

Becerra, Ángela. *El Penúltimo Sueño.* 1st ed. Barcelona: Planeta, 2005. 84-08-05795-2, $25.95. [*Críticas*, January 2006]

Aguilar Camín, Héctor. *La Conspiración de la Fortuna.* 1st ed. México: Planeta, 2005. 970-37-0368-2, $19.95 [*Críticas*, October 2005]

México en Sus Libros. Enrique Florescano with Pablo Mijangos, editors & compilers. 1st ed. México, D.F.: Taurus Aguilar, 2004. 968-19-0783-3, $16.95 [*Críticas*, September 2005]

Historia Económica de México. Coordinator, Enrique Semo. México: Universidad Nacional Autónoma de México, Editorial Oceano de México, 2004. 13 vols. 970-32-0805+3 (obra completa), $9.25 each [*Críticas,* August 2005]

Czarnowsky, Christyne A. and Michael H. Williams. *Managing Your Wired Workforce: A Practical Guide.* Denver, Colo.: Bradford Pub., 2003. 1-883726-79-4, $24.95 [*Colorado Libraries,* 2004]

Abraham Lincoln. Colección Grandes Biografías. Madrid: Edimat Libros, 2003. 84-8403-858-0, €4.95 [*Críticas,* 2004]

Alponte, Juan María. *Colón: el Hombre, el Navegante, la Leyenda.* México, D.F.: Aguilar, 2003. 968-19-1260-8, $16.95 [*Críticas,* 2004]

Olcese Salvatecci, Alfieri. *Cómo Estudiar con Èxito: Téchnicas yHhábitos Para Aprender Major.* México, D.F.: Alfaomega Grupo Editor, 2002. 970-15-0764-9 [*Críticas,* 2003]

Mujeres Como Islas: Antología de Narradoras Cubanas, Dominicanas, Puertoriqueñas. Edición: Olga Marta Pérez, Thelma Jiménez, Andrés Blanco D., eds. Santo Domingo, República Dominicana: Ediciones Ferilibro, 2002. 959-209-419-5 [*Críticas,* 2003]

Tibol, Raquel. *Los Murales de Diego Rivera: Universidad Autónoma Chapingo.* México, D.F.: Editorial RM, Universidad Autónoma Chapingo, 2002. 968-5208-08-5 [*Críticas,* 2003]

Lindsay-Poland, John. *Emperors in the Jungle: the Hidden History of the U.S. in Panama.* Durham, N.C.: Duke University Press, 2003. 0-8223-3098-9, $18.95 [*Críticas,* 2003]

Kaplan, Allison G. and Ann Marlowe Riedling. *Catalog It! A Guide to Cataloging School Library Materials.* Worthington, Ohio: Linworth Pub., 2002. 1-58683-014-7, $44.95 [*Colorado Libraries,* 2002]

Bardach, Ann Louise. *Cuba Confidential: Love and Vengeance in Miami and Havana.* New York: Random, 2002. 0-375-50489-3, $25.95 [*Library Journal,* 2002]

Swan, James. *Fundraising for Libraries: 25 Proven Ways to Get More Money for Your Library.* New York: Neal Schuman, 2002. 1-55570-433-6, $69.95 [*Colorado Libraries,* 2002]

Puíg de Lange, Victoria. *Sol Con Agua.* Nashville, Tenn.: Editorial Vistazo/Ediciones Reio Negro, 2002. 0-9724506-0-2, $17.75 [*Críticas,* 2002]

The Encyclopedia of Latin American Politics. Edited by Diana Kapiszewski; assistant editor, Alexander Kazan. Westport, Conn.: Oryx Press, 2002. 1-57356-306-4, $74.95 [*Library Journal,* 2002]

Vargas Lizano, Isabel. *Y Si Quieres Saber de Mi Pasado.* Con la colaboración de J.C. Vales. Madrid: Santillana Ediciones Generales, S.L., 2002. 84-03-09278-4, $18.95 [*Críticas,* 2002]

Ruy Sánchez, Alberto. *Los Jardines Secretos de Mogador: Voces de Tierra.* México, D.F.: Alfaguara, S.A., 2001. 968-19-0879-1, $16.95 [*Críticas,* 2002]

Chávez, Ricardo and Celso Santajuliana. *El Final de las Nubes.* Barcelona: RBA Libros, S.A., 2001. 84-7901-760-0, $11.95 [*Críticas,* 2002]

The Power of Language / El Poder de la Palabra: Selected Papers from the Second REFORMA National Conference. Edited by Lillian Castillo-Speed and the REFORMA National Conference Publications Committee. Englewood, Colo.: Libraries Unlimited, 2001. 1-563089459, $35.00 [*Colorado Libraries,* 2001]

Martínez, Rubén. *Crossing Over: A Mexican Family on the Migrant Trail.* Metropolitan: Holt, 2001. 0-8050-4908-8, $26.00 [*Library Journal*, 2001]

Guevara, Ernesto "Che." *The African Dream: the Diaries of the Revolutionary War in the Congo.* Translated from the Spanish by Patrick Camiller. With an introduction by Richard Gott and a foreword by Aleida Guevara March. New York: Grove Press, 2001. 0-8021-3834-9, $13.00 [*Library Journal*, 2001]

Cooper, Gail and Garry Cooper. *New Virtual Field Trips.* Englewood, Colo.: Libraries Unlimited, 2001. 1-56308-887-8, $27.50 [*Colorado Libraries,* 2001]

NATIONAL SERVICE & PROFESSIONAL AFFILIATIONS

American Library Association, Life Member

Association for Library Collections & Technical Services (now CORE)
Cataloging, Classification, and Metadata Section
Margaret Mann Citation Committee, 2023-
ALCTS Editorial Board, Member, 2015-2019
Committee on Cataloging: Description and Access, Member, 2008-2012
Test Site for RDA, Manager, 2009-2011
Nominating Committee, Member, 2007-2008
Committee for Education and Training of Catalogers, Chair, 2006-2007, Member, 2003-2007
Competencies & Education for a Career in Cataloging Interest Group, Chair, 2010-2012; Member, 2010-
President's Program Committee, 2015-2016
Education Committee, Member, 2005-2007
Task Force on Competencies and Education for a Career in Cataloging, Chair, 2007-2009
2007 Annual Meeting Pre-conference, "What They Don't Teach in Library School: Competencies, Education and Employer Expectations for a Career in Cataloging," Steering Committee Chair
Fundraising Committee, Member, 2004-2006
Office of Diversity
Committee on Diversity, Chair, 2010-2011
Diversity Research Advisory Committee, Member, 2009-2010
Spectrum Scholar Mentor, 2009
Diversity Grants Review Committee, Member, 2007, 2010, 2012
Office of Statistics and Research
Research and Statistics Committee, Member, 2005-2007; Intern, 2003-2005
Library Research Round Table
Nominating Committee, 2022-2023
Membership Committee, 2019-2021
Board of Directors, Member At-Large, 2009-2012
Office of Accreditation
Accreditation Panel Member (training completed 2004)
Accreditation Review Panel Member (training completed 2004)

REFORMA, Life Member

National Board of Directors, 2005-2013
National Fundraising Chair, 2005-2013
National Recruiting and Mentoring Committee, 2008-2010
Colorado Chapter, Secretary, 2004-2005
Colorado Chapter Liaison to National Board of Directors, 2004-2013

American Association of Law Libraries (AALL), Life Member Online Audiovisual Catalogers Association (OLAC) Colorado Association of Law Librarians (CoALL)

American Association of University Women Association for Library and Information Science Education (ALISE)

University of Denver ALISE Representative, 2003-2008; 2010-2011
Membership Advisory Committee, 2007-2010
Technical Services Education Special Interest Group, 2003-
Garfield Doctoral Dissertation Award Reviewer, 2012
Garfield Doctoral Dissertation Scholarship Reviewer, 2014

American Association of University Professors (AAUP), 2006-

American Grant Writers Association, 2014- Grant Professionals Institute, 2016- National Grants Management Association, 2014-

Grant Reviewer (National and Regional Team Leader), U.S. Department of Education, 1998- Grant Reviewer, Broadband Technologies Opportunity Program, U.S. Department of Commerce, 2009
Grant Reviewer, Institute of Museum and Library Services, 1998-2000
Grant Reviewer, Colorado Department of Education, 2014-
Grant Reviewer, Colorado State Library, 1998-
Grant Reviewer, American Association of Community Colleges *Working Connections* program, 1999
Peer Reviewer, *Journal for Library and Information Science Education,* 2005-
Peer Reviewer, *Journal of Library Metadata,* 2009
Peer Reviewer, *International Journal of Library and Information Science,* 2011
Regular Columnist, *The Bottom Line*, 2013-2016
Book Reviewer, *Library Journal*, 2001
Book Reviewer, *Críticas*, 2002-2009
Book Reviewer, *Colorado Libraries,* 2000-2012

REGIONAL SERVICE & PROFESSIONAL AFFILIATIONS

Mountain Plains Library Association

Professional Development Grants Committee, Member, 2005-2006
Professional Development Policy and Guidelines Sub-committee Chair, 2006

Colorado Association of Libraries

"Student Voices" Column Editor, *Colorado Libraries,* 2005-2006
Conference Planning Committee, Member, 2002
Technical Services and Automation Division, Chair, 2002-2003; Member, 2000-
Academic Libraries Division, Peer Review Conference Papers Committee, Member, 2007-2009
Education Committee, Member, 1988-1993
Diverse Populations Committee, Member, 2009-2013

SERVICE TO THE UNIVERSITY OF DENVER

Center for Teaching and Learning Faculty Advisory Board, 2007-2008; 2010-2012
Center for Community Engagement and Service Learning Advisory Board, 2007-2012
Faculty Senate
Executive Committee, 2008-2013
Nominations, Rules & Credentials Committee, Chair, 2008-2013; Member 2007-2013
Appointment, Promotion, and Tenure Revision Committee, 2010-2012
Grievance Policy Committee Member, 2007-2010
Law Library Director Search Committee Chair, 2012-2013
PROF Grant Review, College Representative to the University Review Team, 2006, 2008
Project Homeless Connect Evaluations, Principal Investigator, 2006-2009
University Technology Council, 2007-2009
University of Denver Hyde Interviews for Incoming Freshmen, 2003-2012

SERVICE TO THE MORGRIDGE COLLEGE OF EDUCATION

Appointment, Tenure & Review Committee
Member, voting, 2003-2005; 2007- 2009
Chair, Clinical Faculty Promotion & Tenure Policy Subcommittee, 2008-2009
Member, Community Engagement Subcommittee, 2007-2009
Member, Tenure Review Panel, 2003
Advancement and Alumni Relations Committee, Chair, 2003-2007; Member, 2002-2007
College Building Committee Member, 2004-2010

College of Education Student Association, Faculty Advisor, 2004-2007; 2009-2010
Faculty Senator, 2007-2013
Research and Scholarship Committee, Chair, 2008-2009; Member, 2002-2003, 2008-2009
Research and Grant Mentoring Committee, Chair, 2009-2010
Research Task Force Member, 2010-2012
Search Committee Member, Assistant Professor for Curriculum & Instruction, 2010-2011
Workload Task Force Member, 2010-2011

SERVICE TO THE LIBRARY & INFORMATION SCIENCE PROGRAM

Library and Information Science Student and Alumni Association, Faculty Advisor, 2002-2008
ALA Student Chapter, Faculty Advisor, 2005-2008
Beta Phi Mu Phi Chapter, Faculty Advisor, 2004-2014
Steering Committee Member, Accreditation by the American Library Association, 2001-2004
Search Committee Member, Associate Professor for LIS, 2006
Search Committee Chair, Assistant Professors for LIS, 2003, 2005, 2006, 2007
Search Committee Ex-Officio Member, Director for LIS, 2004

SERVICE TO SAM HOUSTON STATE UNIVERSITY

Rio Roundup: South Texas Literature Conference, Conference Coordinator, 1993
External Relations, Fund Raising, Grants Committee, Chair, 1993-1995
Advisory Council Committee, Chair, 1993-1995
Students, Admissions, and Advisement Committee, Chair, 1994
Institutional Effectiveness Committee, Member, 1993-1995

SERVICE TO THE COLLEGE OF EDUCATION AND APPLIED SCIENCE

Faculty Affairs Committee, Member, 1993-1995
Curriculum Committee, Member, 1993-1995
Continuing Education Committee, Member, 1993-1995

SERVICE TO THE COMMUNITY

French Teacher & Student Exchange with Laon, France, Monarch High School, Boulder Valley School District (Boulder, Colorado), 2017-
Denver/Boulder Games 2022, Board of Directors, Secretary-Treasurer, 2015-2018
United Way Campaign Committee, College of Education, 2006
Arapahoe County, Election Judge for the County Clerk and Recorder, 2000-2005
Arthritis Foundation, Rocky Mountain Chapter, Certified Educator & Trainer, 1999-2008
Bonfils Blood Center, Silver Level Donor, 2000-2016
Denver Museum of Natural History, Docent, 1992
Tech Prep of the Lower Rio Grande Valley, Inc. (Harlingen, Texas) Board of Directors, 1995-1997
Executive Committee, 1996-1997; Chair, Development Committee, 1995-1997; Chair, Fiscal Agency Committee, 1995-1996; Chair, Colleges and Universities Committee, 1996-1997
Gilpin County (Colorado) Public Library Board of Trustees, 1986-1989; Vice President, 1987-1989
City of Central (Colorado) Economic Development Committee, 1987-1989
Columbine Family Health Centers, Inc. (Nederland and Black Hawk, Colorado) Board of Directors, 1988-1989

CERTIFICATION

Permanent Public Librarian Certificate - Pennsylvania, New York, Texas
Westlaw Expert Witness, 2008-
Certified Grant Writer®, 2016-

AWARDS AND HONORS

Advanced Practitioner for Service Learning and Community Engagement, University of Denver, 2011
Platinum Star Alumnae, College of Information, Library Science & Technologies, University of North Texas, 2009
Commendation for Integration of Technologies in Teaching & Learning Environment, University of Denver, 2006
Outstanding Adjunct Faculty Member Award, College of Education, University of Denver, 2002
Beta Phi Mu, Pi, University of Pittsburgh, 1985
Alpha Lambda Sigma, University of North Texas, 1972
Albert Nelson Marquis Lifetime Achievement Award, Who's Who in America
Who's Who in American Women
Who's Who of Women Executives
Dictionary of International Biography
Who's Who in the East
Who's Who in the South and Southwest
Who's Who in the World
Who's Who of Online Professionals
Who's Who in Library and Information Science
2,000 Notable Women
Who's Who of Emerging Leaders
Who's Who in Professional and Executive Women
Who's Who in American Education
International Who's Who of Professional and Business Women
International Leaders in Achievement
International Educator of the Year
Who's Who in Finance and Industry
Who's Who in Finance and Business

Invited International and National Conference Presentations

Hall-Ellis, Sylvia D. *Presentation of the Robert O. Ellett Endowed Scholarship.* Presentation delivered to the School of Information at San Jose State University Alumni & Student Program, American Library Annal Conference, San Diego, Calif., June 29, 2024.

Driscoll, Margaret, Christy Confetti Higgins, Scott Brown, and Sylvia D. Hall-Ellis. *A View from Within: Open House Tour of Three Canvas Core Courses*. Presentation to be delivered at the School of Information, San José State University Professional Development Seminar, San José, California, October 17, 2019.

Hall-Ellis, Sylvia D. *Invest in Me -- I'm Your Future: Succession Planning for Libraries.* Keynote presentation delivered at the ALCTS President's Symposium, Boston, Mass., January 8, 2016.

Seidel, Kent E. and Sylvia D. Hall-Ellis. *Making Grants Work for You: Strategies for Doctoral Students and Early Career Scholars.* Presentation delivered at the University Council for Educational Administration, Early Career Scholars Session, Indianapolis, Ind., November 9, 2013.

Hall-Ellis, Sylvia D. *So You Want to be a Manager; Leadership Skills and Competencies for Technical Services Managers and Administrators.* Presentation delivered at the 138th Annual Conference, American Library Association, Chicago, Ill., June 29, 2013.

Seidel, Kent E., Karen S. Riley, Lyndsay Agans, Susan Korach, and Sylvia D. Hall-Ellis. *Making Grants Work for You (Instead of Just Working for Grants).* A panel discussion delivered at the University Council for Educational Administration, Early Career Scholars Session, Denver, Colo., November 17, 2012.

Hall-Ellis, Sylvia D. *After the Great TS Reorganization: The Westminster Law Library.* Presentation delivered at the 137th Annual Conference, American Library Association, Anaheim, Calif., June 23, 2012.

Hall-Ellis, Sylvia D. *Conversations with Catalogers in the 21st Century.* A panel discussion sponsored by the ALCTS Competencies for a Career in Cataloging Interest Group, delivered at the 137th Annual Conference, American Library Association, Anaheim, Calif., June 22, 2012.

Hall-Ellis, Sylvia D., moderator. *Mid-Career Leaders Program.* A panel discussion sponsored by the ALA Committee on Diversity delivered at the 136th Annual Conference, American Library Association, New Orleans, La., June 26, 2011.

Hall-Ellis, Sylvia D., moderator. *Diversity Town Hall.* A community conversation sponsored by the ALA Committee on Diversity delivered at the 136th Annual Conference, American Library Association, New Orleans, La., June 24, 2011.

LaBarre, Kathryn, Sylvia D. Hall-Ellis, Karen Anderson, Rick Hasenyager, Christopher Cronin, and Penny Baker. *Briefings from RDA Test Participants.* A panel discussion delivered at the Midwinter Conference, American Library Association, San Diego, Calif., January 7, 2011.

Miksa, Shawne, Marjorie Bloss, and Sylvia D. Hall-Ellis. *Educating the Next Generation of Catalogers: Teaching RDA.* A panel discussion delivered at the 97th Annual Conference, Association for Library and Information Science Education, San Diego, Calif., January 7, 2011.

Hall-Ellis, Sylvia D., Robert Maxwell, John Hostage, and George Prager. *RDA Panel: What Cataloging Managers Need to Know.* Presentation delivered at the 103rd Annual Conference, American Association of Law Librarians, Denver, Colo., July 12, 2010.

Hall-Ellis, Sylvia D. and Stacey L. Bowers. *Catalogers in the RDA Environment: Skill Sets, Expectations and Challenges.* Presentation delivered at the 103rd Annual Conference, American Association of Law Librarians, Denver, Colo., July 11, 2010.

Hall-Ellis, Sylvia D. *Comfortable in Your Cataloging and Metadata Specialist Skin? Or, So You Want to Hire a Cataloger.* Presentation delivered to the ALCTS Research Group at the 134th Annual Conference, American Library Association, Chicago, Ill., July 11, 2009.

Perez, Megan, Sylvia D. Hall-Ellis, and Denise Anthony. *From Novice to Expert: Collaboration for Succession Planning.* A "hot topic" presentation delivered at the 14th ACRL Conference, Seattle, Wash., March 13, 2009.

Hall-Ellis, Sylvia D. *Cataloging in the RDA Environment: Skill Sets, Expectations and Challenges.* Presentation delivered to the ALCTS Research and Publications Committee at the Midwinter Conference, American Library Association, Denver, Colo., January 24, 2009.

Hall-Ellis, Sylvia D. *LIS Cataloging Education for the 21st Century: Expectations and Challenges.* A panel discussion held at the 95th Annual Conference, Association for Library and Information Science Education, Denver, Colo., January 23, 2009.

Chu, Clara, Sylvia D. Hall-Ellis, and Mark Winston. *The Doctoral Degree & Building a Career.* A panel discussion delivered at the ALA Office of Diversity Spectrum Doctoral Fellows E.J. Josey Leadership Institute, Midwinter Conference, American Library Association, Denver, Colo., January 20, 2009.

Hall-Ellis, Sylvia D. and Robert O. Ellett, Jr. *Fundamentals of Cataloging Course: An Overview of the ALCTS Online Course.* Presentation delivered to the ALCTS Big Heads Group, 133rd Annual Conference, American Library Association, Anaheim, Calif., June 30, 2008.

Hall-Ellis, Sylvia D. *Employers' Expectations for Technical Services Librarians: What We Don't Know.* Presentation delivered to the ALCTS Research and Publications Committee Program, 133rd Annual Conference, American Library Association, Anaheim, Calif., June 28, 2008.

Hall-Ellis, Sylvia D., Virginia R. Maloney, and Mary Stansbury. *Institutional Responses to Engaged Scholarship: The Carnegie Foundation Engaged University Classification at Two Universities.* Presentation delivered to the 94th Annual Conference, Association for Library and Information Science Education, Philadelphia, Pa., January 11, 2008.

Hall-Ellis, Sylvia D. *Puzzles, Problems, and Predicaments.* Presentation delivered to the ALCTS Research Discussion Group, 132nd Annual Conference, American Library Association, Washington, D.C., June 23, 2007.

Hall-Ellis, Sylvia D. *Cataloging Education: A New Emphasis for the Library and Information Science Curriculum.* Presentation delivered to the ALCTS Pre-conference, 132nd Annual Conference, American Library Association, Washington, D.C., June 22, 2007. http://www.loc.gov/catdir/cpso/careercat.html

Ellett, Jr., Robert O. and Sylvia D. Hall-Ellis. *Copy Cataloging Done Smarter.* Presentation delivered to the International Conference on Interdisciplinary Information Sciences and Technologies (InSciT2006), October 25-28, 2006.

Hall-Ellis, Sylvia D. and Robert O. Ellett, Jr. *Cooperative Cataloging: Challenges and Opportunities for Defense Libraries.* Presentation delivered to the 1st Annual Conference of Defense Libraries, Spanish Ministry of Defense, Madrid, Spain, July 7, 2006.

Hall-Ellis, Sylvia D. *Cataloger Competencies: Do the Employers Require What the Professors Teach?* Presentation delivered to the ALCTS CCS Heads of Cataloging Discussion Group, 131st Annual Conference, American Library Association, New Orleans, La., June 26, 2006.

Grealy, Deborah S. and Sylvia D. Hall-Ellis. *From Research to Practice: The Scholarship of Teaching and Learning in LIS Education.* Presentation delivered to the at the 92nd Annual Conference, Association for Library and Information Science Education, San Antonio, Tex., January 18, 2006.

Hall-Ellis, Sylvia D. *Employers' Expectations for Entry-Level Catalogers: What Position Announcement Data Indicate.* Research paper delivered to the Technical Services Special Interests Group, 91st Annual Conference, Association for Library and Information Science Education, Boston, Mass., January 12, 2005. http://dlist.sir.arizona.edu/

Hall-Ellis, Sylvia D. *Common Errors in MARC Records Prepared by LIS Students: What Does It Mean?* Research paper delivered to the ALCTS CCS Cataloging Norms Discussion Group, Mid-Winter Conference, 90th American Library Association, San Diego, Calif., January 10, 2004.

Hall-Ellis, Sylvia D. *Visual Arts as Foundation for Successful Library Automation: The Rocky Mountain College of Art & Design Experience.* Paper delivered at the 6th Annual Conference of Higher Education, Charleston, S. C., 1993.

Hall, Sylvia D. *Design Elements for Bibliographic Databases: An Overview.* Paper delivered at the 14th Online National Conference, New York, 1983.

Invited Regional Conference Presentations

Hall-Ellis, Sylvia D., Hudson, Christopher D., Brittany Cronin, and Kathryn Michaels. "The Colorado Law Project: Meeting the Public's Need for Legal Information." Panel discussion delivered at the Mountain Plains Library Association Conference, Billings, Mont., April 9, 2011.

Grealy, Deborah S. and Sylvia D. Hall-Ellis. *Education for Information Professionals in New Mexico: Library & Information Science Graduate Education at the University of Denver.* Presentation delivered at the New Mexico Library Education Summit, Las Vegas, N.M., September 26, 2005.

Hall-Ellis, Sylvia D. *Public Library-School Library Partnerships.* Presentation delivered at the 3rd Annual Colorado Association of Libraries Conference with the Mountain Plains Library Association, Denver, Colo., October 22, 2004.

Hall-Ellis, Sylvia D. *Learn All You Can – Educational Partnership Opportunities for the Lewis and Clark Bicentennial Commemoration.* Paper delivered at the 3rd Annual Lewis and Clark Bicentennial Council National Planning Conference, Bismarck, N.D., April 26, 1998.

Invited State Conference Presentations

Grealy, Deborah S. and Sylvia D. Hall-Ellis. *Academic Library Leadership Changes: Using Succession Planning and Mentoring*. Presentation delivered at the Minnesota Library Education Conference, St. Cloud, Minn., October 10, 2013.

Hall-Ellis, Sylvia D., Merrie Valliant, and Melissa Powell. *RDA: What Is It and What Do You Need To Do With It At Your Library?* Presentation delivered at the Colorado Library Consortium Spring Conference, Ft. Morgan, Colo., April 26, 2013.

Hall-Ellis, Sylvia D. *Service Learning and the Library & Information Science Graduate Education at the University of Denver.* Presentation delivered at the 4th LEADS Scholars Orientation, Denver, Colo., August 5, 2009.

Hall-Ellis, Sylvia D. *Service Learning: Enhancement to Library & Information Science Graduate Education at the University of Denver.* Presentation delivered at the 3rd LEADS Scholars Orientation, Denver, Colo., June 2008.

Hall-Ellis, Sylvia D. *Law Librarianship: A Community Conversation.* Sponsored by the Colorado Association of Law Libraries. Paper delivered at the Colorado Supreme Court Library, Denver, Colo., May 14, 2008.

Hall-Ellis, Sylvia D. *Opportunities and Challenges in Law Librarianship: A Community Conversation.* Presentation delivered at the Sturm College of Law, Denver, Colo., November 7, 2007.

Ellis, Sylvia D. *Grant Writing Resources for Nursing Professionals.* Presentation delivered at the Presbyterian / St. Luke's Health One Medical Center 1st Annual Research Symposium, Denver, Colo., October 17, 2007.

Hall-Ellis, Sylvia D. *Project Homeless Connect 4 Event Evaluation – Insights and Lessons Learned.* Presentation delivered at the Homelessness Research Symposium: What is DU Doing about Homelessness in Denver, Denver, Colo., September 14, 2007.

Hall-Ellis, Sylvia D. *Service Learning and the Library & Information Science Graduate Education at the University of Denver.* Presentation delivered at the 2nd LEADS Scholars Orientation, Denver, Colo., August 10, 2007.

Hall-Ellis, Sylvia D. *Education for Information Professionals in a Digital Environment: Library & Information Science Graduate Education at the University of Denver.* Presentation delivered at the 15th Spring Mountains and Plains Parapros Conference, Denver, Colo., February 24, 2007.

Hall-Ellis, Sylvia D. *Public Library Service to Spanish-Speaking and Latino Residents in Denver: A Case Study.* Presentation delivered at the 4th Annual Colorado Association of Libraries Conference, Denver, Colo., November 10, 2005.

Hall-Ellis, Sylvia D. *Education for Information Professionals in a Digital Environment: Library & Information Science Graduate Education at the University of Denver.* Presentation delivered at the 14th Annual Mountains and Plains Parapros Conference, Aurora, Colo., July 29, 2005.

Hall-Ellis, Sylvia D. *Educational Opportunities: Library & Information Science Graduate Education at the University of Denver.* Presentation delivered at the 13th Annual Mountains and Plains Parapros Conference, Centennial, Colo., August 6, 2004.

Hall-Ellis, Sylvia D. *Library Education & Training: Focus on the West: An LIS Faculty Member's Personal Response*. Presentation delivered at the 1st Annual Colorado Association of Libraries Conference, Keystone, Colo., October 18, 2002.

Hall-Ellis, Sylvia D. *Grant Writing for School Librarians.* Presentation delivered at the 2002 Annual Colorado Education Media Association Conference, Colorado Springs, Colo., February 15, 2002.

Hall-Ellis, Sylvia D. *Grants – Opportunities for the Future.* Paper delivered at the Southeast Regional Accountability Annual Conference, Lamar, Colo., November 12, 1998.

Hall-Ellis, Sylvia D. *The Texas Library Connection and Interlibrary Loan: An Experiment in Resource Sharing.* Paper delivered at the Texas Computer Educators' Association Annual Conference, Austin, Tex., February 6, 1997.

Hall-Ellis, Sylvia D. *Finding Grant Sources on the Internet: A Guide for Librarians.* Paper delivered at the 2nd Annual Institute for School Library Personnel, Pharr-San Juan-Alamo North High School, Pharr, Tex., July 29, 1996**.**

Hall-Ellis, Sylvia D. *Mathematical and Logical Thinking: A Critical Intelligence.* Paper delivered at the 3rd Annual Paraprofessional Conference at the University of Texas - Pan American, Edinburg, Tex., March 8, 1996.

Hall-Ellis, Sylvia D. *Cataloging Trends and Issues: Update Session.* Paper delivered at the 1st Annual Institute for School Library Personnel, South Texas Community College, McAllen, Tex., July 19, 1995.

Hall-Ellis, Sylvia D. *Grant Writing: Tips and Encouragement for School Librarians.* Paper delivered at the 1st Annual Institute for School Library Personnel, South Texas Community College, McAllen, Tex., July 18 and 19, 1995.

Hall-Ellis, Sylvia D. *How to Become an Expert Grant Writer.* Paper delivered at the 3rd Annual High School Principals' Academy, South Padre Island, Port Isabel, Tex., June 19, 1995.

Texas Library Study: Results from Regions I and II. Paper delivered at the 3rd Annual Technology Conference, Texas A&M University, College Station, Tex., November 18, 1994.

Hall-Ellis, Sylvia D. *Academic Achievement and Middle School Students.* Paper delivered at the 8th Annual Young Adult Conference, Sam Houston State University, Huntsville, Tex., November 5, 1994.

Hall-Ellis, Sylvia D. *Multimedia Resources for Library Leaders.* Paper delivered at the Institute for Librarians in A Multicultural Environment, Sam Houston State University, Huntsville, Tex., June 10, 1994.

Hall-Ellis, Sylvia D. *Finding the Resource: Empowering the User, or, the Case for Curriculum Based Subject Access to Learning Resource Center Collections.* Paper delivered at the 81st Annual Texas Library Association Conference, Corpus Christi, Tex., April 12-16, 1994.

Hall-Ellis, Sylvia D. and William H. Pichette. *Sam Houston State University Makes Use of OCLC/AMIGOS Collection Analysis CD.* Paper delivered at the 81st Annual Texas Library Association Conference, Corpus Christi, Tex., April 12-16, 1994.

Hall, Sylvia D. *Funding and Library Development in Pennsylvania: A Symbiotic Relationship.* Paper delivered at the Annual Graduate Student Colloquia, University of Pittsburgh, School of Library and Information Science, 1982.

Hall, Sylvia D. *Leadership for Public Library Trustees.* Paper delivered for the Trustees Division, Pennsylvania Library Association Annual Conference, Lancaster, Penn., 1981.

Seminar and Professional Development Presentations

Taylor, Meredith, and Sylvia D. Hall-Ellis. *Talent Management and Succession Planning.* ALCTS eForum, held March 22, 2017.

Hirsh, Sandra, Heather O'Brien, Michelle Holschuh Simmons, Michael Krasulski, and Sylvia D. Hall-Ellis. *Information Services Today: An Introduction. Part 3: Information Services: Roles in the Digital Age*. Rowan and Littlefield in partnership with Library Journal webinar, recorded February 5, 2015.

Hall-Ellis, Sylvia D. and Jennifer Sweda. *Copy Cataloging in an RDA Environment.* ALCTS eForum, held May 14 and 15, 2013.

Hall-Ellis, Sylvia D. *Law Librarianship: A Community Conversation.* Sponsored by the Colorado Association of Law Libraries, presented at the Colorado Supreme Court Library, Denver, Colo., May 14, 2008.

Hall-Ellis, Sylvia D. and Beatrice Z. Gerrish. *Reading and Libraries: Recent Research in Reading.* Presentation at the Ricks Center for Gifted Education, Denver, Colo., March 4, 2008.

Hall-Ellis, Sylvia D. *Cataloger Competencies: Do the Employers Require What the Professors Teach?* Presentation for the School of Library and Information Science, San José State University, February 12, 2008.

Hall-Ellis, Sylvia D. and Robert O. Ellett, Jr. *Cooperative Cataloging: Rules, Tools, and Conventions for Building a Multi-institutional Catalog.* Sponsored for the Spanish Ministry of Defense, Madrid, Spain, July 10, 2006.

Hall-Ellis, Sylvia D. *Cash for Kids: Grant Writing Opportunities for Youth Services Librarians.* Sponsored by the Colorado Young Adult Librarians; presented at Bemis Memorial Library, Littleton, Colo., November 13, 2002.

Hall-Ellis, Sylvia D. *MARC Records and Authority Control: Planning for Bibliographic Database Migration.* Sponsored and held at the Douglas County Public Library, Castle Rock, Colo., May 28, 2002.

Grant Writing: A Refresher for Librarians. Sponsored by Library and Information Science Program, College of Education, University of Denver; presented at University Center at Chaparral, August 12, 2000.

Hall-Ellis, Sylvia D. *Shaking the Money Tree – Basic Grant Writing for Colorado Educators.* Sponsored by the Office of Educational Telecommunications of the Colorado Department of Education.
Pikes Peak Community College, Colorado Springs, Colo., November 16, 1998.

Pueblo School District 60, Pueblo, Colo., November 12, 1998.
University of Northern Colorado, Greeley, Colo., November 10, 1998.
United Technology Educational Partnership, Grand Junction, Colo., November 9, 1998.

Hall-Ellis, Sylvia D. *Cataloging Multimedia, Kits, Globes and Map Materials in USMARC.* Sponsored and hosted by Region One Education Service Center, Edinburg, Tex., April 24, 1997 and December 12, 1996.

Hall-Ellis, Sylvia D. *New Standards for School Library Media Centers.* Sponsored and hosted by Region One Education Service Center, Edinburg, Tex., April 15, 1997.

Hall-Ellis, Sylvia D. *The School Library Media Specialist in the 21st Century: Visions for the Future.* Sponsored and hosted by Pharr-San Juan-Alamo Independent School District, Pharr, Tex., April 4, 1997.

Hall-Ellis, Sylvia D. *Cataloging Sound Recordings and Audio Materials in USMARC.* Sponsored and hosted by Region One Education Service Center, Edinburg, Tex., March 20, 1997 and November 21, 1996.

Hall-Ellis, Sylvia D. *Evaluating and Selecting CD-ROMS for School Library Media Collections.* Sponsored and hosted by Region One Education Service Center, Edinburg, Tex., March 18, 1997.

Hall-Ellis, Sylvia D. *Cataloging Audiovisual Materials in USMARC.* Sponsored and hosted by Region One Education Service Center, Edinburg, Tex., February 27, 1997, November 7, 1996 and October 24, 1996.

Hall-Ellis, Sylvia D. *Introduction to Dialog: Basic Searching Strategies.* Sponsored and hosted by Region One Education Service Center, Edinburg, Tex., February 14, 1997.

Hall-Ellis, Sylvia D. *Cataloging Books in USMARC.* Sponsored and hosted by Region One Education Service Center, Edinburg, Tex., January 30, 1997, October 10, 1996, September 26, 1996 and August 8, 1996.

Hall-Ellis, Sylvia D. *Advanced Internet Searching Techniques for Librarians.* Sponsored and hosted by Region One Education Service Center, Edinburg, Tex., January 21, 1997.

Hall-Ellis, Sylvia D. *Texas Library Connection Full-Text Searching.* Sponsored and hosted by Region One Education Service Center, Edinburg, Tex., December 13, 1996 and October 25, 1996.

Hall-Ellis, Sylvia D. *Developing Evaluation Strategies for Grants and Proposals.* Sponsored and hosted by Region One Education Service Center, Edinburg, Tex., December 10, 1996.

Hall-Ellis, Sylvia D. *Developing Needs Assessment for Grants and Proposals.* Sponsored and hosted by Region One Education Service Center, Edinburg, Tex., November 12, 1996.

Hall-Ellis, Sylvia D. *Texas Library Connection Union Catalog Searching.* Sponsored and hosted by Region One Education Service Center, Edinburg, Tex., November 8, 1996 and September 6, 1996.

Hall-Ellis, Sylvia D. *Grant Resources on the Internet.* Sponsored and hosted by Region One Education Service Center, Edinburg, Tex., October 23, 1996.

Hall-Ellis, Sylvia D. *Preparing a Response to the Telecommunications Infrastructure Fund Board: Needs Assessment, Professional Development Framework, and Evaluation Strategies.* Sponsored and hosted by Region One Education Service Center, Edinburg, Tex., October 16, 1996.

Hall-Ellis, Sylvia D. *Texas Library Connection: Building the Districtwide Bibliographic Database.* Sponsored and hosted by Mercedes Independent School District, Mercedes, Tex., September 13, 1996 and August 8, 1996. Sponsored and hosted by Los Fresnos Consolidated Independent School District, Los Fresnos, Tex., August 12, 1996.

Hall-Ellis, Sylvia D. *School-to-Work and Special Education: An Inclusive Partnership for Success.* Sponsored and hosted by the Office of Special Education, Region One Education Service Center, Edinburg, Tex., September 11, 1996.

Hall-Ellis, Sylvia D. *Telecommunications Infrastructure Fund Board: An Overview of Funding for Secondary Schools.* Sponsored and hosted by Region One Education Service Center, Edinburg, Tex., August 31, 1996.

Hall-Ellis, Sylvia D. *Cataloging Books, Multimedia, and Realia in USMARC.* Sponsored and hosted by Edinburg Consolidated Independent School District, Edinburg, Tex., August 6, 1996.

Hall-Ellis, Sylvia D. *Internet Resources for Grant Writers.* Sponsored and hosted by Region One Education Service Center, Edinburg, Tex., April 20, 1996.

Hall-Ellis, Sylvia D. *Enhanced Grant Writing Skills for Mathematics Educators: Writing Skills for Campus Teams.* Sponsored and hosted by the Office of General Education, Region One Education Service Center, Edinburg, Tex., March 22, 1996.

Hall-Ellis, Sylvia D. *Internet Resources for Grant Writers.* Sponsored and hosted by the College of Education and Applied Science, Sam Houston State University, Huntsville, Tex., March 9, 1996.

Hall-Ellis, Sylvia D. *Grant Writing for Mathematics Educators: A Development Process for Campus Teams.* Sponsored and hosted by the Office of General Education, Region One Education Service Center, Edinburg, Tex., March 4, 1996.

Hall-Ellis, Sylvia D. *Shaking the Money Tree: Preparing Successful Technology Grant Applications.* Sponsored and hosted by the Office of Technology and Media Services, Region One Education Service Center, Edinburg, Tex., February 29, 1996 and April 29, 1996.

Hall-Ellis, Sylvia D. *District-wide Technology Planning: Technical Assistance for the Texas Education Agency Initiative.* Sponsored and hosted by the Office of Technology and Media, Region One Education Service Center, Edinburg, Tex., February 2, 1996.

Hall-Ellis, Sylvia D. *Enhanced Grant Writing Skills.* Sponsored and hosted by Pharr-San Juan-Alamo Independent School District, Pharr, Tex., January 27, 1996.

Hall-Ellis, Sylvia D. *United States Copyright Act of 1976, Video Transmissions, Computer Software and the Internet.* Sponsored and hosted by the Office of Technology and Media, Region One Education Service Center, Edinburg, Tex., January 24, 1996.

Hall-Ellis, Sylvia D. *The Grant Writing Development Process.* Sponsored and hosted by Pharr-San Juan-Alamo Independent School District, Pharr, Tex., January 20, 1996.

Hall-Ellis, Sylvia D. *MARC Cataloging of Materials for Library Media Centers.* Sponsored and hosted by the Office of Media Services, Region One Education Service Center for the Donna Independent School District, Donna, Tex., August 17, 1995.

Hall-Ellis, Sylvia D. *Classification.* Sponsored by AJ Seminars, Rockville, Maryland; presented at University Hilton Hotel, Houston, Tex., May 10, 1995.

Hall-Ellis, Sylvia D. *Library Technical Services.* Sponsored by AJ Seminars, Rockville, Maryland; presented at University Hilton Hotel, Houston, Tex., April 26, 1995.

Hall-Ellis, Sylvia D. *Grant Writing: An Introduction for Public School Administrators.* Sponsored and hosted by the Office of Administrative Services, Region One Education Service Center, Edinburg, Tex., April 19, 1995.

Hall-Ellis, Sylvia D. *The School Library Media Specialist in the 21st Century: Visions for the Future.* Sponsored and hosted by the United Independent School District, Laredo, Tex., March 31, 1995.

Hall-Ellis, Sylvia D. *Using USMARC.* Sponsored by AJ Seminars, Rockville, Maryland; presented at University Hilton Hotel, Houston, Tex., March 29, 1995.

Hall-Ellis, Sylvia D. *Library Media Center Policies and Guidelines: How to Prepare for School Board Adoption.* Sponsored and hosted by the Office of Technology and Media Services, La Joya Independent School District, La Joya, Tex., March 10, 1995.

Hall-Ellis, Sylvia D. *Developing District-wide Policies and Guidelines for Library Media Centers.* Sponsored and hosted by the Office of Technology and Media Services, La Joya Independent School District, La Joya, Tex., January 10, 1995.

Hall-Ellis, Sylvia D. *MARC Cataloging of Audiovisual Materials for Library Media Centers.* Sponsored and hosted by the Office of Library Media and Technology Services, Cypress-Fairbanks Independent School District, Houston, Tex., December 1, 1994.

Hall-Ellis, Sylvia D. *The School Library Media Specialist in the 21st Century: Visions for the Future.* Sponsored and hosted by United Independent School District, Laredo, Tex., October 14, 1994.

Hall-Ellis, Sylvia D. *The School Library Media Specialist in the 21st Century: Visions for the Future.* Sponsored and hosted by the Laredo Independent School District, Laredo, Tex., October 7, 1994.

Hall-Ellis, Sylvia D. *MARC Cataloging for Library Media Centers.* Sponsored by the Office of Library Media and Technology Services, Cypress-Fairbanks Independent School District, Houston, Tex., October 5, 1994.

Hall-Ellis, Sylvia D. *Jump to the Head of the Class: Undergraduate Library Resources Available at Sam Houston State University.* Sponsored by the Office of the Associate Vice President for Student Services, Sam Houston State University, Huntsville, Tex., October 4, 1994.

Hall-Ellis, Sylvia D. *CD-ROMs - 1994's Newest and the Best for Secondary Level Media Centers.* Sponsored and hosted by Clear Lake Independent School District, Houston, Tex., June 3, 1994.

Hall-Ellis, Sylvia D. *Introduction to Classification.* Sponsored by AJ Seminars, Rockville, Maryland; presented at Holiday Inn, Market Center, Dallas, Tex., May 18, 1994.

Hall-Ellis, Sylvia D. *Basic Descriptive Cataloging.* Sponsored by AJ Seminars, Rockville, Maryland; presented at University Hilton Hotel, Houston, Tex., May 4, 1994.

Hall-Ellis, Sylvia D. *Shaking the Money Tree - Part II: Writing Successful Grant Applications.* Sponsored by Donna Independent School District, Donna, Texas, and Region One Education Service Center Edinburg, Texas; presented at South Texas Community College Library, McAllen, Tex., April 29, 1994.

Hall-Ellis, Sylvia D. *Using MARC.* Sponsored by AJ Seminars, Rockville, Maryland; presented at Holiday Inn, Market Center, Dallas, Tex., April 6, 1994.

Hall-Ellis, Sylvia D. *Automated Authority Control.* Sponsored by AJ Seminars, Rockville, Maryland; presented at University Hilton Hotel, Houston, Tex., March 23, 1994.

Hall-Ellis, Sylvia D. *Automating the District School Library Media Centers: Choices and Opportunities.* Sponsored and hosted by the Office of Technology and Library Media Services, Fort Bend Independent School District, Sugar Land, Tex., March 4, 1994.

Hall-Ellis, Sylvia D. *Shaking the Money Tree - Part I: Preparing Successful Grant Applications.* Sponsored and hosted by the Office of Library Media Services, Donna Independent School District, Donna, Tex., February 4, 1994.

GRADUATE COURSES TAUGHT

San José State University, School of Library and Information Science

INFO 249 – Advanced Cataloging and Classification (Fall 2015, 2016; Summer 2016)
INFO 287 – Special Topics in Cataloging and Classification (Spring 2017, 2018, 2019, 2020, 2021, 2022, 2023, 2024; Fall 2020, 2021, 2022, 2023, 2024)
LIBR 248 – Beginning Cataloging and Classification (Summer 2002, 2003, 2004, 2005, 2006)
LIBR 249 – Advanced Cataloging and Classification (Summer 2003; Fall 2014; Summer 2015)

University of Denver, University College

Grant Writing Certificate Seminar for Non-Profit Organizations (Fall 2020, 2021; Spring 2021)

University of Denver, Morgridge College of Education HED

5991 – Grant Writing in Higher Education (Spring 2011)
LIS 4010 – Organization of Information (Fall 2002-2009; Winter 2005; Spring 2004-2006)
LIS 4020 – Professional Principles and Ethics (Summer 2000)
LIS 4040 – Management of Libraries and Information Centers (Fall 2010; Spring 2003, 2009 (DS); Winter 2005)
LIS 4070 – Cataloging and Classification (Winter 2008, 2009, 2010, 2011, 2012; Fall 2009 (DS)) LIS
4321 – Collection Management (Spring 2005)
LIS 4326 – LIS Research (Winter 2009 (DS); Spring 2009 (DS))
LIS 4350 – Adult Materials and Services (Summer 2006, 2009)
LIS 4379 – Social Sciences Resources (Spring 2009)
LIS 4400 – Cataloging and Classification (Spring 2000, 2001; Winter 2002-2009; Summer 2005, 2006 – course renumbered LIS 4070, September 2007)
LIS 4401 – Descriptive Cataloging (Winter 2001; Spring 2002, 2003, 2006-2009; Summer 2005)
LIS 4402 – Subject Cataloging (Spring 2001, 2009; Summer 2005, 2006, 2007, 2008)
LIS 4403 – Classification Schemes (Fall 2007, 2008, 2009 (DS)) LIS
LIS 4405 – Authority Control (Winter 2009)
LIS 4510 – Materials and Services for Children (Winter 2004; Summer 2005)
LIS 4620 – Grant Writing and Fundraising (Summer 2000, 2002, 2004, 2010; Winter 2006; Fall 2006-2009)
LIS 4700 – Seminar in Technical Services (Fall 2001)
LIS 4700 – Seminar in Public Libraries (Summer 2002)
LIS 4804 – Management of Electronic Records (Spring 2004; Fall 2005)
LIS 4902 – Capstone Projects (Winter 2003, Spring 2008, 2009, 2011)
LIS 4910 – Independent Study (every quarter Winter 2000 through Spring 2011)
LIS 4920 – Service Learning (every quarter Summer 2004 through Spring 2011)
RMS 4954 – Grant Writing (Summer 2013, 2014)
RMS 4959 – Content Analysis Methodology (Spring 2015)
QRM 4978 – Grant Writing (Summer 2011, 2012)

Rutgers University, School of Communication and Information

SC&I 522 – Cataloging and Classification (Summer 2013)

University of Arizona, College of Behavioral and Social Sciences

LIS 602 – Cataloging and Classification (Summer 1995)
LIS 612 – Advanced Online Search and Retrieval (Summer 1995)

Sam Houston State University, College of Education & Applied Science

LIS 532 - Cataloging and Classification (Fall 1993, 1994, 1995)
LIS 563 - Advanced Cataloging and Classification (Summer 1994)
LIS 567 - Research Methods (Spring 1994, Spring 1995)
LIS 591 - Educational Technology (Spring 1994, 1995)
LIS 596 - Networking and Computer Technologies in Education (Fall 1993, Summer 1994, Fall 1995)

Dissertations at the University of Denver

Bowers, Stacey L. *Library Anxiety of Law School Students: A Study Utilizing the Multidimensional Library Anxiety Scale.* Chair, May 5, 2010.

Fattor, Melissa M. *Student Engagement Differences by Ethnicity and Scale for Ninth Grade Students.* Chair, November 1, 2010.

Fulton, Roseanne. *A Case Study of Culturally Responsive Teaching in Middle School Mathematics.* Kent Seidel, Chair, June 18, 2009, Outside Chair.

Grealy, Deborah S. *Tribes and Territories in Library and Information Studies Education.* Bruce Uhrmacher, Chair, June 10, 2008, Committee Member.

McCord, J. Michael. *Developing a Standard of Care for Educational Malpractice.* Chair, April 15, 2011.

Priebe, Sarah J. *Distinguishing Effects of Domain and General Knowledge on Passage Fluency and Comprehension.* Jan Keenan, Chair. July 21, 2011, Outside Chair.

Snyder-Mondragon, Sandra M. *Institutional Factors that Impact the Retention of Graduate Students of Color in Schools of Library and Information Science: A Metaregression of Accredited Library School Statistics on Student Retention and Graduation Rates.* Kathy Green, Chair, July 24, 2009, Committee Member.

Taylor, Karen Pickles. *Effective Teaching.* Elinor Katz, Chair, July 15, 2009, Outside Chair.

Thompson, Jennifer. *Distinguishing a Western Women's College: A History of the Curriculum and Student Experience at Colorado Women's College.* Edith W. King, Chair, July 16, 2010, Committee Member.

Walker, Emelda. *Influence of Organizational Factors on Job Satisfaction of Disability Service Providers at Postsecondary Institutions.* Chair, April 29, 2010.

Dissertation Proposals at the University of Denver

Bowers, Stacey L. *Library Anxiety of Law School Students: A Study Utilizing the Multidimensional Library Anxiety Scale.* Chair, November 5, 2009.

McCord, J. Michael. *Developing a Standard of Care for Educational Malpractice.* Edith W. King, Chair. April 23, 2010.

Thompson, Jennifer. *History of Colorado Women's College.* Edith W. King, Chair, October 30, 2008. Committee Member.

Walker, Emelda. *Influence of Organizational Factors on Job Satisfaction of Disability Service Providers at Postsecondary Institutions.* Chair, July 21, 2009.

Dissertations at Other Institutions

Rodríguez-Mori, Howard. *The Information Behavior of Puerto Rican Immigrants to Central Florida, 2003-2009: Grounded Analysis of Six Case Studies Use of Social Networks during the Migration Process.* Kathleen Burnett, Chair, April 10, 2009, Florida State University, Committee Member.

Schwartz, Brian *More than a Look-up Skill: Medical Information Literacy Education in Osteopathic Medical Schools.* D. Mirah Dow, Chair, July 18, 2017. Emporia State University, Committee Member.

Snow, Karen. *A Study of the Perception of Cataloging Quality among Catalogers.* Shawne D. Miksa, Chair, August 1, 2011. University of North Texas, Committee Member.

Dissertation Proposals at Other Institutions

Schwartz, Brian *More than a Look-up Skill: Medical Information Literacy Education in Osteopathic Medical Schools.* D. Mirah Dow, Chair, December 4, 2015. Emporia State University, Committee Member.

Snow, Karen. *A Study of the Perception of Cataloging Quality among Catalogers.* Shawne D. Miksa, Chair, May 11, 2010. University of North Texas, Committee Member.

Master's Thesis at the University of Denver

Hemingson, Jeff. *Recital Paper.* Lamont School of Music, February 2010, Outside Chair.

Capstones at the University of Denver

Anthony, Alisa. *Correlation of Library and Information Science Program outcomes and Vacant Position Qualifications Listed on the Colorado State Library Jobline by Employers During the Period September 1, 2000 through August 31, 2002.* Chair, Winter Quarter, 2003.

Borden, Donna M. *Improving Emergency Communications Systems: Is a Radio Communications Network the Answer?* Fall Quarter, 2014.

Bowden, Heather L.M. *Exploring Biological Models for Long-term Data Preservation.* Chair, Spring Quarter, 2008.

Casenada, Cassandra Y. *Challenges to the Recruitment, Education, and Retention of Librarians of Color*. Chair, Spring Quarter, 2008.

Chang, Jennifer C. *Legal Research Practice and Preference: A Law Firm Perspective.* Chair, Spring Quarter 2011.

Ellis, Megan S. Fitzgerald. *Design of a Public Library Adult Volunteer Recruitment Program and Training Curriculum.* Chair, Winter Quarter, 2003.

Kircher, Kathy. *Development of a Library Pathfinder for Exobiology and Posting it on the Internet.* Chair, Winter Quarter, 2003.

Melhado, Loretta. *Design of St. John's Episcopal Church Library.* Chair, Spring Quarter, 2008.

Radcliff, Kathy. *Original Cataloging of Archival materials in the HERS Collection in Penrose Library.* Chair, Winter Quarter, 2003.

Sass, Carol Ann. *ACT Periodical Index: Access to Catholic Thinking Periodical Index: Web Index to Select Catholic Periodicals.* Spring Quarter 2000.

Stone, Sergio D. *Conducting Community Analysis for the Bemis Public Library (Littleton, Colorado) Using 2002 U.S. Census Data and the Online Outcome-Based Evaluation Toolkit.* Chair, Winter Quarter, 2003.

Tureson, Tamara. *Design and Use of an Information Audit Tool for Use in a Law Library.* Chair, Winter Quarter, 2003.

Tweed, Beth. *Evaluation of Email Reference Service in a Consumer Health Library Environment.* Chair, Winter Quarter, 2003.

GRANTS AND CONTRACTS

Student Learning in Agriculture STEM through Teacher Professional Development. Research team: Stanton Gartin (PI) and Cyndi Hofmeister, Northeast Junior College; Jeff Cash, Cheryl Sánchez, Anne-Marie Crampton, Lamar Community College; Suzanna Spears, Morgan Community College; Jack Wiley, Kerry Gabrielson, Trinidad State Junior College; Michael J. Miller, Colorado State University; Michael Womochil (Co-PI), Casey Sacks, and Sylvia D. Hall-Ellis, Colorado Community College System. U.S. Department of Agriculture, Agriculture and Food Research Initiative, Food, Agriculture, Natural Resources and Human Sciences Education and Literacy Initiative, $404,460 (2017-2020)

Leading and Achieving: the Colorado Agriculture Regional Consortium. Research team: Jack Wiley (PI), Kerry Gabrielson, Trinidad State Junior College; Jeff Cash (PI), Cheryl Sánchez, Anne-Marie Crampton, Lamar Community College; Suzanna Spears, Morgan Community College; Cyndi Hofmeister, Northeast Junior College; Michael Womochil (Co-PI), Casey Sacks, and Sylvia D. Hall-Ellis, Colorado Community College System. U.S. Department of Agriculture, Hispanic Serving Institutions Education Grants Program, $504,414 (2017-2020)

Cyber Prep Program Planning Grant. Research team: Debbie Sagen (PI), Brenda Lauer, Pikes Peak Community College; Gretchen Martin, Koiosa Insights; and, Sylvia D. Hall-Ellis, Colorado Community College System. U.S. Department of Commerce, Regional Alliances and Multi-stakeholder Partnerships to Stimulate (RAMPS) Cybersecurity Education and Workforce Development, $199,681 (2016-2018)

Career and Technical Education in Colorado: Pathways to Education and Employment. Research team: Heather McKay (PI), Rutgers University; Sarah Heath, Casey Sacks, Sylvia D. Hall-Ellis, Colorado Community College System. U.S. Department of Education, Institute of Education Sciences, $1,400,000 (2017-2021)

Pre-Alliance Planning Grant Colorado Community College Alliance. Research team: Victor Vialpondo (PI) and Janel Highfill, Community College of Aurora; Heidi Loshbaugh (Co-PI), Community College of Denver; Rick Reeves, Bill McGreevy, Liz Cox, and Kristin Aslin, Red Rocks Community College; Cathy Pellish, Front Range Community College; Samuel DeVries, Arapahoe Community College; Sylvia D. Hall-Ellis, Colorado Community College System. National Science Foundation, Louis Stokes Alliance for Minority Participation (LSAMP), $86,817 (2016-2017)

Towards Scalable Differentiated Instruction Using Technology-enabled, Competency-based, Dynamic Scaffolding. Research team: Karen Wilcox (PI) and Vijay Kumar, Center for Computational Engineering, Massachusetts Institute of Technology; Flora McMartin, Broad-based Knowledge; Quinsigamond Community College; and, Casey Sacks, and Sylvia D. Hall-Ellis, Colorado Community College System. U.S. Department of Education, First in the World Developmental Grant, $2,891,882 (2015-2019)

Colorado Strategic Partnerships Emergency Grant. Research team: Elise Lowe-Vaughn (PI), Amy Hodson, Celia Hardin, Barbara McBride, James Newby, Christopher Dewhurst, Nina Holland, Kate Anderson, MaryAnn Roe, Chrystalynn Chrystalynn, Elaine Edon, Mona Barnes, Tom Morgan, Rob Hanni, and Marie Valenzuela, Colorado Department of Labor and Employment; Steve Anton, Joelle Brouner, and, Katie Griego, Colorado Department of Human Services; Rebecca Holmes, Judith Martinez, and Jennifer Jirous, Colorado Department of Education; Emily Templin Lesh, Colorado Workforce Development Council; Cory Everett, Colorado Department of Regulatory Agencies; and, Casey Sacks and Sylvia D. Hall-Ellis, Colorado Community College System. U.S. Department of Labor, Strategic Partnerships Emergency Grant, $5,000,000 (2015-2017)

CAEL Jump Start Program: Competency-Based Education. Research team: Jerry Migler (PI), Casey Sacks, Debra Cohn, Thomas Hartman, and Sylvia D. Hall-Ellis, Colorado Community College System; Matt Jamison, Front Range Community College; Mike Coste, Red Rocks Community College; Amanda Corum, Pueblo Community College; Janet Colvin, Pikes Peak Community College; and, MaryAnn Matheny, Community College of Denver. Council for Adult and Experiential Learning, $15,000 (2015)

Summit on the Redesign of Developmental Education. Research team: Jerry Migler (PI), Casey Sacks, and Sylvia D. Hall-Ellis, Colorado Community College System; Chip Nava, Pueblo Community College; Kim Moultney, Arapahoe Community College; Debbie Ulibarri, Trinidad State Junior College; and, Kris Bernard, Front Range Community College. American Association of Community Colleges, $15,000 (2015-2016)

Equity in Excellence at Colorado Community Colleges. Research team: Keith Howard (PI) and Sylvia D. Hall-Ellis, Colorado Community College System; Estela Mata Bensimon, Center for Urban Education, University of Southern California; and Kerry Gabrielson, Trinidad State Junior College. Colorado Department of Higher Education, Colorado Opportunity Scholarship Program, $150,000 (2015-2016)

MBA High School of Business in Colorado. Research team: Laurie Urich (PI) and Sylvia D. Hall-Ellis, Colorado Community College System; Rudolph Sumpter and Beatrice Gerrish, Boulder Valley Schools; Keith Curry Lance, RSL Research Group. Colorado Department of Higher Education, Colorado Opportunity Scholarship Program, $501,295 (2015-2016)

Fullbridge Program in Colorado. Research team: Keith Howard (PI) and Sylvia D. Hall-Ellis, Colorado Community College System; Suzanna Spears, Fort Morgan Community College; and, Cheryl Sánchez and Anne-Marie Compton, Lamar Community College. Colorado Department of Higher Education, Colorado Opportunity Scholarship Program, $300,000 (2015-2017)

Colorado Community College System Alternative Credit Program. Research team: Jerry Migler (PI), Keith Howard, and Sylvia D. Hall-Ellis, Colorado Community College System. American Council on Education, $13,000 (2015)

Internationalization in Higher Education. Researcher: Samuel D. Museus. Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver, Office of Internationalization, $8,000 (2014-2015)

International Perspectives on Bilingual Education. Researcher: Sharolyn Pollard-Durodola. Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver, Office of Internationalization, $3,700 (2014-2015)

Cultivating Culturally Relevant and Responsive Curriculum and Pedagogy in College. Researcher: Samuel Museus. Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver, iRise Grant, $5,000 (2014-2015)

Project EMERGE (Educational Model for Evaluation and Replicability in Gifted Environments). Research team: Norma Hafenstein (PI) and Bruce Uhrmacher. Technical reviewer for MCE: Sylvia D. Hall-Ellis. Lynde and Harry Bradley Foundation, $235,000 (2014-2015)

Collecting Asian American Refugee Stories. Researcher: Samuel Museus. Technical reviewer for MCE: Sylvia D. Hall-Ellis. American Educational Research Association, Research Grant, $5,000 (2014-2015)

Developing Expertise in Teaching K-5 Mathematics. Research team: Julie Sarama (PI) and Douglas H. Clements (Co-PI), in partnership with the School of Education at the University of Michigan. Technical reviewer for MCE: Sylvia D. Hall-Ellis. National Science Foundation, $130,344 (2013-2015)

Investigation of the Long-Term Outcomes for Special Education Students. Researcher: Antonio Olmos-Gallos. Technical reviewer for MCE: Sylvia D. Hall-Ellis. Jefferson County School District, Office of Assessment, $40,000 (2014)

Refugee Community Collaboration. Researcher: Vicki Tomlin (PI) in partnership with the African Community Center and Jewish Family Service. Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver, Center for Community Engagement and Service Learning, $14,854 (2014-2015)

Access to Mathematics for All. Research team: Richard S. Kitchen (PI), Nicole M. Russell (Co-PI), and Terrence Blackman (Co-PI), Curriculum Studies and Teaching Program, Morgridge College of Education; Álvaro Árias (Co-PI, Department of Mathematics); and, James Gray (Co-PI), Department of Mathematics, Community College of Aurora. Technical reviewer for MCE: Sylvia D. Hall-Ellis. National Science Foundation, The Robert Noyce Scholarship Program, Capacity Building Project, $349,926 (2014-2016)

Cognitive Test Battery for Intellectual Disabilities. Research team: Karen Riley (PI), Lyndsay Agans, Jessica Lerner, and Karin Dittrick-Nathan in partnership with David Hessl (PI), The MIND Institute at the University of California – Davis, and Elizabeth Berry-Kravis, Rush University Medical Center. Technical reviewer for MCE: Sylvia D. Hall-Ellis. National Institutes of Health, Outcome Measures for Use in Treatment Trials for Individuals with Intellectual and Developmental Disabilities (R01), $2,499,996 ($588,672 at DU) (2014- 2019)

Broadening Participation in Engineering among Women and Latino/as: A Longitudinal, Multi-Site Study. Researcher: Patton Garriott (PI) in partnership with the University of North Dakota and the University of Missouri. Technical reviewer for MCE: Sylvia D. Hall-Ellis. National Science Foundation, HER Core Research, $677,390 ($69,992 at DU) (2014-2019)

Designing a Teacher Evaluation System to Improve Teacher Effectiveness for Culturally and Linguistically Diverse Learners. Research team: María del Carmen Sálazar (PI), Jessica Lerner, and Kathy Green. Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver, Professional Research Opportunities for Faculty, $29,988 (2014-2016)

Developing a College-Going Culture in Latina/O Families: Exploring the Influence of Funds of Knowledge on Family Outreach Programs. Researcher: Judy Marquez Kiyama. Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver, Professional Research Opportunities for Faculty, $18,720 (2014-2016)

Assessment of Quality of Life in Neutral Implantation Surgery for the Treatment of Parkinson's Disease. Researcher: Cynthia McRae. Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver, Office of Internationalization, $3,967 (2014-2015)

Pura Vida: Cloud Forest, Curriculum and Cross-Cultural Study. Research team: Norma Hafenstein (PI) and Bruce Uhrmacher (Co-PI). Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver, Office of Internationalization, $8,000 (2014-2015)

Online Course Development for Curriculum and Instruction. Researcher: Ruth Chao. Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver, Office of Teaching and Learning, $3,000 (2014)

Online Course Development for Curriculum and Instruction. Researcher: María del Carmen Sálazar. Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver, Office of Teaching and Learning, $3,000 (2014)

Online Course Development for Curriculum and Instruction. Researcher: Jessica Lerner. Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver, Office of Teaching and Learning, $3,000 (2014)

Online Course Development for Curriculum and Instruction. Researcher: Duan Zhang. Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver, Office of Teaching and Learning, $3,000 (2014)

The Mathematics Education of African Americans, 1866 – 1954. Researcher: Nicole M. Russell. Technical reviewer for MCE: Sylvia D. Hall-Ellis. National Academy of Education, Spencer Foundation Postdoctoral Fellowship, $55,000 (2014-2016)

Early Childhood Care and Education Study. Research team: Carrie Germeroth (PI), Melissa Mincic, and Douglas H. Clements. Technical reviewer for MCE: Sylvia D. Hall-Ellis. State of North Dakota, Department of Public Instruction, $73,500 (2013-2014)

Graduate Level Specialty in Addiction Counselor Training with Emphasis on Integration of Native American Specific Content. Research team: Ruth Chao (PI) and Michael J. Faragher (Co-PI). Technical reviewer for MCE: Sylvia D. Hall-Ellis. The Galena Foundation, $289,732 (2013-2016)

The Collecting Asian American and Pacific Islander Refugee Stories (CARS) Project. Researcher: Samuel Museus. Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver, Center for Community Engagement and Service Learning, $15,000 (2014)

Parents in Transition: A Multiple Case Study of Parent and Family Orientation Programs. Researcher: Judy Marquéz Kiyama. Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver, Faculty Research Fund, $1,500 (2014-2015)

The Sistah Network: Black Women Graduate Students Supporting and Retaining Each Other. Researcher; Nicole M. Russell. Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver, Faculty Research Fund, $2,708 (2014-2015)

Evaluation of the Northeast Denver Babies Ready for College Program. Research team: Carrie Germeroth (PI), Melissa Mincic, and Douglas H. Clements. Technical reviewer for MCE: Sylvia D. Hall-Ellis. Mile High Montessori, $9,922 (2013-2014)

Developing Teaching Expertise in K-5 Mathematics. Research team: Julie Sarama (PI) and Douglas Clements (University of Denver), in partnership with Timothy Boerst (PI), Meghan Shaughnessy, Deborah Ball, Hyman Bass (School of Education at the University of Michigan). Technical reviewer for MCE: Sylvia D. Hall-Ellis. National Science Foundation, $449,827 ($130,344 at the University of Denver (2013-2015)

Early Learning Care and Education Study Program Grant for the State of North Dakota. Research team: Carrie Germeroth (PI), Melissa Mincic, and Sheridan Green. Technical reviewer for MCE: Sylvia D. Hall-Ellis. State of North Dakota Department of Public Instruction, $73,500 (2013-2014)

Local Professional Learning Community for School Leaders. Research team: Susan Korach (PI), Kristina Hesbol, and Rebecca McClure. Technical reviewer for MCE: Sylvia D. Hall-Ellis. Education Development Center, $10,950 (2013)

Healthy Eaters, Lifelong Movers 2: Implementing Evidence-Based School Environment, Policy, and Curricular Changes to Increase Opportunities for Healthy Eating and Physical Activity in Low Income, Rural Colorado. Research team: Elaine Berlansky, University of Colorado at Denver (PI), Nicholas Cutforth, University of Denver (Co-PI), and Allison Reeds. Technical reviewer for MCE: Sylvia D. Hall-Ellis. Colorado Health Foundation, $3,103,108 (2013-2017)

Hughes Rare Books Library Room Renovation in the Sturm College of Law. Project team: Patti H. Marks, Sylvia D. Hall-Ellis, and Leigh Elliott. Mabel T. Hughes Charitable Trust, $34,000 (2013-2014)

The Promise Center Partnership with the Marsico Institute for Early Learning and Literacy and the City and County of Denver. Research team: Karen Riley (PI), Douglas H. Clements (Co-PI), and Sheridan Green. Technical reviewer for MCE: Sylvia D. Hall-Ellis. The Piton Foundation, $223,468 (2013-2014)

Center of Excellence for Problem Gambling. Research team: Ruth Chao (PI) and J. Mike Faragher. Technical reviewer for MCE: Sylvia D. Hall-Ellis. Colorado Department of Behavioral Health, $68,021 (2012-2013)

United Way Implementation and Validation Review. Research team: Douglas H. Clements (PI), Amanda Moreno, and Sheridan Green. Technical reviewer for MCE: Sylvia D. Hall-Ellis. Mile High United Way, $19,737 (2013)

Math/Science Partnership in Rural Districts. Research team: Kristen Bunn (PI, Eagle County Schools), Paul Michalec (Co-PI), and Alegra Reiber. Technical reviewer for MCE: Sylvia D. Hall-Ellis. Colorado Department of Education, Colorado's Mathematics and Science Partnership Program, $750,000 (2013-2014)

Mathematics and Science Education of African Americans. Research team: Nicole Russell (PI), Sylvia D. Hall-Ellis, Steve Fisher (Penrose Library). Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver, Professional Research Opportunities for Faculty, $29,994 (2013-2015)

Online Course Development for Curriculum and Instruction. Researcher: Nicole Russell. Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver, Office of Teaching and Learning, $3,000 (2013)

Discourse and Opportunity: Undocumented Students and Higher Education Policy. Researcher: Ryan Gildersleeve. Technical reviewer for MCE: Sylvia D. Hall-Ellis. National Academy of Education, Spencer Foundation Postdoctoral Fellowship, $55,000 (2012-2014)

An Anthropological Study of the Latino Graduation Ceremony. Researcher: Ryan Gildersleeve. Technical reviewer for MCE: Sylvia D. Hall-Ellis. Spencer Foundation, $39,900 (2012-2013)

Fragile-X and Pharmaceutical Company: Clinical Trial of AFQ056. University of California – Davis Children's Hospital MIND Institute (Sacramento), Children's Hospital Denver, and Rush Children's Hospital at Rush University Medical Center (Chicago). Karen Riley, PI. Technical reviewer for MCE: Sylvia D. Hall-Ellis. Novartis Pharmaceuticals Corporation, $394,206 (2012-2014)

Project Engage, Phase 2, a DAPRA Grant in partnership with Total Immersion Systems, Inc., and Texas A&M University. Research team: Karen Riley (PI) and Lyndsay Agans (Co-PI). Technical reviewer for MCE: Sylvia D. Hall-Ellis. U.S. Department of Defense, $60,000 (2011-2013)

International School Psychology Practicum Exchange. Researcher: Gloria L. Miller. Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver, Center for Community Engagement and Service Learning, $14,951 (2012-2013)

Online Course Development for Curriculum and Instruction. Research team: Bruce Uhrmacher (PI) and Norma Hafenstein (Co-PI). Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver, Office of Teaching and Learning, $18,193 (2012-2014)

Writers in the Schools. Research team: Karen Riley (PI) and Amanda Moreno (Co-PI).Technical reviewer for MCE: Sylvia D. Hall-Ellis. Colorado Humanities, $4,965 (2012-2013)

Learning Ecosystem Validation Grant. Research team: Karen Riley (PI), Lyndsay Agans, Kent Seidel, and Shimelis Assefa. Technical reviewer for MCE: Sylvia D. Hall-Ellis. Bill & Melinda Gates Foundation, $315,000 (2012-2013)

Project Words of Oral Reading and Language Development (WORLD). Research team: Jorge E. Gonzalez (PI), Texas A&M University; Laura Saenz (Co-PI), University of Texas – Pan American; and, Sharolyn Pollard-Durodola (Co-PI), University of Denver. Technical reviewer for MCE: Sylvia D. Hall-Ellis. U.S. Department of Education, Institute of Education Sciences, $53,354 (2012-2015); award $640,718, transfer from Texas A&M University

Increasing the Efficacy of an Early Mathematics Curriculum with Scaffolding Designed to Promote Self-Regulation. Research team: Douglas H. Clements (PI) and Julie Sarama (Co-PI). Technical reviewer for MCE: Sylvia D. Hall-Ellis. U.S. Department of Education, Institute of Education Sciences, $1,445,315 (2008-2014); award $4,541,975, transfer from University at Buffalo, The State University of New York

Using Rule Space and Poset-based Adaptive Testing Methodologies to Identify Ability Patterns in Early Mathematics and Create a Comprehensive Mathematics Ability Test. Research team: Douglas H. Clements (PI) and Julie Sarama (Co-PI). Technical reviewer for MCE: Sylvia D. Hall-Ellis. National Science Foundation, $323,791 (2010-2014); award $1,194,944, transfer from University at Buffalo, The State University of New York

Comprehensive Postdoctoral Training in Scientific Education Research. Researcher: Julie Sarama (PI). Technical reviewer for MCE: Sylvia D. Hall-Ellis. U.S. Department of Education, Institute of Education Sciences, $133,458 (2010-2014); award $613,353, transfer from University at Buffalo, The State University of New York

Longitudinal Study of a Successful Scaling Up Project: Extending TRIAD. Research team: Douglas H. Clements (PI), Julie Sarama (Co-PI), and Abt Associates (Carolyn Layzer, Fatih Unlu, Laurie Bozzi, Lily Fesler, Alina Martinez, Cristofer Price, James van Orden). Technical reviewer for MCE: Sylvia D. Hall-Ellis. Institute of Education Sciences, $384,940 (2011-2015; award $1,250,286, transfer from University at Buffalo, The State University of New York

Early Childhood Education in the Context of Mathematics, Science, and Literacy. Research team: Julie Sarama (PI), Douglas H. Clements (Co-PI). Technical reviewer for MCE: Sylvia D. Hall-Ellis. National Science Foundation, $990,020 (2010-2014; award $2,285,228, transfer from University at Buffalo, The State University of New York

Early Childhood Clearinghouse Information Center Redesign. Research team: Karen Riley (PI) and Amanda Moreno (Co-PI).Technical reviewer for MCE: Sylvia D. Hall-Ellis. Office of the Lt. Governor of Colorado, $12,000 (2012-2013)

Morgridge Rural Educational Leadership Initiative. Research team: Lyndsay Agans (PI), Linda Brookhart (Co-PI), Susan Korach, and Rebecca McClure. Technical reviewer for MCE: Sylvia D. Hall-Ellis. Morgridge Family Foundation, $100,000 (2012-2014)

Center of Excellence for Problem Gambling. Research team: Patrick Sherry (PI) and J. Mike Faragher. Technical reviewer for MCE: Sylvia D. Hall-Ellis. Colorado Department of Behavioral Health, $55,000 (2012-2013)

Intermodal Transportation Institute Research Initiatives. Researcher: Patrick Sherry. Technical reviewer for MCE: Sylvia D. Hall-Ellis. University Transportation Centers Program, Research and Innovative Technology Administration, U.S. Department of Transportation. $600,000 (2012-2014)

Mile High United Way Social Innovation Fund Early Literacy Initiative. Gloria L. Miller, PI, Amanda Moreano, Kim Hartnett-Edwards, and Sheridan Green. Technical reviewer for MCE: Sylvia D. Hall-Ellis. Mile High United Way, $89,992 (2012-2013)

International School Psychology Practicum Exchange. Researcher: Gloria L. Miller. Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver, Center for Community Engagement and Service Learning, $1,000 (2012-2013)

Refugee Student Art Outreach. Researcher: Karin Dittrick-Nathan. Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver, Faculty Research Fund, $3,000 (2012-2013)

Resistance, Resilience, and Reciprocity: Centering the Voices of Black Doctoral Women with Faculty Aspirations. Researcher: Nicole M. Russell. Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver, Faculty Research Fund, $2,965 (2012-2013)

Assessing Learning through Student Notebooks. Research team: Keith Miller, Nancy Sasaki, and Kathy Green. Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver, Professional Research Opportunities for Faculty, $30,000 (2012-2014)

International School Psychology Practicum Exchange. Researcher: Gloria L. Miller. Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver, Office of Internationalization, $2,000 (2012-2013)

ELO in Colorado. Research team: Cynthia Hazel and Duan Zhang. Technical reviewer for MCE: Sylvia D. Hall-Ellis. Colorado Legacy Foundation, $150,000 (2012-2013)

Creating Online LIS Courses. Research team: Mary C. Stansbury (PI), Shimelis Assefa, Denise Anthony, Xiao Hu, and Krystyna Matusiak. Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver, Center for Teaching and Learning, $15,000 (2011-2013)

Maritime Piracy Seminar. Researcher: Ved Nanda, The Nanda Center, Sturm College of Law. Technical reviewer for Sturm College of Law: Sylvia D. Hall-Ellis. Arsenault Family Foundation, $15,000 (2012-2013).

Early Childhood Librarianship: An Interdisciplinary, Experiential Learning MLIS. Researcher: Mary C. Stansbury (PI). Technical reviewer for MCE: Sylvia D. Hall-Ellis. Laura Bush's 21st Century Librarians Program, Institute for Museums and Library Services, $249,066 (2012-2014)

Learning Ecosystem Planning Grant. Research team: Karen Riley (PI), Lyndsay Agans, Kent Seidel, and Shimelis Assefa. Technical reviewer for MCE: Sylvia D. Hall-Ellis. Bill & Melinda Gates Foundation, $281,217 (2011-2012)

Advanced Service Learning Practitioner Faculty Grant, Sylvia D. Hall-Ellis, University of Denver, Center for Community Engagement and Service Learning, $400 (2011)

Evaluating and Enhancing the EspeciallyMe Program. Research team: Lori D. Patton and Nicole Russell. Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver, Center for Community Engagement and Service Learning, Public Good Fellowship Grant, $24,780 (2012)

Choosing Excellence: Let Every Child Bloom. Research team: Shimelis Assefa (PI) and Mary C. Stansbury (Co-PI). Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver, Center for Community Engagement and Service Learning, Public Good Grant, $7,657 (2012)

K-8 STEM Content Specific Professional Development to Improve Elementary Student Achievement. Research team: Kent Seidel (PI), Nicole Russell (Co-PI), Kimberly Hartnett-Edwards, Paul Michalec, Jeff Farmer, Keith Miller, Alegra Reiber, and Nancy Sasaki. Technical reviewer for MCE: Sylvia D. Hall-Ellis. Colorado Department of Education, Improving Teacher Quality Grant, (Title II ESEA), $307,299 (2011-2012)

Building a Better Principal Pipeline to Boost Student Achievement. Researcher: Susan Korach. Technical reviewer for MCE: Sylvia D. Hall-Ellis. Denver Public Schools; a subcontract from the Wallace Foundation Grant, $170,000 (2011-2017)

Center of Excellence for Problem Gambling. Research team: J. Mike Faragher (Co-PI) and Bobbie Vollmer (PI). Technical reviewer for MCE: Sylvia D. Hall-Ellis. Colorado Department of Behavioral Health, $79,999 (2011-2012)

An Exploration of Novice Teachers' Core Competencies: Impacts on Student Achievement, and Effectiveness of Preparation. Research team: Kent Seidel (PI), Kathy Green (Co-PI), Kimberly Hartnett-Edwards, and Duan Zhang. Technical reviewer for MCE: Sylvia D. Hall-Ellis. Institute of Education Sciences, Effective Teachers and Effective Teaching, $990,987 (2012-2015)

Project Engage, a DAPRA Grant in partnership with Total Immersion Systems, Inc., and Texas A&M University. Research team: Karen Riley (PI) and Lyndsay Agans (Co-PI). Technical reviewer for MCE: Sylvia D. Hall-Ellis. U.S. Department of Defense, $49,964 (2011-2014)

User-centered Evaluation of Music Search Engines. Researcher: Xiao Hu. Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver, Faculty Research Fund, $2,931 (2011-2012)

Educational Practicum in Vietnam and China to Promote the Inclusion of Young Children with Disabilities. Researcher: Gloria L. Miller. Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver, Office of Internationalization, $5,000 (2011-2012)

Evaluation of Colorado's Enhancing Quality in Infant-Toddler (EQIT) Initiative. Research team: Virginia R. Maloney and Amanda Moreno. Technical reviewer for MCE: Sylvia D. Hall-Ellis. Buell Foundation, $395,884 (2011-2013)

Creating Engaging Environments to Teach Pre-Algebra Mathematics to Elementary Students. Research team: Álvaro Arias, Mario López, María del Carmen Salazar, and Lyndsay Agans. Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver Interdisciplinary Grant, $60,000 (2011-2012)

Morgridge Education Technology Accessible (META) Resource Project. Research team: Lyndsay Agans (PI) and Shimelis Assefa (Co-PI). Technical reviewer for MCE: Sylvia D. Hall-Ellis. Morgridge Family Foundation, $36,000 (2011)

MCE Connect: A 21st Century Framework for Faculty Development. Research team: Bruce Uhrmacher (PI), Shimelis Assefa (Co-PI), Lyndsay Agans (Co-PI), Kimberly Hartnett-Edwards, Norma Hafenstein, Xiao Hu, Paul Michalec (Co-PI), María del Carmen Salazar (Co-PI), and Sandra Snyder-Mondragon. Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver, Center for Teaching and Learning, $22,355 (2011-2012)

Parent Education and Parent Leadership and Advocacy. Research team: Virginia Maloney (PI) and Amanda Moreno, Marsico Institute for Early Learning and Literacy. Technical reviewer for MCE: Sylvia D. Hall-Ellis. Colorado Health Foundation, $27,358 (2010-2011)

Intentional School Culture. Researcher: Cynthia Hazel. Technical reviewer for MCE: Sylvia D. Hall-Ellis. Denver Public Schools, $38,040 (2010-2011)

Healthy Eaters, Lifelong Movers: Implementing Evidence-Based School Environment, Policy, and Curricular Changes to Increase Opportunities for Healthy Eating and Physical Activity in Low Income, Rural Colorado. Research team: Elaine Berlansky, University of Colorado at Denver (PI), Nicholas Cutforth, University of Denver (Co-PI), and Allison Reeds. Technical reviewer for MCE: Sylvia D. Hall-Ellis. Colorado Health Foundation, $1,683,277 (2011-2014)

Second Life Learning Community. Research team: Don McCubbrey (PI), Sylvia D. Hall-Ellis (Co-PI), Walter LaMendola, and Paul Novak. University of Denver, Center for Teaching and Learning, $13,000 (2010-2011)

Reintroducing the Value of Law Librarians to Academic and Public Librarians in Colorado through the Identification and Use of Emerging Technologies. Research team: Sylvia D. Hall-Ellis (Co-PI), Stacey L. Bowers (PI), and Christopher Hudson, in partnership with Denver Public Library, Arapahoe Library District, and the Colorado State Supreme Court Library. University of Denver, Center for Community Engagement and Service Learning, $5,773 (2010-11)

Reintroducing the Value of Law Librarians to Public Librarians through the Identification and Use of Emerging Technologies and Resources. Research team: Stacey Bowers (PI) and Sylvia D. Hall-Ellis (Co-PI). American Association of Libraries, Wolters Kluwer Law & Business Grant Program, $2,725 (2010-2011)

Faculty Service Learning Pod. Research team: María del Carmen Salazar and Nicholas Cutforth (Curriculum and Instruction Program), Frank Tuitt (Higher Education Program), Cynthia Hazel and Gloria Miller (Child, Family, and School Psychology Program), and Sylvia D. Hall-Ellis (Library and Information Science Program). University of Denver, Center for Community Engagement and Service Learning, $8,000 (2010-2011)

Lincoln Collaborative. Research team: Antonio Esquibel (Principal, Lincoln High School), María del Carmen Salazar (Curriculum and Instruction Program), and. Sylvia D. Hall-Ellis. School Improvement Grant, Denver Public Schools, $375,000 (2010-2012)

Future LEADers of America: Leaders III. Research team: Denver Public Library (Kristen Svendson, PI), the University of Denver (Sylvia D. Hall-Ellis), the Colorado Chapter of REFORMA (Orlando Archibeque), and the Colorado Association of Libraries (Martin Garnar). Laura Bush's Recruiting Librarians for the 21st Century Program, Institute for Museums and Library Services, $988,366 (2009-2012)

Teaching for Success in the Library Environment: LIS 4030 in Library 2.0. Research team: Deborah S. Grealy (PI) and Sylvia D. Hall-Ellis (Co-PI). University of Denver, Center for Teaching and Learning, $ 9,350 (2009-10)

Writing Group Faculty Grant, Sylvia D. Hall-Ellis, University of Denver, Center for Community Engagement and Service Learning, $750 (2008-2009)

Collaborative Learning Faculty Grant, Sylvia D. Hall-Ellis, University of Denver, Center for Teaching and Learning, $1,500 (2008)

Connecting Information Literacy to Learning. Research team: Lori Micho, Merrie Valliant, Amanda Samland, and Sylvia D. Hall-Ellis. Colorado State Library, LSTA Discretionary Grant Program, $19,548 (2008-2009)

Law Librarianship Fellows Program. Research team: Sylvia D. Hall-Ellis (PI), Stacey Bowers (Co-PI), and Christopher Hudson, Westminster Law Library. Laura Bush's 21st Century Librarians Program, Institute for Museums and Library Services, $999,370 (2008-2012)

Grant Writing in a Cooperative Learning Environment. Sylvia D. Hall-Ellis. University of Denver, Center for Teaching and Learning, $2,000 (2008-2009)

Project Homeless Connect 6 Event Evaluation. Research team: Sylvia D. Hall-Ellis and Duan Zhang. University of Denver Center for Community Engagement and Service Learning, $9,785 (2008)

Project Ecuador: International Learning Service Libraries – A Faculty Development Experience in Ecuador. Sylvia D. Hall-Ellis, Office of Internationalization, University of Denver, $600 (2007)

Project Ecuador: International Learning Service Libraries – A Faculty Development Experience in Ecuador. Sylvia D. Hall-Ellis, International Service Learning Office, University of Denver, $400 (2007)

Project Homeless Connect 5 Event Evaluation. Research team: Sylvia D. Hall-Ellis and Duan Zhang. University of Denver Center for Community Engagement and Service Learning, $1,000 (2007)

Project Homeless Connect 4 Event Evaluation. Research team: Sylvia D. Hall-Ellis and Duan Zhang. University of Denver Center for Community Engagement and Service Learning, $4,595 (2007)

Future LEADers of America: Leaders II. Research team: Denver Public Library (Kristen Svendson, PI), the University of Denver (Sylvia D. Hall-Ellis), and the Colorado Chapter of REFORMA (Orlando Archibeque). Laura Bush's Recruiting Librarians for the 21st Century Program, Institute for Museums and Library Services, $988,518 (2007-2010)

Strategic Planning Assistance for the Denver Medical Library. Sylvia D. Hall-Ellis. Denver Medical Library, Inc., $30,000 (2006-2007)

Destiny Software for JMAC Student Lab. Sylvia D. Hall-Ellis, gift from the Sagebrush Corporation, Minneapolis, Minnesota, $10,000 (2006)

Libraries: Tools for Education and Development Worldwide: A Faculty Development Experience in France. Sylvia D. Hall-Ellis, Office of Internationalization, University of Denver, $800 (2005)

Denver Public Library: Opportunities for Change. Sylvia D. Hall-Ellis, Colorado Community Based Research Network, $2,000 (2005)

Future LEADers of America. Research team: Denver Public Library (Letty Icolari and Steve Taylor, PIs), Emporia State University (Jim Agee), and the University of Denver (Sylvia D. Hall-Ellis). Recruiting Librarians for the 21st Century Program, Institute for Museums and Library Services, $670,315 (2005-2008)

American Association of University Professors Summer Institute Professional Development Grant. Sylvia D. Hall-Ellis, American Association of University Professors, $300 (2005)

Beta Phi Mu Alumni Tea. Sylvia D. Hall-Ellis, gift from the Office of Alumni and Parent and Relations, University of Denver, $2,000 (2005)

Spectrum Software for LIS Student Lab. Sylvia D. Hall-Ellis, gift from the Sagebrush Corporation, Minneapolis, Minnesota, $5,000 (2005)

Developing Research Capacity in Community Organizations and Residents through Training and Technical Assistance. Nicholas J. Cutforth (PI) and Sylvia D. Hall-Ellis. Piton Foundation, $25,000 (2005-2006)

Libraries: Tools for Education and Development Worldwide: A Faculty Development Experience in Argentina. Sylvia D. Hall-Ellis, Office of Internationalization, University of Denver, $500 (2004)

Developing Research Capacity in Community Organizations and Residents through Training and Technical Assistance. Research team: Nicholas J. Cutforth (PI), Gary Lichtenstein and Sylvia D. Hall-Ellis, Piton Foundation, $25,000 (2003-2004)

Increasing Spanish-Speaking and Hispanic Diversity among Library and Information Science Students at the University of Denver: Development of a Student Recruitment Model. Researcher: Sylvia D. Hall-Ellis (PI), Office of Multicultural Excellence, University of Denver, $2,750 (2003-2004)

Collection Development Enrichment to Support the Cataloging & Classification Specialization and School Librarianship within the Library & Information Science Program at the University of Denver. Research team: Sylvia D. Hall-Ellis (PI) and Deborah S. Grealy. Women's Library Association, University of Denver, $4,000 (2003)

Collection Development Enrichment to Support the Library & Information Science Program at the University of Denver. Research team: Deborah S. Grealy (PI) and Sylvia D. Hall-Ellis. Women's Library Association, University of Denver, $4,000 (2001)

Wireless LAN for Library Education. Research team: Deborah S. Grealy (PI) and Sylvia Hall-Ellis. University of Denver, Center for Teaching and Learning, $24,000 (2001-2002)

Upward Bound – A Program for South Texas Youth. Research team: Monte Churchill, Executive Director of Community Relations; Gary R. Sauceda, Outreach Coordinator; Raymond Hernandez, (PI) Associate Dean for Student Success; and Sylvia D. Hall-Ellis, South Texas Community College (McAllen, Texas). U.S. Department of Education, Office of Postsecondary Education, $2,672,003 (1999-2003)

Write Now! Improving Elementary Students' Writing Skills. Research team: Caryl G. Thomason, Assistant Superintendent (PI); Karen Tankersley, Principal; and, Hal Anderson, Director of Technology, Cheyenne Mountain School District 12 (Colorado Springs, Colorado); and Sylvia D. Hall-Ellis. Colorado Department of Education, Educational Telecommunications Unit, $189,453 (1999-2001)

Operation Quick Start -- Distance Learning in Rural Colorado. Research team: Randal Weigum, Technology Coordinator (PI); Bonnie Barns, Director of Federal Programs and Staff Development; and, Adam "Joe" Raskop, Executive Director, Southeastern Board of Cooperative Educational Services (Lamar, Colorado); and Sylvia D. Hall-Ellis. Colorado Department of Education, Educational Telecommunications Unit, $400,000 (1999-2001)

Advanced Technological Training for Information Professionals for the 21st Century. Research team: Mario Reyna, Division of Business Director (PI) and Sylvia D. Hall-Ellis, South Texas Community College (McAllen, Texas). Phi Delta Kappa and the National Science Foundation, $250,000 (1999-2001)

Working Connections – Training Information Technologies Professionals for the 21st Century. Research team: Mario Reyna, Division of Business Director (PI) and Sylvia D. Hall-Ellis, South Texas Community College (McAllen, Texas). Microsoft Corporation and the American Association of Community Colleges, $1,147,775(1999-2001)

The ROAD (Research Oriented Amplification of Development to Literacy) Program. Research team: Deborah J. Leong (PI), Metropolitan State University; Elena Bodrova, Metropolitan State University; Dmitri Semenov, Robert J. Marzano, and Sylvia D. Hall-Ellis, Mid-continent Regional Educational Laboratory (Aurora, Colorado). Hewlett-Packard Foundation, $25,000 (1998-1999)

Press to Literacy. Research team: Deborah J. Leong (PI), Metropolitan State University; Elena Bodrova, Metropolitan State University; Dmitri Semenov, Robert J. Marzano, and Sylvia D. Hall-Ellis, Mid-continent Regional Educational Laboratory (Aurora, Colorado). The Denver Post and the Robert S. McCormick Foundation, $49,818 (1998-1999)

International Telementor Center. Research team: David Neils, David B. Frost (PI), and Sylvia D. Hall-Ellis, Mid-continent Regional Educational Laboratory (Aurora, Colorado). Hewlett-Packard Philanthropy, $100,000 (1998-1999)

America Reads: Providing Tutor Training for the America Reads Challenge. Research team: Louis F. Cicchinelli (PI) and Sylvia D. Hall-Ellis, Mid-continent Regional Educational Laboratory (Aurora, Colorado). U.S. Department of Education, Office of Educational Research and Improvement, $306,000 (1998-1999)

Comprehensive School Reform. Research team: Louis F. Cicchinelli (PI), J. Timothy Waters, and Sylvia D. Hall-Ellis, Mid-continent Regional Educational Laboratory (Aurora, Colorado). U.S. Department of Education, Office of Educational Research and Improvement, $285,000 (1998-1999)

Sustainable Energy Education (SEE) Program for Grades 4-8: Preparing Today's Youth for Lifelong Learning and Responsible Actions in Energy Conservation. Research team: Mary Gromko, Colorado Department of Education; Gene McCarthy, Rocky Flats Field Office, U.S. Department of Energy; Gina Kissell, National Renewable Energy Laboratory; and Barbara L. McCombs (PI), Janet L. Bishop, and Sylvia D. Hall-Ellis, Mid-continent Regional Educational Laboratory (Aurora, Colorado). State of Colorado Governor's Office for Energy Conservation, $499,936 (1997-1999)

Review of Kansas Curriculum Standards in Mathematics and Language Arts. Research team: Robert J. Marzano (PI), John S. Kendall, David B. Frost, and Sylvia D. Hall-Ellis, Mid-continent Regional Educational Laboratory (Aurora, Colorado). Submitted to the Kansas State Department of Education, $25,903 (1998)

International Telementor Center. Research team: David Neils, John Kuglin, Chris Rapp, David B. Frost (PI), and Sylvia D. Hall-Ellis, Mid-continent Regional Educational Laboratory (Aurora, Colorado). Hewlett-Packard Company, $54,752 (1998)

Genesis Mission: Education Public Outreach. Developed in partnership by the Jet Propulsion Laboratory, California Institute of Technology, Los Alamos National Laboratory, Lockheed Martin Astronautics, and the Mid-continent Regional Educational Laboratory (Aurora, Colorado). Research team: John T. Sutton (PI), Alice Krueger, Martha Henry, Greg Rawls, Shae Isaacs, Jeff Johnson, Deb Jordan, Arlene Mitchell, David B. Frost, Jana Caldwell, J. Timothy Waters, and Sylvia D. Hall-Ellis. National Aeronautics and Space Administration, $139,700,000; subcontract award, $4,750,000 (1997-2007)

North Dakota Mathematics Assessment Project. Developed in partnership by the North Dakota Department of Education and Mid-continent Regional Educational Laboratory (Mid-continent Regional Educational Laboratory). Research team: Ann Clapper, Clarence Bina, Greg Gallagher, North Dakota Department of Education; Don Burger (PI), Hillary Michaels, and Sylvia D. Hall-Ellis, Mid-continent Regional Educational Laboratory (Aurora, Colorado). U.S. Office of Education, $1,618,214; subcontract award, $389,076 (1997-2001)

Pacific Resources for Education and Learning Distance Education: Project Evaluation. Developed in partnership by the Pacific Educational Community, the Pacific Resources for Education and Learning (PREL), and Mid-continent Regional Educational Laboratory (McREL). Research team: John W. Kofel (PI), Executive Director, PREL; J. Timothy Waters, Executive Director; Joan Buttram, Robert Keller, and Sylvia D. Hall-Ellis, Mid-continent Regional Educational Laboratory (Aurora, Colorado). U.S. Office of Education, Star Schools Program, $10,000,000; subcontract award, $500,000 (1997-2002)

Identification of Bilingual Gifted and Talented Children: A Comprehensive School Grants for Bilingual Education. Developed in partnership by Hidalgo (Texas) ISD, Los Fresnos (Texas) CISD, Progreso (Texas) ISD, University of Texas – Pan American (Edinburg, Texas), and Education Service Center, Region One (Edinburg, Texas). Research team: Hilda Medrano, Dean, College of Education, University of Texas – Pan American; Linda Phemister (PI), Janie Navarro, and Sylvia D. Hall-Ellis, Education Service Center, Region One. U.S. Department of Education, Office of Bilingual Education and Minority Languages Affairs, $1,670,633 (1997-2002)

Academics 2000: First Things First -- The Texas Goals 2000. Developed for Jim Hogg (Hebbronville, Texas) County ISD, Mirando City (Texas) ISD, and San Isidro (Texas) ISD. Research team: Hilda Medrano, Dean, College of Education, University of Texas - Pan American (Edinburg, Texas); Angie Lehmann, Amy Mares, Ellen Gonzalez (PI), and Sylvia D. Hall-Ellis, Education Service Center, Region One (Edinburg, Texas). Texas Education Agency, $339,987 (1997-2000)

Southwestern Bell's Learning Communities Initiative. Developed for Tech Prep of the Rio Grande Valley, Inc. (Harlingen, Texas); the Center for Professional Teacher Development, University of Texas – Brownsville; Teach for America – Rio Grande Valley (McAllen, Texas); and Education Service Center, Region One (Edinburg, Texas). Research team: Patricia G. Bubb, Executive Director (PI), Tech Prep of the Rio Grande Valley; Martin Winchester, Executive Director, Teach for America – Rio Grande Valley; Aileen Johnson, Director, School of Education, University of Texas – Brownsville; and Sylvia D. Hall-Ellis. Southwestern Bell Foundation, $100,000 (1997-1998)

Texas School to Work: Regional Implementation. Developed for Tech Prep of the Rio Grande Valley, Inc. (Harlingen), South Texas Community College (McAllen), Texas State Technical College (Harlingen), Texas Southmost College (Brownsville), Empowerment Zone of the Rio Grande Valley (Mercedes), Project VIDA (Weslaco), Youth Fair Chance (McAllen), and Education Service Center, Region One (Edinburg). Research team: Patricia G. Bubb (PI), Tech Prep of the Rio Grande Valley; Stephen Vassberg, Texas State Technical College; Ellen Trevino, Youth Fair Chance; Wanda Garza, Project VIDA; Leonardo Olivares, University of Texas – Pan American; Michael Bell, South Texas Community College; and Sylvia D. Hall-Ellis. Texas Workforce Commission, $4,250,000 (1997-2002).

Comprehensive Bilingual Education Grant for Hidalgo ISD and Roma ISD. Developed for Hidalgo (Texas) ISD, Roma (Texas) ISD, College of Education, University of Texas – Pan American (Edinburg, Texas), and Education Service Center, Region One (Edinburg, Texas). Research team: Tomas Thomas (PI), Director, Office of Bilingual Education and Sylvia D. Hall-Ellis. U.S. Department of Education, Office of Bilingual Education and Minority Languages Affairs, $1,531,361 (1997-2002)

Lopez High School, Porter High School, Rivera High School, Central Middle School, and Perkins Middle School, Brownsville (Texas) Independent School District. Telecommunications Infrastructure Fund Board, $1,473,611 (1997-1998)

Donna High School, Todd Middle School, and Solis Middle School, Donna (Texas) Independent School District. Telecommunications Infrastructure Fund Board, $704,052 (1997-1998)

Memorial Middle School and Nellie Schunior Middle School, La Joya Independent School District (Texas). Telecommunications Infrastructure Fund Board, $293,641 (1997-1998)

Martin High School, Christen Middle School, Cigarroa Middle School, Lamar Middle School, Laredo (Texas) Independent School District. Telecommunications Infrastructure Fund Board, $1,200,000 (1997-1998).

Lasara Middle School, Lasara (Texas) Independent School District. Telecommunications Infrastructure Fund Board, $246,210 (1997-1998)

Los Fresnos High School and Resaca Middle School, Los Fresnos (Texas) Consolidated Independent School District. Telecommunications Infrastructure Fund Board, $500,000 (1997-1998)

Lyford Junior High School, Lyford (Texas) Independent School District. Telecommunications Infrastructure Fund Board, $354,997 (1997-1998)

Travis Middle School, McAllen (Texas) Independent School District. Telecommunications Infrastructure Fund Board, $269,139 (1997-1998)

Mission High School, Mission (Texas) Independent School District. Telecommunications Infrastructure Fund Board, $297,010 (1997-1998)

Progreso High School, Progreso (Texas) Independent School District. Telecommunications Infrastructure Fund Board, $300,000 (1997-1998)

San Perlita High School, San Perlita (Texas) Independent School District. Telecommunications Infrastructure Fund Board, $293,490 (1997-1998)

Myra Green Junior High School, Raymondville (Texas) Independent School District. Telecommunications Infrastructure Fund Board, $225,000 (1997-1998)

Rio Grande City High School, Ringgold Middle School, Gruella Middle School, Rio Grande City (Texas) Independent School District. Telecommunications Infrastructure Fund Board, $809,934 (1997-1998)

Rio Hondo Junior High School, Rio Hondo (Texas) Independent School District. Telecommunications Infrastructure Fund Board, $297,024 (1997-1998)

Roma High School, Roma (Texas) Independent School District. Telecommunications Infrastructure Fund Board, $333,178 (1997-1998)

San Benito High School, Miller Jordan Junior High School, San Benito (Texas) Consolidated Independent School District. Telecommunications Infrastructure Fund Board, $547,000 (1997-1998)

Santa Maria High School and Santa Maria Middle School, Santa Maria (Texas) Independent School District. Telecommunications Infrastructure Fund Board, $400,000 (1997-1998)

Salvador High School, United Independent School District (Laredo, Texas). Telecommunications Infrastructure Fund Board, $250,879 (1997-1998)

Weslaco High School, Cabaza Middle School, Cuellar Middle School, Weslaco (Texas) Independent School District. Telecommunications Infrastructure Fund Board, $874,242 (1997-1998)

Principals' Assessment and Training Center. Developed for Education Service Center, Region One (Edinburg, Texas). Research team: Roberto Zamora, Leonel Barrera, William H. Parry, and Sylvia D. Hall-Ellis. Texas Principals' Leadership Initiative, Texas Association of Secondary School Principals, Texas Association of Elementary School Principals, and the Sid Richardson Foundation. $461,439 (1996-1998)

The Texas Library Connection -- Integrating and Sharing Resources. Developed for Hidalgo County Library System (McAllen), Cameron County Library System (Brownsville), South Texas Community College (McAllen), the University of Texas - Pan American (Edinburg), University of Texas – Brownsville, and Education Service Center, Region One (Edinburg). Research team: William R. McGee, Coordinator, Hidalgo County Library System; Joe Garcia, Director, Cameron County Library System; Michael D. Bell, Library Director, South Texas Community College; Eleanor Folger Foster, University Library, University of Texas - Pan American; Jaime Vela (PI), Director of Instructional Technology and Media Services, Ron Pontius, Instructional Technology, and Fabiola Fuentes, Media Services, Education Service Center, Region One; and Sylvia D. Hall-Ellis. Office of Library Media Services, Technology Services, Texas Education Agency. $8,000 (1996-1997)

Developing Leadership Communities for Improving Algebra I for All Students. Developed for a partnership of the Region One Statewide Systemic Initiative Team. Research team: Noel Villarreal (PI), Eduardo Cancino, and Sylvia D. Hall-Ellis, Education Service Center, Region One (Edinburg). Texas Statewide Systemic Initiative for Reform in Mathematics, Science and Technology Education to The Charles A. Dana Center for Mathematics and Science Education, The University of Texas at Austin. $25,000 (1996-1997)

Academics 2000: First Things First -- The Texas Goals 2000. Developed for Edinburg (Texas) CISD. Research team: Hilda Medrano, Dean, College of Education, University of Texas - Pan American (Edinburg); Helen Jones, Director (PI), Gifted and Talented Education, Edinburg CISD; and Sylvia D. Hall-Ellis, Education Service Center, Region One (Edinburg). Texas Education Agency, $750,000 (1996-2001)

Texas Teachers Empowered for Achievement in Mathematics (TEXTEAM) Institute for Algebra I. Developed for Hidalgo ISD, Jim Hogg (Hebbronville) County ISD, La Joya ISD, La Villa ISD, Lyford ISD, Mission CISD, Pharr-San Juan-Alamo ISD, Rio Hondo ISD, San Isidro ISD, San Perlita ISD, Santa Maria ISD, Santa Rosa, Sharyland ISD, Valley View ISD, Webb (Laredo) CISD, Weslaco ISD, and Zapata County (Zapata) ISD. Research team: Noel Villarreal (PI), Chuck McInteer, Ellen M. Gonzalez, Education Service Center, Region One (Edinburg); and Sylvia D. Hall-Ellis. Charles A. Dana Center for Mathematics and Science Education, University of Texas - Austin, $15,975 (1996)

Community Learning Center for La Villa, Texas. Developed for Edcouch-Elsa Independent School District. Research team: Noe Gonzalez (PI), Assistant Superintendent, Edcouch-Elsa Independent School District, and Sylvia D. Hall-Ellis. Delta Region Subzone, Rio Grande Valley (Texas) Rural Empowerment Zone, $325,000 (1996-1997)

Monte Alto (Texas) Community Learning Center. Developed for Monte Alto Independent School District. Research team: Homero A. Diaz (PI), Superintendent, Monte Alto Independent School District, and Sylvia D. Hall-Ellis. Delta Region Subzone, Rio Grande Valley (Texas) Rural Empowerment Zone, $300,000 (1996-1997)

Community Learning Center for La Villa, Texas. Developed for La Villa Independent School District. Research team: Sam Gonzalez (PI), Assistant Superintendent, La Villa Independent School District; and Sylvia D. Hall-Ellis. Delta Region Subzone, Rio Grande Valley (Texas) Rural Empowerment Zone, $325,000 (1996-1997)

Building Project for Taylor Elementary. Developed for Mercedes (Texas) Independent School District. Research team: Mrs. Denise Rivera, Librarian, and Eduardo Infante, Principal, Taylor Elementary School; Ismael S. Cantu (PI), Federal Programs Director, Mercedes Independent School District; and Sylvia D. Hall-Ellis. Delta Region Subzone, Rio Grande Valley (Texas) Rural Empowerment Zone, $375,000 (1996-1997)

Border Education Network (BEN) - Distance Education through Cable Television. Developed for Edinburg (Texas) Consolidated Independent School District. Research team: Noe Torres (PI), Library Media Specialist, Magdalena Rosas, Library Media and Technology Coordinator, Edinburg Consolidated Independent School District; and Sylvia D. Hall-Ellis, Education Service Center, Region One (Edinburg). Edinburg (Texas) Consolidated School District, $250,000 (1996-1997)

Multiservice One-Stop Open Enrollment Charter School. Developed for the Information Referral Resource Assistance, Inc. (McAllen, Texas). Research team: Pablo Perez and Aguie Pena (PI), Executive Director, Information Referral Resource Assistance, Inc.; Roberto Zamora and Sylvia D. Hall-Ellis, Education Service Center, Region One (Edinburg). Texas Education Agency, $3,066,000 (1996-2001)

Project OK: A Community Youth Opportunities Grant for Summer, 1996. Developed for McAllen (Texas) Independent School District, St. Joseph the Worker Catholic Church, and the Office of Adult Education, Education Service Center, Region One. Research team: Father Bart Flatt, St. Joseph the Worker Catholic Church; Noe Calvillo (PI), Office of Adult Education; Maria Louisa Garcia, McAllen Independent School District; and Sylvia D. Hall-Ellis, Education Service Center, Region One (Edinburg). Texas Protective and Regulatory Agency through the Office of the Mayor, City of McAllen, $350,000 (1996-2001).

Early Childhood: a Time of Discovery. Developed for a partnership of Lasara ISD, Rio Hondo ISD, San Perlita ISD, the School of Education, University of Texas - Brownsville, and Education Service Center, Region One (Edinburg). Research team: Hugo Rodriguez, Dean, School of Education, University of Texas - Pan American; Leonel Barrera and Jack Damron, Field Service Agents, Ellen M. Gonzalez (PI), Administrator for Student Instructional Services, Ruth Solis, Education Specialist in Special Education, and Sylvia D. Hall-Ellis, Education Service Center, Region One (Edinburg). Texas Education Agency, $722,090 (1996-2001)

Innovative Gifted and Talented Programs for Early Childhood and Elementary Education Students. Developed for a partnership of Edinburg (Texas) CISD, the School of Education, University of Texas - Pan American (Edinburg), and Education Service Center, Region One (Edinburg). Research team: Hilda Medrano, Dean,

School of Education, University of Texas - Pan American; Helen de la Garza (PI), Director of Elementary Curriculum and Instruction, Edinburg CISD; and Sylvia D. Hall-Ellis. Texas Education Agency, $750,000 (1996-2001)

Reading Recovery in Early Elementary Grades. Developed for a partnership of La Villa (Texas) ISD the School of Education, University of Texas - Pan American (Edinburg), and Education Service Center, Region One (Edinburg). Research team: Hilda Medrano, Dean, School of Education, University of Texas - Pan American; Marcario Salinas (PI), Supervisor of Elementary Curriculum and Instruction, La Villa ISD; and Sylvia D. Hall-Ellis, Education Service Center, Region One. Texas Education Agency, $750,000 (1996-2001)

Connected Mathematics Project for Middle and Junior High Students. Developed for a partnership of Michigan State University, The Charles A. Dana Center for Mathematics and Science Education, The University of Texas at Austin and Region One Statewide Systemic Initiative Team. Research team: Jack Damron, Chuck McInteer, Noel Villarreal (PI), and Sylvia D. Hall-Ellis, Education Service Center, Region One (Edinburg). National Science Foundation through Michigan State University to the Charles A. Dana Center at the University of Texas - Austin, $539,610 (1996-1999)

Sharing Resources: Testing the Interlibrary Loan Potential of the Texas Library Connection -- Integrating Media Resources. Developed under the sponsorship of the Hidalgo County Library System (McAllen) and Education Service Center, Region One (Edinburg). Research team: William H. McGee, Hidalgo County System Coordinator; Fabiola Fuentes, Library Media; Ronald Pontius (PI), Instructional Technology, Education Service Center, Region One; and Sylvia D. Hall-Ellis. Library Media Services Program, Office of Technology Services, Texas Education Agency, $25,000 (1996-1997)

State and Federal Adult Education JOBS Program. Developed for Education Service Center, Region One (Edinburg). Research team: Noe Calvillo (PI), Director, Adult Education Program, and Sylvia D. Hall-Ellis. Adult Education Program, Texas Education Agency, $532,846 (1995-1996)

Creating Safe and Drug-Free Schools and Communities. Developed for a partnership of the Region One Consortium for Safe and Drug-Free Education Environments. Research team: Clara Contreras (PI), Health Specialist, and Sylvia D. Hall-Ellis, Education Service Center, Region One (Edinburg). Texas Education Agency, $150,000 (1995-1996)

Developing Leadership Communities for Improving Mathematics Performance for All Students on Title I Campuses. Developed for a partnership of the Region One Statewide Systemic Initiative Team. Research team: Jack Damron, Chuck McInteer, Noel Villarreal (PI), and Sylvia D. Hall-Ellis, Education Service Center, Region One (Edinburg). Texas Statewide Systemic Initiative for Reform in Mathematics, Science and Technology Education to The Charles A. Dana Center for Mathematics and Science Education, The University of Texas at Austin, $50,669 (1995-1996)

The Impact of Library Resource Centers on Academic Achievement in Selected Public Schools in South Texas. Sylvia D. Hall-Ellis (PI). Developed under the sponsorship of the Department of Library Science, College of Education and Applied Science, Sam Houston State University (Huntsville). Texas Association of School Librarians, Children's Services Round Table, and Young Adults Round Table (Austin, Texas), $2,500 (1995)

School Library Media Specialists Fellowship Program. Sylvia D. Hall-Ellis (PI). Developed under the sponsorship of the Department of Library Science, College of Education and Applied Science, Sam Houston State University (Huntsville, Texas). U.S. Department of Education, HEA Title II-B, Library Education and Human Resource Development Program, $44,000 (1995-1996)

Planning for Educational Technology. Research team: Ruth Ann Riggins (PI), Director of Library Media and Technology Services, Donna (Texas) Independent School District; Noe Torres, Education Service Center,

Region One; Patricia G. Bubb, Tech Prep of the Rio Grande Calley, Inc; Michael D. Bell, South Texas Community College; and Sylvia D. Hall-Ellis, Sam Houston State University. Developed under the sponsorship of Donna (Texas) Independent School District, Education Service Center, Region One (Edinburg), Tech Prep of the Rio Grande Valley, Inc. (Harlingen), South Texas Community College (McAllen), and the Department of Library Science, Sam Houston State University (Huntsville). Funded through Infusion of Educational Technology Planning Grant Program (H.B. 18: Models). Texas Education Agency, $18,000 (1993-1994)

The Impact of Library Resource Centers on Academic Achievement in Selected Public Schools in South Texas. Sylvia D. Hall-Ellis (PI) and Mary Ann Berry. Developed under the sponsorship of the Department of Library Science, College of Education and Applied Science, Sam Houston State University (Huntsville). Sam Houston State University Research Enhancement Fund, $7,500 (1993-1994)

Electronic Mail Resource Sharing System: Management and Operation of the Iowa Computer-Assisted Network. State Library of Iowa, $294,000 (1986-1993)

The Iowa Locator: A CD-ROM Resource Sharing Tool. State Library of Iowa, $567,000 (1986-1992)

Statewide Database Development: An OCLC Tape Analysis To Determine Feasibility. State Library of South Dakota, $15,000 (1987)

The Iowa Locator: A Feasibility Study. State Library of Iowa, $50,000 (1986)

Electronic Mail Resource Sharing System: A Feasibility Study for Libraries in the State of Iowa. State Library of Iowa, $5,000 (1985)

Access Pennsylvania: A Feasibility Study. State Library of Pennsylvania, $50,000 (1984)

Automating Library Administrative and Management Tasks: Procurement and Distribution of Microcomputer Systems for District Library Centers in the Commonwealth of Pennsylvania. State Library of Pennsylvania, $495,000 (1982)

Sharing Serial Titles Resources: Procurement and Distribution of Microfiche Readers for 550 Libraries in the Commonwealth of Pennsylvania. State Library of Pennsylvania, $500,000 (1982)

Electronic Mail System: A Pilot Project for Libraries throughout the Commonwealth of Pennsylvania. State Library of Pennsylvania, $125,000 (1982)

Literacy Program for Adults in Rural Upstate New York State: Program Outreach and Evaluation - Phase 3. Appalachian Regional Commission, $50,000 (1981)

Database Building: A Cooperative Project of the Finger Lakes Library System (Ithaca), Four County Library System (Binghamton), and the Southern Tier Library System (Corning). New York State Library, $450,000 (1980-1985)

Faces of the Southern Tier: A Professional Photographer-in-Residence. New York State National Endowment for the Humanities, $25,000 (1980)

Literacy Program for Adults in Rural Upstate New York State: Program Implementation - Phase 2. Appalachian Regional Commission, $50,000 (1980)

Small Business Resources Center: A Pilot Project for Rural Public Libraries. New York State Library, $50,000 (1980)

Media Programming: A Professional Development Program for Public Librarians in Upstate New York: A Program in Allegheny, Chemung, Schuyler, Steuben, and Yates Counties. New York State Library, $35,000 (1979)

Information and Library Resources for Inmates and Prisoners in Selected Upstate New York Facilities: A Cooperative Program in Allegheny, Chemung, Schuyler, Steuben, and Yates Counties. New York State Library, $25,000 (1979)

Library Resources for Homebound Adults in Upstate New York: An Outreach Program in Allegheny, Chemung, Schuyler, Steuben, and Yates Counties. New York State Library, $40,000 (1979)

Literacy Program for Adults in Rural Upstate New York State: Program Initiation and Establishment - Phase 1. Funded by the Appalachian Regional Commission. Awarded to the Corning (New York) Public Library, $50,000 (1979)

Information Reference Services to Homebound Adults. New York State Library, $31,000 (1978)

Books-By-Mail Services to Homebound Adults. New York State Library, $31,000 (1978)

System Headquarters Services and Programs for Public Libraries in District 10. Funded through Library Services and Construction Act Title I. Texas State Library and Historical Commission, $880,000 (1976)

County Library Development Grant for Atascosita County. Funded through Library Services and Construction Act Title I. Texas State Library and Historical Commission, $15,000 (1976)

Spanish Language Materials Collection Development Program. Texas State Library and Historical Commission, $40,000 (1975)

Establishment of System Headquarters for Alamo Regional Library System (District 10) Headquartered at the San Antonio (Texas) Public Library. Texas State Library and Historical Commission, $800,000 (1975)

SELECTED CONSULTANTSHIPS

Project Strategic Planning & Funding Proposal Development

Walden University, 2015.
Pikes Peak Library District, 2014.
Douglas County Public Libraries, 2011-2012.
Denver School for Science and Technology, 2008-2011.
Johnson & Wales University, Denver Campus, 2007-2009.
Challenges, Choices, and Images K-12 Charter School, Denver Public Schools, 2007.
Denver Medical Library, Inc., 2006-2010.
Bemis Public Library (Littleton), Ergonomic Design and Facilities Enhancement Consultant, 2003.
Curtis Park Community Center (Denver), Community Technology Center Evaluation and Proposal Development Consultant, 2003.
Colorado Community Based Research Network (Denver), Funding Research Associate, 2002.
Our Lady of the Rosary Academy (Edgewater), Learning Resource Center Development Project Consultant, 2001-2003
University of Southern Colorado (Pueblo). Technology Integration and Curriculum Enhancement into Higher Education Learning Environment. Proposal Development Consultant, 2000.
Jefferson County Library System (Lakewood), 1999-2000.
Southeastern BOCES (Lamar, CO). Distance Learning Curriculum Content Development Project. Proposal Development Consultant, 1998-2004.
Cheyenne Mountain School District 12 (Colorado Springs, CO). Technology Integration into Elementary Writing Curriculum Project. Proposal Development Consultant, 1998.
Telecommunications Infrastructure Fund Board Round #2 Application, 1997. Technical assistance to the following: La Villa (Texas) Independent School District; Mirando City (Texas) Independent School District; Monte Alto (Texas) Independent School District; San Isidro (Texas) Independent School District.
Telecommunications Infrastructure Fund Board Round #1, 1996. Technical assistance to the following: Brownsville (Texas) Independent School District; Donna (Texas) Independent School District; Edinburg (Texas) Consolidated Independent School District; Harlingen (Texas) Consolidated Independent School District; Jim Hogg County Independent School District (Hebbronville, Texas); La Feria (Texas) Independent School District; La Joya (Texas) Independent School District; La Villa (Texas) Independent School District; Los Fresnos (Texas) Consolidated Independent School District; Progreso (Texas) Independent School District; Raymondville (Texas) Independent School District; Rio Hondo (Texas) Independent School District; San Benito (Texas) Independent School District; Sharyland Independent School District (Mission, Texas); Weslaco (Texas) Independent School District; Zapata (Texas) County Independent School District.
South Texas Community College (McAllen). Strategy Development to Meet the Technology Instructional Needs for Vocational, School-To-Work and Academic Programs, 1994-2000. Development Consultant.
Donna (Texas) Independent School District. Planning for the Infusion of Technology in Middle Schools Serving High At-Risk Students, 1994-1995. Research Associate.
Pettus (Texas) Independent School District. Planning for District-wide Automation in School Library Media Centers: Preparation of Data, and CD-ROM Hardware/Software Configuration Evaluation, 1994. Principal Investigator.
Fort Bend Independent School District (Sugar Land, TX). Planning for District-wide Automation in School Library Media Centers, Preparation of Data, and CD-ROM Hardware/Software Configuration Evaluation, 1994-1995. Principal Investigator.
Northern Waters Library Services (Ashland, WI). Professional Consulting Services to Make Recommendations on the Development of System-Wide Efforts of the Northern Waters Library Service, 1988-1989. Research Associate.
State Library of Iowa (Des Moines). The Iowa Locator Compact Disc to Support Multi-Type Libraries Resource Sharing including Database Design, Building, Production, and Distribution, 1986-1991. Project Director.
State Library of Iowa (Des Moines). Iowa Computer-Assisted Network Development, Enhancement, and Operation, 1985-1992. Technical Director.
State Library of South Dakota (Pierre). Statistical Sampling and Analysis of Multi-Institutional OCLC Archive Tape for Statewide Online Database Building, 1985-1986. Research Associate.
District of Columbia Public Library (Washington, DC). Planning Document for the Retrospective Conversion of Bibliographic Records and Automation Issues in the 1990's, 1984-1985. Research Associate.

State Library of Pennsylvania (Harrisburg). Database Development for High School Libraries, 1984-1985. Research Associate.
MINITEX (Minneapolis, MN). Workshops for Retrospective Conversion, Bar Coding, Library Statistics, and OCLC Serials Format, 1985. Presenter and Research Associate.
ABC Film Consortium (Altoona, Bellefonte, Johnstown, PA). Database Building, System Design, and Implementation of Online Film Booking System, 1983-1985. Database Manager.

Library Automation -- System Design & Implementation

Douglas County Library District (Castle Rock, CO). Library Automation Technical and System Performance Specifications, 2001.
Pharr-San Juan-Alamo Independent School District (Pharr, TX). Library Automation Technical and System Performance Specifications, 1997. Project Development Consultant.
Harlingen (Texas) Independent School District. Planning for District-wide Automation in Junior High School Library Media Centers: Preparation of Data, and CD-ROM Hardware/Software Configuration Evaluation, 1996. Principal Investigator.
Sharyland (Texas) Independent School District. Design and Construction of New Elementary School Library and Technology Resources Center, 1995-1996. Principal Investigator.
South Texas Independent School District (Mercedes, TX). Design and Construction of a New High School Library and Technology Resources Center, 1995-1996. Principal Investigator.
Citizens' Library (Washington, PA). Online Community Resources Files: Design and Implementation, 1984. Research Associate.
Altoona (Pennsylvania) Hospital. Integrated Online System Upgrade Study, 1984. Research Associate.
State Library of South Dakota (Pierre). Automation Plan and State Database Development, 1982-1983. Principal Investigator.
State Library of Pennsylvania (Harrisburg). COM Production and Preparation of the Technical Specifications Document, Procurement, and Distribution of Microcomputers in the Commonwealth of Pennsylvania, 1983-1984. Research Associate.
Altoona (Pennsylvania) Area Public Library. Integrated System (Circulation/Online Catalog) Study, 1982-1983. Principal Investigator.
COPSCAULD (Council of Pennsylvania State College and University Library Directors, Edinboro, PA). Design of Online Media Catalog, 1982. Principal Investigator.
Erie (Pennsylvania) County Library System. Operations Research and Design for Automated Circulation, Hardware Upgrade and Re-Retrospective Conversion, 1982. Research Associate.
Michigan Library Consortium (Lansing, MI). Tape Management System Design and Implementation, 1982-1984. Research Associate.
State Library of Pennsylvania (Harrisburg). Preparation of the Technical Specifications Document, Procurement and Distribution of Microfiche Readers in the Commonwealth of Pennsylvania, 1982. Research Associate.
Community College of Allegheny County, Allegheny Campus (Pittsburgh, PA). Integrated Systems Study, 1981. Principal Investigator.
Community College of Allegheny County, South Campus (West Mifflin, PA). Retrospective Conversion Training Program for Handicapped Students, 1981. Technical Director.
Southern Tier Library System (Corning, NY). OCLC Acquisitions Subsystem Evaluation, 1981. Principal Investigator.
South Central Reference and Research Council (Ithaca, NY). South Central Regional Delivery System, 1980. Principal Investigator.
Southern Tier Library System (Corning, NY). Newspapers on Microfilm in the Chemung-Southern Tier Library System, 1979-1981. Principal Investigator.

Cataloging & Bibliographic Database Building

Challenges, Choices, and Images K-12 Charter School, Denver Public Schools, 2007.
Denver Medical Library, Inc., 2006-2010.
Ricks Gifted and Talented School Library, 2005-
American Humane Society (Englewood), 2004-2006.
Fisher Early Learning Center Library, 2004-

Colorado Community Based Research Network (Denver), 2004-
Boulder Valley School District (Boulder), 2002-2003.
Douglas Public Library District (Castle Rock), 2001-2002.

Bibliographic Center for Research, Inc. (Denver). Original Cataloging, 2001-2003 & 1992-1993. Professional Cataloger. Libraries include Arapahoe Library District (Centennial); Clarke College (Clarke, IA); Kaiser Permanente Center for Health Research (Portland, KS); Douglas County Library System (Carson City, NV); Grinnell College (Grinnell, IA); Kansas State University (Manhattan, KS); Kansas State Library (Topeka, KS); McPherson College (McPherson, KS); Newman University (Wichita, KS); Montana Technical University (Helena, MT); Montana State Library (Helena, MT); University of Texas Southwest Medical Center Library (Dallas, TX); Community College of Southern Nevada (Las Vegas, NV); Pikes Peak Library District (Colorado Springs); Mesa Community College (Grand Junction); Coe College (Cedar Rapids, IA); Briar Cliff College (Sioux City, IA); Tri-Care Health Systems (Aurora); The Penrose-St. Francis Healthcare System (Colorado Springs); Westminster Public Library (Westminster); Lutheran Medical Center Medical Library (Wheat Ridge); American Heritage Center, University of Wyoming (Laramie, WY); National Wildlife Research Center Library (Lakewood); University of Colorado Health Sciences Center, Denison Memorial Library (Denver); Water Resources Library, Denver District Office, Bureau of Land Management (Lakewood); Mesa State Community College Learning Resources Center (Pueblo); Front Range Community College Learning Resources Center (Westminster).

Colorado Historical Society Library (Denver). Original Cataloging of Serials for Multi-Institutional Union Listing Project, 1993. Technical Services Associate. Institutional partners: Denver Art Museum, Denver Museum of Natural History Library, and Denver Botanical Gardens Library.

Arapahoe Library District (Centennial). Original Cataloging of Major Media, 1991.

Original Cataloging Projects: Davis and Elkins College (Elkins, WV), 1989-1990; Waldorf College (Forest City, IA), 1989-1990; Kennametal Corporation (Latrobe, PA), 1984-1985; Pennsylvania Public Libraries Film Center (Harrisburg), 1982-1985.

Retrospective Conversion Projects: North Central Regional Library Service (Mason City, IA), 1987-1988; Southeastern Library Services (Davenport, IA), 1986-1987; Virginia Theological Seminary (Alexandria), 1984-1985; California University of Pennsylvania (California, PA), 1984-1985; Kennametal Corporation (Latrobe, PA), 1984-1985; West Virginia University (Morgantown), 1983-1985; Altoona Area Public Library (Altoona, PA), 1983-1984; George Washington University (Washington, DC), 1983-1984; Indiana University of Pennsylvania (Indiana, PA), 1983-1985; Health Education Center (Pittsburgh), 1983-1984; Central Pennsylvania District Library Center (Bellefonte, PA), 1982-1985; Duquesne University Law School Library (Pittsburgh), 1982-1983; Allegheny County Law Library (Pittsburgh), 1982-1984; Calgon Technical Information Center (Pittsburgh), 1982; Dow Corning Corporation, Technical Information Center (Midland, MI), 1982-1983; Tri-System Public Library Retrospective Conversion Project (Binghamton, Corning, and Ithaca, NY), 1978-1981, Technical Project Director.

Updated June 2024

ATTACHMENT 11

MARC 21 Format for BIBLIOGRAPHIC DATA

Library of Congress
Network Development and MARC Standards Office

1999 Edition
Update No. 1 (October 2000) through Update No. 39 (December 2024)

This online publication provides access to both the full and concise versions of the *MARC 21 Format for Bibliographic Data*. The "full" bibliographic format contains detailed descriptions of every data element, along with examples, input conventions, and history sections. The "concise" bibliographic format contains abridged descriptions of every data element, along with examples. The full and concise versions are identified in the header of each field description.

Changes to the *MARC 21 Format for Bibliographic Data* that resulted from Update No. 39 (December 2024) are displayed in red print. The date located in the header of the full version of each field indicates the last month and year of update.

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ATTACHMENT 12

MARC STANDARDS

Frequently Asked Questions (FAQ)

Network Development and MARC Standards Office
Library of Congress

General Information

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- How do I report errors in MARC 21 documentation?
- How do I propose making a change to the MARC 21 formats?
- How do I request new or revised MARC 21 organization codes?
- How do I request MARC 21 relator, sources, or description convention codes?

Record Requirements and Record and File Specifications for MARC 21

- Where do I find the U.S. National Level/Minimal Level Record Requirements for the MARC 21 formats?
- What are the appropriate record and file specifications for the formats?

- What are the specifications for character sets?

Electronic resources and MARC 21

- How do I code electronic resources in a MARC 21 record?

General Information

What is MARC 21? What does the acronym "MARC" mean?

MARC is the acronym for MAchine-Readable Cataloging. It defines a data format that emerged from a Library of Congress-led initiative that began nearly forty years ago. It provides the mechanism by which computers exchange, use, and interpret bibliographic information, and its data elements make up the foundation of most library catalogs used today. MARC became USMARC in the 1980s and MARC 21 in the late 1990s.

How does MARC 21 differ from the USMARC and CAN/MARC formats?

MARC 21 is not a new format. After having discussions and making minor changes to both formats that accommodated USMARC and CAN/MARC users' specific needs, the USMARC and CAN/MARC (Canadian MARC) formats were "harmonized" into MARC 21 in 1997. See //www.loc.gov/marc/annmarc21.html for more information about the harmonization.

Who maintains the MARC 21 formats?

The Network Development and MARC Standards Office at the Library of Congress and the Standards and the Support Office at the Library and Archives Canada maintain the MARC 21 formats. Input for development is provided by MARC 21 users from around the world, including libraries, library networks and utilities, and library system vendors. See //www.loc.gov/marc/overview.html for more information about the development and maintenance of the formats.

What are the Network Development and MARC Standards Office and the Standards Division?

The Network Development and MARC Standards Office plans and develops library and information network standards at the Library of Congress. It is the maintenance agency for several national standards, including the MARC 21 formats.To contact it, please e-mail ndmso@loc.gov.

The Standards Division at the Library and Archives Canada maintains and supports the MARC 21 formats and other library standards. To contact it, please e-mail BAC.Normesdecatalogage-Cataloguingstandards.LAC@canada.ca.

Are there any discussion groups or forums for the MARC 21 formats?

The MARC Forum is a listserv maintained by the Network Development and MARC Standards Office and is open to anyone interested in the implementation, maintenance and development of the MARC 21 formats. The forum provides an opportunity for members of the information community to participate in discussions related to the formats. Vendor, network, technical service, automation, and reference staff and researchers are encouraged to participate. While there is a close linkage between MARC 21 and the cataloging of materials, the focus of the

forum is on the use of MARC 21 as a communications format.

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MARC 21 Documentation

What documentation is available and and how do I obtain it?

The MARC Standards page has links to both extensive documentation on MARC 21, including both the full and concise formats, code and field lists, information about MARC 21 development, and documentation to help users with the MARC 21 format. There is a format overview listing changes to MARC documentation. Some documentation is also available in translation. A bibliography is also available on the Library's MARC Standards webpage.

Documentation of French versions of some of the formats in Canada is available at Library and Archives Canada.

How often is MARC 21 documentation updated?

The MARC 21 formats are updated two times per year, in the spring and fall. Other documentation is updated as it becomes necessary.

May I use excerpts from MARC 21 documentation?

Using excerpts is permissible as long as credit is given.

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MARC 21 Tutorials

Is there a tutorial for the MARC 21 formats?

Understanding MARC Bibliographic is a good introduction to the MARC 21 bibliographic format and includes a bibliography, discussion questions and examples. It is widely used and has been translated into several different languages.

Understanding MARC Authority Records is a good introduction to the MARC 21 authority format and includes a bibliography, discussion questions and examples.

Both *Understanding MARC Bibliographic* and *Understanding MARC Authority Records* are also available as booklets from the Cataloging Distribution Service.

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MARC 21, SGML, XML and other metadata standards

Are SGML or XML versions of the MARC 21 formats available?

The Network Development and MARC Standards Office has developed a framework for working with MARC data in a XML environment. This framework is intended to be flexible and extensible, allowing users to work with MARC data in ways that meet their specific needs. The framework contains many components such as schemas, stylesheets, and software tools developed and maintained by the Library of Congress. Conversion utilities between MARC (ISO 2709) and MARCXML are also available. Please see www.loc.gov/marc/marcxml.html.

The Network Development and MARC Standards Office also developed a MARC to SGML and SGML to MARC conversion program. The following documents contain the program and additional information:

- MARC DTDs: Background and Development
- MARC DTDs: Beta Test Version
- MARC-SGML and SGML-MARC Conversion Program User Guide
- MARC-SGML and SGML-MARC Conversion Programs Maintenance Guide

A list of some tools that work with HTML, SGML and XML applications is at // www.loc.gov/marc/marctools.html.

Is MARC 21 mapped to other metadata standards? Are other standards mapped to MARC 21?

MARC 21 has been mapped to the following metadata standards:

- MODS
- Dublin Core
- MARC Character Sets to UCS/Unicode
- Digital Geospatial Metadata
- RDA (See Tools tab)

The following metadata standards have been mapped to MARC 21:

- MODS
- Dublin Core
- UNIMARC to MARC 21
- ONIX
- Digital Geospatial Metadata to MARC
- RDA (See Tools tab)

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MARC 21 Translations

Are there any translations of the MARC 21 formats?

The MARC 21 Translations page contains a list of documents that are either direct translations or close adaptations of the MARC 21 formats and other MARC documentation. Where applicable, information regarding differences between the translations and MARC 21 is provided. The formats are listed alphabetically by the language of each translation and include full bibliographic citations and contact information.

I would like to translate a MARC 21 publication. What should I do?

Translations of the MARC 21 formats and other MARC documentation are greatly encouraged because of their usefulness to the entire MARC 21 community. The Network Development and MARC Standards Office does ask that intellectual credit information be included in the translation. The following statement is recommended:

> "The MARC 21 [insert name of publication that was translated] was originally prepared by the Network Development MARC Standards Office, Library of Congress

and the Standards Division, Library and Archives Canada. It has been translated with permission."

Once you complete your translation, please send the Network Development and MARC Standards Office an official announcement that includes your publication's bibliographic information and contact information on obtaining copies. If possible, send a printed copy for our collection of translations. If the translation is available on the Internet, please include its URL for inclusion on the MARC 21 Translations page. Listing a translation is not mandatory; however translations are extremely useful to other MARC 21 users.

A Translators's Tools page contains additional information about translating MARC 21 documents.

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Tools, Systems and Services That Work With MARC 21

Is there a list of tools compatible with the MARC 21 formats?

A list of some of the bibliographic tools that support the MARC 21 formats is at www.loc.gov/marc/marctools.html. It includes software programs that provide enhanced usability to MARC 21 records and systems. Some of the tools are freeware or open source.

Is there a list of MARC 21 record services?

A list of some of the record services that support the MARC 21 formats is at www.loc.gov/marc/marcrecsvrs.html. It includes services that distribute MARC 21 records, such as records for copy cataloging, records supplied with materials, records used for recon purposes, updated records, conversion services, etc.

What systems are compatible with the MARC 21 formats?

A list of some of the systems that support the MARC 21 formats is at www.loc.gov/marc/marcsysvend.html. The list includes systems that collect, organize and manage MARC 21 records.

How do I add a record service, vendor system or tool to these lists?

Vendors, software producers, and anyone else who provides vendor records, system services, or who has developed specialized MARC tools, are encouraged to fill out a submission form.

Please note: Individuals who submit the form on someone else's behalf should put their contact information in the "Citation Contact" field and the name of the individual/company on whose behalf the form is submitted in the "Product Contact" field.

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Making Changes to the MARC 21 Formats and Code Lists

How do I report errors in MARC 21 documentation?

If you notice an error or omission in either the print or online MARC 21 documentation, please contact ndmso@loc.gov. Describe the error and where it

occurs. Please be as specific as possible.

How do I propose making a change to the MARC 21 formats?

Proposals for changes to the formats may originate from any MARC 21 user. Please either fill out the MARC 21 Formats Proposed Change Form or contact the Network Development and MARC Standards Office at the Library of Congress or the Standards division at the Library and Archives Canada. Maintenance agency staff at the Library of Congress and the Library and Archives Canada write, edit and review proposals and discussion papers twice a year and distribute them via the MARC Forum listserv and the MARC Standards web site. Discussions at the semiannual MARBI (Machine-Readable Bibliographic Information) meetings in the United States and the annual CCM (Canadian Committee on MARC) meeting in Canada, along with suggestions received by e-mail and the listserv, are used by the maintenance agencies to make final decisions on the proposals.

How do I request new or revised MARC 21 organization codes?

Before requesting a MARC 21 organization code, please first search the *MARC Code List for Organizations*. If you do not find a code for your organization, click on one of these links to access a request form in the language of your choice.

[ENGLISH] [ESPAÑOL] [PORTUGUÊS]

You may use the online form to request up to three codes. If more than three codes are needed, please submit a list of the organizations with their names and addresses (including street, city, state, postal code, and country) via email to ndmso@loc.gov Please include contact information. Note: Attachments to e-mail messages are not accepted.

The *MARC Code List for Organizations* is updated frequently, as codes are often added. Since information in a request must be verified and then incorporated into the list, there is a short delay between the time of the request and the appearance of a newly-assigned code in the database. Names and addresses are revised when changes are reported.

Requests for the assignment of new codes or changes involving organizations in Canada should be sent to the Interlibrary Loan Division at the Library and Archives Canada.

Requests for the assignment of new codes or changes involving organizations in the United Kingdom should be sent to the UK National Agency for MARC Organisation Codes at the British Library.

Requests for the assignment of new MARC organization codes or for changes to codes may also be sent via fax to +1-202-707-0115 or by surface mail to:

Library of Congress
Network Development and MARC Standards Office
101 Independence Avenue, S.E.
Washington, DC, 20540-4402 USA

How do I request MARC 21 relator, sources or description convention codes?

Requests for relators, sources or description convention codes should be sent to ndmso@loc.gov.

Requests can also be faxed to +1-202-707-0115 or sent by surface mail to:

Library of Congress
Network Development and MARC Standards Office
101 Independence Avenue, S.E.
Washington, DC, 20540-4402 USA

Requests should include a full bibliographic citation and a scan, photocopy or Internet link for the item to be added.

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Record Requirements and Record and File Specifications for MARC 21

Where do I find the U.S. National Level/Minimal Level Record Requirements for the MARC 21 formats?

There is no list of of "mandatory" data elements that must appear in a MARC 21 record. Thereotically, a record could simply consist of a leader and a 245 (title) field. However, there is a list of the MARC 21 data elements required to meet minimal and national level requirements in the United States for the bibliographic and authority formats. Please note that other countries may have different lists of required data elements.

What are the appropriate record and file specifications for the formats?

Information about the file specifications for the MARC 21 formats is in *MARC 21 Specifications for Record Structure, Character Sets, and Exchange Media*. This document is also available from the Cataloging Distribution Service. For a basic introduction to MARC 21 file and record structure, you may also want to look at *Understanding MARC Bibliographic*.

What are the specifications for character sets?

MARC 21 records intended for broad, standard interchange should be encoded according to the following specifications. Either an 8-bit based encoding system (called MARC-8 in MARC 21 documentation) or a variable 8/16-bit encoding following ISO/IEC 10646 (UCS) and Unicode UTF-8 encoding rules (called UCS/Unicode UTF-8 in MARC 21 documentation) may be used.

A very large repertoire of characters is defined for use in the MARC-8 environment. For standard MARC 21 interchange, the use of UCS/Unicode UTF-8 is limited to this same repertoire, a subset of UCS/Unicode. This is necessary for interchange until all systems fully accommodate the complete UCS/Unicode repertoire of characters. This restriction will be periodically reviewed as the character encoding environment develops.

Please see //www.loc.gov/marc/specifications/speccharintro.html for detailed information on MARC 21 character sets.

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Electronic resources and MARC 21

How do I code electronic resources in a MARC 21 record?

The document *Guidelines for Coding Electronic Resources in Leader/06* assists users coding fixed fields in records for electronic resources. *Guidelines for the Use of Field 856* provides guidance on using field 856 (Electronic location and access) in all the MARC 21 formats. *Guidelines for Distinguishing Cartographic Electronic Resources from other Electronic Resources* assists catalogers working with cartographic electronic resources.

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Go to:

- MARC Standards Home Page
- Library of Congress Home Page



Library of Congress

Library of Congress Help Desk (07/12/2006)

ATTACHMENT 13

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MARC

Its History and Implications

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MARC

ITS HISTORY AND IMPLICATIONS



by HENRIETTE D. AVRAM
Chief, MARC Development Office

Based on an article entitled
"Machine-Readable Cataloging (MARC) Program,"
which appears in the
Encyclopedia of Library and Information Science,
volume 17.
Published here by courtesy of Marcel Dekker, Inc.

LIBRARY OF CONGRESS ▫ WASHINGTON ▫ 1975

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A841
1975

Library of Congress Cataloging in Publication Data

Avram, Henriette D
MARC, its history and implications.

"Based on an article entitled 'Machine-readable cataloging (MARC) program,' which appears in the Encyclopedia of library and information science, Volume 17."
Bibliography: p.
Supt. of Docs. no.: LC 1.2:M18 16
1. MARC System—History. I. United States. Library of Congress. II. Title.
Z699.4.M2A84 025.3'028'54 76-608015
ISBN 0-8444-0176-5

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INTRODUCTION

Many words have been written on the subject of MARC, the events that led to the pilot project, the development of the format, the operational Distribution Service, the influence of MARC on standardization, and the impetus it gave to library automation projects and to the creation of networks here and abroad. This article serves to gather together all aspects of the national and international MARC system.

Much of what follows has been fairly well documented in many published reports, journal articles, etc., and this article therefore relies heavily on that material. A bibliography* based on the article's main headings has been included for those readers who wish to explore any aspect of MARC in greater depth.

*The bibliography was compiled by Josephine S. Pulsifer, MARC Development Office, Library of Congress.

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BACKGROUND, 1961-1965

The Library of Congress' (LC) investigations of the possibility of using automated techniques for its internal operations began in the late 1950's. As a result of the interest generated by these investigations, the Librarian of Congress requested a grant from the Council on Library Resources (CLR) for a study to determine the feasibility of applying automated techniques to the operations of LC. The study, published in 1963,[1] recommended that a group be established to design and implement the procedures required to automate the cataloging, searching, indexing, and document retrieval functions. A systems staff was assembled in the Office of the Librarian to proceed with the recommendations. During this same period, motivated by the increasing attention given to automation in libraries, CLR awarded a contract for a study of the possible methods of converting the data on LC cards to machine-readable form for the purpose of printing bibliographical products by computer. The report of the study[2] was the subject of a conference held at LC in January 1965, under the sponsorship of LC, the Committee on Automation of the Association of Research Libraries (ARL), and CLR. Participants included representatives from universities, research agencies, government agencies, and private industry. The conferees concluded that:

1. Availability of machine-readable catalog records produced and distributed by LC would help those libraries that have automated systems.
2. The machine-readable record should include all the data presently available on LC's printed card, plus additional information to produce a multipurpose record.
3. Agreement by a broad segment of the library community on the elements to be included in the record was most desirable, and the design of the record at LC was probably the best means of achieving standardization.

Three LC staff members were assigned to the task of analyzing cataloging data from a machine processing point of view. A report,[3] issued in June 1965, was reviewed by over 150 LC staff members and their comments were issued as a supplement to the report. Comments were also elicited from many representatives of the library community.

The report was discussed at a conference supported by CLR and held at LC in November 1965. The enthusiasm generated at this meeting again demonstrated the desirability of LC becoming the distribution source of

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machine-readable records. As a result, LC sought funds from CLR to conduct a pilot project and in December 1965 received a grant to test the feasibility and utility of the distribution of cataloging data in machine-readable form from LC to user libraries. The project was named MARC, for *ma*chine-*r*eadable *c*ataloging.

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MARC PILOT PROJECT, 1966-1968

Planning for the pilot project began early in January 1966. CLR funds were used for contractual support: a) to develop procedures and programs for the conversion, file maintenance, and distribution of MARC data, as well as programs to use the data at the participating libraries, and b) to assist in the evaluation of the project. The Library invited participation in the pilot project, and from the 40 libraries that responded affirmatively, 16 were chosen. Selection was based on type of library (special, government, state, university, public, and school), geographic location,* availability of personnel, equipment, and funds, proposed use of MARC data, and willingness to evaluate the utility of the data and prepare written reports.

The participants selected were: Argonne National Laboratory, Georgia Institute of Technology, Harvard University, Indiana University, Montgomery County Public Schools, Nassau (County) Library System, National Agricultural Library, Redstone Scientific Information Center, Rice University, University of California Institute of Library Research, Los Angeles, University of Chicago, University of Florida, University of Missouri, University of Toronto, Washington State Library, and Yale University. By February 1966, the LC staff assigned to the project was prepared to call a conference of the participants for the purpose of describing: a) the concepts, objectives, schedules, functions and requirements of the experiment, b) the operation at LC, c) the MARC format,** d) the materials to be sent weekly to participants, and e) the content of the reports expected from the participants. The February meeting was considered the official opening of the pilot project.

LC set for itself the herculean task of completing within eight months the design of procedures and computer programs required both for the LC operations and for the participants. The MARC I format had to be stabilized by April 1966 to begin programming. Consequently, the time spent in analysis and design was severely limited and the form of material was restricted to book materials.

The first distribution was to begin in September 1966. Actually, the

*It was thought that for the project to provide the most useful information, different types of libraries and geographical areas should be represented. The first (types of libraries) was a valid decision; the second (geographical areas) is questionable.

**The pilot project format, later in the life of the project, was called MARC I to differentiate it from the distribution format (MARC II), which was designed later.

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first test tape was mailed in October and the weekly service began in November.

The months following the initial distribution were hectic for all. The computer programs provided to participating libraries were not, in all cases, error free and had to be modified, the participants were busily engaged in writing their own tailor-made programs, LC was learning better production methods "on the job" to reduce the large number of incorrectly edited and inadequately verified records. The load on the telephone lines between the participants' locations and Washington, D.C., was heavy from November 1966 through the next several months.

The pilot project had originally been scheduled to end in June 1967. This termination date, however, seemed unrealistic. Setup time had taken longer than anticipated at the participating libraries and, with June as a cut-off date, there could be little operational experience. LC stated at the midwinter meeting of the American Library Association (ALA)* in January 1967 that the pilot would be extended. During the next six month period, it became obvious that MARC served a useful purpose and, encouraged by the enthusiasm of the library community, LC announced at the June 1967 ALA/MARC meeting that a full-scale operational MARC Distribution Service was in the planning stages. The pilot project would continue through June 1968 while the operational system was being planned and implemented. The pilot service was extended to four additional participants—California State Library, Illinois State Library, Cornell University, and the State University of New York Biomedical Communications Network.

The participating libraries experimented with card catalog and book catalog production, current awareness listings, filing arrangement by computer, etc. Not all participants were successful in mounting an operational system but, nonetheless, all cooperated to the fullest in reporting back to LC the pros and cons of each aspect of the project. In particular, the need for timely receipt of data and quality of records was stressed.

Part of the rationale for the pilot project was the test of a machine format under operational conditions in order to design a next generation format based on the experience gained. In addition to the substantive evaluation of the MARC I format provided by the participating libraries, an important event occurred during the project which exerted a strong influence on the design of MARC II. The interest expressed by the British National Bibliography (BNB) in mounting a UK/MARC Pilot Project and the many visits from foreign librarians directed thinking toward a standard communications format suitable for interchanging bibliographic data, not

*LC made arrangements to hold MARC meetings during ALA conferences as a vehicle of communication with pilot participants.

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from one organization (LC) to many, but among organizations, perhaps crossing national boundaries.

The philosophy behind MARC II was the design of one format structure (the physical representation on a machine-readable medium) capable of containing bibliographic information for all forms of material (books, serials, maps, music, journal articles, etc.) and related records (name and subject reference records, etc.). The *structure*, or "empty container," the *content designators* (tags, indicators, and subfield codes) used to explicitly identify or to additionally characterize the data elements, and the *content*, the data itself (author's name, titles, etc.), are the three components of the format. It was recognized that under ideal conditions the universe of material would be studied at one time for a more coordinated approach to the assignment of content designators. However, those responsible knew the magnitude of such a task, the time required, and the need for specialists to be involved. Consequently, to make progress in the near term, it was decided to handle one form of material at a time, beginning with books.[4]

LC staff held many meetings discussing the book format contents and content designators. The intent was to provide a multipurpose record "rich" enough in detail to allow inclusion or exclusion of data elements based on the user's needs. The resultant MARC II format for books reflects the consensus of a large number of librarians and systems personnel.

Another significant outcome of the pilot project was the design of an extended character set for roman alphabet languages. At the onset of the project, a character set was specified based on the work in progress by the Library Typewriter Keyboard Committee of the Resources and Technical Services Division of ALA. Once the pilot was in operation, LC, in consultation with the National Agricultural Library and the National Library of Medicine, turned its attention to the development of an extended character set to cover all the major roman alphabet languages as well as the romanized forms of nonroman alphabets.

In December 1967, a meeting funded by CLR was held at LC for the purpose of discussing the MARC II format and the proposed character set. This meeting was particularly significant since the participants, based on shared experiences in the pilot project, were setting the framework for an operational MARC system which would have wide implications for the entire library community and the future of automated library systems.

At the conclusion of the pilot project in June 1968, LC had distributed approximately 50,000 machine-readable records for English language book materials. All concerned were a little wiser than at the onset of the experience. LC had learned a great deal about the procedures and the funds needed to convert cataloging data to machine-readable form. The participants realized the complexities inherent in applying the computer as

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a tool for library operations and the requirement for management support, time for implementation, and funds. All organizations were aware of the close cooperation required between computer and library personnel for a successful project.

A project report[5] was published in 1968 describing the experiences of LC and participating organizations, the expanded character set, and the MARC II format.

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From June 1967 through June 1968, LC staff, in addition to concentrating on the MARC II format design and the expanded character set, were engaged in the redesign of the procedures and programs for the operational MARC Distribution Service. The pilot project was officially terminated in June 1968 and from July through March 1969, the Library shifted over to a period of testing the new procedures and programs.

During this practice period, a proposal was written by LC to the Information Science and Automation Division of ALA recommending that a series of workshops (which became known as the MARC Institutes) be held throughout the country for the purpose of briefing library staffs on the MARC II format, LC procedures, and the uses of MARC data by libraries during the pilot project. The first institute was held in Seattle, Washington, in July 1968. This series continued for several years and was attended by over 2,000 individuals.

The first *Subscriber's Guide to the MARC Distribution Service* (which later became *Books: A MARC Format*,[6]) was published in August 1968 so that institutions planning to subscribe to MARC would have the necessary information for programming. The *Guide* was followed by a test tape in the fall of 1968 to provide the means of checking user programs.

In March 1969, the operational system was launched covering all English-language monographs* cataloged by LC including titles acquired through the National Program for Acquisitions and Cataloging (NPAC). The distribution cycle was weekly and approximately 1,000 records appeared on each MARC tape.

Before the actual implementation of the distribution service, a great deal of interest was generated in MARC procedures. Consequently, in 1969, LC issued, through ALA, the first edition of the *MARC Manuals.*[7] This publication contained the *Data Preparation Manual: MARC Editors*, the *Transcription Manual: MARC Typists*, the *Subscriber's Guide to the MARC Distribution Service*, and *Computer and Magnetic Tape Unit Usability Study* (an analysis to determine which computers and peripheral devices could be used to process MARC tapes).

Because of hardware limitations and time and funding constraints, the new MARC system was designed as a batch tape system composed of four

*Initially, only U.S. imprints were distributed but this was rapidly expanded to include all English-language monographs.

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subsystems: input, file maintenance, retrieval, and output. The programs within each subsystem were generalized, data independent where possible, table driven where the characteristics of the data were known (i.e., validation of tags across forms of material), and parameterized to the extent possible to allow the specification of unique requirements (e.g., output formatting).

From the beginning of the design phase, LC staff recognized that the system would require updating to use disk as the storage medium and to provide for online correction.* In 1971, work was begun on the Multiple Use MARC System (MUMS) to provide online capability and on the redesign of the MARC input and maintenance system.

In accordance with the original plans to specify MARC formats for forms of material other than books, LC published formats for serials[8] and maps[9] in 1970, films[10] in 1971 and manuscripts[11] in 1973. The music and sound recordings format is in draft form at the time this is written and should be published in 1975.[12] In the design of all formats, LC worked with other organizations that had expert knowledge of the material concerned.

The distribution service has been expanded as funding permitted. Distribution of records for films began in 1972, and for serials, maps, and French-language monographs in 1973. Distribution of records for books in German, Spanish, and Portuguese began in 1975. Annual production in 1975 is approximately 140,000, and the data base had reached a total of 604,729 records by the end of March 1975. The present service is available in several forms. These include: a) All MARC records, b) Books (All) covering records for English-language monographs including titles acquired through NPAC, titles in all languages in the Cataloging in Publication (CIP) Program, and French-, German-, Spanish-, and Portuguese-language monographs, c) Books (English) as described in Books (All) above, but excluding the French-, German-, Spanish-, and Portuguese-language records, d) Films, covering motion pictures, filmstrips, transparencies, slide sets, and other projected materials, in all languages, e) Maps, covering records for single and multisheet thematic maps, map sets, and maps treated as serials, in roman-alphabet languages, and f) Serials, covering all serials receiving printed card cataloging, including romanized records for titles in nonroman alphabets. Records for Books (English) and Films can be purchased in annual cumulations. Test tapes for all services are available for experimental purposes.

In 1973, LC suggested to the ALA RTSD/RASD/ISAD* Committee on

*In the LC environment, online input of new records is not desirable but there is a definite need for online correction and verification to reduce the volume of paper work and expedite the processing of records.

*Resources and Technical Services Division/Reference and Adult Services Division/ Information Science and Automation Division

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Representation in Machine-Readable Form of Bibliographic Information (MARBI) that a MARC advisory committee be formed to work with LC regarding changes to the various MARC formats. The MARBI committee decided it would be the MARC advisory committee and LC was asked to prepare a paper[13] proposing how such a committee would operate in relationship to the MARC Development Office (MDO). The LC proposals and recommendations were adopted by the MARBI committee during its meeting at the 1974 ALA midwinter meeting.

The term "change" includes additions, modifications and deletions of content data (in both fixed and variable fields) and content designators made to the format as well as additions, modifications and deletions made to the tape labels. The changes under consideration fall into five categories: a) changes resulting from a change in cataloging rules or systems, b) changes made to satisfy a requirement of LC, c) changes made to satisfy a subscriber's request, d) changes to support international standardization, and e) changes made to expand the MARC program to include additional services.

Guidelines have been established to handle the above categories of changes and a time period set for the MARBI committee, working through the MARC users, to react to a proposed change. LC agreed to notify MARC subscribers two months prior to including any change in the MARC Distribution Service.

LC plans to continue to expand MARC until all of LC cataloging (approximately 250,000 titles annually)* is encompassed within the MARC system. In certain nonroman alphabets this extension may mean romanization. Equally as important as the bibliographic records is the availability of name and subject authority records. The procedures to input subject records and to maintain the files have been operational for some time. The design of similar procedures for name records, as well as distribution procedures for name and subject records, began in 1974. Distribution of subject authority records is scheduled to begin in 1976. Name authority record distribution has been postponed pending more comprehensive design of LC's authority system.

Although the primary advantage of the distribution service is considered to be the cost savings resulting from centralized cataloging and from centralized editing and transcription of machine-readable records, another byproduct of MARC is often overlooked. It is impossible to estimate the resources (people and time) saved by national and international organizations implementing automated systems through the use of MARC publications. LC language and country codes and character sets have been

*Since LC redistributes all changed records and in addition, each CIP record is updated at least once to a full MARC record, the actual number of records distributed is significantly larger than the number of titles cataloged and included within the scope of MARC at any time.

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widely adopted and the various MARC editorial and transcription manuals adapted to local needs. Thus, through the efforts of a dedicated LC staff, significant cost savings have been effected throughout the world.

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With the assurance of an ongoing MARC Distribution Service, libraries throughout the country began to discuss and, in some instances, to plan the conversion of their existing catalogs. Such uncoordinated conversion activities would result in costly duplication of titles in machine-readable form. Any future amalgamation of the multiple data bases into a single unified national data base would entail a formidable task of human editing to make the name and subject headings assigned by many libraries consistent with authorized forms.

Since LC was also interested in the conversion of its retrospective records, it appeared timely to investigate the feasibility of a large-scale centralized conversion of retrospective cataloging records and their distribution to the library community.

In 1968, a proposal was submitted to CLR for a feasibility study to be conducted by LC. CLR, recognizing the far-reaching significance of a centralized conversion effort, responded immediately by providing funds. The responsibility for the conduct of the study which was dubbed RECON (*Re*trospective *Con*version) was assigned to a working task force. An advisory committee composed of members of the library profession was appointed to provide guidance for the study. Both groups included representatives from LC as well as from other organizations.

A report[14] published in 1969 described the work performed during the feasibility study and stated the major conclusions reached and recommendations made by the task force. The task force examined in detail: a) the hardware and software required for a large-scale conversion, b) existing LC files to select the one most suitable for conversion, c) the rationale for setting priorities for conversion, and how best to accomplish the job, and d) the costs of hardware, software, and manpower for a conversion project.

As a result of its investigations, the task force arrived at the following conclusions:[15]

> "1. The MARC Distribution Service should be expanded to cover all languages and all forms of material as rapidly as resources and technology allow. There should be no conversion of any category of retrospective records until that category is being currently converted.
>
> "2. Conversion of some portion of retrospective records to machine-readable form should be an early goal for library

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automation efforts.

"3. Conversion for a national bibliographic data base requires standardization of bibliographic content and machine format. Standards for conversion of retrospective records should be the same as those for current records.

"4. The highest priority for retrospective conversion should be given to records most likely to be useful to the largest number of libraries. As nearly as possible, subsequent priorities should be determined by the same criteria.

"5. Large-scale conversion should be accomplished as a centralized project. Decentralized conversion would be more costly and unlikely to satisfy requirements for standardization. The project should be under the direction of the Library of Congress."

Based on these conclusions the task force recommended that conversion should take place in reverse chronological order, by language, using the LC Cataloging Distribution Service Division record set, which is arranged in sequence by date. Each record would be compared against the LC Official Catalog for updating purposes.

The order of conversion should be: a) English-language monograph records issued from 1960 to date, b) Romance- and German-language monograph records issued from 1960 (this conversion would not begin until MARC had been expanded to include these languages), and c) English-language monograph records issued from 1898 to 1959. Every effort should be made to convert 'a' and 'b' above within four years.

An initial method of conversion was prescribed and it was proposed that further studies be initiated to determine: a) the best means of obtaining standard records for items not represented in the LC Official Catalog to build a complete national bibliographic data store, and b) the feasibility of establishing a national union catalog by recording holdings of libraries in the data store.

The task force further recommended that an implementation committee be established to investigate sources of funds for a detailed system design for a large-scale conversion effort and the initiation of a pilot project to test the proposed conversion system.

The implementation committee was never formed. However, LC took the initiative and proposals were submitted to CLR and the U.S. Office of Education (OE) to augment the resources committed by LC with additional funds required to support both a pilot project and the continuation of the activities of the working task force. Both CLR and OE responded positively and in August 1969, the RECON Pilot Project was initiated, with the additional funds designated for the studies by the task force and the travel expenses of both the task force and the advisory committee.

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The pilot project conducted by LC covered five major areas:

1. Conversion techniques postulated in the RECON feasibility report were tested in an operational environment by converting English-language monographs cataloged in 1968 and 1969 but not included in the MARC Distribution Service. (Many of the 1968 titles were formerly distributed to the participants of the MARC Pilot Project in the MARC I format.)
2. Procedures and programs to implement format recognition* were developed.
3. Problems associated with the conversion of records in other languages and cataloged according to other conventions and cataloging rules were analyzed for their effect on a conversion effort.
4. The state of the art of input devices for a large conversion effort was monitored. This included the testing of two devices in a production mode.
5. Microfilming techniques and their associated costs were studied to determine a best method for copying the sections of the LC Cataloging Distribution Service Division record set. Microfilming was suggested because the record set is a "high use" file that cannot be withdrawn in whole or in part for any substantial period of time.

The pilot project continued for two years (August 1969-August 1971) and is fully documented in a report[16] published in 1972. The findings of the project are briefly summarized below.

1. Format recognition applied to unedited records is a practical computer technique, eliminating the need for human editing prior to keying. The costs for keying and proofing for format recognition remain approximately the same as for processing records fully edited by humans. However, applying format recognition in place of human editing does effect a cost reduction of approximately 12 percent in manpower costs.
2. The magnetic tape selectric typewriter, currently in use, was found to be as cost efficient as any other offline device given the requirements for easy accommodation of variable length records and an expanded character set. Cathode ray tube terminals were also investigated for use in an online mode for corrections. Only one device was available with the expanded character set. The results of testing direct-read optical character readers (OCR) to convert LC cards to machine-readable form were negative; no device could perform adequately.

*Format recognition is a technique for the automatic assignment of tags, indicators, subfield codes, and fixed fields to machine-readable bibliographic records.

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3. Filming all cards in a given series of the Cataloging Distribution Service Division record set against a form and reproducing hard copy proved to be the most efficient method of producing source documents. The desired subset of records would then be selected for conversion.

4. Processing of older catalog records and those in foreign languages is more complex than processing current English-language records for books and therefore conversion costs will be higher.

5. The lowest RECON unit cost that can be anticipated for a record processed by format recognition is approximately $3.06.*

Approximately 58,000 records were converted during the pilot project. The 1969 titles were distributed free of charge to MARC subscribers in 1971 and the 1968 titles were made available through sale.

The most significant technical achievement of the pilot project was the development and implementation of the format recognition process. Automatic identification of the data elements of machine-readable records had been tested in other organizations, namely the Institute of Library Research at the University of California, Berkeley, and the Bodleian Library, Oxford. However, LC was the first to attempt to assign the content designators** and the fixed fields for a full MARC II record by program. The cataloging source data*** are transcribed from left to right and from top to bottom. The data are input as fields, which are detected by the program because each field ends with a carriage return, and each field continuation is indicated by a carriage return and tab. The title paragraph is the only field where the program is given an additional clue in the form of a delimiter**** separating the title, edition, and imprint. The format recognition program searches first for the collation statement which is easily located and always present. Once the collation statement is found and identified, the fields preceding and following collation are analyzed and identified separately using a variety of clues, such as first characters present, punctuation, etc. The first pass of the program provides gross identification (in most instances only a partial tag is provided) and the remainder of the process is a re-examination of each field to provide final and complete tags, indicators, and subfield codes. After each variable field is fully identified, the data are scanned for information required to set the fixed fields. Tables of keywords consisting of items such as U.S.

*Projected costs were based on the MARC Pilot and Distribution Service experience because RECON was an experiment rather than a production effort. Time was expended on testing devices, alternative methods, etc., and consequently there was no basis for determining accurate cost projections.

**Content designators are tags, indicators, and subfield codes.

***The source document is either an LC printed card or a MARC worksheet.

****A special character used to separate units of data.

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cities, foreign cities, geographical names, meetings, and honorary titles associated with personal names are used for matching purposes to aid in the identification of a variable field, or a data element within a field, as well as providing, in some instances, the information needed to fill in a fixed field.

As of 1975, format recognition is used for the processing of MARC records for books in all languages within the MARC scope—English, French, German, Spanish, and Portuguese. The program has been operational since May 1971. RECON records were processed to test the technique in a production environment until January 1972. At that time, satisfied with the results, LC proceeded to use the technique for the processing of current MARC records.

Concurrent with the RECON Pilot Project, the task force considered certain basic issues of retrospective conversion that were of national scope. The studies, with conclusions and recommendations, were reported in a publication[17] in 1973. Underlying all the work performed was the reaffirmation of the importance of a coordinated retrospective conversion activity to keep duplication of effort to a minimum and to achieve a high degree of compatibility among records.

The special studies involved four areas which are described below along with the findings of the task force.

1. There have been many attempts made and a great deal of effort expended to determine a subset (hereafter referred to as level) of the MARC format that would still allow a library using it to be part of any future national network. A level of a MARC record can be distinguished by differences in: a) the data content of a record, and b) the extent to which its contents are separately identified. Upon agreement as to the use to be made of machine-readable cataloging records, two or more parties can define a level of the MARC format to satisfy that use. The task force was concerned with the creation of machine-readable records for national use, i.e., either the recording of holdings to a national union catalog or the distribution of cataloging information in machine-readable form to library networks, systems, or individual institutions. The task force concluded that a level of MARC records can be defined for each of these functions. Since the union catalog function is well defined, a level of less completeness than the full MARC could be determined. However, the record for the distribution function must satisfy the needs of diverse installations and applications and, consequently, must be the fullest MARC record.

2. A large pool of machine-readable bibliographic records exists. Since MARC is still limited in its coverage, there is the potential of using this pool of records to accelerate the building of a national data base and to reduce the duplication of input with a resultant cost savings. The task

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force undertook to investigate representative machine-readable data bases and to assess their potential for this purpose. The study indicated that the per record cost of converting non-MARC records to MARC, comparing them with the records in the LC Official Catalog (to ensure consistency and completeness) and updating their contents, approached the per record LC/MARC cost. However, if the record was similar to an LC/MARC record in terms of fullness of catalog entry, format, and character set, i.e., a high potential record, then comparing only its access points with the LC Official Catalog record and updating those access points when required, would result in a conversion cost estimated to be in the order of one-half of present LC/MARC conversion costs.

3. The National Union Catalog (NUC) serves two major functions: the provision of cataloging data and a finding list for the locating of a title. With the advent of LC/MARC and the proliferation of library automation projects, it was logical for the task force to consider the implications of a national union catalog in machine-readable form. Online access to a national union catalog did not appear to be likely in the near future. Attention was consequently turned to the automatic production of the NUC in book form or microform. This mode of production would relieve humans of the drudgery of preparing the catalogs, make the information more rapidly available, and provide the facility for additional access points to the data. The task force selected the register/index as the optimum format for the NUC. This type of catalog is composed of a register of complete bibliographic entries arranged in numeric sequence according to a number assigned to each entry when the register is prepared. The register is never cumulated. The indexes are derived from the register entry and contain a brief bibliographic entry and the register number. The indexes are cumulated at predetermined intervals. This format has the advantage of providing several points of access without having to print the full bibliographic record more than once. The task force concluded that the cost of the automated system with its associated advantages would not exceed the cost of the present manual system, and the cost of producing the quinquennial would be significantly reduced. In addition, the data base might eventually form the basis for an online network of regional bibliographic centers.

4. Experience in the RECON Pilot Project indicated that a large-scale conversion project as projected in the RECON feasibility study demanded far more resources (staff, space, and funds) than there is hope of obtaining. To convert chronologically by language as recommended in the feasibility study, on a lesser scale, would be too slow to satisfy those libraries requiring machine-readable records for their automation efforts. Therefore, the task force examined alternative strategies, hoping to arrive at a means of more rapidly responding to the needs of libraries, but

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concluded that there was no perfect solution to the problem since preferences for languages, dates, and forms of material are dependent on the type and size of library involved. Systematic conversion, i.e., orderly conversion by language and date, has the advantage of allowing the user to predict with reasonable certainty what is in machine-readable form. It has the disadvantage that users may wait for long periods of time before desired records may be available. Conversely, nonsystematic conversion (based on some criteria such as all records in a given bibliography) might have the advantage of more rapidly converting records desired by a larger number of organizations, but it would have the disadvantage that, without querying the data base, the user cannot predict which titles are in machine-readable form.

The task force concluded that LC should concentrate on going forward as rapidly as possible to convert all of its current cataloging to machine-readable form and that an agency, established expressly for the purpose of a large-scale retrospective activity, should undertake to convert the retrospective LC records that are most in demand* and be responsible for adapting records from libraries other than LC for inclusion in the national data base. The task force recommended that since the problem of retrospective conversion is of concern to all of the nation's libraries, the National Commission on Libraries and Information Science (NCLIS) might be the appropriate agency to determine a course of action and explore sources of funding to implement a national program.

To date, no central agency has been established nor has NCLIS taken any express action concerning retrospective conversion. LC, when resources permit,** continues to convert retrospective titles selected from the Cataloging Distribution Service Division as well as MARC Pilot records that were not converted during the RECON Pilot Project. These records are distributed as part of the MARC service.

There is continuing interest in a centralized conversion activity. The concern of the participants in a series of meetings[18] sponsored by CLR is one manifestation of this interest. The purpose of these meetings is to seek a means of exchanging machine-readable records among organizations until such time as a national service may exist to perform this function centrally. The records under consideration are of two types: a) records converted from LC cataloging copy not included in the MARC Distribution Service (i.e., either items cataloged prior to the MARC service for a particular language or form of material or records not yet within the scope of MARC), and b) records representing titles not cataloged by LC. The

*Initially, these records might be those ordered from the LC Cataloging Distribution Service Division most frequently.

**The MARC Editorial Division, responsible for the conversion of MARC records, is geared to peak load conditions. When the volume of records diminishes for any period of time, the gap is filled in by converting retrospective titles.

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emphasis here is placed on all records, both retrospective and prospective, being converted by organizations other than LC. As progress is made on the automation projects of individual institutions and as regional networks evolve, it is an accepted fact that institutions will be doing local conversion. The excessive cost of duplicate conversion that will result if machine-readable data is not shared, as well as the problems of an inconsistent data base, can only be resolved if a single organization assumes the responsibility and has the resources for building a national data base.

The COMARC Pilot Project, funded by CLR, was undertaken in 1975 to test the feasibility and utility of accepting, from outside sources, records in the MARC format for books cataloged by LC but outside the scope of MARC. The access points will be compared and updated against the LC Official Catalog, and the records distributed as a separate service. Participants will be selected on the basis of record completeness in bibliographic content and adherence to the MARC format. In addition, if the NUC symbol for the holding library is included in the record, it will be posted to LC's automated Register of Additional Locations (RAL). The concept of COMARC is actually one of the alternative strategies suggested by the RECON Working Task Force, but using a somewhat different approach. Associated with COMARC, CLR also funded a study under LC's direction to define an NUC reporting format.

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Libraries acknowledged the importance of standardization long before MARC came into being. Machine systems, however, showed the need for an extra measure of conformity over what had been apparent in the past. What appears in the printed record is human readable, not bit configurations representing characters or codes or explicitly identifying content data. Variations in the placement or the formatting of words, paragraphs, and numbers in the printed record are not too damaging to the initiated, but can be intolerable to efficient machine processing. The interest of libraries in the computer for library operations was increasing in the 1960's. The availability of cataloging data in machine-readable form supplied by LC, the need to input cataloging data locally (data not within the scope of MARC or titles not cataloged by LC), the possibility of sharing these locally generated records, the potential for using computer programs across organizations to reduce the high cost of designing and writing software, and the need for hardware capable of handling large character sets were all factors that put increased emphasis on the establishment of and conformity to standards.

The impetus given to standardization by LC/MARC is doubtless one of its most important results. The establishment of bibliographic standards did not happen chronologically but in many instances overlapped, i.e., the development of a new standard might begin while a proposed standard was in the process of adoption. Consequently, reporting of the standards cannot be made in strict chronological order.

Format for Information Interchange. During the operation of the MARC Pilot Project, BNB personnel visited LC to investigate the possibility of a UK/MARC Pilot Project. At a later date, when BNB decided to proceed with its MARC project, its staff worked with the MARC staff on the MARC II format in an effort to satisfy the requirements of both agencies. This cooperation had long term effects. Both agencies recognized the future implications of an interchange format and the importance of two major publishing countries agreeing on a standard. Not only would it be possible to exchange machine-readable records between the U.S. and the U.K., but the way would be open for other countries to follow the lead and develop their own MARC projects. This possibility was particularly interesting to LC because of NPAC, where LC uses the descriptive cataloging as given by other countries in the program, adding or modifying main and added name entries, subject headings, etc., to the record as

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necessary. The entire process is a manual operation using printed records. The potential exists for updating machine-readable records from countries in the program and thus reducing the cost of conversion at LC.

Recognizing the worldwide impact of sharing machine-readable records, LC and BNB, in addition to being active in their respective national standards organizations, in 1969 submitted the then proposed American National Standards Institute (ANSI) format and its equivalent, the proposed British Standards Institute (BSI) format to the International Organization for Standardization (ISO). The MARC projects in the United States and Great Britain and the developing ANSI, BSI, and ISO standards created the environment for many countries* to begin to plan for and implement their own national MARC system.**

The MARC format *structure*, as a vehicle for information interchange, was adopted in the U.S. by the three national libraries, ALA, ARL, the Committee on Scientific and Technical Information (COSATI), the Educational Resources Information Center (ERIC), the Association for Scientific Information Dissemination Centers (ASIDIC) and others. The format structure became an ANSI standard in 1971[19] and an international standard in 1973 (ISO 2709-1973 (E)).[20]

International Standard Bibliographic Description. In 1969, the International Federation of Library Associations (IFLA) convened an International Meeting of Cataloguing Experts. Since the Paris Principles had set the framework for an international cataloging code, it seemed appropriate to call an international meeting to discuss the next step, a standard bibliographic description. A working paper[21] prepared by Michael Gorman of the BNB, with the support of a United Nations Educational and Scientific Organization (UNESCO) grant, demonstrated the difference in the order of data and in punctuation patterns of various national bibliographies (NUC represented the U.S. bibliography). A working party was selected to draft an international standard bibliographic description for monographs. An international standard bibliographic description would provide a standard set of descriptive elements in a standard order using standard punctuation to separate the elements. Such a description would facilitate: a) the comprehension of the description in printed form regardless of language, and b) the automatic recognition of elements of the description for machine identification. The first published draft of the

*Australia, Canada, Denmark, France, Germany, Italy, Japan, Latin America, Norway, Sweden, etc.

**In addition to national libraries and bibliographies, many organizations based outside of the U.S., such as UNISIST, the International Labor Organization, Information Services in Physics, Electrotechnology, Computers and Control, the International Atomic Energy Agency, have adopted or recommended adoption of the format structure.

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International Standard Bibliographic Description (ISBD) was issued in 1971, followed by the first standard edition in 1974.[22]*

Content Designators. The ISBD for monographs, the ISO standard format structure for bibliographic interchange, Dr. Franz Kaltwasser's paper[24] concerning universal bibliographic control and the ever-increasing number of national MARC formats, were all positive steps toward international cooperation. Problems remained, however. One of the significant areas of nonstandardization among national MARC formats was in the assignment of content designators to elements of information in the machine-readable records. Accordingly, IFLA established, under the auspices of the Committees on Cataloguing and Mechanization, an international Working Group on Content Designators. The Working Group held its first meeting in Grenoble, France, during the 1973 IFLA conference. Obstacles in the way of agreement on content designators include: a) diverse functions of the bibliographic agencies, b) lack of an internationally accepted cataloging code, c) lack of agreement among different bibliographic communities on organization of data content in machine-readable records, and d) lack of agreement as to the functions of content designators.

The Working Group realized that the issues concerning data organization and functions of content designators could be resolved (subsequently agreement on these points was reached in a meeting in Brussels in February 1974) but that the lack of an internationally accepted cataloging code and the dissimilarities in the functions of different bibliographic services were areas over which it had no control.

Encouraged by the fact that it has been possible to work around these differences in the formulation of the ISBD, the Working Group proceeded to adopt the concept of a SUPERMARC[25,26] as an international system for exchange, leaving the various national systems as they now exist. Each country would have an agency that would translate its own machine-readable records into the format of the SUPERMARC system; likewise, each agency would translate SUPERMARC records into its own national format.

The international machine-readable record was divided into functional blocks (e.g., intellectual responsibility block, descriptive block, subject block, etc.). There was unanimous agreement that the descriptive block would follow the ISBD and it is this block where agreement on content designators and content is most likely possible.

It is recognized that the content and consequently the content designation of certain blocks is dependent on cataloging codes and practices. Therefore, the best that can be hoped for in the near term is

*A recommended ISBD for serials was also published in 1974.[23]

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agreement on content designation at a level of specificity less than that presently used by national systems. For example, the intellectual responsibility block contains names of persons and organizations associated with the work described. In national systems, each type of name may be further expanded to multiple levels of subtypes and subfields coded in a variety of ways. In the international record, the expansion may be limited to indicating personal, family, corporate, and conference names and primary, alternate, and secondary responsibility.

The concept is a record composed of two principal parts: a) the identification of the item (descriptive block modelled after the ISBD), and b) all other elements making up the bibliographic record, e.g., headings, subjects, classification numbers, etc. This will allow the user to accept the descriptive block for inclusion in his system and provide the option of using or discarding the other elements of information.

A draft of the MARC international format has been widely distributed for comment before being discussed at an open meeting in Paris in October 1975.

Other Activities. The expanded roman-alphabet character set designed by LC was adopted by ALA, has been used in information systems throughout the world, and is the basis for the current work in progress in ISO/TC46/SC4/WG1, Character Sets for Documentation and Bibliographic Use. Draft international standards for extended Latin, Cyrillic, and Greek character sets have been distributed for comment. The acceptance of a character set for bibliographic use, indicating marketability to hardware vendors, led to the manufacture of a typewriter sphere, a print train, and several cathode ray tube terminals.

Country of publication codes and language codes originally established by LC for the MARC Pilot Project and, based on experience, modified for the MARC Distribution Service, have also been accepted as the codes for several systems. Although these codes have not been adopted as ANSI or ISO standards, they do have an impact on current standardization activities.

The challenge to the individuals involved in standards setting is great. Much remains to be accomplished. Progress has been made, however, and it appears that "International MARC" may become a reality.

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Use of MARC at the Library of Congress. The main thrust of LC's bibliographic automation program during the years 1966-70 was the distribution of MARC data. In terms of LC, MARC up to 1974 covered approximately 40 percent of the Library's total cataloging effort.

In 1970, sights began to turn inward, and MDO was established in the Processing Department* to concentrate on automating the functions concerned with technical processing. An article describing the automation programs of the Processing Department was published in 1972.[27] The program can be considered to have a three-pronged approach: a) expansion of the MARC Distribution Service, b) design and implementation of a core bibliographic system,** and c) products and services for LC and the library community. It is principally in item 'c' above that the MARC data base is used at LC at this time. Several of these projects are briefly described below.

A. Book catalogs

1. The Main Reading Room catalog consists of records included in MARC (books and serials) and records input especially for the project. Catalogs have been produced, via computer printer, arranged by call number, author, title, and subject for use in LC. Plans include the general distribution of the catalogs in this form as well as photocomposed issues at a later date. The subject catalog of the Main Reading Room collection is now in press.

2. The Science Reading Room file is also composed of MARC records (books and serials) in addition to records input specifically for the project. Computer printed catalogs have been produced for use in LC.

3. The catalog of *Films and Other Materials for Projection* for the last

*Before June 1970, staff responsible for MARC, RECON, etc., was part of the Information Systems Office (ISO), organizationally situated in the Office of the Librarian. At the same time that MDO was established, ISO was transferred to the Administrative Department.

**This includes automation of the Order Division functions and the Process Information File (PIF) which are presently in various stages of operation, implementation, and design. The Core Bibliographic System includes the use of LC name and subject authority records to produce book catalogs as well as linking them to MARC records as a cataloging aid. Several ongoing operational projects, such as the building and maintenance of the subject heading file, are modules of this activity.

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quarter of 1972 and the first two quarters of 1973 was produced from the MARC films data base in 1974. This catalog is issued in two sections in one volume: a) title main entries and added author entries, and b) subject added entries. "See" and "see also" references are included. The film catalog is now issued regularly as a quarterly publication with annual and quinquennial cumulations.

All machine produced book catalogs and other bibliographic listings are arranged by means of a program called Library Sort Key Edit (LIBSKED). This program was designed to implement the new LC filing rules[28] formulated by the Technical Processes Research Office of the Processing Department.

B. Printed cards

MARC records are input to the Cataloging Distribution Service Division's automated system to compose and print LC cards, complete with overprinted headings, for use in the LC catalogs. On-demand production of cards for film and map titles in response to orders from subscribing libraries or for cards which are out of stock is operational. Since April 1975, all LC cards for books, films, and maps in machine-readable form have been produced by the automated system, including depository sets, cards for stock, cards and references for LC's book catalogs, and overprinted cards for LC's catalogs.

C. MARC Retriever

The MARC data base is being used more and more frequently in LC as a bibliographic reference to supplement the card catalogs. The machine-readable records provide access via fields not used as headings in the card catalogs, and the richness of the MARC format offers new possibilities for the retrieval of information.

The MARC Retriever was originally seen as a research tool to promote the use of the MARC data base in new and unexplored ways. This experimental mode is still of interest in LC but, in addition, the system is used operationally for many purposes in LC as well as to provide special searches to outside organizations. The Retriever allows the user to search the contents of any variable field, subfield, or fixed field, as well as any specific tag, indicator, or subfield code value.

Recent searches include: a) monthly lists of books on Africa, Mainland China, Latin America, Eastern Europe, b) books in translation, c) children's books in translation, d) serials in French published in France, Belgium, and Canada, e) railroad maps, f) maps of East Africa, Kenya,

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Tanzania, and Uganda, g) CIP records in history, LC class schedules E and F, h) festschriften, i) atlases published in 1972, j) books about Africa containing statistical information, etc.

The records retrieved are arranged and printed according to the user's specifications. The sort may be on author, title, subject, classification, date, etc. Output may be printed in card or list form, with the amount of information displayed (short form or full record printout) a user option.

D. Other uses in LC

The LC Division for the Blind and Physically Handicapped selects pertinent records from the MARC files for inclusion in its system for the production of bibliographic tools, e.g., printed cards, book catalogs for such items as talking and braille books, etc.

As the scope of MARC expands and as the ongoing projects such as the automation of the PIF become operational, more and more use will be made of MARC at LC, both for technical processing and reference.

The MARC file is now searchable by author/title and title search key. Searches which result in many matching records may be further refined by a qualification technique. The file is being searched on a production basis by multiple units of the Processing Department, as well as by several units of the Reference Department.

Plans include expanding searching capabilities, as well as the eventual two-way linking between the authority records (name and subject) and each bibliographic record where the name or subject or both were used. This linking will enhance the present book catalog production system as well as provide the means to use the MARC files as a cataloging aid.
the proper record.

Use of MARC by Subscribers. At present (March 1974) there are 74 organizations subscribing to the MARC services.* The 74 subscribers purchase the following subscriptions:

MARC, Complete	13
MARC, Books (All)	28
MARC, Books (English)	19
MARC, Films	4
MARC, Serials	12
MARC, Maps	3

*The last MARC Survey was conducted in the spring of 1972 and the results published later in that year. The subscriber figures cited in this section have been updated to reflect the current situation.

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This list can be further subdivided within the category MARC, Complete. For example, there are 13 complete subscriptions and three map subscriptions meaning that 16 map subscriptions are actually in force. Dividing the subscriptions in this manner results in the following:

Books, Foreign	41
Books, English	70
Films	17
Serials	25
Maps	16

Since an organization may order more than one type of service, the actual number of individual subscriptions as given above totals 169. The subscribers are made up of 18 commercial enterprises, 23 organizations outside the United States (one of these has been previously counted in with the commercial enterprises), and the remainder divided among large research, college and university, state, special, and national libraries and library centers. Institutions are difficult to identify accurately since any one institution may perform the functions of another type, e.g., a university library may act as a center, serving, in addition to itself, several other organizations. Therefore, it is not possible to derive an accurate tally of subscribers by type of library. The subscribers discussed above are considered primary users. All of the commercial vendors and library centers as well as some of the organizations in the other categories of users provide services to other institutions. These latter institutions are considered secondary users of MARC data and, according to LC's best estimates, total approximately 1,500.

There are difficulties inherent in any presentation of MARC uses. This difficulty is in part created by the tendency of library functions to overlap. For example, the search/select function is not an end unto itself but instead may be a component of a system to print catalog cards or of an SDI system. There are also various levels of the use of MARC data, depending on the mix of manual and automated processing. MARC records are, in some cases, simply used as a source of bibliographic information with the rest of the processing purely manual, or MARC records become an integral part of an automated system. Some systems are wholly dependent on MARC; in others, MARC is some percentage of the total data base. There are systems that are totally batch oriented, others are partially batch oriented and partially online, and still others operate principally in an online mode. These various differences in systems do not affect the function performed, e.g., looking up a title to find where it is located, regardless of how the system is designed or how the files are organized.

The following discussion of MARC uses attempts to avoid the problems described above by addressing MARC uses in general terms and not probing into individual systems.

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The majority of uses of MARC data fall into the technical processing area. This is not surprising, since before the reference function can be served adequately, items must be put under bibliographic control. Furthermore, it is in technical processing that the professional librarian needs to be relieved of performing repetitive tasks or supervising others in the performance of such tasks. However, the reference function is somewhat satisfied by SDI services, LC's MARC Retriever, and the searching of index files of author, title, and subject.

Current MARC tapes are used for selection purposes by printing out the records and routing them to persons responsible for selecting materials for acquisition, or by comparing the tapes against stored profiles and printing the records that match. Printed indexes are also prepared from the MARC files (weekly or cumulative) and made available for selection.

To the extent that MARC records are available for items to be ordered, manual bibliographic searching is eliminated, and the MARC records selected are used to produce the orders and associated documents and the records are added to the institution's in process or master file.

MARC records are used in the production of catalog cards and book form catalogs. Book catalogs have appeared in dictionary form, register/index form, or as separate author, title, and subject catalogs (or any combination thereof). The level of sophistication of catalog production varies greatly. The production forms include computer line printing, photocomposition, and microform.

A bibliography in microform, called *Books in English*, is produced by merging BNB/MARC records with relevant LC/MARC records. A catalog of English-language acquisitions of a university library and affiliated institutions is also produced by selecting appropriate records from these two data bases.

Shared cataloging systems* with access to LC/MARC and locally input cataloging records by LC card number and/or search keys are also in operation. Member libraries search the files for a specific record. If the record is in the file and if the cataloging data is acceptable to the institution, printed cards in the format and quantity desired by the institution are sorted (prearranged in a filing sequence) and prepared off-line for the selected record. If the record is not available, the member library inputs the locally cataloged record which then becomes available to all other participants and the printed cards are prepared from the locally input record. In some systems, records can also be output on tape for any library desiring its cataloging data in machine-readable form. The online posting of the locations of the requesting library and the use of this file for interlibrary loan is also in operation.

*The Ohio College Library Center is the most advanced system at this time providing this type of service.

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The production of catalog cards remains the most popular operation, although in many instances card production is not the raison d'être of the system. The production of book preparation materials (book cards, pockets, and spine labels) as well as circulation cards, are useful byproducts of some systems.

In one system, the MARC record is used as a bibliographic source and agency subject terms, call numbers, etc., are added. The entire MARC file is maintained as a composite data base and a subset of the file relevant to the specialization of the organization is selected by such criteria as LC class numbers or subject headings, added to the records in the system not included in MARC and both types made available online to participating libraries. A full free text search is provided with a modified Keyword in Context (KWIC) display for titles, series names, conference names, corporate names, publishers' names, and subject headings. Additional online searching capabilities include other names, LC call numbers, LC card numbers, international standard book numbers, Dewey Decimal numbers, local library card numbers, and local library location indicators. This sophisticated searching capability is in addition to the production of several library products, e.g., current awareness listings, book catalogs, etc.

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SUMMARY

MARC is an assemblage of formats, publications, procedures, people, standards, codes, programs, systems, equipment, etc., that has evolved over the years stimulating the development of library automation and information networks.

Any discussion about MARC in particular involves discussing library automation in general. Progress in the field is evident. There is a definite advance from the automation of discrete functions toward the automation of modules leading to integrated systems. Emphasis is being placed on the implementation of online systems and the use of one system to provide services to many other organizations.

Library automation activities in 1974 appear to fall into the following categories:

1. Institutions are automating their technical processing functions and, as a byproduct, providing services, e.g., cards, listings, etc., to other organizations.
2. Institutions are automating a particular aspect of their service, e.g., book catalog production, and as a byproduct, their procedures and programs are used to produce a like product for another organization.
3. Institutions are creating automated systems designed principally as a bibliographic center to provide services, e.g., printed cards, union catalogs, etc., for other organizations that do not intend to automate.

Libraries have passed through an era of much talk but few results into the 1970's where the automation of library operations is no longer a promise but a demonstrated success. Faced with economic realities, the availability of bibliographic information in machine-readable form, and the possibility of sharing these resources through computer technology, there is an increasing awareness that standardization, nationally and internationally, is the sine qua non of the information system.

The benefits that accrue to a library and its clients from the establishment of and the conformity to standards are many. Products from different sources will mesh. Records from different libraries will be interchanged. Machine systems will be more easily developed and shared. Union catalogs will be possible without costly editing for consistency, thus facilitating interlibrary loan. Cost of local changes to catalog records will be minimized. It will be advantageous for vendors to manufacture

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hardware to handle the requirements of libraries. The process of ordering, cataloging, etc., will be more uniform. Therefore, less searching and bibliographic verification will be necessary and duplication of effort will be avoided. Networking will be facilitated. Various data bases will be accessible through the use of standard protocol. Service to the user will be improved and that is really what MARC is all about.

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[For sale by the Supt. of Docs., U.S. Govt. Print. Off., Washington, D.C. 20402. $3.50 LC 1.2:M18/2]

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[For sale by the Supt. of Docs., U.S. Govt. Print. Off., Washington, D.C. 20402. $1.00 LC 1.2:M18/11]

Also available free on request from Subscriber Accounts Unit, LC Cataloging Distribution Service Division, Building 159, Navy Yard Annex, Washington, D.C 20541.

1st-3rd editions, 1968-1969, have title: Subscriber's Guide to the MARC Distribution Service.

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Preliminary edition, 1970; Addendum no. 1, June 1971; 2d edition, pre-print edition, 1973.

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ATTACHMENT 14

WHAT IS A MARC RECORD, AND WHY IS IT IMPORTANT?

Part I: What Does MARC Mean?
Part II: Why Is a MARC Record Necessary?
Part III: MARC Terms and Their Definitions
Part IV: Where do MARC Records Originate?
Part V: MARC Data Issues
Part VI: In Conclusion

It is impossible these days to read a library journal, attend a library conference, or even have an informal chat with other librarians without hearing the phrases "MARC format," "MARC records," or "MARC-compatible." Many library professionals have not had an opportunity to take formal courses explaining the important topics of library automation and the role of MARC, yet automated library systems may be important parts of their libraries.

This booklet will explain -- in the simplest terms possible -- what a MARC record is, and it will provide the basic information needed to understand and evaluate a MARC record.

Part I:

What Does MARC Mean?

What is a MARC record? A MARC record is a MA chine-Readable Cataloging record.

And what is a machine-readable cataloging record?

Machine-readable: "Machine-readable" means that one particular type of machine, a computer, can read and interpret the data in the cataloging record. The following pages will explain why this is important and how it is made possible.

Cataloging record: "Cataloging record" means a bibliographic record, or the information traditionally shown on a catalog card. The record includes (not necessarily in this order): 1) a description of the item, 2) main entry and added entries, 3) subject headings, and 4) the classification or call number. (MARC records often contain much additional information.)

1) Description: Librarians follow the rules in *Anglo-American Cataloguing Rules*, 2nd ed., 2002 revision to compose the bibliographic description of a library item. This "description" is shown in the paragraph sections of a card.

It includes the title, statement of responsibility, edition, material specific details, publication information, physical description, series, notes, and standard numbers.

2) Main entry and added entries: AACR2 also contains rules for determining "access points" to the record (usually referred to as the "main entry" and "other added entries"), and the form these access points should take. Access points are the retrieval points in the library catalog where patrons should be able to look up the item.

In other words, the rules in AACR2 are used to answer questions such as: For this book, should there be entries in the catalog for more than one author or more than one title? Should the title of the series be noted? How should the author's name be written? Is this a "title main entry" item (no author)?

3) Subject headings (subject added entries): The librarian uses the *Sears List of Subject Headings* (Sears), the *Library of Congress Subject Headings* (LCSH), or some other list of standard subject headings to select the subjects under which the item will be listed. Use of an approved list is important for consistency, to ensure that all items on a particular subject are found under the same heading and therefore in the same place in the catalog.

For instance, the subject heading list indicates that all books about cats should be assigned the subject CATS. Using this authorized heading eliminates the possibility of listing some books under CATS and others under FELINES. Even if a book is called *All About Felines*, the subject heading will be typed CATS. That way, all books on that subject will be listed in one place in the catalog for the patron to find. The patron does not have to imagine all the possible synonyms for the word he is looking for.

4) Call number: The librarian uses a Dewey Decimal or Library of Congress classification schedule to select the call number for an item. The purpose of the call number is to place items on the same subject together on the same shelf in the library. Most items are sub-arranged alphabetically by author. The second part of the call number usually represents the author's name, facilitating this subarrangement.

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Part II:

Why Is a MARC Record Necessary?

Why can't a computer just read a catalog card? The information from a catalog card cannot simply be typed into a computer to produce an automated catalog. The computer needs a means of interpreting the information found on a cataloging record. The MARC record contains a guide to its data, or little "signposts," before each piece of bibliographic information.

The place provided for each of these pieces of bibliographic information (author, title, call number, etc.) is called a "field." The records in simpler computer files sometimes have a fixed number of fields, and each field contains a fixed number of characters.

However, to allow proper cataloging of books and other library items, the best file structure allows for records with an unlimited number of fields and unlimited field lengths. This flexibility is necessary because not all titles are the same length (*The robe* versus *Alexander and the terrible, horrible, no good, very bad day*). Some books are part of a series, requiring a field for that information, while others have no series statement. And audiovisual items have much longer physical descriptions (5 filmstrips : sd., col. ; 35 mm. + teaching manual) than do most books (403 p. : ill. ; 22 cm.).

The computer cannot expect a certain type of information to begin and end at the same position in every bibliographic record. The statement of responsibility will not always begin with the 145th character of the record and end at the 207th position, for example. Therefore each MARC record contains a little "table of contents" to the record, according to a predefined standard.

Data "signposts:" The computer must have assistance if it is to read and interpret the bibliographic record. The box charts on the right illustrate the information these "signposts" need to convey.

If a bibliographic record has been marked correctly and saved in a computer data file, computer programs can then be written to punctuate and format the information correctly for printing a set of catalog cards, or for displaying the information on a computer screen. Programs can be written to search for and retrieve certain types of information within specific fields, and also to display lists of items meeting the search criteria.

Why one standard? You could devise your own method of organizing the bibliographic information, but you would be isolating your library, limiting its options, and creating much more work for yourself. Using the MARC standard prevents duplication of work and allows libraries to better share bibliographic resources. Choosing to use MARC enables libraries to acquire cataloging data that is predictable and reliable. If a library were to develop a "home-grown" system that did not use MARC records, it would not be taking advantage of an industry-wide standard whose primary purpose is to foster communication of information.

Using the MARC standard also enables libraries to make use of commercially available library automation systems to manage library operations. Many systems are available for libraries of all sizes and are designed to work with the MARC format. Systems are maintained and improved by the vendor so that libraries can benefit from the latest advances in computer technology. The MARC standard also allows libraries to replace one system with another with the assurance that their data will still be compatible.

MARC 21: The Library of Congress serves as the official depository of

United States publications and is a primary source of cataloging records for US and international publications. When the Library of Congress began to use computers in the 1960s, it devised the LC MARC format, a system of using brief numbers, letters, and symbols within the cataloging record itself to mark different types of information. The original LC MARC format evolved into MARC 21 and has become the standard used by most library computer programs. The MARC 21 bibliographic format, as well as all official MARC 21 documentation, is maintained by the Library of Congress. It is published as *MARC 21 Format for Bibliographic Data*.

A comparison of the same record with textual information and with MARC tags illustrates the compactness of the MARC 21 format. It's a matter of storage space. Look at the box charts below . The MARC 21 format uses "260" "$a" "$b" and "$c" to mark the field that holds imprint data instead of storing the words "publication area," "place of publication," "name of publisher," and "date of publication" in each record. This convention makes more efficient use of computer storage space.

Record with textual "signposts"

"SIGNPOSTS"	DATA
Main entry, personal name with a single surname: The name:	Arnosky, Jim.
Title and Statement of responsibility area, pick up title for a title added entry, file under "Ra..." Title proper: Statement of responsibility:	Raccoons and ripe corn / Jim Arnosky.
Edition area: Edition statement:	1st ed.
Publication,	New York :

distribution, etc., area: Place of publication: Name of publisher: Date of publication:	Lothrop, Lee & Shepard Books, c1987.
Physical description area: Pagination: Illustrative matter: Size:	25 p. : col. ill. ; 26 cm.
Note area: Summary:	Hungry raccoons feast at night in a field of ripe corn.
Subject added entries, from Library of Congress subject heading list for children: Topical subject:	Raccoons.
Local call number:	599.74 ARN
Local barcode number:	8009
Local price:	$15.00

Same record with MARC tags

"SIGNPOSTS"	DATA

100	1#	$a	Arnosky, Jim.
245	10	$a	Raccoons and ripe corn /
		$c	Jim Arnosky.
250	##	$a	1st ed.
260	##	$a	New York :
		$b	Lothrop, Lee & Shepard Books,
		$c	c1987.
300	##	$a	25 p. :
		$b	col. ill. ;
		$c	26 cm.
520	##	$a	Hungry raccoons feast at night in a field of ripe corn.
650	#1	$a	Raccoons.
900	##	$a	599.74 ARN
901	##	$a	8009
903	##	$a	$15.00

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Part III:

MARC Terms and Their Definitions

This section covers how to read, understand, and use a MARC record. It deals with what librarians using a library automation system will see and need to understand on their computer screens when adding, editing, or examining records. The emphasis will be on those areas commonly used in cataloging for schools and small public libraries, i.e. books and audiovisual materials. However, what is covered in this section applies equally to all forms of materials, including sound recordings, computer software, maps, and other non-book items.

Recently approved changes, some of which have already been implemented, to the MARC 21 bibliographic format have involved the concept of Format Integration. "Format Integration" means that the same "signposts" are used to mark data in records for all types of publications, rather than having different sets of "signposts" for each type. More technically, under Format Integration, one group of tags is used for records of all types of materials rather than having a tag set defined for each type.

The box chart in the previous section showed a MARC record labelled with "signposts." The proper names of these "signposts" are *field*, *tag*, *indicator*, *subfield*, *subfield code*, and *content designator*. These MARC 21 terms are covered in this section.

1. FIELDS are marked by TAGS.

A field: Each bibliographic record is divided logically into fields. There is a

field for the author, a field for title information, and so on. These fields are subdivided into one or more "subfields." As previously noted, the textual names of the fields are too lengthy to be reproduced within each MARC record. Instead they are represented by 3-digit tags. (Though online catalogs may display the names of the fields, the names are supplied by the system software, not by the MARC record.)

A tag: Each field is associated with a 3-digit number called a "tag." A tag identifies the field -- the kind of data -- that follows. Even though a printout or screen display may show the tag immediately followed by indicators (making it appear to be a 4- or 5-digit number), the tag is always the first 3 digits.

The tags used most frequently are:

010 tag	marks the **Library of Congress Control Number** (LCCN)
020 tag	marks the **International Standard Book Number** (ISBN)
100 tag	marks a **personal name main entry** (author)
245 tag	marks the **title information** (which includes the title, other title information, and the statement of responsibility)
250 tag	marks the **edition**
260 tag	marks the **publication information**
300 tag	marks the **physical description** (often referred to as the "collation" when describing books)
490 tag	marks the **series statement**
520 tag	marks the **annotation or summary note**
650 tag	marks a **topical subject heading**
700 tag	marks a **personal name added entry** (joint author, editor, or illustrator)

Here is an example of a field. The number 100 is the tag, defining it as a personal name main entry (author) field.

```
100 1#   $a Pirsig, Robert M.
```

The Cataloging Distribution Service of the Library of Congress distributes a detailed listing of all tags in both the 2-volume publication *MARC 21 Format for Bibliographic Data* and a summarized single volume work entitled *MARC 21 Concise Formats*. For continued work with MARC records, these sets are highly recommended. They are detailed documents containing many examples. (See the bibliography for complete reference.)

In the MARC record, 10% of the tags are used over and over, and the other 90% are seen only occasionally or rarely. After even a short exposure to the MARC 21 format, it is not unusual to hear librarians speaking in "MARCese." Librarians who work with MARC records soon memorize the numbers for the fields common to the materials they catalog.

An outline of those 10% of the tags which are used most frequently is included with this brochure in Part VII. A brief list of some of the other tags is included in Part VIII.

2. Some fields are further defined by INDICATORS.

Indicators: Two character positions follow each tag (with the exception of Fields 001 through 009). One or both of these character positions may be used for indicators. In some fields, only the first or second position is used; in some fields, both are used; and in some fields, like the 020 and 300 fields, neither is used. When an indicator position is not used, that indicator is referred to as "undefined" and the position is left blank. It is the convention to represent a blank, or undefined, indicator position by the character "#".

Each indicator value is a number from 0 to 9. (Although the rules say it can be a letter, letters are uncommon.) Even though two indicators together may look like a 2-digit number, they really are two single-digit numbers. The allowable indicator values and their meanings are spelled out in the MARC 21 documentation. In the example which follows, the first 3 digits are the tag (245 defines this as a title field) and the next 2 digits (a 1 and a 4) are indicator values. The 1 is the first indicator; 4 is the second indicator.

```
245 14   $a The emperor's new clothes /
         $c adapted from Hans Christian Andersen
            and illustrated by Janet Stevens.
```

A ***first indicator*** value of 1 in the title field indicates that there should be a separate title entry in the catalog. In the card catalog environment, this means that a title card should be printed for this item and an entry for "Title" added to the tracings. A first indicator value of 0 would mean that a title main entry is involved; the card would be printed with the traditional hanging indention, and no additional tracing for the title would be required (since it is the main entry).

Nonfiling characters: One of the more interesting indicators is the second indicator for the title field. It displays the number of characters at the beginning of the field (including spaces) to be disregarded by the computer in the sorting and filing process. For the title *The emperor's new clothes*, the second indicator is set to "4" so that the first four characters (the "*T,*" the "*h,*" the "*e,*" and the space) will be skipped and the title will be filed under "*emperor's.*"

3. SUBFIELDS are marked by SUBFIELD CODES and DELIMITERS.

A subfield: Most fields contain several related pieces of data. Each type of data within the field is called a **subfield**, and each subfield is preceded by a **subfield code**. Fields 001 through 009 have no subfields.

For example, the field for a book's physical description (defined by the tag 300) includes a subfield for the extent (number of pages), a subfield for other physical details (illustration information), and a subfield for dimensions (centimeters):

```
300 ##   $a 675 p. : $b ill. ; $c 24 cm.
```

A subfield code: Subfield codes are one lowercase letter (occasionally a number) preceded by a delimiter. A delimiter is a character used to separate subfields. Each subfield code indicates what type of data follows it. (For each field in the MARC 21 bibliographic format, the MARC 21 documentation lists and describes the valid subfield codes.)

A delimiter: Different software programs use different characters to represent the delimiter on the screen or on printouts. Examples are a double dagger (‡), an "at sign" (**@**), a dollar sign (**$**), an underline (_), or the graphic symbol "‡". In this publication the dollar sign ($) is used as the delimiter portion of the subfield code.

In the example above, the subfield codes are **$a** for the extent, **$b** for other physical details, and **$c** for dimensions.

4. CONTENT DESIGNATORS is an inclusive term used to refer to tags, indicators, and subfield codes.

The three kinds of content designators -- tags, indicators, and subfield codes -- are the keys to the MARC 21 notation system. In his book, *MARC for Library Use* (2nd ed. (Boston: G.K. Hall & Co., 1989), p. 5), Walt Crawford calls the MARC system a "shorthand notation" system. The three types of content designators are the shorthand symbols that label and explain the bibliographic record.

5. Some GENERAL RULES.

There are some general rules that help define what all the numbers used as field tags mean. Please note that in discussions of MARC 21 tags, the notation XX is often used to refer to a group of related tags. For example, 1XX refers to all the tags in the 100s: 100, 110, 130, and so on.

A. Tags divided by hundreds. The basic divisions of the MARC 21 bibliographic record are:

0XX	Control information, numbers, codes
1XX	Main entry
2XX	Titles, edition, imprint (in general, the title, statement of responsibility, edition, and publication information)
3XX	Physical description, etc.
4XX	Series statements (as shown in the book)
5XX	Notes
6XX	Subject added entries
7XX	Added entries other than subject or series
8XX	Series added entries (other authoritative forms)

The 9XXs have been left for locally-defined uses, such as local barcode numbers. Local libraries, vendors, or systems can define and use them for attaching other types of information to records. (X9Xs in each of these groups -- 09X, 59X, etc. -- are also reserved for local use, except 490.)

The list of the most common tags shows how each fits into one of these divisions: 100 is an author main entry, 520 is a summary note, and so on.

B. Access points: Access points (a main entry, subject added entries, and other added entries) are an important part of the bibliographic record. These are the headings for which separate cards were created for the traditional card catalog, and which a patron or librarian can search in an online catalog. Most of the access points are in:

1XX	fields (main entries)
4XX	fields (series statements)
6XX	fields (subject headings)
7XX	fields (added entries other than subject or series)
8XX	fields (series added entries)

These are the fields that are under authority control.

"Authority control" means following a recognized or established form. Usually, a cataloger chooses subject and name headings from a list of approved headings. In a conversation, if you talked about visiting the "Getty Museum" and the "J. Paul Getty Museum" in California, your listener would know you meant the same thing. But if a cataloger sometimes uses "Getty Museum" and other times uses "J. Paul Getty Museum" as headings in a catalog, the library user will have a difficult time finding all the books on that subject. If a cataloger follows the Library of Congress's list of established forms for names, he or she will use the heading "J. Paul Getty Museum." As long as the cataloger always uses one established form, all the books on that museum will be found in one place in the catalog.

For names, the best authority is the Library of Congress Name

Authority file. This file is available in machine-readable format from the Cataloging Distribution Service (CDS) of the Library of Congress or online at http://authorities.loc.gov. The form of the name used (personal name, corporate name, conference or meeting name, series title, or uniform title) can be checked against this authority.

For topics or geographic names, the common subject authority lists are the *Library of Congress Subject Headings* or the *Sears List of Subject Headings*. The form of a subject heading should match one on the list or follow the rules for construction.

In a desktop computer system, it is difficult to store all of the Library of Congress authority files. Five gigantic volumes are required to list the *Library of Congress Subject Headings*. The portion used by a school or special librarian would be only a fraction of the whole.

What is more important on the computer-based library catalog is what is termed "local authority control." Local authority control allows the librarian to look at the list of subject headings or the list of author names and ask to reuse one that has already been entered. In that way, all headings for the same person or same subject will be entered exactly the same way -- which is the point of authority control. Names shown in Cataloging in Publication (CIP) data in books are also based on Library of Congress authority records at the time of publication. The forms shown for current publications in an online catalog after a retrospective conversion of data should be correct, since nearly every book or data vendor's database is based on Library of Congress MARC files.

The term "retrospective conversion" describes a project that converts bibliographic records from their present form -- such as shelflist cards or a brief circulation record -- to full machine-readable bibliographic records. The term retrospective is used because the project is done for a library's existing collection -- everything placed in the library up to the present time. Usually the retrospective conversion is done by "matching" a library's old records (whether on cards or in a non-MARC format) to a database of full records in machine readable form. Rather than rekeying old records, a librarian can purchase the equivalent MARC records.

C. Parallel content: The fields requiring authority control are also the fields that use parallel tag construction. In general, in the 1XX, 4XX, 6XX, 7XX and 8XX fields, a personal name will have the last two digits 00. Therefore, for a main entry (1XX) that is a personal name (X00), the correct tag is 100. For a subject heading (6XX) that is a personal name, the tag is 600, and so on. This parallel content can be summarized as follows:

X00 Personal names
X10 Corporate names
X11 Meeting names
X30 Uniform titles
X40 Bibliographic titles
X50 Topical terms
X51 Geographic names

By combining this chart with the chart "Tags divided by hundreds" (above), it becomes evident that if the subject of a book (6XX) is a person (Lincoln, Abraham), the tag will be 600; if the subject of the book is a corporation (Apple Computer, Inc.), the tag will be 610; if the subject of the book is a topic (Railroads), the tag will be 650; if the subject of a book is a place (United States), the tag will be 651. An added entry (7XX) for a joint author (a personal name) will have tag 700.

The Dewey Decimal classification uses a similar construct in its tables for geographic locations or standard subdivisions.

6. Unique information appears at the beginning of the MARC record.

Preceding the main bibliographic record parts -- which are known to all librarians because of their presence on catalog cards -- the MARC record contains some less familiar information. Automated cataloging systems usually provide default data or prompts to help a cataloger input this information.

A. Leader: The leader is the first 24 characters of the record. Each position has an assigned meaning, but much of the information in the leader is for computer use. MARC record creation and editing programs usually provide a window or prompts to assist the cataloger in filling in any leader data elements that require input. The details required for interpreting the leader are in Part IX of this brochure.

B. Directory: MARC records are called "tagged" records. Before it becomes a tagged record, a MARC record (in what is called the MARC communications format), looks very different -- like one long run-on sentence. In the communications format, the fields are not preceded by tags. However, immediately following the leader is a block of data called a directory. This directory tells what tags are in the record and where they are placed (by a count of the characters to the position where each field begins). The directory is constructed (by computer) from the bibliographic record, based on the cataloging information, and, if any of the cataloging information is altered, can be reconstructed in the same way. Part XI displays a record in MARC 21 communications format, including its directory.

C. The 008 field: The 008 field is referred to as Fixed-Length Data Elements, or Fixed Field Codes. Its 40 characters contain important information, but in an abbreviated form. Although it is not yet used to its fullest in online catalog systems, this field can be used to identify and retrieve records matching specific criteria.

For example, there is a code in this field to indicate whether a book is large-print, a code to identify the country of publication, a code to identify juvenile materials, a code to indicate the language of the text, and so on. The details required for interpreting the 008 field for books are in Part X.

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Part IV:

Where Do MARC Records Originate?

Shared cataloging information -- shared bibliographic records -- has been a reality for a number of years. Many librarians have chosen to maximize limited resources by acquiring cataloging data rather than creating it themselves. For almost a century they have been able to order sets of catalog cards for their new books from the Library of Congress, or, more recently, from book jobbers.

Others typed their own cards, using the Cataloging in Publication (CIP) data found on the verso of the title page of many books. Librarians also adapted the partial or full cataloging records printed in library journals or in bibliographies.

Once computers became available, it was no longer necessary for librarians everywhere to constantly "reinvent the wheel." Why should hundreds of catalogers each use valuable time to compose nearly identical cataloging records for the same item when one cataloger could do it and share the record that had been created? Why should hundreds of typists retype that same record on cards when a computer could be programmed to print them?

After the MARC record was developed, libraries shared in the benefits of machine-readable cataloging whether they had an online system or not. The cards, purchased from the Library of Congress or from a jobber, were computer-printed from bibliographic records based on Library of Congress MARC files.

Colleges and universities with large library budgets joined bibliographic utilities such as OCLC, WLN, RLIN, and A-G Canada. For an on-going fee plus communication costs, their technical service departments went online with the utilities' powerful mainframe computers. These ventures allowed those libraries to use and contribute MARC records. Catalog cards could be ordered, and a printer could be hooked up to the system to receive data over

the phone lines and print book labels.

Now we are in an exciting age when powerful, inexpensive computers are available for the management of library operations in all types and sizes of libraries. Computer software programs allow an individual library to have its own self-contained circulation system or online public access catalog. These programs often can read, store, and print MARC records. Today's computers use hard disks and floppy disks for storage of information rather than the tape drives used by mainframe computers. For computers, data is commonly sent and received on floppy disks. From the floppy disks, bibliographic records are uploaded to the stationary hard disk.

As library automation technology changes and as cataloging needs change, the MARC 21 formats and related MARC 21 documentation are changing also. Although the MARC format was originally developed by the Library of Congress and the MARC 21 format documentation is maintained and published there, the Library does not make changes or revisions unilaterally.

Two groups which are responsible for reviewing and revising MARC 21 format documentation are MARBI and the MARC Advisory Committee. The Machine-Readable Bibliographic Information (MARBI) Committee is a committee of the American Library Association (ALA) and is composed of three representatives from each of the three function-oriented divisions of ALA: ALCTS (technical services function); LITA (automation); and RUSA (reference). ALA tries to assure that all types of expertise are represented on MARBI. The MARC Advisory Committee is composed of representatives from the national libraries, the bibliographic utilities, vendor groups, and other library and scholarly associations. MARBI meets in conjunction with the MARC Advisory Committee at each ALA conference (annual and mid-winter). The major activity of the Committee is the review of discussion papers and proposals submitted by or through the Library of Congress for changes or additions to existing MARC formats, or the development of new MARC format support in emerging areas.

In 1987, the Library of Congress issued the first edition of the document *MARC 21 Specifications for Record Structure, Character Sets, and Exchange Media* to aid libraries and other organizations who create or acquire MARC 21 records. Subsequent editions were published in 1990, 1994, and 2000. This document provides technical information on the structure of MARC records, the character sets used in MARC records, and the format for distribution media for MARC 21 records. It is intended for the use of personnel involved in the design and maintenance of systems for the exchange and processing of MARC records.

With the proliferation of computer systems in libraries, it became apparent that a standard was also needed for the exchange of MARC records on floppy diskette. Working closely with representatives from book and data vendors and library automation systems vendors, MARBI and the Advisory Committee recommended proposals which resulted in the necessary changes and additions to the MARC 21 format to fully specify record transfer using diskettes.

More recently, specifications have been developed also for the distribution of MARC records via file transfer (FTP). The diskette and FTP distribution specifications first appeared in the 1994 edition of MARC 21 specifications.

Librarians, vendors -- anyone at all -- who distributes cataloging data should be able to provide standard MARC 21 cataloging in standard format. Library automation systems vendors should be able to design their systems to correctly receive and process standard MARC records. Individual librarians using computers to manage their libraries are the direct beneficiaries of all this MARC 21 standards work.

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Part V:

MARC Data Issues

As computers and technology continue to advance, important issues arise about the quality of library data and computer-based library automation systems. You need to be aware of these issues and their importance to your library.

A. Data questions: When bibliographic records are evaluated, some important questions which need to be addressed are: *What is the quality of the MARC data? Which MARC 21 fields are present? Is the data based on Library of Congress MARC records? If so, is the full information that is available on those files evident in the records? Is anything added to the record?*

Some librarians ask several vendors of bibliographic data for printed examples of their MARC records in order to compare their fullness and compliance with MARC 21 standards.

Clearly, the contents of the bibliographic records will determine the success of a library's automated operations to a very great extent, for you and your patrons. It is very important to ensure receipt of the highest quality records available.

B. Software questions: The next logical questions to ask are: *Does the library automation system being evaluated make full use of the cataloging information? Does it retain all the data and the MARC 21 content designators?*

Does the system load in the full record, with no unreasonable or false limitations on such things as the number of subject headings it will index or the length of the note fields? Even though the disk contained excellent, full records, any library automation system will be able to use only what was transferred to the hard disk. (If a circulation system loads in only circulation data, it is important to keep the MARC 21 data disks for upgrading to full

bibliographic records at a later time, in order to expand to an online catalog.)

Are the MARC tags, indicators, and subfield codes still present on the librarian's data entry screen? Are the indicators used correctly? Are the subfield codes used correctly? (The information in Part VII will help in evaluating correct use of the content designators.)

After records are added to a database, it is important to store them in the MARC 21 bibliographic format. Future projects may require their use. The MARC format is an industry-wide standard. As additional programs become available, a library's ability to participate in them could hinge on the quality of its bibliographic records.

That brings up one other point. Does the system allow for downloading, or writing the records back out to a disk, to use in other projects such as a union catalog project? Will a program be available to write them in the MARC communications format? (See Part XI for a discussion of various communication and screen formats.)

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Part VI:

In Conclusion

In these pages you've learned what the acronym MARC means. You've seen why a standard format for identifying elements of bibliographic data became necessary and why it is still important. You've learned to d efine and identify the three types of MARC content designators: tags, subfield codes, and indicators. Most important, with this knowledge you can understand the questions that should concern you when considering the purchase of bibliographic data or of a library automation system.

To build on this basic introduction to the topic, additional reading on the subject or courses in online cataloging can be beneficial. Further readings are suggested in the bibliography. MARC may appear difficult at first, but with knowledge and use, it will begin to make sense. As you become more familiar with MARC, the simpler it will become.

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Library of Congress

Library of Congress Help Desk (10/27/2009)

ATTACHMENT 15

3XX - Physical Description, Etc. Fields - General Information

MARC 21 Bibliographic **June 2024**

300 - Physical Description (R)
306 - Playing Time (NR)
307 - Hours, etc. (R)
310 - Current Publication Frequency (R)
321 - Former Publication Frequency (R)
334 - Mode of Issuance (R)
335 - Extension Plan (R)
336 - Content Type (R)
337 - Media Type (R)
338 - Carrier Type (R)
340 - Physical Medium (R)
341 - Accessibility Content (R)
342 - Geospatial Reference Data (R)
343 - Planar Coordinate Data (R)
344 - Sound Characteristics (R)
345 - Moving Image Characteristics (R)
346 - Video Characteristics (R)
347 - Digital File Characteristics (R)
348 - Notated Music Characteristics (R)
351 - Organization and Arrangement of Materials (R)
352 - Digital Graphic Representation (R)
353 - Supplementary Content Characteristics (R)
355 - Security Classification Control (R)
357 - Originator Dissemination Control (NR)
361 - Structured Ownership and Custodial History (R)
362 - Dates of Publication and/or Sequential Designation (R)
363 - Normalized Date and Sequential Designation (R)
365 - Trade Price (R)
366 - Trade Availability Information (R)
370 - Associated Place (R)
377 - Associated Language (R)
380 - Form of Work (R)
381 - Other Distinguishing Characteristics of Work or Expression (R)
382 - Medium of Performance (R)
383 - Numeric Designation of Musical Work or Expression (R)
384 - Key (R)
385 - Audience Characteristics (R)
386 - Creator/Contributor Characteristics (R)
387 - Representative Expression Characteristics (R)
388 - Time Period of Creation (R)

FIELD DEFINITION AND SCOPE

Information pertaining to physical characteristics, graphic representation, physical arrangement,

publication frequency, and security information. For digital items, fields are provided for recording reference and coordinate data.

CONTENT DESIGNATOR HISTORY

Field 301 - Physical Description for Films (Pre-AACR 2) (VM, USMARC only) [OBSOLETE, 1983]
Field 302 - Page Count (BK) [OBSOLETE, 1990]
Field 303 - Unit Count (AM, USMARC only) [OBSOLETE, 1983]
Field 304 - Linear Footage (AM, USMARC only) [OBSOLETE, 1983]
Field 305 - Physical Description for Sound Recordings (Pre-AACR 2) (MU) [OBSOLETE, 1993]
Field 308 - Physical Description for Films (Archival) (VM) [OBSOLETE, 1990]
Field 315 - Frequency (CF, MP) [OBSOLETE, 1993]
Field 334 - Mode of Issuance [NEW, 2021]
Field 335 - Extension Plan [NEW, 2020]
Field 336 - Content Type [NEW, 2009]
Field 337 - Media Type [NEW, 2009]
Field 338 - Carrier Type [NEW, 2009]
Field 341 - Accessibility Content [NEW, 2018]
Field 344 - Sound Characteristics [NEW, 2011]
Field 345 - Projection Characteristics of Moving Image [NEW, 2011]
Field 345 - Projection Characteristics of Moving Image [RENAMED, 2020]
Field 346 - Video Characteristics [NEW, 2011]
Field 347 - Digital File Characteristics [NEW, 2011]
Field 348 - Format of Notated Music [NEW, 2015]
Field 348 - Format of Notated Music [RENAMED, 2021]
Field 350 - Price (BK, AM, MU, VM) [OBSOLETE, 1983]
Field 350 - Price (CF, SE) [OBSOLETE, 1993]
Field 353 - Supplementary Content Characteristics [NEW, 2021]
Field 359 - Rental Price (VM) [OBSOLETE, 1983]
Field 361 - Structured Ownership and Custodial History [NEW, 2023]
Field 363 - Normalized Date and Sequential Designation [NEW, 2007]
Field 365 - Trade Price [NEW, 2003]
Field 366 - Trade Availability Information [NEW, 2003]
Field 370 - Associated Place [NEW, 2014]
Field 377 - Associated Language [NEW, 2011]
Field 380 - Form of Work [NEW, 2010]
Field 381 - Other Distinguishing Characteristics of Work or Expression [NEW, 2010]
Field 382 - Medium of Performance [NEW, 2010]
Field 383 - Numeric Designation of Musical Work [NEW, 2010]
Field 383 - Numeric Designation of Musical Work [RENAMED, 2024]
Field 384 - Key [NEW, 2010]
Field 385 - Audience Characteristics [NEW, 2013]
Field 386 - Creator/Contributor Characteristics [NEW, 2013]
Field 387 - Representative Expression Characteristics [NEW, 2022]
Field 388 - Time Period of Creation [NEW, 2014]

ATTACHMENT 16

Directory of OCLC members

Find an active OCLC member library or its symbol. Enter whatever you know; part of a name, city, etc. You can expand your results to include active participating libraries by unchecking the "Show only OCLC Members" checkbox.

Institution Name

OCLC Symbol

Show only OCLC Members

Search Clear form

About OCLC (https://www.oclc.org/en/about.html?cmpid=md_footer)

Careers (https://www.oclc.org/en/careers.html?cmpid=md_footer)

Inclusivity and Belonging (https://www.oclc.org/en/about/inclusivity-and-belonging.html?cmpid=md_footer)

Finance (https://www.oclc.org/en/about/finance.html?cmpid=md_footer)

Leadership (https://www.oclc.org/en/about/leadership.html?cmpid=md_footer)

Membership (https://www.oclc.org/en/membership.html?cmpid=md_footer)

Trust Center (https://www.oclc.org/en/trust.html?cmpid=md_footer)

Library management (https://www.oclc.org/en/services/a-z.complete-library-management.html?cmpid=md_footer)

Metadata (https://www.oclc.org/en/services/a-z.metadata.html?cmpid=md_footer)

Resource sharing (https://www.oclc.org/en/services/a-z.resource-sharing.html?cmpid=md_footer)

Member stories (https://www.oclc.org/en/member-stories.html?cmpid=md_footer)

All products and services » (https://www.oclc.org/en/services/a-z.html?cmpid=md_footer)

Learn

Research (https://www.oclc.org/research/home.html?cmpid=md_footer)

WebJunction (https://www.webjunction.org/home.html?cmpid=md_footer)

Events (https://www.oclc.org/en/events.html?cmpid=md_footer)

On-demand webinars (https://www.oclc.org/cmpid=md_footer)

Community center (https://community.oclc.org/?cmpid=md_footer)

Developer Network (https://www.oclc.org/developer/home.en.html?cmpid=md_footer)

BibFormats (https://www.oclc.org/bibformats/en/home.html?cmpid=md_footer)

System status dashboard (https://oclc.service-now.com/status)

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Hanging together (https://hangingtogether.org/)

President's Leadership blog (https://www.skipprichard.com/)

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ATTACHMENT 17

6XX - Subject Access Fields-General Information

MARC 21 Bibliographic **November 2019**

600 - Subject Added Entry - Personal Name (R)
610 - Subject Added Entry - Corporate Name (R)
611 - Subject Added Entry - Meeting Name (R)
630 - Subject Added Entry - Uniform Title (R)
647 - Subject Added Entry - Named Event (R)
648 - Subject Added Entry - Chronological Term (R)
650 - Subject Added Entry - Topical Term (R)
651 - Subject Added Entry - Geographic Name (R)
653 - Index Term - Uncontrolled (R)
654 - Subject Added Entry - Faceted Topical Terms (R)
655 - Index Term - Genre/Form (R)
656 - Index Term - Occupation (R)
657 - Index Term - Function (R)
658 - Index Term - Curriculum Objective (R)
662 - Subject Added Entry - Hierarchical Place Name (R)
688 - Subject Added Entry - Type of Entity Unspecified (R)
69X - Local Subject Access Fields (R)

DEFINITION AND SCOPE

6XX fields contain subject access entries and terms. Most of these fields contain subject added entries or access terms based on the lists and authority files identified in the second indicator (Subject heading system/thesaurus) or in subfield $2 (Source of subject heading or term). One field contains uncontrolled subject access data.

For **mixed materials** and collections under archival control, considerable use is made of the 6XX fields to reflect the subject content of the described materials through controlled and uncontrolled headings and terms. The 7XX fields are used less frequently to provide access.

Descriptions of the first indicator and all subfield codes, as well as input conventions for the 600, 610, 611, and 630 fields, are given in the following *General Information* sections: *X00, X10, X11 and X30*. The second indicator is described in the specific section for each field. All content designators for the 647-688 fields are described in the specific section for each field.

CONTENT DESIGNATOR HISTORY

Field 600-651 - Subject added entries
Indicator 2 - Subject heading system/thesaurus
In 1982 the use of the second indicator value in subject added entry fields 600-651 was expanded from specifying the organization that **assigned** the subject added entry to specifying the subject heading system, thesaurus, or authority file **used** by an organization to assign the subject added entry. Accordingly, values 0-3 and 5-6 became authoritative-agency data elements and their definitions were changed to the names of the list or authority file. The definition of value 4 was changed from Other subject heading. Prior to 1975, value 5 was defined in the visual materials specifications as Subject heading to be printed only in LC book catalog. Prior to 1977, value 5 was defined in the archival and manuscripts control specifications as National Union Catalog of Manuscripts (NUCMC) subject heading.

Field 647 - Subject Added Entry-Named Event [NEW, 2016]

Field 648 - Subject Added Entry-Chronological Term [NEW, 2002]

Field 652 - Subject Added Entry-Reversed Geographic [OBSOLETE, 1980]

Field 652 was an agency-defined field used by the Library of Congress for reversed geographic added entries assigned to materials classed in LC classification number span G1000-G9999. For each regular *Topic-Place* subject heading assigned, a reversed *Place--Topic* heading was also assigned. Both indicator positions were undefined. The subfield codes were: $a (Geographic name or place element), $x (General subject subdivision), $y (Chronological subject subdivision), $z (Geographic subject subdivision).

Field 662 - Subject Added Entry - Hierarchical Place Name [NEW, 2005]

Field 680 - PRECIS Descriptor String [OBSOLETE, 1991] [CAN/MARC only]

PRECIS Descriptor String is a sequence of subject index terms in which each term is preceded by a code which determines how it should appear in entries generated by a computer. The first indicator was undefined. The second indicator values 0-9 were used to link alternative subject statements to the corresponding Dewey classification number. Subfields $a-$z contained the text of the PRECIS Descriptor String.

Field 681 - PRECIS Subject Indicator Number (SIN) [OBSOLETE, 1991] [CAN/MARC only]

PRECIS Subject Indicator Number (SIN) is a fixed-length number ending in a modulus 11 check digit. It identifies uniquely the address of the PRECIS data consisting of string and Reference Indicator Number (RIN). The first indicator was undefined. The second indicator values 0-9 were used to link the indicator to the corresponding PRECIS string and other associated subject data. Only subfield $a (PRECIS subject indicator number (SIN)) was defined.

Field 683 - PRECIS Reference Indicator Number (RIN) [OBSOLETE, 1991] [CAN/MARC only]

PRECIS Reference Indicator Number (RIN) is a fixed-length number ending in a modulus 11 check digit which identifies the address of a term in the machine-held thesaurus used as the source of 'See' and 'See also' references in a printed index. The first indicator was undefined. The second indicator values 0-9 were used to link the index numbers to the corresponding PRECIS descriptor string. Only subfield $a (Reference indicator number (RIN)) was defined.

Field 688 - Subject Added Entry - Type of Entity Unspecified [NEW, 2019]

ATTACHMENT 18

650 - Subject Added Entry-Topical Term (R)

MARC 21 Bibliographic - Full **July 2022**

First Indicator
Level of subject
- No information provided
0 - No level specified
1 - Primary
2 - Secondary

Second Indicator
Thesaurus
0 - Library of Congress Subject Headings
1 - Library of Congress Children's and Young Adults' Subject Headings
2 - Medical Subject Headings
3 - National Agricultural Library subject authority file
4 - Source not specified
5 - Canadian Subject Headings
6 - Répertoire de vedettes-matière
7 - Source specified in subfield $2

Subfield Codes

Main term portion
$a - Topical term or geographic name entry element (NR)
$b - Topical term following geographic name entry element (NR)
$c - Location of event (NR)
$d - Active dates (NR)
$e - Relator term (R)
$g - Miscellaneous information (R)
$4 - Relationship (R)

Subject subdivision portion
$v - Form subdivision (R)
$x - General subdivision (R)
$y - Chronological subdivision (R)
$z - Geographic subdivision (R)

Control subfields
$0 - Authority record control number or standard number (R)
$1 - Real World Object URI (R)
$2 - Source of heading or term (NR)
$3 - Materials specified (NR)
$6 - Linkage (NR)
$7 - Data provenance (R)
$8 - Field link and sequence number (R)

FIELD DEFINITION AND SCOPE

Subject added entry in which the entry element is a topical term.

Topical subject added entries may consist of general subject terms including names of events or objects. Subject added entries are assigned to a bibliographic record to provide access according to generally accepted thesaurus-building rules (e.g., *Library of Congress Subject Headings* (LCSH), *Medical Subject Headings* (MeSH)). Field 650 may be used by any institution assigning subject headings based on the lists and authority files identified in the second indicator position or in subfield $2 (Source of heading or term).

A title (e.g., Bible and atheism), a geographic name (e.g., Iran in the Koran), or the name of a corporate body (e.g., Catholic Church and humanism) used in a phrase subject heading are also recorded in field 650.

GUIDELINES FOR APPLYING CONTENT DESIGNATORS

■ INDICATORS

First Indicator - Level of subject

Used to distinguish primary and secondary descriptors.

- No information provided

0 - No level specified

Level of the subject term could be determined but is not specified.

650 00$a Flour industry**$v**Periodicals.

1 - Primary

Main focus or subject content of the material.

650 17$a Career Exploration.**$2**ericd

650 #7$a Career Exploration.**$2**ericd

650 17$a Cooks.**$2**ericd

2 - Secondary

Less important aspect of the content of the material.

650 27$a Food Service.**$2**ericd

650 27$a Junior High Schools.**$2**ericd

650 27$a Simulation.**$2**ericd

[Primary and secondary subject content identified.]

Second Indicator - Thesaurus

Subject heading system or thesaurus used in constructing the subject heading.

0 - Library of Congress Subject Headings

Subject added entry conforms to and is appropriate for use in the *Library of Congress Subject Headings* (LCSH) and the Name authority files that are maintained by the Library of Congress.

1 - Library of Congress Children's and Young Adults' Subject Headings

Subject added entry conforms to the Library of Congress *Children's and Young Adults' Subject Headings* used for the Library of Congress Children's and Young Adults' Cataloging (CYAC) Program and is appropriate for use according to CYAC guidelines.

2 - Medical Subject Headings

Subject added entry conforms to and is appropriate for use in the National Library of Medicine authority files.

3 - National Agricultural Library subject authority file
Subject added entry conforms to and is appropriate for use in the National Agricultural Library subject authority file.

4 - Source not specified
Subject added entry conforms to a controlled list that cannot be identified by second indicator values 0-3, 5-6 or by a code in subfield $2. Field 653 (Index Term-Uncontrolled) is used to record terms that are not derived from controlled subject heading lists.

5 - Canadian Subject Headings
Subject added entry conforms to and is appropriate for use in the *Canadian Subject Headings* that is maintained by the Library and Archives Canada.

6 - Répertoire de vedettes-matière
Subject added entry conforms to the *Répertoire de vedettes-matière* that is maintained by the Bibliothèque de l'Université Laval and/or name authority files maintained by libraries in Canada using French as the language of description.

7 - Source specified in subfield $2
Subject added entry conforms to a set of subject heading system/thesaurus building rules. The identifying code is given in subfield $2.

■ SUBFIELD CODES

$a - Topical term or geographic name entry element
Topical subject or a geographic name used as an entry element for a topical term. Parenthetical qualifying information associated with the term is not separately subfield coded.

650 #0$a Amish.
650 #0$a Kalmyk cattle.
650 #0$a Astronauts.
650 #0$a Egypt in the Bible.
650 #0$aBASIC (Computer program language)
650 #0$a Bull Run, 2d Battle, 1862.
650 #0$a Concertos (String orchestra)
650 #0$a Vocal music**$z**France**$y**18th century.
650 #0$a Dentistry**$v**Juvenile films.
650 #5$a Canadian wit and humor (English)

$b - Topical term following geographic name entry element
Topical term that is entered under a geographic name contained in subfield $a. This construction is not used in AACR2 formulated records.

650 #0$a Caracas.**$b**Bolivar Statue.

$c - Location of event

$d - Active dates
Time period during which an event occurred.

$e - Relator term

Specifies the relationship between the topical heading and the described materials, e.g., depicted.

650 **#0$a**Seabiscuit (Race horse),**$e**depicted.
[Photograph of Seabiscuit, the race horse.]

650 **#0$a**Unicorns,**$e**depicted.
[Bayeux Tapestry, showing a unicorn.]

$g - Miscellaneous information

Data element that is not more appropriately contained in another defined subfield.

$v - Form subdivision

Form subdivision that designates a specific kind or genre of material as defined by the thesaurus being used. Subfield $v is appropriate only when a form subject subdivision is added to a main term.

650 **#0$a**Scuba diving**$v**Periodicals.

650 **#0$a**Vomiting**$x**Treatment**$v**Handbooks, manuals, etc.

$x - General subdivision

Subject subdivision that is not more appropriately contained in subfields $v (Form subdivision), $y (Chronological subdivision), or $z (Geographic subdivision). Subfield $x is appropriate only when a general topical subdivision is added to a main term.

650 **#0$a**Racetracks (Horse-racing)**$z**United States**$x**History.

650 **#0$a**Numismatics**$x**Collectors and collecting.

$y - Chronological subdivision

Subject subdivision that represents a period of time. Subfield $y is appropriate only when a chronological subject subdivision is added to a main term.

650 **#0$a**Music**$y**500-1400.

$z - Geographic subdivision

Geographic subject subdivision. Subfield $z is appropriate in field 650 only when a geographic subject subdivision is added to a main term.

650 **#0$a**World War, 1939-1945**$x**Campaigns**$z**Tunisia.

650 **#0$a**Real property**$z**Mississippi**$z**Tippah County**$v**Maps.

$0 - Authority record control number or standard number

See description of this subfield in Appendix A: *Control Subfields*.

$1 - Real World Object URI

See description of this subfield in Appendix A: *Control Subfields*.

$2 - Source of heading or term

MARC code that identifies the source list from which the subject added entry was assigned. It is used only when the second indicator position contains value 7 (Source specified in subfield $2). Code from: *Subject Heading and Term Source Codes*.

650 #7$a Educational buildings**$z**Washington (D.C.)**$y**1890-1910.**$2**lctgm

650 17$a Acoustic measurement.**$2**test

$3 - Materials specified
Part of the described materials to which the field applies.

$4 - Relationship
Code or URI that specifies the relationship from the entity described in the record to the entity referenced in the field. A source of relationship codes is: *MARC Code List for Relators*.

$6 - Linkage
See description of this subfield in Appendix A: *Control Subfields*.

$7 - Data provenance
See description of this subfield in Appendix J: *Data Provenance Subfields*.

$8 - Field link and sequence number
See description of this subfield in Appendix A: *Control Subfields*.

INPUT CONVENTIONS

Ambiguous Headings - See Appendix E.

Punctuation - Field 650 ends with a mark of punctuation or a closing parenthesis. If the final subfields are subfield $2 or $3, the mark of punctuation precedes those subfields.

650 17$a Career Exploration.**$2**ericd

650 #0$a Ballads, English**$z**Hudson River Valley (N.Y. and N.J.)

Main term portion followed by a subject subdivision does not end with a mark of punctuation unless the main term portion ends with an abbreviation, initial/letter, or open date.

650 #0$a Rain and rainfall**$z**Washington (State)**$z**Seattle**$v**Maps.

Spacing - No spaces are used in initialisms, acronyms, or abbreviations.

650 #0$aMARC formats.

650 #0$aC.O.D. shipments.

Display Constant

- *[dash associated with the content of subfield $v, $x, $y, or $z]*

Dash (-) that precedes a subject subdivision in an extended subject heading is not carried in the machine-readable record. It may be system generated as a display constant associated with the content of subfield $v, $x, $y, and $z.

Content designated field :

650 #0$a Nuclear energy**$x**History.

Display example:
Nuclear energy-History.

Initial Article - Initial articles (e.g., The) occurring at the beginning of topical subject added entry fields are usually omitted in most languages (except when the intent is to file on the article).

Any diacritics and/or special characters occurring at the beginning of fields are retained. Note that such characters are usually ignored for purposes of sorting and filing.

CONTENT DESIGNATOR HISTORY

$b - Topical term following geographic name as entry element [OBSOLETE, 1981]
Subfield was restored for use in retrospective record conversion in 1987.
$g - Miscellaneous information [NEW, 2014]
$0 - Authority record control number [NEW, 2007]
$0 - Authority record control number [REDEFINED, 2010]
$1 - Real World Object URI [NEW, 2017]
$4 - Relator code [NEW, 2005]
$4 - Relator code [RENAMED, 2017] [REDESCRIBED, 2017]
Subfield $4 was renamed and redescribed to allow for the recording of relationship URIs in addition to MARC and non-MARC codes.
$7 - Data provenance [NEW, 2022]

ATTACHMENT 19

050 - Library of Congress Call Number (R)

MARC 21 Bibliographic - Full **December 2017**

First Indicator
Existence in LC collection
- No information provided
0 - Item is in LC
1 - Item is not in LC

Second Indicator
Source of call number
0 - Assigned by LC
4 - Assigned by agency other than LC

Subfield Codes
$a - Classification number (R)
$b - Item number (NR)
$0 - Authority record control number or standard number (R)
$1 - Real World Object URI (R)
$3 - Materials specified (NR)
$6 - Linkage (NR)
$8 - Field link and sequence number (R)

FIELD DEFINITION AND SCOPE

Classification or call number that is taken from *Library of Congress Classification* or *LC Classification Additions and Changes*. The brackets that customarily surround alternate class/call numbers are not carried in the MARC record; they may be generated based on the presence of repeated $a subfields.

Second indicator values distinguish between content actually assigned by the Library of Congress and content assigned by an organization other than LC.

Note that only subfield $u is locally defined. The entire field description is repeated here for ease of use of this document.

GUIDELINES FOR APPLYING CONTENT DESIGNATORS

■ INDICATORS

First Indicator - Existence in LC collection
Whether or not the item is contained in the LC collections.

- No information provided
Used for all call numbers assigned by agencies other than the Library of Congress.

050 #4$a**NB933.F44**$bT6

0 - Item is in LC
Item is in the LC collections under the call number given in the field.

Other agencies should use this value when transcribing from LC cataloging copy on which the call number is neither enclosed within brackets nor preceded by a Maltese

cross.

050 00$a**Z695.7**$b.B37 1980

1 - Item is not in LC

Item is not in the LC collections, or that it is not shelved under that number.

Used by other agencies when transcribing from LC copy on which the call number appears in brackets or is preceded by a Maltese cross. Brackets that customarily surround call numbers for items not in LC are not carried in the MARC record; they may be generated for display.

050 10$a**BJ1533.C4**$bL49

Second Indicator - Source of call number

Whether the source of the class/call number is the Library of Congress or another organization.

0 - Assigned by LC

Used when an institution is transcribing from LC cataloging copy.

050 00$a**JK609**$b.M2

4 - Assigned by agency other than LC

■ SUBFIELD CODES

$a - Classification number

Classification number portion of the call number. The source of the classification number is *Library of Congress Classification* and the *LC Classification-Additions and Changes*. Subfield $a is repeated to record an alternative class number. The alternate class number is recorded following the last subfield of the call number. If the alternate class number also includes an item number, the item number is included in the same subfield $a as the alternate class number; it is not separately subfielded.

050 00$a**QC861.2**$b.B36
050 00$a**Z695.7**$b.B37 1980
050 00$a**Z7164.N3**$bL34 no. 9**$a**Z7165.R42**$a**HC517.R42
050 00$aRC951

$b - Item number

Item number portion of the call number. An item number is the Cutter, date, term, etc. that is added to a classification number to distinguish an item from any other item assigned the same classification number.

Organizations that use the *Cutter-Sanborn Three-Figure Author Table* may conform to Library of Congress item number practice by applying *Subject Cataloging Manual: Shelflisting* conventions.

050 00$a**JX1974.7**$b.M5
050 00$a**Z673.L7**$bY
050 10$a**HF5726**$b.B27 1980

050 00$a**E506.5 6th**$bG

050 00$a**E514.6 10th**$b.T76 1905
[The above two call numbers are call numbers for regimental histories.]

$0 - Authority record control number or standard number
See description of this subfield in Appendix A: *Control Subfields*.

$1 - Real World Object URI
See description of this subfield in Appendix A: *Control Subfields*.

$3 - Materials specified
Part of the described material to which the field applies. The subfield is used with archival-type materials; its use is parallel with the use of subfield $3 in other fields.

$6 - Linkage
See description of this subfield in Appendix A: *Control Subfields*.

$8 - Field link and sequence number
See description of this subfield in Appendix A: *Control Subfields*.

INPUT CONVENTIONS

LCCNs - When the call number field consists only of a class number (letters followed by numbers, possibly including a period and also a space), no subfield $b is used.

050 00$aQA37

050 00$aE525.5 123d

General rule is that the item number part of the call number begins at the last capital letter in the call number or the period, if present, preceding it.

050 00$a**HF5549.5.R44**$bM35

Exceptions to the general rule for item numbers:

If the call number is followed by only a date, with no Cutter number, the date is contained in subfield $b.

050 00$a**E457.92**$b1967

If the call number is followed by volume numbering that includes uppercase letters, these letters are ignored in locating the last capital letter.

050 00$a**JX1977**$b.A2 St/ESA/35

050 00$a**HA1501**$bA, Nr. 615

050 00$a**HD28**$b.Y555 vol. 55 Suppl.

If the call number begins with CS71, subfield $b contains the date.

050 00$a**CS71.C323**$b1977

If the call number is for a classification schedule (i.e., it is a call number beginning with Z696.U5), the class letter(s) for the particular classification and any following digit(s) are recorded in subfield $a (as part

of the classification). Subfield $b contains the date.

050 00$a**Z696.U5E3**$b1958
050 00$a**Z696.U5H-HJ**$b1981

Abbreviations *subser.* and *Suppl.* are recorded in subfield $b, even when there is no item number.

Capitalization - Alphabetic characters in the classification number portion of the field are generally uppercase.

Spacing - Any spaces that are desired as part of the call number must be input.

050 00$a**DK274.3 1968**$b.K39
050 00$a**VM341**$b.M9 vol. 48
050 00$a**CS71.C323**$b1977

Display Constant

[...] *[brackets]*

Brackets that customarily surround call numbers for items not in LC or alternate class/call numbers are not carried in the MARC record. They may be system generated as a display constant associated with the first indicator value 1 or additional $a subfields.

Content designated field:
050 10$a**HF5726**$b.B27 1980
Display example:
[HF5726.B27 1980]

CONTENT DESIGNATOR HISTORY

Indicator 1 - Existence in LC collection
- No information provided
Prior to the definition of code 4 in the second indicator position in 1982, the first indicator in the visual materials specifications was undefined. Visual materials records created prior to 1982 may contain a # meaning *undefined* in the first indicator position.

Indicator 2 - Series call number (SE) [OBSOLETE]
In the serials specifications, the use of the second indicator position to indicate the type of series was made obsolete in 1976. The values were: 0 (No series involved), 1 (Main series), 2 (Subseries), 3 (Sub-subseries).

Indicator 2 - Source of call number
- No information provided [OBSOLETE]
Second indicator was defined in 1982. Prior to that change, 050 was an agency-assigned field and contained only call numbers assigned by the Library of Congress. LC records created before the definition of this indicator may contain a blank (#) meaning *undefined* in this position.

$d - Supplementary class number (MU) [OBSOLETE, 1981]
$0 - Authority record control number or standard number [NEW, 2017]
$1 - Real World Object URI [NEW, 2017]

ATTACHMENT 20

082 - Dewey Decimal Classification Number (R)

MARC 21 Bibliographic - Full **June 2024**

First Indicator
Type of edition
0 - Full edition
1 - Abridged edition
7 - Other edition specified in subfield $2

Second Indicator
Source of classification number
- No information provided
0 - Assigned by LC
4 - Assigned by agency other than LC

Subfield Codes

$a - Classification number (R)
$b - Item number (NR)
$m - Standard or optional designation (NR)
$q - Assigning agency (NR)
$0 - Authority record control number or standard number (R)
$1 - Real World Object URI (R)
$2 - Edition information (NR)
$6 - Linkage (NR)
$7 - Data provenance (R)
$8 - Field link and sequence number (R)

FIELD DEFINITION AND SCOPE

Classification number is taken from the *Dewey Decimal Classification*, accessed through electronic or printed versions.

Second indicator values distinguish between content assigned by the Library of Congress (LC) and content assigned by an organization other than LC.

GUIDELINES FOR APPLYING CONTENT DESIGNATORS

■ INDICATORS

First Indicator - Type of edition

Indicates the edition from which the Dewey Decimal classification is taken.

0 - Full edition

Class number was taken from the full edition.

082 04$a388/.0919**$2**22

1 - Abridged edition

Class number was taken from the abridged edition.

082 14$a914.3**$2**13

7 - Other edition specified in subfield $2

The edition is specified in subfield $2 (Edition information).

082 74$a839.82**$2**5/nor/20071204**$q**NO-OsNB

Second Indicator - Source of classification number

Designates whether the source of the class number is the Library of Congress or another organization.

- No information provided

No information is provided about the source of the class number.

082 0#$aC848/.5407/05**$2**20

0 - Assigned by LC

Source of the class number is the Library of Congress.

May be used by organizations transcribing from LC copy.

082 00$a975.5/4252/00222**$2**22

4 - Assigned by agency other than LC

Source of the class number is an organization other than the Library of Congress.

082 04$a220.47**$2**22

■ SUBFIELD CODES

$a - Classification number

Classification number assigned using an edition of the Dewey Decimal Classification. The source of the classification number is the *Dewey Decimal Classification*, accessed through electronic or printed versions.

082 00$a355.02/17**$2**22

082 04$a**343.7306/8**$a347.30368**$2**20
[The second number is optional]

For DDC numbers for Canadian literature, an uppercase “C” is added as a prefix. For works intended for a juvenile audience, a lowercase “j” is added as a prefix. The “j” prefix is not added to DDC numbers in records for juvenile textbooks.

082 0#$aC848**$2**20
082 0#$aj574**$2**20
082 0#$ajC813**$2**20

$b - Item number

Item number portion of the number. This subfield may also contain a copy (or set) number.

$m - Standard or optional designation

Designates whether the classification number contained in the field is from the standard or optional part of the schedules or tables of the scheme identified by the first indicator (Type of edition) and by subfield $2 (Edition information). The following codes are used: a (standard) and b (optional).

082 00$a345.73/0772**$2**220**$m**a

082 00$a347.305772**$2**220**$m**b

$q - Assigning agency

MARC organization code of the institution that assigned the classification number.

Code from: *MARC Code List for Organizations*.

082 04$a004**$2**22/ger**$q**DE-101b

$0 - Authority record control number or standard number

See description of this subfield in Appendix A: *Control Subfields*.

$1 - Real World Object URI

See description of this subfield in Appendix A: *Control Subfields*.

082 04$a363.37/7**$2**223**$1**https://id.oclc.org/worldcat/ddc/E3y6vCbQkp9TXgwpKd37hYQWhD

$2 - Edition information

Information on the edition from which the DDC number was assigned. If DDC numbers are assigned from more than one edition, each DDC number or range of numbers is contained in a separate 082 field. If the DDC number is assigned from a printed version, record edition number (use “23” for print-on-demand), a slash (/), the language of the edition, a slash (/), and the year of publication or printing. If a DDC number is assigned from an electronic version, record edition number (use “23” or “22” for WebDewey, as appropriate), a slash (/), the language of the edition, a slash (/), and the date on which the DDC number was assigned by the cataloger. Languages are recorded according to the three-character codes in the *MARC Code List for Languages*. Dates are recorded according to *Representation of Dates and Times* (ISO 8601) in the pattern *yyyymmdd*.

082 00$a792.8/2**$2**23/eng/20190402

$6 - Linkage

See description of this subfield in Appendix A: *Control Subfields*.

$7 - Data provenance

See description of this subfield in Appendix J: *Data Provenance Subfields*.

$8 - Field link and sequence number

See description of this subfield in Appendix A: *Control Subfields*.

INPUT CONVENTIONS

Spacing - Lowercase "s" (for series) is separated from the number by one space.

082 00$a**920.073 s**$a973.3/092**$a**B**$2**22

Display Constant

[...] *[brackets]*

Square brackets enclosing a DDC number that appear on printed products are not carried in the MARC record. They may be system generated as a display constant associated with the field tag.

Content designated field:

082 **00$a**659.1 s**$a**659.1/57**$2**22

Display example:
659.1 s [659.1/57] 22

Standard or optional designation - If subfield $m is present, only one subfield $a should be coded, unless the value in subfield $m applies to all numbers in repeated occurrences of subfield $a. Otherwise, the field is repeated.

CONTENT DESIGNATOR HISTORY

Indicator 1 - Type of edition
- No edition information recorded (BK, MU, VM, SE) [OBSOLETE]
Code # (No edition information recorded) was valid 1979-1987. Records created before the definition of the first indicator in 1979 may contain a blank (#) meaning *undefined* in this indicator position.
2 - Abridged NST version (BK, MU, VM, SE) [OBSOLETE]
This value was made obsolete in 1989. The U.S. Library of Congress discontinued assigning class numbers from the abridged NST version to items included in *New Serial Titles* as of 1981.
7 - Other edition specified in subfield $2 [NEW, 2011]

Indicator 2 - Source of classification number
- No information provided [OBSOLETE] [USMARC only, BK, CF, MU, VM, SE]
Code # (No information provided) was valid 1982-1987. Records created before the definition of the second indicator in 1982 may contain a blank (#) meaning *undefined* in this indicator position.

$a - Classification number
$b - DDC number-abridged NST version (SE) [OBSOLETE]
$b - Item number
Prior to 1975, the definitions of subfields $a and $b in the serials specifications were reversed: $a (DDC number-abridged NST version), $b (DDC number). This definition of subfield $b was made obsolete when the first indicator and subfield $2 were defined in 1979. The current subfield $b was defined in 1987.
$m - Standard or optional designation [NEW, 2008]
$q - Assigning agency [NEW, 2008]
$0 - Authority record control number or standard number [NEW, 2024]
$1 - Real World Object URI [NEW, 2024]
$2 - Edition number [RENAMED, 2021] [REDESCRIBED, 2021]
$7 - Data provenance [NEW, 2022]

ATTACHMENT 21

AMENDED ARTICLES OF INCORPORATION

OF

OCLC, Inc.

FIRST The name of the corporation shall be OCLC, Inc. (the "Corporation").

SECOND The place in this State where the principal office of the Corporation is to be located is in the City of Dublin, Franklin County, Ohio.

THIRD The purpose or purposes for which the Corporation is formed are to establish, maintain, and operate a computerized library network and to promote the evolution of library use, of libraries themselves, and of librarianship, and to provide processes and products for the benefit of library users and libraries, including such objectives as increasing availability of library resources to individual library patrons and reducing the rate of rise of library per-unit costs, all for the fundamental public purpose of furthering ease of access to and use of the ever-expanding body of worldwide scientific, literary, and educational knowledge and information.

FOURTH The affairs of the Corporation shall be managed by the Board of Trustees. The qualifications of the Trustees, together with their terms of office, manner of election, removal, change of number, filling of vacancies and of newly-created trusteeships, powers, duties and liabilities, shall, except as otherwise provided in these Articles, or by the laws of the State of Ohio, be as prescribed by the Code of Regulations.

FIFTH There shall be two classes of members of the Corporation and they shall be OCLC Members, and Trustee Members. The voting powers of each class of members shall be only as defined in the Code of Regulations or as stated in these Articles.

SIXTH There shall be a Global Council composed of Member Delegates as prescribed in the Code of Regulations.

SEVENTH These Articles may be amended at any business meeting of the Trustee Members called for that purpose provided that notice of the proposed amendment(s) has been sent to the Trustee Members at least ten (10) days prior to said meeting. A two-thirds (2/3) vote of all of the authorized Trustee Members of the Corporation is required for approval.

EIGHTH The duration of the Corporation shall be perpetual.

NINTH No part of the earnings, dues, or receipts of the Corporation shall inure to the benefit of or be distributed to its members, trustees, officers, or other private persons, except only that the Corporation shall be authorized and empowered to pay reasonable compensation for services rendered and expenses incurred and to make payments or distributions in furtherance of the purposes set forth in Article Third hereof. No substantial part of the activities of the Corporation shall be the carrying on of propaganda, or otherwise attempting to influence legislation, and the Corporation shall not participate in, or intervene in (including the publishing or distribution of statements) any political campaign on behalf of, or in opposition to**,** any candidate for public office. Notwithstanding any other provision of these Articles, the Corporation shall not carry on any other activities not permitted to be carried on (a) by a corporation exempt from Federal income

tax under Section 501(c)(3) of the Internal Revenue Code of 1986, as amended (or the corresponding provision of any future United States internal revenue law) (the "Code") or (b) by a corporation, contributions to which are deductible under Section 170(c)(2) of the Code.

TENTH Upon the dissolution of the Corporation, the Board of Trustees shall, after paying or making provision for the payment of all of the liabilities of the Corporation, dispose of all of the assets of the Corporation exclusively for the purposes of the Corporation in such manner, or to such organization or organizations as are described in Section 170(c)(1) or (2) of the Code, as the Board of Trustees shall determine. Any of such assets not so disposed of shall be disposed of by the Court of Common Pleas of the county in which the principal office of the Corporation is then located, exclusively for such purposes or to such organization or organizations, as said Court shall determine, which are organized and operated exclusively for such purposes.

ELEVENTH These Articles supersede all prior Articles or Amended Articles.

ATTACHMENT 22

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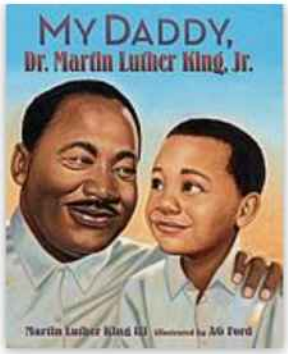
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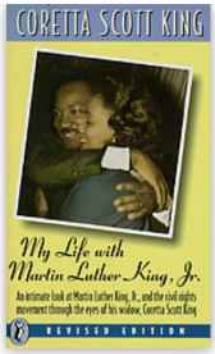
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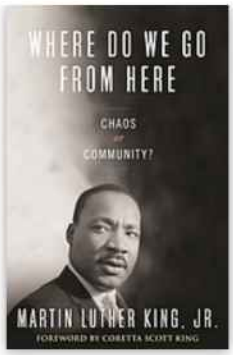
Curated by M.L. King III



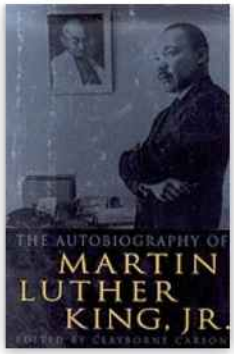
My daddy, Dr. Martin Luther...
Martin Luther King



My life with Martin Luther...
Coretta Scott King



Where do we go from here : chao...
Martin Luther King



The autobiography ...
Martin Luther King

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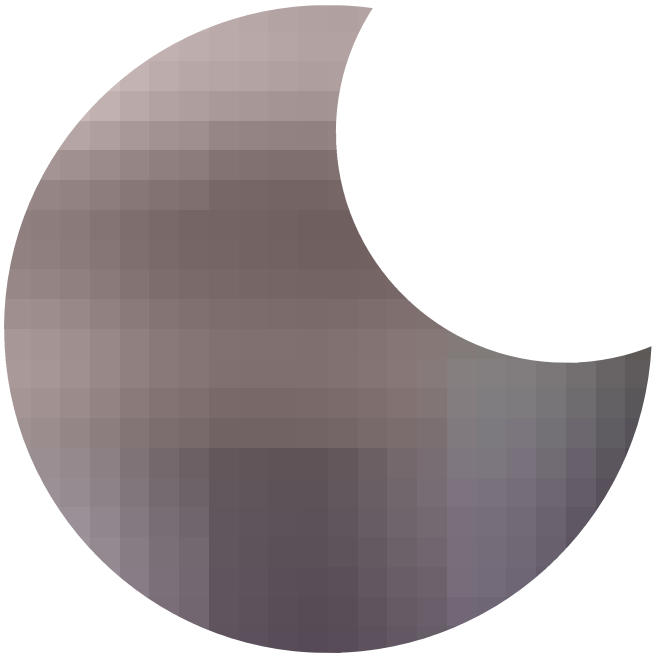
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ATTACHMENT 23

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Understanding the arXiv identifier

The canonical form of identifiers from January 2015 (1501) is arXiv:YYMM.NNNNN, with 5-digits for the sequence number within the month.

The article identifier scheme used by arXiv was changed in April 2007. All existing articles retain their original identifiers but newly announced articles have identifiers following the new scheme. As of January 2015, the number of digits used in the second part of the new identifier, the sequence number within the month, is increased from 4 to 5. This will allow arXiv to handle more than 9999 submissions per month (see monthly submission rates).

Identifier scheme since 1 April 2007 (0704-)

All new articles have identifiers with the following form:

```
arXiv:YYMM.number
```

```
e.g. arXiv:1501.00001 or arXiv:0706.0001
```

where identifiers up to month 1412 are zero-padded to 4-digits in the last block, and those from 1501 onward are zero-padded to 5-digits. Specific versions are referred to by adding the version number:

```
arXiv:YYMM.numbervV
```

```
e.g. arXiv:1501.00001v1 or arXiv:0706.0001v2
```

In general, the form is `arXiv:YYMM.number{vV}` , where

- `YY` is the two-digit year (07=2007 through 99=2099, and potentially up to 06=2106)
- `MM` is the two-digit month number (01=Jan,...12=Dec)
- `number` is a zero-padded sequence number of 4- or 5-digits. From 0704 through 1412 it is 4-digits, starting at `0001`. From 1501 on it is 5-digits, starting at `00001`. 5-digits permits up to `99999` submissions per month. We cannot currently anticipate more than 99999 submissions per month although extension to 6-digits would be possible.
- `vV` is a literal `v` followed by a version number of 1 or more digits starting at `v1`.

Note that the identifier no longer contains any classification information and thus reclassification after an article is announced is possible. Classification information is indicated in other ways. For example, the stamp added to the side of the PDF versions of arXiv articles has the form:

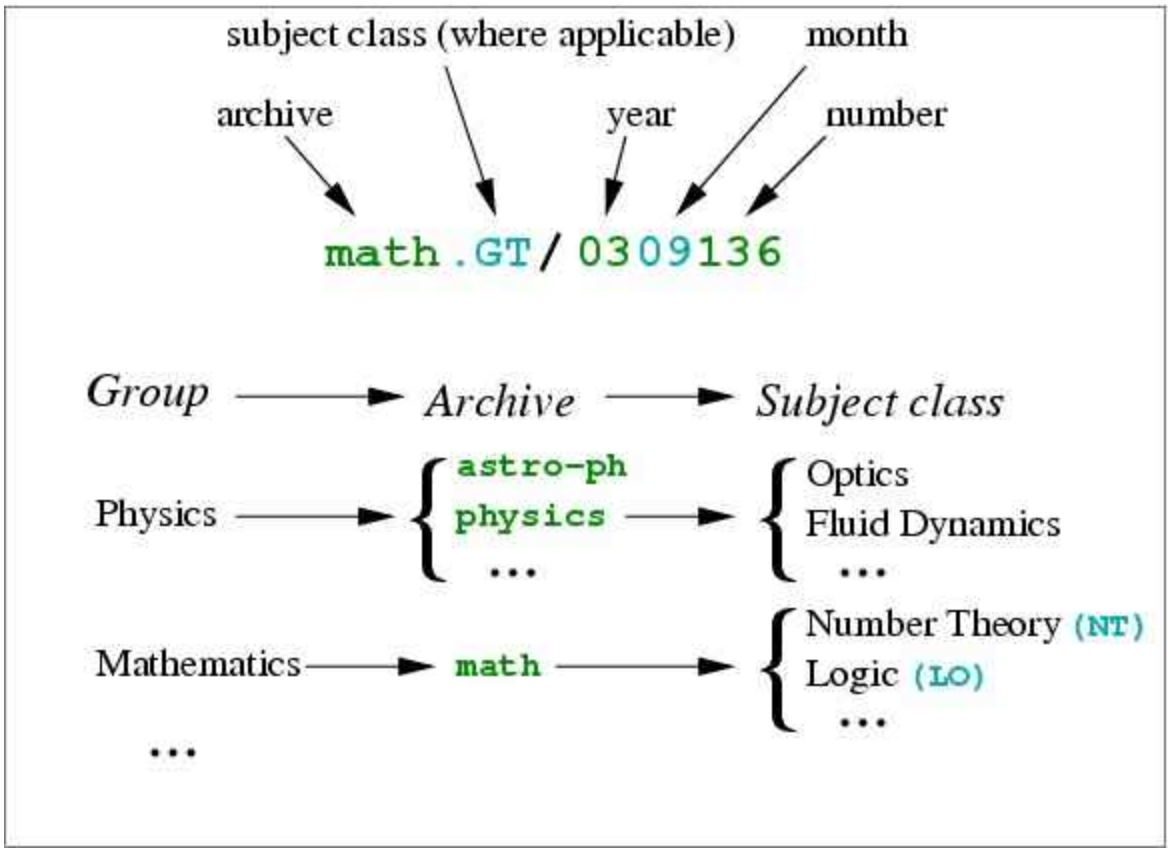
```
arXiv:0706.0001v1 [q-bio.CB] 1 Jun 2007
```

which indicates `v1` of the article `arXiv:0706.0001` which has primary classification `q-bio.CB`, and was submitted on 1 June 2007.

The identifier `arXiv:YYMM.numbervV` provides a complete and unique citation for an arXiv article. Without the version number (e.g. `arXiv:YYMM.number`), the identifier refers to the *most recent version* of the article. We recommend that in citations the specific version number, the subject classification and the date information be included in the same way that it is in the stamp on the side of the PDF. See also References to and in arXiv Documents.

Identifiers up to March 2007 (9107-0703)

Identifiers from 1991 through 2007-03 followed the form shown in the image below. The full list of groups, archives and subject classes is listed on the front page:



Subject classes do not exist for some of the older archives in the **Physics** group. Instead, each archive represents a subject class, e.g., **hep-ex**, **hep-lat**, **hep-ph**, and **hep-th**. The **astro-ph** archive currently has no subject classes, while **cond-mat** and **physics** are classified by subject classes that appear only in the metadata (not in the identifier).

This scheme uses two upper-case characters to identify the subject class, e.g., math (Geometric Topology) = **math.GT**, cs (Software Engineering) = **cs.SE**, and nlin (Chaotic Dynamics) = **nlin.CD**.

Motivation for 2007 change of identifier scheme

Some change to the arXiv identifier scheme was needs to permit submissions expected to exceed 1000 articles per month in some archives in 2007 (likely `math`, `cond-mat` and `astro-ph`). The old identifier scheme imposed a limit of 999

submissions per month in any one archive. Obviously, we could have just added an extra digit (`arch-ive/YYMMNNNN`) or perhaps made the `NNN` alphanumeric. However, we took the opportunity to address other issues too.

The primary motivation for removing subject-classification information from the identifier was to decouple these two properties (identification and classification). This will increase our flexibility to adjust the classifications of individual articles as necessary (for example, it has long been possible to adjust classification of articles *within* the `cs` and `math` archives and we see this as beneficial). It also makes it easier to adjust our classification schemes as disciplines and arXiv usage evolve (for example, we need to sub-divide astro-ph since it currently too large). Various schemes with optional or redundant classification information in the identifier were considered (extending from the redundant 2-letter subject classes in `math` etc.) but these were rejected because such many-to-1 resolution of identifier-to-article means that interacting services cannot compare identifiers and know whether they refer to the same arXiv article without local knowledge of arXiv's identifier scheme.

We feel that is a useful to have a single canonical form for identifiers within a month, with the same number of digits following the period. Thus identifiers from 0704 through 1412 have the sequence number (the number following the period) padded to 4-digits. The use of 4-digits places a limit of 9999 identifiers in a single month and it is possible that this will be exceeded in 2015 (8871 articles in 1410, 8668 in 1409). To ensure that the canonical form changes at a convenient year-boundary the sequence number is padded to 5-digits from month 1501 onward, starting with identifier 1501.00001.

Further information for interacting services

There are additional (gruesome) details of arXiv identifiers for interacting services. These are unlikely to be of interest/use unless you are handling internal data distributed by arXiv.

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Availability of submissions

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Note that all submissions are subject to moderation which may result in delays.

A note about arXiv-id assignments

The final arXiv identifier cannot be assigned until the paper is announced, so please do not ask for it ahead of announcement. It is not possible to make exceptions, nor accelerate the announcement schedule regardless of your circumstance.

Note: The arXiv identifier cannot be back-dated, so identifiers will be assigned in the month of first announcement. It may be the case that a submission appears in a different identifier month than its original submission date due to various factors.

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On Deferred Mailings

Occasionally, arXiv defers a mailing, either for locally celebrated holidays such as Thanksgiving or for ad hoc reasons. Information about deferred mailings may be found on the arXiv status page, or on the arXiv blog.

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- Mon 20 January
- Thu 19 June

- Sun 6 July
- Mon 1 September
- Thu 27 November
- December Holidays are not yet scheduled

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arXiv:1609.07939 (cond-mat)

[Submitted on 26 Sep 2016]

Demonstration of liquid crystal for barocaloric cooling application

Zhongjian Xie, Yao Zhu

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Current vapor-compression technology is based on the gas-liquid transition of hazardous gas. The alternative cooling technology focuses on the solid caloric material. A new liquid barocaloric material, i.e. the liquid crystal, is proved to be potential for cooling application primarily (based on other literatures). Its phase transition needs a small stress (tens of MPa) and can be operated near room temperature. It has a large entropy change of ~200 this http URL-1 (0.2 this http URL-1). There is no breakage problem due to its liquid form. It will provide the advantage for some unique cooling application cases comparing with solid caloric material. Moreover, this material is sustainable and non-toxic, which can meet the original intention of the alternative cooling technology.

Comments: a new material for barocaloric cooling application
Subjects: **Soft Condensed Matter (cond-mat.soft)**
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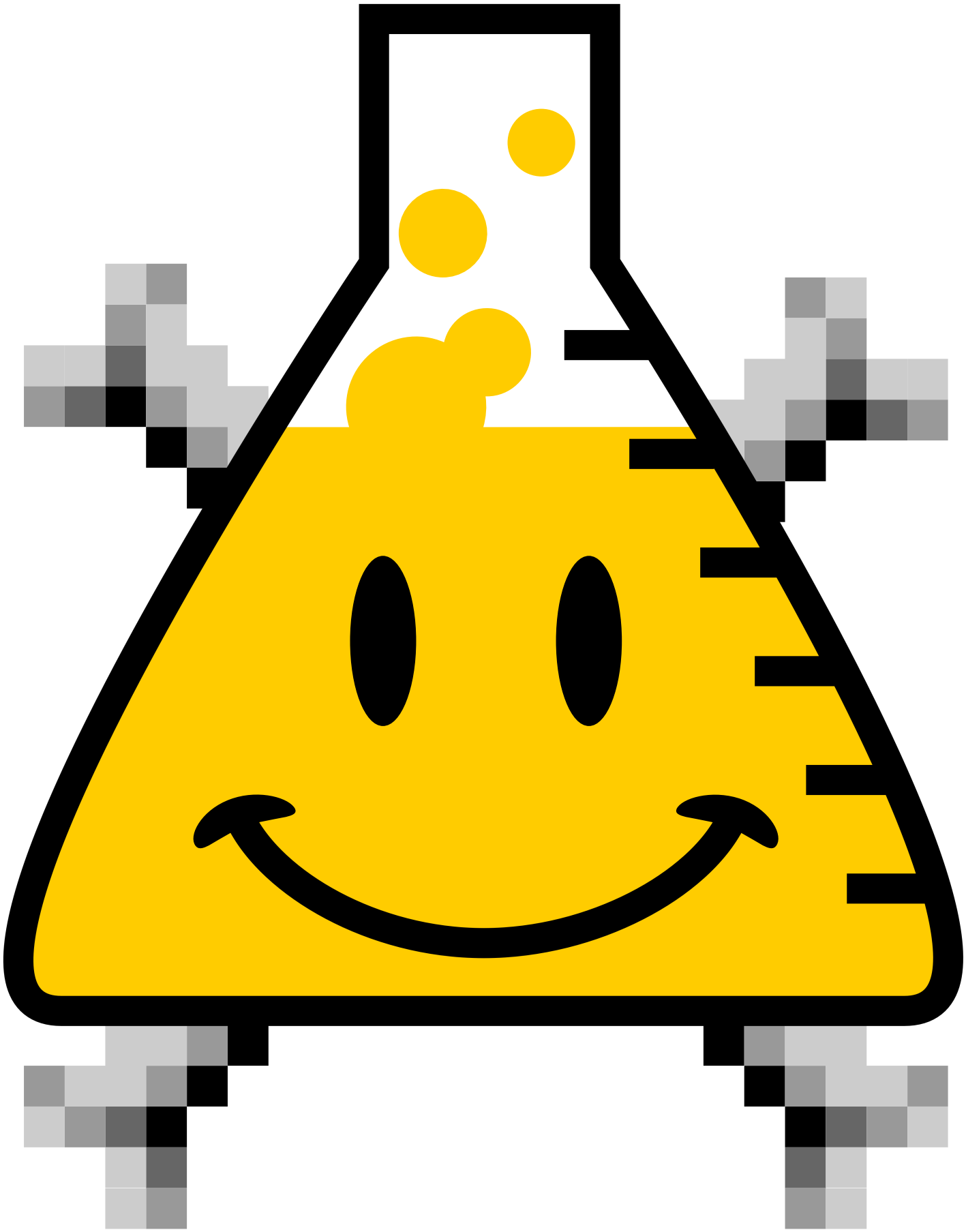
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Demonstration of liquid crystal for barocaloric cooling application

September 2016

DOI:10.48550/arXiv.1609.07939

Authors:



Zhongjian Xie
Shenzhen University

Y. Zhu
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Abstract

Current vapor-compression technology is based on the gas-liquid transition of hazardous gas. The alternative cooling technology focuses on the solid caloric material. A new liquid barocaloric material, i.e. the liquid crystal, is proved to be potential for cooling application primarily (based on other literatures). Its phase transition needs a small stress (tens of MPa) and can be operated near room temperature. It has a large entropy change of ~200 J.K-1.kg-1 (0.2 J.K-1.cm-1). There is no breakage problem due to its liquid form. It will provide the advantage for some unique cooling application cases comparing with solid caloric material. Moreover, this material is sustainable and non-toxic, which can meet the original intention of the alternative cooling technology.

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Elastocaloric effect of Ni-Ti wire for application in a cooling device

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Apr 2002 · Biochim Biophys Acta

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August 2010 · Physics and Chemistry of Liquids

E. Kilit · H. Yurtseven

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September 1985 · Thermochimica Acta

Nodar Topuridze · L. D. Kldiashvili · L. I. Nadareiahvili · [...] · K. G. Dzhaparidze

Some thermodynamic parameters (phase transition temperatures, entropy and enthalpy changes) of liquid crystal systems (nematic liquid crystal-440 and optically active substances mixture) were studied. Two types of optically active additives were established: I type additives concentration increases results in monotonous decrease of Δ H and Δ S, while the maximum was observed with II type ... [Show full abstract]

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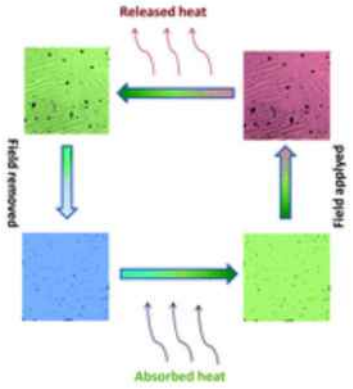
Advanced materials for solid-state refrigeration

Lluís Mañosa,*[a] Antoni Planes[a] and Mehmet Acet[b]

Author affiliations

Abstract

Recent progress on caloric effects are reviewed. The application of external stimuli such as magnetic field, hydrostatic pressure, uniaxial stress and electric field give rise respectively to magnetocaloric, barocaloric, elastocaloric and electrocaloric effects. The values of the relevant quantities such as isothermal entropy and adiabatic temperature-changes are compiled for selected materials. Large values for these quantities are found when the material is in the vicinity of a phase transition. Quite often there is coupling between different degrees of freedom, and the material can exhibit cross-response to different external fields. In this case, the material can exhibit either conventional or inverse caloric effects when a field is applied. The values reported for the many caloric effects at moderate fields are large enough to envisage future application of these materials in efficient and environmental friendly refrigeration.



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J. Mater. Chem. A, 2013, **1**, 4925-4936

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Advanced materials for solid-state refrigeration

March 2013 · Journal of Materials Chemistry A 1(16):4925-4936
DOI:10.1039/C3TA01289A

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University of Barcelona



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Abstract

Recent progress on caloric effects are reviewed. The application of external stimuli such as magnetic field, hydrostatic pressure, uniaxial stress and electric field give rise respectively to magnetocaloric, barocaloric, elastocaloric and electrocaloric effects. The values of the relevant quantities such as isothermal entropy and adiabatic temperature-changes are compiled for selected materials. Large values for these quantities are found when the material is in the vicinity of a phase transition. Quite often there is coupling between different degrees of freedom, and the material can exhibit cross-response to different external fields. In this case, the material can exhibit either conventional or inverse caloric effects when a field is applied. The values reported for the many caloric effects at moderate fields are large enough to envisage future application of these materials in efficient and

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... The search for caloric materials to be applied in solid-state refrigeration has recently become one of the most active fields in condensed-matter science. [1] [2] [3][4][5][6] The caloric effect is related to a change of the material's entropy under the sudden application of an external field: magnetic, electric, or mechanical. [1,2,7,8] Depending on the origin of the entropy change, the caloric effects can be classified as magnetocaloric (MC), electrocaloric (EC) and mechanocaloric (mC), the last of which includes the elastocaloric and barrocaloric effects. ...

... [1][2][3][4][5][6] The caloric effect is related to a change of the material's entropy under the sudden application of an external field: magnetic, electric, or mechanical. [1, 2, 7,8] Depending on the origin of the entropy change, the caloric effects can be classified as magnetocaloric (MC), electrocaloric (EC) and mechanocaloric (mC), the last of which includes the elastocaloric and barrocaloric effects. [1] For all three individual effects prototype cooling devices have already been proposed. ...

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Preprint

May 2016

Hana Uršič · Vid Bobnar · Barbara Malic · Zdravko Kutnjak

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... [1] For instance, gas boilers typically present a coefficient of performance (COP) below 2, even when accounting for heat recovery, while heat pumps may exhibit a COP ranging from 3 to 5. [2][3][4] Under moderate magnetic, electric, or mechanical field variations, auspicious caloric materials experience large adiabatic temperature variations (|ΔT| ≈ 1-10 K) as a result of phase transformations entailing large isothermal entropy changes (|ΔS| ≈ 10-100 J K −1 kg −1). [5, 6] Gas adsorption processes inducing large structural changes, designated as breathing transitions, have also been proposed as an innovative strategy to drive very large thermal changes in porous materials by means of hydrostatic pressure. [7,8] Solid-state cooling and heat pumping capitalize on such caloric effects for engineering refrigeration and heating cycles, presenting, in some cases, COPs exceeding 10. [9][10][11] From a practical point of view, large and reversible |ΔT| and |ΔS| are both necessary for achieving rapid and efficient thermal devices under recursive application and removal of the known solid electrolyte [38,39] in which at temperatures above T t the lithium cations are highly mobile and the molecular anions [CB 11 H 12] − reorient disorderly [40,41] (Figure 1). ...

... This technique, known as the quasi-direct method, has been extensively employed in the scientific literature to determine both isothermal entropy and adiabatic temperature changes for a wide variety of caloric materials. [5, [16][17][18][19]22,23,27] The reliability of the quasi-direct method has been previously demonstrated through straightforward comparison with direct measurements. [46] It is worth noting that in the field of BC effects and materials, direct measurements present challenges due to the typical use of liquids as pressuretransmitting fluids, which makes achieving adiabatic conditions difficult. ...

Colossal Reversible Barocaloric Effects in a Plastic Crystal Mediated by Lattice Vibrations and Ion Diffusion

Article Full-text available

May 2024

Ming Zeng · Carlos Escorihuela-Sayalero · Tamio Ikeshoji · Kartik

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... Despite adiabatic demagnetization in paramagnetic salts for achieving low temperatures, 32 recently the materials displaying giant electrocaloric effects have emerged as good alternatives to the standard fluid compression technology. 33 The values reported for EC effects at moderate electric fields are shown to be large enough to envisage future applications of the investigated materials in efficient and environmentally friendly solid-state refrigeration devices. [34][35][36] Even though the reported materials were found to exhibit excellent electrocaloric properties on a laboratory scale, only a restricted family among them could be upscaled toward industrial levels and implemented as refrigerants in EC devices. ...

... Equation (32) and (33) are cubic algebraic equations, which should have in principle three roots. If the discriminant for the equation D > 0, we should have one real and two imaginary solutions, the latter are not physically admissible. ...

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... (BGR, 2025;BGR, 2014). Besides elastocalorics (application of mechanical stress), other caloric effects have been observed in certain materials (Fähler et al., 2012; Mañosa et al., 2013; Moya et al., 2014). These include the magnetocaloric effect (application of a magnetic field) (Tishin and Spichkin, 2016;Smith et al., 2012;Kitanovski et al., 2015;Zimm et al., 1998), electrocaloric effect (application of an electric field) (Defay et al., 2013;Le Goupil et al., 2014) and the barocaloric effect (application of hydrostatic pressure) (Mañosa et al., 2010;cf. ...

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... Currently, the refrigeration technologies based on magnetocaloric effect, elastocaloric effect, electrocaloric effect (ECE) and Peltier effect have been extensively studied. 3, 4 Compared to other refrigeration technologies, the ECE refrigeration is regarded as the most potential candidate owing to its easy miniaturization, low cost and high coefficient of performance (COP) and eco-friendly features. ...

Enhanced electrocaloric effect in NaNbO3-based lead-free ceramics via adjusting the ratio of relaxor ferroelectric phase over normal…

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... During magnetic phase transitions, such as the transition from a ferromagnetic to a paramagnetic state, entropy anomalies occur, making it possible to take advantage of the magnetocaloric effect to generate a cooling effect. Research into materials such as antiperovskites and double perovskites has revealed significant changes in magnetic entropy and high relative cooling powers, making these compounds promising for refrigeration applications [8] [9][10][11][12]. ...

Theoretical study of magnetic, magnetocaloric, and hysteresis behavior of the antiperovskite compound Mn3AlN

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Feb 2025 · APPL PHYS A-MATER

Mohammed Salama · El Mostafa Jalal · Hasnae Saadi · Mohammed El Bouziani

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... It is found that |δT(H)| increases quadratically with H, as also reported for a different SCO compound. 11 The magnetocaloric response of magnetic materials can be computed via the quasi-direct method from the temperature dependence of the entropy at

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and from specific heat data, as ...

Magnetocaloric effects in the prototype spin crossover complex [Fe(L)2](BF4)2 in pulsed magnetic fields

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Catalina Salazar Mejía · Tino Gottschall · Klara Lünser · Lluís Mañosa

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... 10 Material scientists are exploring alternatives to the conventional vapor-compression cooling technology, leading to the emergence of solid-state refrigeration. 11, 12 Based on the caloric effect, this approach involves generating or absorbing heat in response to an external field, which can be electrical, magnetic, or mechanical. 13,14 In the mechanical category, barocaloric (bC) 15-18 and elastocaloric (eC) 19,20 effects are prominent, allowing a system to change its temperature through hydrostatic and stress deformations, respectively. ...

Enhanced Elastocaloric Effects in {\gamma}-graphyne

Preprint

Dec 2024

Guilherme Kanegae · Marcelo Lopes Pereira Junior · Douglas S. Galvao · Alexandre F. Fonseca

View Show abstract

... Manganese arsenide (MnAs) is one of the most promising materials for the magnetic refrigeration [1] [2] [3]. It is in fact characterized by a giant magnetocaloric effect close to room temperature that makes it a very attractive material for common refrigeration applications. ...

Low energy Ne ion beam induced-modifications of magnetic properties in MnAs thin films

Preprint

Nov 2016

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... This chapter focuses on modelling of avalanche dynamics in martensitic transformations which are solid to solid first-order phase transitions responsible for unique phenomena such as shape memory and pseudoelasticity [29] or caloric effects [30] . In particular, we will mostly deal with avalanches in shape-memory alloys undergoing martensitic transitions from an open crystalline structure to a close-packed structure with lower symmetry [29,31,32]. ...

Modelling avalanches in martensites

Preprint

Oct 2016

Francisco J Pérez-Reche

View Show abstract

... In the realm of sustainable cooling technologies, caloric cooling using solids, characterized by zero carbon emissions and high energy-saving potential, has emerged as a promising alternative to vapor compression. The caloric cooling cycle is realized by employing materials that exhibit various caloric effects, typically arising from external physical field-driven first-order phase transitions [4] [5][6]. Based on the applied fields, the developed caloric cooling methods are primarily categorized as magnetocaloric [7,8], electrocaloric [9,10], and mechanocaloric techniques [11][12][13][14]. Mechanocaloric effects are stress-induced and can be further divided into elastocaloric (by uniaxial Polymers 2024, 16, 3360 2 of 14 stress) [15][16][17][18], twistocaloric (by shear stress) [19], barocaloric (by hydrostatic pressure) effects [20], and others, based on the deformation mode and stress distribution. ...

Mechanocaloric Effects Characterization of Low-Crystalline Thermoplastic Polyurethanes Fiber

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Jiongjiong Zhang · Yilong Wu · You Lv · Yuan Zhu

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[17][18] [19] . ...

Twistocaloric effect versus elastocaloric effect in shape memory alloys for low-force mechanocaloric design

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Dec 2024 · J PHYS D APPL PHYS

Jiaxing Zheng · Zeyi Li · Chao Lv · Huilong Hou

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... Vapor compression remains the predominant technology in refrigeration facilities, yet the high global-warming potential of volatile liquid refrigerants has raised extensive concerns on environmental degradation [1]. Elastocaloric refrigeration, which is based on the elastocaloric effect (eCE) of solid-state materials, offers an eco-friendly cooling alternative that circumvents potential impacts on the global environment [2] [3][4]. Shape-memory alloys (SMAs) show great potential as candidate materials for elastocaloric cooling due to their ability to exhibit an elastocaloric response through the utilization of released and absorbed latent heat in association with stress-induced martensitic transformation. Consequently, very pronounced isothermal entropy change (ΔS iso) or adiabatic temperature change (ΔT ad) can be expected upon the application or removal of certain uniaxial stresses [5]. ...

Giant Elastocaloric Effect and Improved Cyclic Stability in a Directionally Solidified (Ni50Mn31Ti19)99B1 Alloy

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Honglin Wang · Yueping Wang · Guoyao Zhang · Liang Zuo

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... [9][10][11][12] Fundamentally, the caloric effect originates from the martensitic transformation from a high-temperature phase to a low-temperature phase with different structures in shape memory alloys. [13] [14][15] Therefore, the volume fraction of martensitic transformation affects the values of isothermal entropy change (DS) or adiabatic temperature change (DT ad). For Ni-Mn-Sn alloys, the hightemperature phase typically exists in the forms of

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Jan 2024

Wen Sun · Hanyang Qian · Qi Fu · Guowei Li

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... A similar effect has been observed in antiferromagnets. 51, 52 In Table I, the ECE properties of different materials are compared. Taken together, the negative electrocaloric properties of PMZ-0.5 AFE thin films are favorable and show great potential for solidstate cooling device applications. ...

Giant negative electrocaloric effect in modified PbZrO3 antiferroelectric thin films doped with Mn

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Aug 2024 · APPL PHYS LETT

Yongxi Liang · Wenhua Li · Xingui Tang · Kai Yan

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... Solid-state caloric systems based on the magnetocaloric effect (MCE) are recognized as a promising alternative technology to address these problems. Further development of existing studies and applications is expected to contribute to the solution [2, 3]. There are many material systems as MCE materials, such as Gd-Si-Ge [4], La-Fe-Si [5], Fe-Rh [6], Mn-Fe-P-As [7], Co-Mn-Ge [8], and Ni-(Co)-Mn-X (X=In [9], Sn [10], Sb [11], Ga [12]). ...

Investigation of the effect of martensitic phase transition temperature and Curie temperature difference on magnetic and…

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Mert Mirac Cicek · Senem Sarıtaş · Baris Emre · Eyüp Kavak

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Elastocaloric, barocaloric and magnetocaloric effects in spin crossover polymer composite films

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Jul 2024

Klara Lünser · Eyüp Kavak · Kübra Gürpınar · Lluís Mañosa

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... Caloric properties of materials are determined by their reversible thermal response to an external field. When the field is applied/ removed keeping the temperature constant the response can be quantified by a change of entropy, while it is measured by a change of temperature when the field is applied or removed in adiabatic conditions [1, 2]. These changes are expected to be very large in the vicinity of a phase transition and, particularly, near a first-order transition due to the contribution of the latent heat to the thermal response. ...

Caloric properties of materials near a tricritical point

Preprint

Jun 2024

Eduardo Mendive Tapia · Antoni Planes

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... With high efficiency, solid-state caloric refrigeration, including magnetocaloric (MC), electrocaloric, elastocaloric, and barocaloric refrigeration, [8][9][10][11][12][13][14] [15] [16][17][18][19][20] is acknowledged as a promising candidate to substitute traditional VC cooling. The refrigerants used in these types of caloric refrigeration are solid caloric materials, which exhibit a reversible entropy change during a phase transition triggered by an external field, introducing zero ozone depletion potential and an extremely low global warming potential. ...

A full solid-state conceptual magnetocaloric refrigerator based on hybrid regeneration

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... Therefore, energy-saving, environmentally friendly and high-performance refrigeration technologies are desired for replacing the energy-intensive and polluted vapor compression refrigeration technology. Solid-state refrigeration technology featuring caloric effects in materials is one of the promising alternatives [4] . The caloric effect in solid-state refrigeration is primarily manifested through the adiabatic temperature change (|ΔT ad |) and the isothermal entropy change (ΔS Tra) induced by an external field, which arises from the latent heat of phase transformation near reversible phase transformation [5][6][7]. ...

Large reversible multicaloric effects over a broad refrigeration temperature range in Co and B co-doped Ni–Mn–Ti alloys

Article

Mar 2024 · MAT SCI ENG A-STRUCT

Bo Li · Zhenpeng Liu · Dou Li · Shuangming Li

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... Elastocaloric refrigeration could be characterized by the adiabatic temperature change (ΔT adi) or the isothermal entropy change (ΔS iso). [2] Furthermore, hysteresis reflected the energy dissipation during transformation, which was detrimental to the reversibility of transformation. [3][4][5] Low hysteresis was important for achieving high energy conversion efficiency and for enhancing the reversibility of transformation. ...

Enhanced superelasticity and reversible elastocaloric effect in nano-grained NiTi alloys with low stress hysteresis

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Min Zhou · Wei维 Wang王 · Haojian浩健 Su苏 · Laifeng来风 Li李

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... Solid-state cooling represents an energy efficient and ecologically friendly solution to the environmental problems posed by conventional refrigeration technologies based on compression cycles of greenhouse gases [1] [2][3][4][5][6] . Upon small and moderate magnetic, electric and/or mechanical field shifts, promising caloric materials experience large adiabatic temperature variations (|ΔT|~1-10 K) as a result of phase transformations entailing large isothermal entropy changes (|ΔS|~10-100 J K −1 kg −1). ...

Prediction and understanding of barocaloric effects in orientationally disordered materials from molecular dynamics…

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Advanced materials for solid-state refrigeration

March 2013

Lluís Mañosa · Antoni Planes · Mehmet Acet

Recent progress on caloric effects are reviewed. The application of external stimuli such as magnetic field, hydrostatic pressure, uniaxial stress and electric field give rise respectively to magnetocaloric, barocaloric, elastocaloric and electrocaloric effects. The values of the relevant quantities such as isothermal entropy and adiabatic temperature-changes are compiled for selected materials. ... [Show full abstract]

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Advanced materials for solid-state refrigeration

L. Mañosa, A. Planes, M. Acet • Published 15 March 2013 •
Materials Science, Physics • Journal of Materials Chemistry

Recent progress on caloric effects are reviewed. The application of external stimuli such as magnetic field, hydrostatic pressure, uniaxial stress and electric field give rise respectively to magnetocaloric, barocaloric, elastocaloric and electrocaloric effects. The values of the relevant quantities such as isothermal entropy and adiabatic temperature-changes are compiled for selected materials. Large values for these quantities are found when the material is in the vicinity of a phase… Expand

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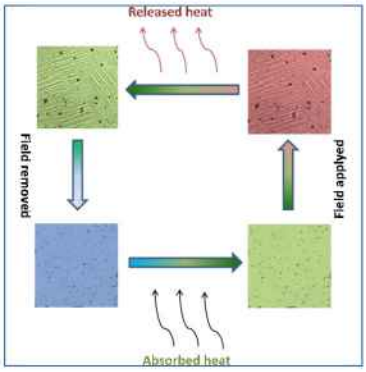


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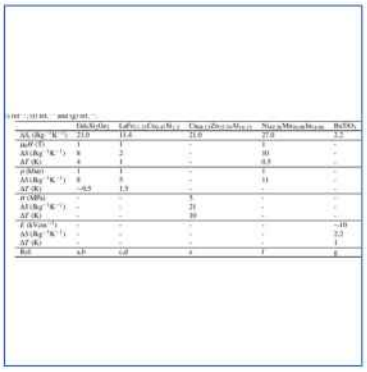


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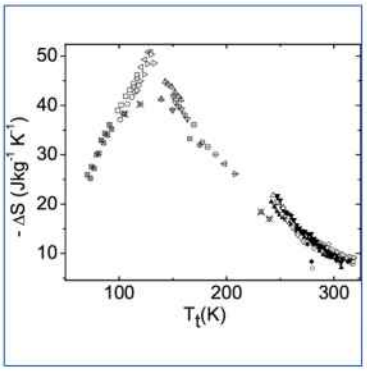


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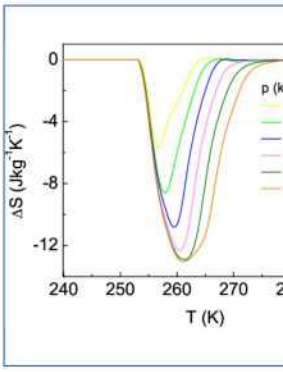


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B. Kehileche | Younes Chiba | A. Tlemçani | N. Henini — Engineering, Physics

International Journal of Air-Conditioning and… · 2023

The application of external stimuli such as the magnetic and electric field in magnetocaloric and electrocalo materials, and stress and pressure in elastocaloric and barocaloric materials give… Expand

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L. Mañosa | A. Planes — Materials Science, Physics · 2018

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Solid-state cooling by stress: A perspective

Materials Science, Physics · 2020

L. Mañosa A. Planes

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Elastocaloric switching effect induced by reentrant martensitic transformation

Takumi Odaira Shengyu Xu Xiao Xu T. Omori R. Kainuma Materials Science, Physics · 2020

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Enhancing the temperature span of thermal switch-based solid state magnetic refrigerators wit field sweeping

D. J. Silva J. Ventura J. Amaral V. Amaral Engineering, Physics · International Journal of Energy Researc

2018

Magnetocaloric refrigeration has been pointed out as the most promising alternative to the ubiquitous vapo compression refrigeration technology due to its high coefficient of performance.… Expand

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Giant Barocaloric Effects in Natural Rubber: A Relevant Step toward Solid-State Cooling.

N. M. Bom W. Imamura E. O. Usuda L. S. Paixão A. M. G. Carvalho Materials Science ·

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C. Aprea A. Greco A. Maiorino C. Masselli Materials Science, Physics · 2017

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High performance of carbon nanotube elastocaloric refrigerators over a large temperature span

Tatiana Naomi Yamamoto Silva · A. F. Fonseca · Materials Science, Physics · Physical review B · 2022

: Compression of greenhouse gases still dominates the market of refrigeration devices. Although well stablished and efficient, this technology is neither safe for the environment nor able to be… Expand

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Electrocaloric Materials for Solid-State Refrigeration

Shengguo Lu · Qiming Zhang · Materials Science, Physics · 2009

The electrocaloric effect (ECE) in dielectric materials has great potential in realizing solid-state cooling dev with compact size and high efficiency, which are highly desirable for a broad… Expand

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Recent Progress in Exploring Magnetocaloric Materials

B. Shen · Jirong Sun · F. Hu · Hui Zhang · Zhaohua Cheng · Materials Science, Physics · 2009

The magnetic refrigeration technique based on the magnetocaloric effect (MCE) has attracted increasing interest because of its high efficiency and environment friendliness. In this article, our… Expand

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Giant solid-state barocaloric effect in the Ni-Mn-In magnetic shape-memory alloy.

L. Mañosa · D. González-Alonso · +5 authors · M. Acet · Materials Science, Physics · Nature Materials · 2010

TLDR It is shown that the application of a moderate hydrostatic pressure to a magnetic shape-memory all gives rise to a caloric effect with a magnitude that is comparable to the giant magnetocaloric effect reporte this class of materials.Expand

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Caloric Effects in Ferroic Materials: New Concepts for Cooling

S. Fähler · U. Rößler · +7 authors · K. Albe · Materials Science, Engineering · 2012

Refrigeration is one of the main sinks of the German and European electricity consumption and accordingl contributes to worldwide CO2 emissions. High reduction potentials are envisaged if caloric… Expand

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Materials Challenges for High Performance Magnetocaloric Refrigeration Devices

Anders Smith C. Bahl R. Bjørk K. Engelbrecht K. K. Nielsen N. Pryds Materials Science, Physics

Magnetocaloric materials with a Curie temperature near room temperature have attracted significant intere some time due to their possible application for high-efficiency refrigeration devices.… Expand

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A solid-state refrigerator based on the electrocaloric effect

Yanbing Jia Y. Ju Physics, Engineering · 2012

The electrocaloric effect offers an attractive alternative to the Peltier effect for compact high-efficiency solic state refrigeration. We report an implementation and experimental characterization… Expand

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Ambient pressure colossal magnetocaloric effect tuned by composition in Mn1−xFexAs

A. de Campos D. L. Rocco +9 authors Nilson A. de Oliveira Materials Science, Physics · Nature Materials 2006

TLDR The properties of Mn1−xFexAs are reported on that exhibit the colossal effect at ambient pressure, which brings layered magnetic regenerators with huge refrigerating power closer to practical applications around room temperature.Expand

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The Magnetocaloric Effect and Magnetic Refrigeration Near Room Temperature: Materials and Models

V. Franco J. S. Blázquez B. Ingale A. Conde Materials Science, Physics · 2012

In the past 20 years, there has been a surge in research on the magnetocaloric response of materials, due mainly to the possibility of applying this effect for magnetic refrigeration close to room… Expand

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Electrocaloric materials for future solid-state refrigeration technologies

M. Valant Materials Science, Engineering · 2012

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Inverse barocaloric effect in the giant magnetocaloric La-Fe-Si-Co compound.

L. Mañosa D. González-Alonso +6 authors S. Majumdar Materials Science, Physics · Nature Communications · 2011

TLDR It is found that application of a pressure of only 1 kbar causes a temperature change of about 1.5 K which is larger than the magnetocaloric effect in this compound for magnetic fields that are available with permanent magnets. Expand

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050 00$aTA404.2 $b.J674
082 04$a543.0284 $223
210 0#$aJ. mater. chem. A $b(Print)
222 #0$aJournal of materials chemistry. A $b(Print)
245 00$aJournal of materials chemistry. $nA, $pMaterials for energy and sustainability.
246 30$aMaterials for energy and sustainability
264 #1$aCambridge, UK : $bRoyal Society of Chemistry, $c[2013]-
300 ##$avolumes : $bcolor illustrations ; $c28 cm
310 ##$aForty-eight no. a year
336 ##$atext $btxt $2rdacontent
337 ##$aunmediated $bn $2rdamedia
338 ##$avolume $bnc $2rdacarrier
362 1#$aBegan with Volume 1, number 1 (Jan. 7, 2013).
530 ##$aAlso issued online.
580 ##$aSeparated from: Journal of materials chemistry.
588 ##$aDescription based on: Volume 1, number 1 (Jan. 7, 2013); title from cover.
588 ##$aLatest issue consulted: Volume 1, number 14 (Apr. 14, 2013).
650 #0$aMaterials $xResearch $vPeriodicals.
650 #0$aChemistry, Analytic $vPeriodicals.
650 #0$aEnvironmental sciences $xResearch $vPeriodicals.
710 2#$aRoyal Society of Chemistry (Great Britain), $eissuing body.
780 17$tJournal of materials chemistry $x0959-9428 $w(DLC)sn 91014399
$w(OCoLC)23295112
850 ##$aDLC
945 ##$aJournal of materials chemistry. A, Materials for energy and sustainability.
948 ##$aLTI 10/24/2014

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450 __ |**w** nne |**a** Materials research
906 __ |**t** 8334 |**u** fk07 |**v** 0
953 __ |**a** td14

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LCCN Permalink: https://lccn.loc.gov/sh85099890

HEADING: Periodicals

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040 __ |**a** DLC |**c** DLC |**d** DLC

053 _0 |**a** AP |**c** General periodicals

053 _0 |**a** PN4700 |**b** PN5650 |**c** History

150 __ |**a** Periodicals

360 __ |**i** subdivision |**a** Periodicals |**i** under specific subjects, e.g. |**a** Engineering--Periodicals; United States--History--Periodicals

450 __ |**a** Journals (Periodicals)

450 __ |**a** Magazines

550 __ |**w** g |**a** Library materials

550 __ |**w** g |**a** Mass media

550 __ |**w** g |**a** Serial publications

550 __ |**a** Newspapers

550 __ |**a** Press

670 __ |**a** UMI business vocab. |**b** (Journals)

680 __ |**i** Here are entered works on the periodicals of the world and, with appropriate subdivisions, works on special aspects or sections of periodicals. Works on periodicals in a specific language, or in a specific country or larger area, are entered under the adjectival form of the language or area, e.g. |**a** Arabic periodicals; Canadian periodicals.

906 __ |**t** 0420 |**u** te03 |**v** 0

910 __ |**a** Proposal saved by tc03 on 05/14/2012 at 17:15:30

953 __ |**a** xx00 |**b** td14

906 __ |**t** 1206 |**v** 0

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HEADING: Analytical chemistry

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040 __ |**a** DLC |**c** DLC |**d** DLC |**d** WaU

053 _0 |**a** QD71 |**b** QD142

150 __ |**a** Analytical chemistry

360 __ |**i** subdivision |**a** Analysis |**i** under substances or chemicals for works on methods of analyzing these items or analyzing a sample to determine the presence or quantity of these items, and for works presenting the results of analyzing substances not produced naturally, e.g. |**a** Concrete--Analysis; Corn--Analysis

450 __ |**a** Analysis, Chemical

450 __ |**a** Analytic chemistry

450 __ |**a** Chemical analysis

450 __ |**w** nne |**a** Chemistry, Analytic

550 __ |**w** g |**a** Chemistry

670 __ |**a** McGraw-Hill dictionary of chemistry, 2003 |**b** (analytical chemistry: The branch of chemistry dealing with techniques which yield any type of information about chemical systems)

670 __ |**a** Analytical chemistry, via American Chemical Society website, Aug. 10, 2020 |**b** (Analytical chemistry is the science of obtaining, processing, and communicating information about the composition and structure of matter. In other words, it is the art and science of determining what matter is and how much of it exists. In 2012 (salary survey data), analytical chemistry was the most popular field of work for ACS chemists. Analytical chemists use their knowledge of chemistry, instrumentation, computers, and statistics to solve problems in almost all areas of chemistry and for all kinds of industries. For example, their measurements are used to assure the safety and quality of food, pharmaceuticals, and water; to assure compliance with environmental and other regulations; to support the legal process; to help physicians diagnose diseases; and to provide measurements and documentation essential to trade and commerce)

670 __ |**a** Webster's new world college dictionary, ©2010, via Collins dictionary website, Aug. 10, 2020 |**b** (analytical chemistry: a branch of chemistry that deals with the identification of compounds and mixtures (qualitative analysis) or the determination of the proportions of the constituents (quantitative analysis): techniques commonly used are titration, precipitation, spectroscopy, chromatography, etc.)

670 __ |**a** Dictionary.com, Aug. 10, 2020 |**b** (analytical chemistry: the subdivision of chemistry dealing with the qualitative and quantitative determination of chemical components of substances)

675 __ |**a** A dictionary of chemistry, 2020

906 __ |**t** 8737 |**u** fk02 |**v** 0

910 __ |**a** Proposal saved by tc03 on 10/21/2020 at 14:01:26

953 __ |**a** xx00 |**b** fj26

906 __ |**t** 2010 |**v** 0

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HEADING: Environmental sciences

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053 _0 |**a** GE

150 __ |**a** Environmental sciences

450 __ |**a** Environmental science

550 __ |**w** g |**a** Science

670 __ |**a** Work cat.: 91-77966: Readings in environmental studies, c1992.

670 __ |**a** Random House |**b** (environmental science)

670 __ |**a** Barnhart dict. of new English |**b** (environmental science, group of sciences dealing with the environment)

670 __ |**a** Biol. & agr. index: |**b** v. 44, p. 668 (Environmental sciences)

670 __ |**a** LC data base, 3/24/92 |**b** (environmental sciences, environmental science)

670 __ |**a** Hennepin |**b** (Environmental sciences)

675 __ |**a** Web. 3

680 __ |**i** Here are entered works on the composite of physical, biological, and social sciences concerned with the conditions of the environment and their effects. Works on the interrelationships of organisms and their environment, including other organisms, are entered under |**a** Ecology. |**i** Works on the relationship of humans to the natural environment are entered under |**a** Human ecology. |**i** Works on the relationship of humans to their sociocultural environment are entered under |**a** Social ecology.

681 __ |**i** Notes under |**a** Ecology; Human ecology; Social ecology

906 __ |**t** 9234 |**u** te03 |**v** 0

952 __ |**a** 63 bib. recird(s) to be changed

953 __ |**a** jb03

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053 _0 |**a** ZA3075 |**b** ZA3085 |**c** Information resources

150 __ |**a** Research

360 __ |**i** subdivision |**a** Research |**i** under names of countries, cities, etc.; and under subjects

450 __ |**a** Science |**x** Research

450 __ |**a** Science research

450 __ |**a** Scientific research

550 __ |**a** Information services

550 __ |**a** Learning and scholarship

550 __ |**a** Methodology

550 __ |**a** Research teams

680 __ |**i** Here are entered general works on research, and with local subdivision, works on research carried out in specific places. Works on research about a particular region, country, etc. are entered under the name of the region, country, etc. with the subdivision |**a** Research.

906 __ |**t** 64-- |**u** ---- |**v** 0

910 __ |**a** Record saved by jr02 on 12/19/2019 at 14:38:08

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953 __ |**a** xx00

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001	830991078	
005	20201230165758.7	
008	Date Entered on File	'120705'
	Type of Date/Publication Status	'c' - Continuing resource currently published
	Date1/Beginning Date of Publication	'2013'
	Date2/Ending Date of Publication	'9999'
	Place of Publication, Production, or Execution Code	'enk' - England
	Frequency	'w' - Weekly
	Regularity	'n' - Normalized irregular
	Type of Continuing Resource	'p' - Periodical
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	Specific Material Designation (t)	'a' - Regular print
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210	0 J. mater. chem. A **$b** (Print)	
222	0 Journal of materials chemistry. A **$b** (Print)	
245	0 0 Journal of materials chemistry. **$n** A, **$p** Materials for energy and sustainability.	
246	3 0 Materials for energy and sustainability	
264	1 Cambridge, UK : **$b** Royal Society of Chemistry, **$c** [2013]-	

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310 Forty-eight no. a year
336 text **$b** txt **$2** rdacontent
337 unmediated **$b** n **$2** rdamedia
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362 1 Began with Volume 1, number 1 (Jan. 7, 2013).
530 Also issued online.
580 Separated from: Journal of materials chemistry.
588 Description based on: Volume 1, number 1 (Jan. 7, 2013); title from cover.
588 Latest issue consulted: Volume 1, number 14 (Apr. 14, 2013).
650 0 Materials **$x** Research **$v** Periodicals.
650 0 Analytical chemistry **$v** Periodicals.
650 0 Environmental sciences **$x** Research **$v** Periodicals.
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710 2 Royal Society of Chemistry (Great Britain), **$e** issuing body.
780 1 7 **$t** Journal of materials chemistry **$x** 0959-9428 **$w** (DLC)sn 91014399 **$w** (OCoLC)23295112
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ATTACHMENT 32





Journal of materials chemistry. A, Materials for energy and sustainability

Author: Royal Society of Chemistry (Great Britain) (Issuing body)

Journal, Magazine, English, 2013
Edition: View all formats and editions
Publisher: Royal Society of Chemistry, Cambridge, UK, 2013

Genre:
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Physical Description:
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RESEARCH ARTICLE | FEBRUARY 16 2016

Elastocaloric and barocaloric effects in polyvinylidene di-fluoride-based polymers

Satyanarayan Patel; Aditya Chauhan; Rahul Vaish; P. Thomas

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Appl. Phys. Lett. 108, 072903 (2016)

https://doi.org/10.1063/1.4942000 **Article history**

Connected Content

A correction has been published: Erratum: “Elastocaloric and barocaloric effects in polyvinylidene di-fluoride-based polymers” [Appl. Phys. Lett. **108**, 072903 (2016)]

Polyvinylidene di-fluoride-based polymers were investigated for elastocaloric and barocaloric effects. Bulk samples were subjected to uniaxial tensile and hydrostatic loading. Resulting strain profile (function of temperature) was used to predict the temperature change. A peak elastocaloric effect of 1.8 K was observed at 298 K (15 MPa). Alternately, a large barocaloric effect of ~6 K was observed at 300 K (200 MPa). This was further improved to an astounding ~19 K near 368 K (200 MPa). The results of this study are expected to greatly benefit the field of ferroelectric solid-state refrigeration and open another horizon for future exploration of multicaloric effects in ferroelectric polymers.

Topics

Ferroelectric materials, Magnetism, Phase transitions, Ferroelectric polymers, Cooling capacity, Entropy, Refrigerators, Thermomechanical effects, Inorganic compounds, Hydrostatics

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Article

Elastocaloric and barocaloric effects in polyvinylidene di-fluoride-based polymers

Applied Physics Letters

February 2016 · 108(7):072903

DOI:10.1063/1.4942000

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Citations (62) References (49)

Abstract

Polyvinylidene di-fluoride (PVDF)-based polymers were investigated for elastocaloric and barocaloric effects. Bulk samples were subjected to uniaxial tensile and hydrostatic loading respectively. Resulting strain profile (function of temperature) was used to predict the temperature change. A peak elastocaloric effect of 1.8K was observed at 298K (15MPa). Alternately, a large barocaloric effect of ~6K was observed at 300K (200MPa). This was further improved to an astounding ~19K near 368K (200MPa). The results of this study are expected to greatly benefit the field of ferroelectric solid-state refrigeration and open another horizon for future exploration of multicaloric effects in ferroelectric polymers.

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Citations (62) References (49)

... Regarding σb-CE, there is a lack of data in the literature for many materials classes [3]. In the specific case of polymers, this effect is only systematically studied in PVDF-TrFE-CTFE [30] , to the best of our knowledge. Nevertheless, it was demonstrated that σb-CE presents the most promising icaloric efficiencies, justifying research efforts in this direction [3]. ...

... For σb-CE, however, a detailed description of the physico-chemical mechanisms associated to the observed ΔT is still missing, and further studies are necessary to unravel this question. Moreover, no abrupt changes in |ΔT| are verified as temperature increases, indicating the absence of SIC or other phase transitions, differently from what was previously reported in mechanocaloric studies with V-NR [27,28] and PVDF-polymers [30] . Furthermore, around room temperature, the ΔT values observed in our data set for 173 MPa are significantly higher than those obtained for σb-CE in PVDF-TrFE-CTFE at similar pressures, as showed in Table 1. ...

... Systematic errors (an offset) of 0.002 and random errors of 0.001 are estimated. The measured ε vs. T curves allow to indirectly quantifyΔST by using the following thermodynamic relation [30, 38,39]: ...

Large barocaloric effects at low pressures in natural rubber

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View Show abstract

... The thermal entropy increases and the configuration entropy decreases, giving a total entropy change of zero. The thermal entropy change can be calculated using the fourth Maxwell relation [1] [2] [3][4] [5]: ...

... It has previously been assumed that T is the argument and V is the function, but this corresponds to heating via heat exchange: when a quantity of heat is introduced into the sample, its temperature changes, and then its volume changes. This is not the process considered in [1] [2] [3][4][6][7][8][9][10][11][12]. For heating via heat exchange, this derivative should obviously be calculated in the traditional way. ...

... It should be noted that the absolute value of this derivative is not necessarily identical to that of thermal expansion oV=oT ð Þ P ; since heating via heat exchange and compression are different processes. Elastomers heat up both under pressure and under expansion [1, 2, [8] [9][10][11][12], and their thermal entropy therefore increases in both cases. ...

Entropy change in materials under compression and expansion

Article

Jan 2019 · MATER LETT

Igor Stepanov

View Show abstract

... In the last few years, several materials have reported large barocaloric (BC) responses that translate to exceptionally high isothermal entropy change (ΔS T), adiabatic temperature change (ΔT s), and material coefficient of performance (COP) values [10]. Multiple materials classes have shown promising BC properties including shape memory alloys [12], polymers [13] , elastomers [2,[14][15][16], thermoplastic elastomers [17], plastic crystals [10,18], spin crossover materials [19,20], cork [21], n-alkanes [22], organic and inorganic salts [23], and organic and inorganic perovskites [24,25]. Among these material classes, soft materials (including polymers, elastomers, plastic crystals, and thermoplastic elastomers) are particularly attractive due to their high BC response, high compressibility, low cost, and commercial availability. ...

... In addition to material COP, similar to past work by Colman et al. [27], we compared the thermal transport and barocaloric performance by plotting ΔT k vs [10,23,24] Plastic crystal 10 a ad [100] Neopentyl

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ΔT.Δp −1 represents the barocaloric temperature change normalized by applied pressure; for a BC device both these quantities should be as high as possible [11]. ...

Barocaloric properties of reduced graphene oxide-shape memory polymer nanocomposites

Article Full-text available

Dec 2024 · J MATER SCI

Naveen Weerasekera · Kavish Sudan · Kameswara Pavan Kumar Ajjarapu · Bikram Bhatia

View Show abstract

... Alternatively to ferroics, elastomeric polymers have also attracted some attention regarding the σ-CE [17][18][19] [20] [21][22][23]. Elastomers have shown to be particularly suitable for mechanocaloric applications, since they present good fatigue properties combined with high caloric potential [24]. ...

... In order to compare the barocaloric properties of PDMS around room temperature with different relevant barocaloric materials from the literature [12,14, 20, [40][41][42][43], we present the normalized temperature change (|ΔTS/Δσ|) as a function of temperature (Fig. 5a) and as a function of ΔTS (Fig. 5b). A remarkable |ΔTS/Δσ| of ~70 K GPa -1 was obtained for PDMS, which remains practically constant within a large temperature range. ...

Giant room-temperature barocaloric effects in PDMS rubber at low pressures

Preprint

Mar 2017

Alexandre Magnus Gomes Carvalho · W. Imamura · E. O. Usuda · Nicolau Bom

View Show abstract

... [32,33] Nevertheless, most of the previously reported mC materials exhibit large thermal effects only in a temperature interval away from room temperature and even involve issues of mechanical fatigue and phase-transition hysteresis. [34][35][36] Continuous experimental efforts on nonconventional mC systems, such as rubber elastomers

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for practical refrigeration applications. Figure 6 provides the values of adiabatic temperature changes, isothermal entropy changes, and mechanocaloric strength for our systems ([5,10] and [5,12]) at room temperature, which are compared with other leading experimental mechanocaloric materials including eC [64,65,67,70,[85][86][87][88][89][90][91][92][93][94][95] and BC [7,11,17,18,[21][22][23][24]37, 40, [96][97][98][99][100][101][102][103][104] materials. In practice, |ΔT| and |ΔS| associated with caloric materials are measured with direct, quasi-direct, or indirect methods. ...

Room-Temperature Colossal Elastocaloric Effects in Three- Dimensional Graphene Architectures: An Atomistic Study

Article Full-text available

Jun 2022 · ADV FUNCT MATER

Wanlin Guo · Zhiqiang Zhao · Zhuhua Zhang

View Show abstract

... The BC effect has been demonstrated and investigated in a wide variety of materials (Boldrin, 2021) including soft materials, organic-inorganic salts, perovskites, and magnetic shape memory alloys (Mañosa et al., 2010; Patel et al., 2016; Li et al., 2019;Miliante et al., 2020). Despite their typically low thermal conductivity, soft materials are particularly attractive due to their large BC response, high compressibility, and low cost. ...

... In addition to plastic crystals, a wide range of polymers have shown promising BC properties. Patel et al. (2016) observed a BC ΔT s ≈ 6°C at room temperature (Δp ≈ 200 MPa) in polyvinylidene difluoride-based polymers. Furthermore, the BC effect was investigated in several elastomers. ...

Barocaloric Properties of Thermoplastic Elastomers

Article Full-text available

May 2022

Kameswara Pavan Kumar Ajjarapu · Kavish Sudan · Bikram Bhatia · Naveen Weerasekera

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... A 1.8 K elastocaloric temperature change was observed in PVDF

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temperature 19 and an electrocaloric temperature change of up to 11 K. 21 Here, we are concerned with the elastocaloric response of liquid crystal-containing elastomers. ...

... 19 In poly(vinylidene fluoride-trifluoroethylene-chlorofluoroethylene), a slighly larger temperature change (2.2 K) was observed when this material was subject to an applied stress of 150 MPa. 20 Comparatively, PVDF exhibits a barocaloric temperature change of up to 19 K at an elevated ambient temperature 19 and an electrocaloric temperature change of up to 11 K. 21 Here, we are concerned with the elastocaloric response of liquid crystal-containing elastomers. ...

Elastocaloric effect in amorphous polymer networks undergoing mechanotropic phase transitions

Preprint Full-text available

Mar 2021

Jeremy A. Koch · Jeremy A. Herman · Timothy J. White

View Show abstract

... The low energy efficiency of conventional cooling techniques, difficulty in scaling mechanically driven compressors to smaller size, 2 regulations in chlorofluorocarbon (CFCs) and hydrochlorofluorocarbon (HCFC) emissions (The Montreal and Kyoto protocols), 3,4 and growing refrigeration and cooling sectors are forcing researchers to seek environment-friendly, highly efficient alternatives. In the past few decades, several solid-state refrigeration technologies based on Peltier (thermoelectric; TE), 5-8 magnetocaloric (MC), [9][10][11] elastocaloric (eC), 2,12 barocaloric (BC), 2, 11,13 and electrocaloric effect (ECE) 14,15 have been proposed and widely studied to achieve higher energy efficiency and faster refrigeration without vibration and to reduce environmental harm (Fig. 1). ...

... Solid-state refrigeration-based compact coolers are more attractive because they can provide efficient cooling for vehicles, buildings, and optoelectronic devices with various advantages over fluid based VC cooling: (1) they can be easily and accurately driven and controlled by miniature actuators and offer the possibility of chip scale cooling, 16 (2) have no mixing or leaking problems, which are common in fluid systems, and (3) can be designed and fabricated with anisotropic thermal conductivity (heat conduction loss is very small). 17 The limitations of the above techniques are based on their cooling performance, costeffectiveness, and real-time device performance. ...

Prospects and challenges of electrocaloric phenomenon in ferroelectric

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... Because of the large energy consumption [1]and the environmental concerns related to greenhouse gases produced by traditional cooling technology, more and more attempts were conducted to industriously replace the traditional vaporcompression cooling technology, such as magnetocaloric (MC) [2], elastocaloric (eC) [3, 4] , barocaloric (BC) [4] and electrocaloric (EC) materials [5]. Among them, MC cooling was regarded as the most mature technique, but the expensive rare-earths-containing magnets required for huge magnetic fields restricted the development in practical application [6]. ...

... Because of the large energy consumption [1]and the environmental concerns related to greenhouse gases produced by traditional cooling technology, more and more attempts were conducted to industriously replace the traditional vaporcompression cooling technology, such as magnetocaloric (MC) [2], elastocaloric (eC) [3,4], barocaloric (BC) [4] and electrocaloric (EC) materials [5]. Among them, MC cooling was regarded as the most mature technique, but the expensive rare-earths-containing magnets required for huge magnetic fields restricted the development in practical application [6]. ...

Composition dependence of giant electrocaloric effect in Pb Sr1-TiO3 ceramics for energy-related applications

Article Full-text available

Oct 2018

Ge Pengzu · Xiao-Dong Jian · Xiong-Wei Lin · Sheng-Guo (David) Lu

View Show abstract

... More recently, Lloveras et al. 10 reported giant σb-CE in (NH4)2SO4 below room temperature; and large σ-CE observed in natural or synthetic elastomers has reappeared gradually. 11,12,13, 14, 15,16,17 On the contrary of what is observed in SMAs and ionic salts, elastomers show significant σb-CE values even in absence of phase transition during the application of mechanical stress. The mechanocaloric properties (ΔTS and ΔST) of elastomers are usually large due to the rearrangement of the polymer chains under stress (even without crystallization). ...

... We compared the barocaloric properties of ASR around room temperature with relevant barocaloric materials. 8, 14, 15,16,17,21 We plotted a normalized adiabatic temperature change (|ΔTS/Δσ|) as a function of |ΔTS| (Fig. 4A). Obviously, larger simultaneous ΔTS and

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Article

Oct 2017

W. Imamura · E. O. Usuda · Lucas Paixão · Alexandre Magnus Gomes Carvalho

View Show abstract

... Recently, new caloric effects such as the barocaloric effect [9] and elastocaloric effect [10] were observed in ferroelectric materials although they have been extensively investigated in other materials [11]. The remarkable barocaloric effect and elastocaloric effect in ferroelectric materials can even trump the corresponding electrocaloric responses [9,10]. ...

... Recently, new caloric effects such as the barocaloric effect [9] and elastocaloric effect [10] were observed in ferroelectric materials although they have been extensively investigated in other materials [11]. The remarkable barocaloric effect and elastocaloric effect in ferroelectric materials can even trump the corresponding electrocaloric responses [9, 10]. Introducing mechanical stress and the multicaloric effect driven by either single stimulus or multiple stimuli are supposed to be strategies to enhance the caloric properties in ferroelectrics [12]. ...

Multicaloric effects in PbZr 0.2 Ti 0.8 O 3 thin films with 90 ° domain structure

Article Full-text available

Jun 2017 · EPL-EUROPHYS LETT

F. Wang · Bo Li · Yun Ou · Wei Wang

View Show abstract

... On the other hand, σ b -CE is the least studied i-caloric effect, with a lack of literature for many classes of materials (such as polymers). Concerning PVDF polymers, there a single work reporting experimental results for PVDF-TrFE-CTFE (ΔT ~ 18 K and ΔS T ~ 120 J kg -1 K -1 for Δσ = 200 MPa), obtained from indirectly measurements (30) . In the specific case of NR, only very recently experimental results of σ b -CE were reported (31). ...

... For the highest pressures, the maximum ΔT is registered at 263 K, reaching ~21 K for 390 MPa. This value surpasses the barocaloric ΔT obtained for PVDF-TrFE-CTFE (30), or for any other intermetallic

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Giant Barocaloric Effects in Natural Rubber: A Relevant Step toward Solid-State Cooling

Article

May 2017

W. Imamura · Lucas Paixão · Nicolau Bom · E. O. Usuda

View Show abstract

... In the recent years, barocaloric materials have been demonstrated to exhibit very large thermal changes, some of them as large as ΔS ≥ 100 J K -1 kg -1 (the same order of magnitude as refrigerant gases) under the application of low/moderate pressures of p = 70 -1000 bar (while refrigerant gases normally operate at p ≤ 150 bar). [17][18][19][20][21] [22][23][24][25][26][27][28][29][30][31][32][33][34] These barocaloric materials belong to many different families of compounds, such as ammonium or phosphate salts [35][36][37][38][39][40][41][42][43] , superionic conductors 44,45 , spin crossover materials 46-52 , n-alkanes 53 , hybrid organic-inorganic materials [54][55][56][57][58][59] [60][61] , organic plastic crystals 62-69 and polymers [70] [71] [72] . Even more recently, barocaloric effects have been combined with gas adsorption/desorption processes in solid-to-solid breathing-transitions in MOFs, giving rise to larger thermal changes of ΔS ~ 300 J K -1 kg -1 under pressures as small as p ≤ 16 bar. ...

Structure and thermal property relationships in the thermomaterial di- n -butylammonium tetrafluoroborate for multipurpose cooling and cold-…

Article Full-text available

Jan 2023

Richard J. C. Dixey · Maria Antonia Senaris-Rodriguez · Javier García Ben · Juan Manuel Bermúdez-García

View Show abstract

... Several types of materials have been classified as promising for application on solid-state refrigeration (SSR) subject to r-CE [3], one of these materials are polymers which present good performance on elastocaloric [6][7][8], barocaloric [9][10][11][12] [13] , or twistocaloric [14,15] effects. The investigations regarding polymers showed some of the desirable properties suggested by Lloveras and Tamarit [16] for their use as solid-state refrigerants. ...

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Article Full-text available

Jul 2023 · J MATER SCI

Flavio Colman · Nicholas Dicati Pereira da Silva · W. Imamura · E. Radovanovic

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... In this study, we selected a uniaxially polarized piezoelectric polyvinylidene difluoride (PVDF) sheet, which is known to show a relatively large ΔT ad and ΔS iso owing to the strain-induced alignment of polarized polymetric chains. [44, 45] The PVDF sheet used here showed piezoelectric constants of ...

Elastocaloric Kirigami Temperature Modulator

Article Full-text available

Apr 2022 · ADV FUNCT MATER

Takamasa Hirai · Ryo Iguchi · Asuka Miura · Ken-ichi Uchida

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... In addition, pC performance under raw material conditions is of another interest. Former studies on NPG have widely performed using QENS and PDSC approaches (Li et al., 2019b;Lloveras et al., 2019b; Patel et al., 2016) in exact adiabatic conditions, however, pC performance of NPG at non-adiabatic environments (as in a typical pC refrigeration device) is not studied. Also, particle level characterization data of the raw form of NPG is not available in current literature. ...

Particle Level Material Characterization Of Neopentyl Glycol (NPG) For Intermediate Thermal Energy Storage

Experiment Findings

Mar 2022

Naveen Weerasekera

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... In contrast to the magnetocaloric, electrocaloric and elastocaloric

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solid-state materials: plastic crystals, 9,10,12 silver halide, 11 magnetic phase transition alloys, [13][14][15][16][17][18][19][20][21] electronic phase transition materials, 22 ferro/ferrielectric materials, 23,24 perovskite-structure materials, [25][26][27] spin-crossover materials, 28,29 elastic polymers, [30] [31] [32][33][34][35][36] and so on. ...

Giant Barocaloric Effect with Wide Refrigeration Temperature Range in Ethylene Vinyl Acetate Copolymer

Article

Feb 2022

Chengliang Zhang · Dunhui Wang · Suxin Qian · Zhida Han

View Show abstract

... Rubbers and polymers are the classes of elastocaloric materials defined SMP [28, 29] and they are cheaper than Ni-Ti alloys and due of a longer fatigue life but enormous strains (up to 600%) are required to observe the elastocaloric effect, i.e. the coupled significant elongations yield SMP not to easily employable for practical applications in experimental prototypes. ...

A Numerical Analysis on a Single Bunch of Wires of Susstain-EI: The First Italian Elastocaloric Device

Article Full-text available

Dec 2021

Luca Cirillo · Adriana Greco · Claudia Masselli

View

... Enhanced E-CEs via strain-induced crystallization (SIC) in NR at room temperature were reported recently [25][26][27] . Polyvinylidene difluoride based on the α-β phase transition also shows promising E-CEs [28, 29] . Nevertheless, the regular arrangement of polymer molecular chains into a lattice is constrained due to the relatively high molecular weight, resulting in restricted crystalline rates with limited latent heat contributions. ...

Solid-state cooling by elastocaloric polymer with uniform chain-lengths

Article Full-text available

Jan 2022

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... In view of these advantages, in the last years many efforts have been devoted to the development and study of new barocaloric materials. As a consequence, giant Materials 2021, 14, 5947 2 of 8 (ΔS > 10 J K −1 kg −1 , ΔT > 5 K) and even colossal (ΔS > 100 J K −1 kg −1 , ΔT > 20 K) barocaloric effects have been found in different families of materials, such as metallic alloys [5][6][7][8], inorganic ammonium salts [9][10][11], organic plastic crystals [12][13][14][15], superionic conductors [16,17], spin-crossovers [18][19][20], hybrid organic-inorganic compounds [21][22][23][24], and organic polymers [25][26] [27][28][29] [30] . ...

Simple and Low-Cost Footstep Energy-Recover Barocaloric Heating and Cooling Device

Article Full-text available

Oct 2021

Javier García Ben · Ignacio Delgado Ferreiro · Jorge Salgado Beceiro · Juan Manuel Bermúdez-García

View Show abstract

... The SMP is a class embracing the so-called soft materials like rubber or polymers [38] [39][40]. As general consideration, these materials are cheaper than Ni-Ti alloys as well as improved is the fatigue life; the major limit is represented by the much larger elongations (volume variations) needed to make the elastocaloric effect manifesting (up to 600%) that make them not to easy to be employed in experimental devices. ...

Preliminary Numerical Investigation on the Optimization of a Single Bunch of Elastocaloric Elements to be Employed in an Experimental…

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Jul 2021

Luca Cirillo · Adriana Rosaria Farina · Adriana Greco · Claudia Masselli

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... For the polyvinylidene fluoride (PVDF) based ferroelectric polymers, the polar to the nonpolar phase transition is very sensitive to external mechanical stresses. High eC effects have been reported and adiabatic temperature changes of~2 K were measured directly in PVDF polymers near room temperature under uniaxial stresses of~10 MPa [38, 39]. Meanwhile, some typical ferroelectric perovskite thin films also present finite eC effects at room temperature. ...

Giant room temperature elastocaloric effect in metal-free thin-film perovskites

Article Full-text available

Dec 2021

Cheng Li · Yu Hui Huang · Jian-Jun Wang · Zijian Hong

View Show abstract

... In 1982, barocaloric effect was reported for PMMA, with a ΔT S of approximately 9 • C (at 95 • C) at pressure change of 193 MPa [1]. In 2016, BCE was reported for PVDF polymer [being a base for terpolymer P(VDF-TrFE-CTFE) (poly (vinylidene fluoride-trifluoro ethylene-chlorotrifluoroethylene)], with the effect attributed to the transition from α to β phase, where α is the non-polar phase and β the polar phase [2, 3]. ...

Giant barocaloric effect in commercial polyurethane

Article

Jun 2021 · POLYM TEST

Jean Rodrigo Bocca · Silvia Luciana Fávaro · C. S. Alves · E. Radovanovic

View Show abstract

... The class of soft materials with elastocaloric properties called Shape Memory Polymers, i.e., SMP, like rubber or polymers, compared with Ni-Ti alloys, is characterized by smaller tensile stress and costs, greater cooling capacity and fatigue life but larger volume variation; moreover the fatigue cracks can be repaired at high temperature, which constitutes a remarkable potential for elastocaloric cooling, since this

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that, because of the alignment of polymer chains, can always manifest the elastocaloric effect. Among them, Natural Rubber, which is totally environmentally friendly, has shown 12 K as ΔTad under very small tensile stress applied (2 MPa) [53]. ...

Numerical Optimization of a Single Bunch of NiTi Wires to Be Placed in an Elastocaloric Experimental Device: Preliminary Results

Article Full-text available

May 2021

Luca Cirillo · Adriana Rosaria Farina · Adriana Greco · Claudia Masselli

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... The ferroelectric polymer PVDF-TrFE-CTFE (trifluoroethylene-chlorotrifluoroethylene) displays giant BCEs associated with both conformational and polar degrees of freedom. 63 Away from the ferroelectric phase transition, giant BCEs of $20 J kg À1 K À1 are achievable across a broad temperature range under 1 kbar, while at the ferroelectric phase transition (T $ 320 K), DS peaks at $50 J kg À1 K À1 at the same applied pressure. In all these materials, the changes in conformational freedom are not associated with a phase transition and, therefore, should, in theory, not be hysteretic (although nitrile rubber does display a small hysteresis 62). ...

Fantastic barocalorics and where to find them

Article Full-text available

Apr 2021

D. Boldrin

View Show abstract

... There are many polymers with the MCE based on ferroelectric polymers such as polyvinylidene fluoride (PVDF). [71][72] [73] [74] According to results of x-ray diffraction experiments, a crystal transformation from the anti-polar α to the polar β phase was observed in PVDF terpolymers. The transformation can be induced by pressure or an electric field. ...

Giant mechanocaloric materials for solid-state cooling

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... The original paper 6 reports on the elastocaloric and barocaloric effects in polyvinylidene di-fluoride-based polymers. Predictions were made based on original and previously reported experimental data in conjunction with Maxwell's relations. ...

Erratum: “Elastocaloric and barocaloric effects in polyvinylidene di-fluoride-based polymers” [Appl. Phys. Lett. 108 , 072903 (2016)]

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Sep 2018

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... The elastocaloric effect is generally associated with super elasticity and the shape memory effect. Materials that exhibit a significant elastocaloric effect near room temper ature include shape memory alloys, such as Ni-Tibased alloys [8][9][10][11], Cubased alloys [12], and Febased alloys [13], shape memory polymers [14] , including natural rubber [15,16], and magnetic shape memory alloys [17]. Metallic elastocaloric materials are generally considered more attractive due to their higher densi ties, but natural rubber and shape memory polymers require lower forces to achieve high elastocaloric effects, which may make them more suitable for some applications. ...

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J. Li. Tamarit, B. Legendre & J. M. Buisine

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Colossal barocaloric effects near room temperature in plastic crystals of neopentylglycol

P. Lloveras · A. Aznar · +9 authors · J. Tamarit · Materials Science, Physics · Nature Communications · 2019

TLDR This work shows that plastic crystals of neopentylglycol (CH3)2C(CH2OH)2 display extremely large thermal changes near room temperature due to molecular reconfiguration, and that these changes are com exploited commercially in hydrofluorocarbons. Expand

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Determination of the phase diagram of the binary system C(CH2OH)4–(NH2)(CH3)C(CH2OH) Guinier diffractometry and differential scanning calorimetry

R. Russell · R. Chellappa · D. Chandra · Materials Science · 2004

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Polymorphism in 2-Amino-2-Methyl-l,3 propanediol plastic crystal

M. Barrio · J. Font · D. López · J. Muntasell · J. Tamarit · F. Cossío · Materials Science · 1991

Several techniques were used to characterize the polymorphism in polyalcohol 2-amino-2-methyl-1, 3 prop (CH2OH)2CH3C NH2, which exhibits a solid crystalline plastic phase. Three equilibrium… Expand

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Thermo-barometric analysis of some pyramidic mesogens

J. Buisine H. Zimmermann R. Poupko Z. Luz J. Billard Chemistry · 1987

Abstract The phase behaviour under pressure of four members (n = 7, 9, 10 and 11) of the hexaalkyloxytri-
homologous series have been investigated by thermo-barometric analysis. The… Expand

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The formation of the plastic crystal phase in several pentaerythritol derivatives

N. Doshi M. Furman R. Rudman Chemistry · 1973

In the calculation on the crystal structure of urea oxalic acid (2:1) (Harkema, Bats, Weyenberg & Feil, 1972
constants was used. The correct values for the cell constants are:… Expand

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PVT data for liquid and solid cyclohexane, cyclohexanone and cyclopentanol up to 3000 bar

K. Wisotzki A. Würflinger Chemistry · 1981

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High pressure differential thermal analysis of cyclohexanol-d11(C6D11OH) and carbon tetrachl

U. Bardelmeier A. Würflinger Chemistry · 1989

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Miscibility and molecular interactions in plastic phases: Binary system pentaglycerin/ tris(hydroxymethyl)aminomethane

M. Barrio J. Font +5 authors Y. Haget Materials Science, Chemistry · 1993

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The Metabolemeter IV-Phase Transitions of Binary Mixtures of Mesogens Detected on About C Samples

J. Buisine J. Billard Chemistry · 1985

Abstract For perfet solutions, thermobarograms for binary mixtures of mesogens enclosed in a metallic cel
Experimental tests are performed with the metabolemeter on two mixtures of… Expand

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Solid-solid phase transitions determined by differential scanning calorimetry.

L. Breed E. Murrill Chemistry, Materials Science · 1970

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The Metabolemeter II-Detection of Mesogenic Polymorphism under Pressure Using Small Qua

J. Buisine B. Soulestin J. Billard Chemistry · 1983

Abstract Every first order phase transition for mesogens can be detected by the continuous recording, as a temperature, of the pressure of the sample enclosed in a metallic cell. Studies… Expand

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Solid state phase transitions in pentaerythritol and related polyhydric alcohols

D. Benson R. W. Burrows J. Webb Materials Science, Environmental Science · 1986

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J. Li. Tamarit, B. Legendre & J. M. Buisine

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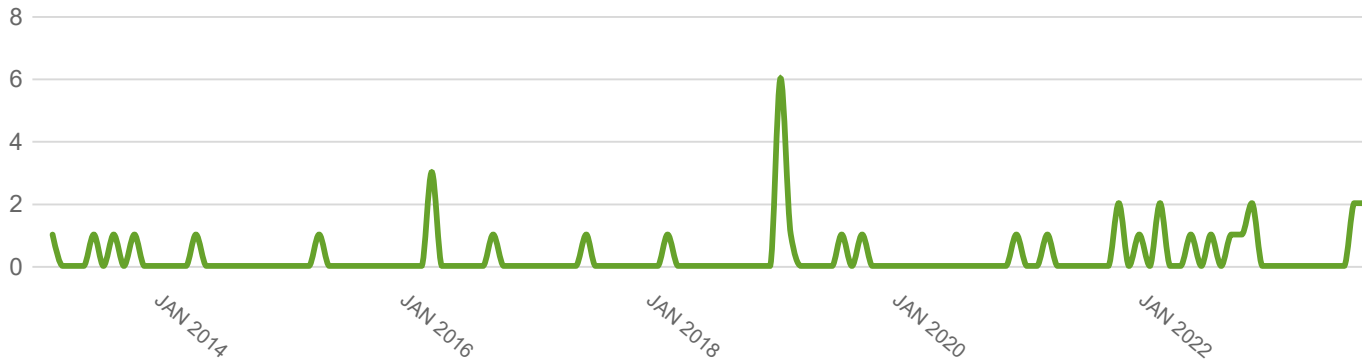
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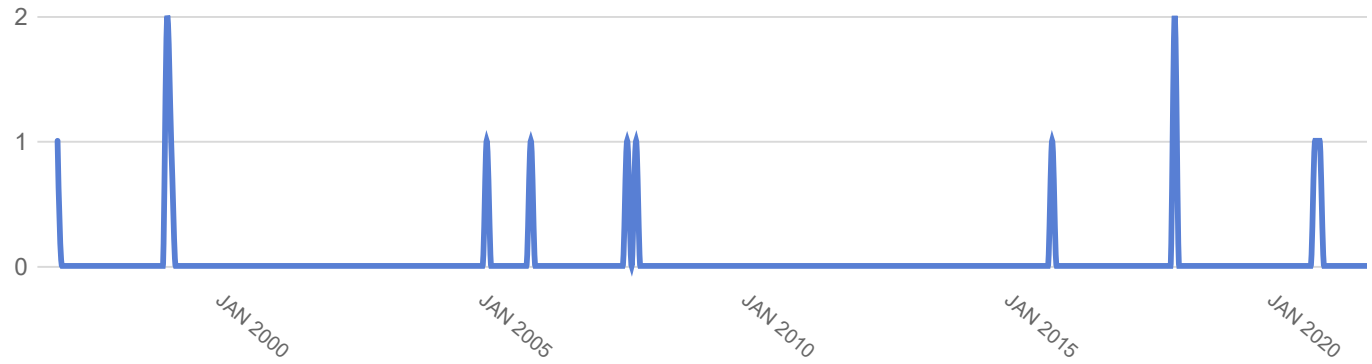
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Giant room temperature elastocaloric effect of $PbTiO_3$ ferroelectric materials with 90° domain structure

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The influence of domain structures and domain switching on the elastocaloric effect in $PbTiO_3$ (PTO) with 90° domain structure under the applied stress field at room temperature has been studied using a phase field model. The calculation results indicate that both positive and negative elastocaloric effects can be obtained depending on the directions of the applied stress. The adiabatic temperature change (ΔT_σ) almost linearly increases with increase of the applied uniaxial stress fields, and the largest value of negative ΔT_σ is about −3.8 K which was obtained at the tensile stress field of about 2 GPa. Moreover, a negative ΔT_σ with the magnitude of −7.2 K can be obtained by controlled polarization switching under the applied stress fields. These results provide an efficient way to obtain a large elastocaloric effect in ferroelectric materials through domain engineering at room temperature.

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Introduction

Solid-state caloric effects are particularly attractive because they can provide a promising approach to energy efficient and environmentally friendly refrigeration technologies.[1–4] Caloric effects can be described as an isothermal change in entropy achieved by the application of external stimulus including magnetic field (magnetocaloric effect),[5] electric field (electrocaloric effect),[6,7] stress (elastocaloric effect)[8] and hydrostatic pressure (barocaloric effect).[9] Recently, the elastocaloric effect in ferroelectric materials has been attracted great attention due to the possibility of enhancing the adiabatic temperature change (ΔT) by combining the electrocaloric effect and the elastocaloric effect in the same material.[8,10] What's more, the giant elastocaloric effect of shape memory alloys are encountered numerous problems of structural and functional fatigue when the size of the materials downscale to nano-level.[11,12] Ferroelectric materials may provide the potential to increase the reliability of operation and reduces the risk of failure.[13] Therefore, numerous accounts of experimental and theoretical studies on the elastocaloric effect in ferroelectric materials have been explored.

Until now, the effects of domain rotation on the elastocaloric effect of ferroelectric materials have been speculated in the bulk ceramics and single crystals.[10,12,14–16] However, only the single domain model has been considered in the phenomenological theory and first-principles calculations of the elastocaloric effect in ferroelectric materials.[2,17] Nevertheless, the domain structures and domain switching are proved to be significant to the properties of ferroelectric materials. The influence of domain structure on the electrocaloric effect of ferroelectric materials, which governed by the change of polarization, have been widely studied. For example, Lee *et al.* have demonstrated that the enhancement of electrocaloric effect is competed with the reduction of c-domains volume fraction and 90° domain walls of $PbTiO_3$ (PTO) thin film have an important role in enhancing the electrocaloric effect.[18] The electrocaloric coefficient in a $PbZr_{0.4}Ti_{0.6}O_3$ nanodot with vortex domain structure is 30% more than that in the monodomain structure by using first-principles investigation.[19] Our previous works have demonstrated that the 180° and 90° domain walls have great contributions to the promotion of electrocaloric effect investigated using a phase-field model combined with thermodynamics analysis at room temperature.[20,21] The polarization can be changed when ferroelectric materials subjected to an external stress due to the piezoelectric property. In addition, the polarization change resulted in strain variation could evaluate the elastocaloric effect of ferroelectric materials. Therefore, this is of great interest and importance to reveal that domain structures under the external stress field and the influences on the elastocaloric effect of ferroelectric materials.

In this work, the elastocaloric effect of PTO ferroelectric materials with 90° domain structure is investigated at room temperature. The adiabatic temperature change is calculated as functions of the applied stress filed using a phase field approach combined with the thermodynamics analysis. The

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influences of domain structures on the elastocaloric effect of ferroelectrics have been studied in details.

Theory

In the phase field model, the spontaneous polarization vector $\boldsymbol{P} = (P_1, P_2, P_3)$ is used as the order parameter. The evolution of domain structures in the PTO can be obtained using the time dependent Ginburg–Landau (TDGL) equation[22]

$$\frac{\partial P_i(\boldsymbol{r}, t)}{\partial t} = -\boldsymbol{L}\frac{\delta \boldsymbol{F}}{\delta P_i(\boldsymbol{r}, t)} \quad (i = 1, 2, 3) \tag{1}$$

where $\boldsymbol{r}$ represents the spatial vector and $i = 1, 2, 3$ corresponds to the x, y, and z directions, respectively. $\boldsymbol{L}$ is a kinetic coefficient and $\boldsymbol{F}$ is the total free energy of the PTO ferroelectric material. The total free energy of PTO is composed of bulk free energy, domain wall energy, electric energy, and elastic energy,[23]

$$\boldsymbol{F} = \int_V \left[F_{\text{bulk}}(P_i) + F_{\text{grad}}(P_{i,j}) + F_{\text{elec}}(P_i, E_i) + F_{\text{elas}}(P_i, \sigma_{kl})\right] \mathrm{d}V \tag{2}$$

The bulk free energy density of the system is described by a six-order Landau–Devonshire polynomial as[24]

$$F_{\text{bulk}}(P_i) = \alpha_1(P_1^2 + P_2^2 + P_3^2) + \alpha_{11}(P_1^4 + P_2^4 + P_3^4) + \alpha_{12}(P_1^2P_2^2 + P_2^2P_3^2 + P_1^2P_3^2) + \alpha_{111}(P_1^6 + P_2^6 + P_3^6) + \alpha_{112}[P_1^4(P_2^2 + P_3^2) + P_2^4(P_1^2 + P_3^2) + P_3^4(P_1^2 + P_2^2)] + \alpha_{123}P_1^2P_2^2P_3^2 \tag{3}$$

where α_{11}, α_{12}, α_{111}, α_{112} and α_{113} are constant phenomenological coefficients. $\alpha_1 = (T - T_0)/2\varepsilon_0 C_0$ is a function of temperature, where ε_0 is the dielectric constant of the vacuum, and C_0 is the Curie constant. T and T_0 are the room temperature in this phase field model and Curie temperature, respectively.

The contribution of domain walls to the total free energy of ferroelectric is described by the gradient energy. The lowest order of the gradient energy density which compatible with the cubic symmetry is taken as,[25]

$$F_{\text{grad}} = \frac{1}{2}g_{ijkl}\left(\partial P_i/\partial x_j\right)\left(\partial P_k/\partial x_i\right) \tag{4}$$

where $P_{i,j} = \partial P_i/\partial x_j$ denotes the spatial differentiation of the polarization components and g_{ijkl} is the gradient energy coefficient.

The electric energy density F_{elec} is comprised of external electric energy density and the depolarization energy density F_{dep}. In this work, the external electric field does not applied. Then, the electric energy density F_{elec} is given by F_{dep}[25]

$$F_{\text{dep}}(P_i, E_i) = -\frac{1}{2}\left(E_1^{\text{d}}P_1 + E_2^{\text{d}}P_2 + E_3^{\text{d}}P_3\right) \tag{5}$$

where E_1^{d}, E_2^{d} and E_3^{d} are the components of the depolarization field along the x, y and z axes, respectively.

The elastic energy density is written as,[23]

$$F_{\text{elas}} = \frac{1}{2}c_{ijkl}e_{ij}e_{kl} \tag{6}$$

where c_{ijkl} is the elastic modulus and e_{ij} is the elastic strain. When an externally applied homogeneous stress σ_{kl} applies, using the superposition principle, the total elastic strains of the system can be calculated by[23]

$$e_{ij} = \varepsilon_{ij} - \varepsilon_{ij}^0 + S_{ijkl}\sigma_{kl} \tag{7}$$

where ε_{ij} and ε_{ij}^0 are the total strain and the spontaneous strain, respectively. S_{ijkl} is the elastic compliance tensor. The structural change associated with a proper ferroelectric phase transition is described by spontaneous polarization and can be calculated by

$$\varepsilon_{ij}^0 = Q_{ijkl}P_{ij}P_{kl} \tag{8}$$

where Q_{ijkl} is the electrostrictive coefficients.

The adiabatic temperature changes (ΔT_σ) of the ferroelectric materials upon the application of a stress field is given by[2]

$$\Delta T_\sigma = -\frac{T}{C}\int \left(\frac{\partial \varepsilon}{\partial T}\right)_\sigma \mathrm{d}\sigma \tag{9}$$

where C is the heat capacity. According to the Maxwell relationship,[2] $\left(\frac{\partial \varepsilon}{\partial T}\right)_\sigma = \left(\frac{\partial S}{\partial \sigma}\right)_T$ the adabatic temperature is a function of entropy.

The entropy (S) is determined by,

$$S_\sigma(T, \sigma) = -T\left(\frac{\partial G(P)}{\partial T}\right)_\sigma \tag{10}$$

Then, ΔT_σ can be evaluated in terms of polarization change rather than strain change which are directly supported by first-principles calculations[8] and thermodynamic approach.[26]

For convenience, we employ the following set of dimensionless variables,[23]

$$\begin{array}{lll} P^* = P/P_0, & r^* = \sqrt{|\alpha_0|/G_{110}}r, & t^* = |\alpha_0|Lt, \\ \alpha_1^* = \alpha_1/|\alpha_0|, & \alpha_{11}^* = \alpha_{11}P_0^2/|\alpha_0|, & \alpha_{12}^* = \alpha_{12}P_0^2/|\alpha_0|, \\ \alpha_{111}^* = \alpha_{111}P_0^4/|\alpha_0|, & \alpha_{112}^* = \alpha_{112}P_0^4/|\alpha_0|, & \alpha_{123}^* = \alpha_{123}P_0^4/|\alpha_0|, \\ Q_{11}^* = Q_{11}P_0^2, & Q_{12}^* = Q_{12}P_0^2, & Q_{44}^* = Q_{44}P_0^2, \\ \sigma_{kl}^* = \sigma_{kl}/\left(|\alpha_0|P_0^2\right), & s_{11}^* = s_{11}\left(|\alpha_0|P_0^2\right), & s_{12}^* = s_{12}\left(|\alpha_0|P_0^2\right), \\ s_{44}^* = s_{44}\left(|\alpha_0|P_0^2\right), & G_{11}^* = G_{11}/G_{110}, & G_{12}^* = G_{12}/G_{110}, \\ G_{44}^* = G_{44}/G_{110}, & G_{44}'^* = G'_{44}/G_{110}, & E^* = E/(|\alpha_0|P_0), \end{array} \tag{11}$$

where the superscript asterisk * indicates the dimensionless of the corresponding variables. $P_0 = 0.757\ \text{cm}^{-2}$ is the magnitude of the spontaneous polarization at room temperature. The reference value of gradient energy coefficients is $G_{110} = 1.73 \times 10^{-10}\ \text{m}^4\ \text{N/C}^2$ and $\alpha_0 = |\alpha_1|_{T=25\ ^\circ\text{C}}$. The values of the dimensionless (normalized) material coefficients used in the simulations are chosen as ref. 27. In the present study, the out-of-plane component in the z direction is neglected, because it was found that the in-plane components are independent of z direction, and the out-of-plane component is close to zero. Then, the two-dimensional (2D) simulations of polarization and polarization switching under the plane-strain condition are conducted. A model size of 32×32 discrete grids with a cell size of $\Delta x^* = \Delta y^* = 1$ and periodic boundary conditions is adopted along the x and y directions. The mechanical and electrical

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boundary conditions of the free standing PTO are $\sigma_{ij}n_j = 0$ and $D_i n_i = 0$, respectively.

Results and discussion

Firstly, Fig. 1(a) shows the domain structure of PTO without applied stress which is obtained by solved the TDGL equation. Different colors denote different magnitudes of the polarization, and the directions of the arrows denote the directions of the polarization. Due to the energy minimization, it is clear that the PTO forms a 90° domain structure with the head-to-tail arrangement. A compressive and tensile stress fields σ^* with a dimensionless level of −20–20 (corresponded about −2 GPa to 2 GPa) was applied, acting on the plane parallel to the polarization direction in ferroelectric phase [100] and [010], denoted as σ^*_{xx} and σ^*_{yy} respectively. Note that it is difficult to apply large uniaxial stresses and to avoid the cracks in the materials experimentally,[8,28] the applied stress field do not continue to increase. In fact, the 90° domain structure can switch into single domain structure when the external stress is sufficient large. The adiabatic temperature change ΔT_σ at various magnitude of external stress fields along x and y direction have been plotted in Fig. 1(b). It is revealed that ΔT_σ almost linearly changes with the increases of the applied stress field. The tendency is similar with the results of BTO single crystals calculated by using a thermodynamic approach.[26] In particular, there exist a negative temperature change at the tensile stress field and a positive temperature change at the compressive stress field in both x and y direction. It is demonstrated that both positive and negative elastocaloric effects can be arisen in the $BaTiO_3$ ultra-thin films depending on the direction and magnitude of the applied stress.[2,14] In this PTO system, the overall entropy increase under the tensile stress and decrease under the compressive stress, resulting in a negative and positive caloric effect, respectively. Furthermore, the negative temperature change increases as the tensile stress field increases, and the positive temperature change increases as the compressive stress field increases. In addition, the largest negative ΔT_σ found here is about −3.8 K at the dimensionless tensile stress field $\sigma^*_{xx} = 20$. The result is different from the positive temperature change of 6 K in PTO studied by first principle under the same stress condition at room temperature.[8] The possible reason may be that

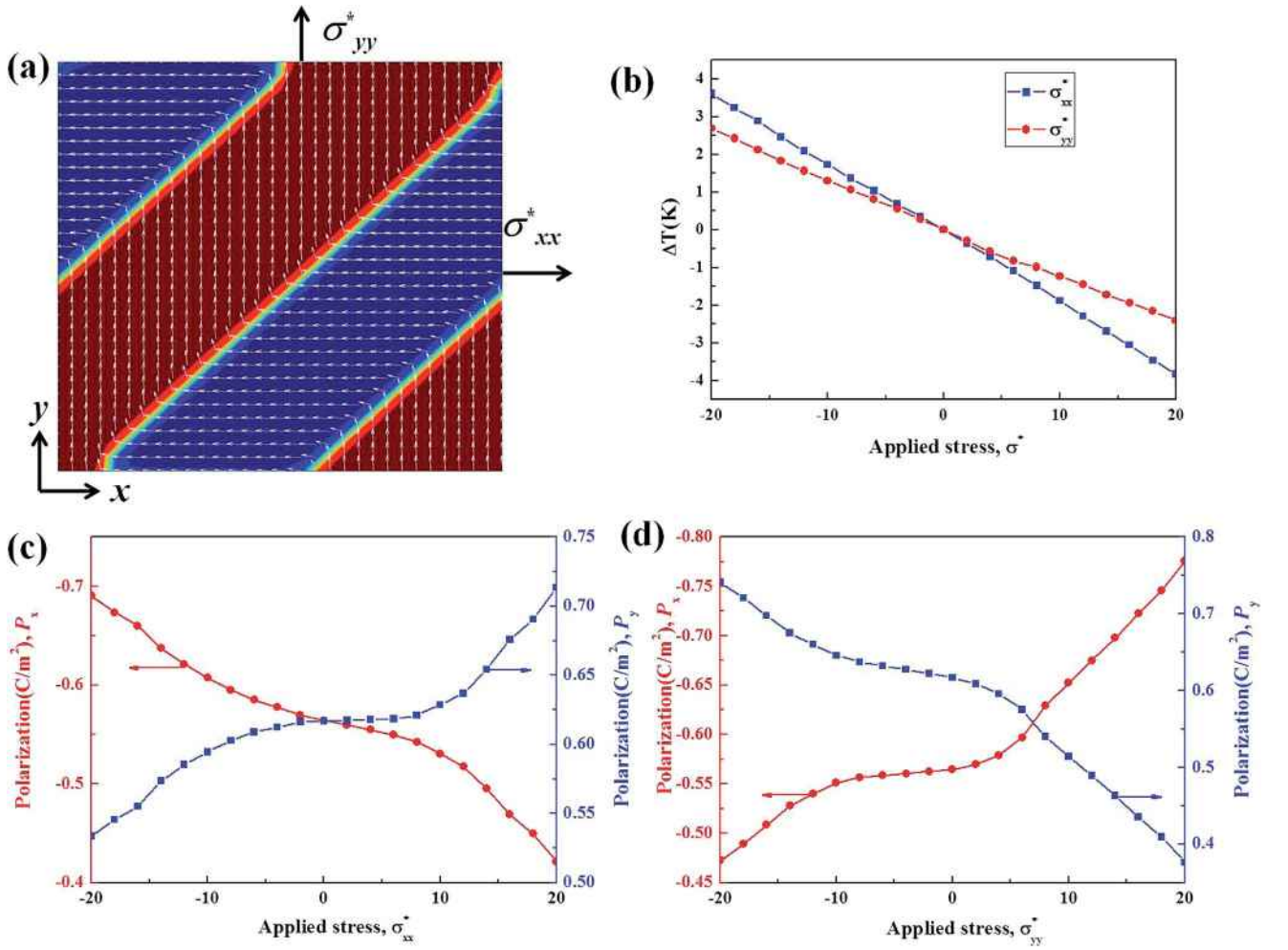


Fig. 1 (a) The 90° domain structure of PTO without applied stress; (b) the dependence of the adiabatic temperature change ΔT_σ in PTO on the applied stress; the average polarization components P_x and P_y under the applied stress (c) σ^*_{xx} and (d) σ^*_{yy}.

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the single domain structure provides a different initial state of PTO in their studies and then the district caloric effect are obtained. To the best of our knowledge, there are no report about the experimental studies of elastocaloric effect in PTO. However, the elastocaloric effect of bulk lead zirconate titanate (PZT) ceramics in the temperature of 1.3 K under the application of 0.4 GPa pressure at room temperature[15] which compares well with our computed value of 0.7 K under compressive stress with the same magnitude. Note that a positive temperature change was produced under the compressive stress in these experiments due to the PZT samples were poled which fit well with our calculation results.

According to eqn (10), ΔT_σ can be evaluated in terms of polarization change. In 90° domain structure, the changes of polarization components P_x and P_y could provide a deep insight into the relation of polarization with the applied stress field. Fig. 1(c) and (d) show the changes in the average polarization components, P_x and P_y, with the applied compressive and tensile stress along x and y direction, respectively. The results indicate that the polarization components change nonlinearly with the applied stress fields, unlike that of ΔT_σ. Moreover, the polarization components change dramatically when the applied stress fields increase to some extent, particularly $\sigma^*_{xx} > 8$, $\sigma^*_{xx} < -4$, $\sigma^*_{yy} > 4$ and $\sigma^*_{yy} < -10$. Take $\sigma^*_{xx} < -4$ and $\sigma^*_{yy} < -10$ for example, the domain structures of $\sigma^*_{xx} = -4$, $\sigma^*_{xx} = -20$, $\sigma^*_{yy} = -10$ and $\sigma^*_{yy} = -20$ are shown in Fig. 2(a)–(d), respectively. It can be seen that 90° polarization switching are just getting started when $\sigma^*_{xx} = -4$ or $\sigma^*_{yy} = -10$, and then the switching accomplished by domain wall motion occur obviously under $\sigma^*_{xx} = -20$ or $\sigma^*_{yy} = -20$, which is in consistent with the polarization switching behaviors of PTO with 90° domain structures under an external stress simulated by phase field method.[23] The domains with original orientations parallel to the x-axis shrink when $\sigma^*_{xx} > 8$ or $\sigma^*_{yy} < -10$, corresponding to the decrease of P_x and the increase of P_y, whereas the domains with original orientations parallel to the x-axis grow when $\sigma^*_{yy} > 4$ or $\sigma^*_{xx} < -4$, corresponding to the increase of P_x and the decrease of P_y. However, ΔT_σ has not show a tendency of suddenly change due to the change of polarization $P^2 = P_x^2 + P_y^2$ has been compensated since the polarization components have the opposite change behaviors.

The polarization switching behaviors have great effects on the polarization change, finally affect the adiabatic temperature change. Therefore, the adiabatic temperature change could be controlled by the domain structures and the polarization switching. Thus, ΔT_σ under the applied stress fields in different directions has been explored. The three-dimensional diagram of ΔT_σ under the applied stress in both x and y directions has been exhibited in Fig. 3(a). The maximum value of ΔT_σ reaches to −7.2 K under the condition of $\sigma^*_{xx} = 20$ and $\sigma^*_{yy} = 20$, which is much larger than that of at $\sigma^*_{xx} = 20$ (−3.8 K) or at $\sigma^*_{yy} = 20$ (−2.4 K). The value is close to the giant room-temperature elastocaloric effect of 5.5 K at 300 K in ultrathin $BaTiO_3$ films. And the domain structure under the condition of $\sigma^*_{xx} = 20$ and $\sigma^*_{yy} = 20$ is showed in Fig. 3(b). It can be seen that the domain structure is quite different from that of $\sigma^*_{xx} = 20$ (Fig. 3(c)) or $\sigma^*_{yy} = 20$ (Fig. 3(d)). The domains with original orientations parallel to the x-axis shrink in the condition of $\sigma^*_{xx} = 20$, whereas the domains with original orientations parallel to the

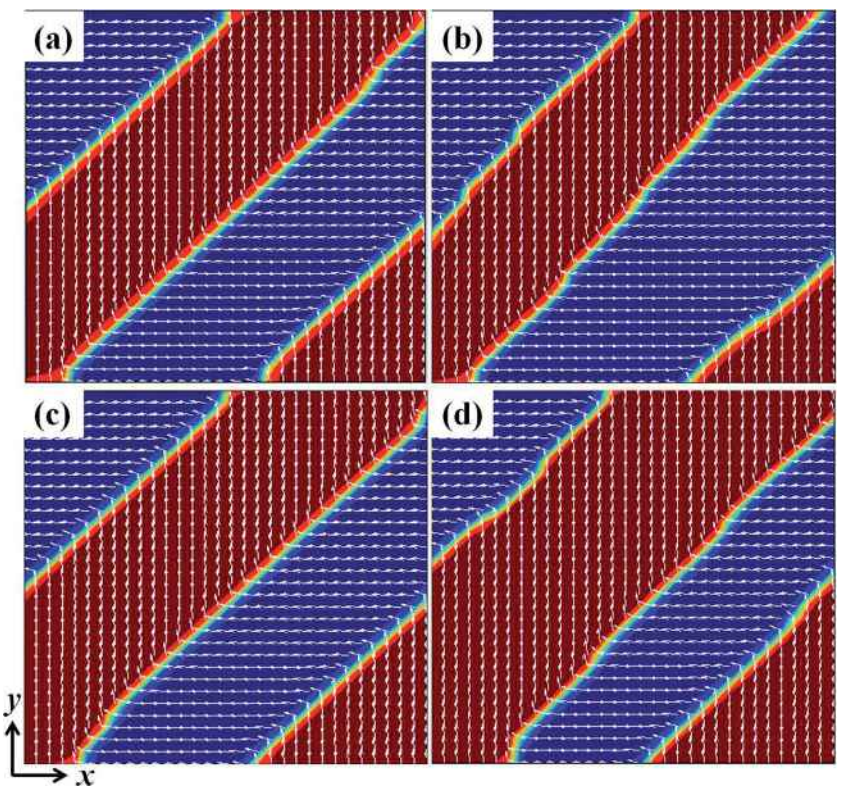


Fig. 2 The domain structures under (a) $\sigma^*_{xx} = -4$, (b) $\sigma^*_{xx} = -20$, (c) $\sigma^*_{yy} = -10$ and (d) $\sigma^*_{yy} = -20$.

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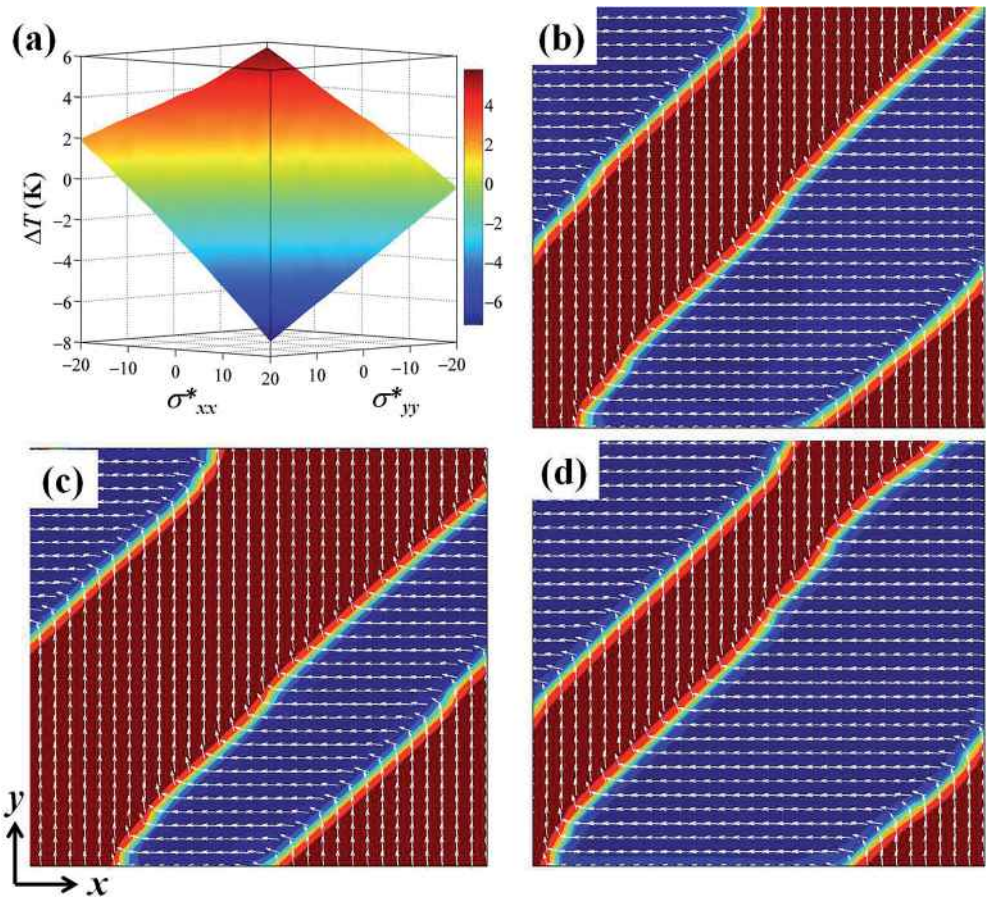


Fig. 3 (a) Three-dimensional plots of ΔT_σ under the stress in both x and y directions. The domain structures under (b) $\sigma^*_{xx} = 20$ and $\sigma^*_{yy} = 20$, (c) $\sigma^*_{xx} = 20$, (d) $\sigma^*_{yy} = 20$.

y-axis shrink in the condition of $\sigma^*_{yy} = 20$. However, the domain shrink process has been prevented when the both applied stress directions of $\sigma^*_{xx} = 20$ and $\sigma^*_{yy} = 20$ loaded, which make ΔT_σ enhanced largely.

Conclusion

In summary, the elastocaloric effect of 2D PTO ferroelectric materials with 90° domain structure at room temperature has been studied using the phase field model combined with thermodynamics analysis. The results indicate that both positive and negative elastocaloric effects can be obtained depending on the directions of the applied stress. ΔT_σ almost linearly increases with increase of the applied uniaxial stress fields, and the largest value of negative ΔT_σ is about −3.8 K which obtained at the tensile stress field $\sigma^*_{xx} = 20$. Moreover, domain switching can be controlled by the applied stress field. Finally, the maximum ΔT_σ of −7.2 K under the condition of $\sigma^*_{xx} = 20$ and $\sigma^*_{yy} = 20$ has been obtained.

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ATTACHMENT 43

Demonstration of liquid crystal for barocaloric cooling application

Zhongjian Xie[1], Yao Zhu

Abstract

Current vapor-compression technology is based on the gas-liquid transition of hazardous gas. The alternative cooling technology focuses on the solid caloric material. A new liquid barocaloric material, i.e. the liquid crystal, is proved to be potential for cooling application primarily (based on other literatures). Its phase transition needs a small stress (tens of MPa) and can be operated near room temperature. It has a large entropy change of ~200 $J.K^{-1}.kg^{-1}$ (0.2 $J.K^{-1}.cm^{-1}$). There is no breakage problem due to its liquid form. It will provide the advantage for some unique cooling application cases comparing with solid caloric material. Moreover, this material is sustainable and non-toxic, which can meet the original intention of the alternative cooling technology.

Introduction

Current vapor-compression technology is based on the gas-liquid transition of hazardous gas. The alternative cooling technology focuses on the solid caloric material. Then, what about the liquid caloric material?

Currently, all the investigations on mechanocaloric (mC) cooling devices are based on the elastocalorc (eC) effect of shape memory alloys (SMAs).[1–3] The devices based on the barocaloric (BC) effect have not yet been reported. Uniaxial stress is easier applied whereas hydrostatic pressure needs to be applied in all axes. For eC effect, the positions for the application of uniaxial stress and for the heat exchange can be separate, which facilitates the design of the device. For solid BC material, the application position of hydrostatic pressure conflicts with the position of the heat exchange. This may be difficult for designing a cooling device. The liquid BC material is thus proposed with three advantages compared to the solid one. Firstly, the problem of position conflict of heat transfer and pressure in solid BC material can be solved. The pressure can be just applied in one axis, and then all the liquid material will get a same hydrostatic pressure. The area for heat exchange can be in transverse axis. Secondly, there is no breakage problem for the liquid BC material, whereas it is a drawback for the solid mC material. Thirdly, the gas coolant in vapor compressor may be directly replaced by the liquid BC material with the least technology transformation.

In the investigation for cooling device based on eC effect of hard SMAs, the problem of large stress is prominent. Thus, the soft mC materials with a low stimulus stress/pressure need to be found. Moreover, the compressor in current refrigerator normally works at around 1 MPa,[4] which has already made a noise. Thus, larger stress/pressure for potential coolant (mC material) is not expected.

In this letter, in order to meet the needs of liquid BC material and small stimulus pressure for cooling device, the BC effect of liquid crystal is proposed and is proved based on other literatures.

Direct measurement of barocaloric temperature change in liquid crystal

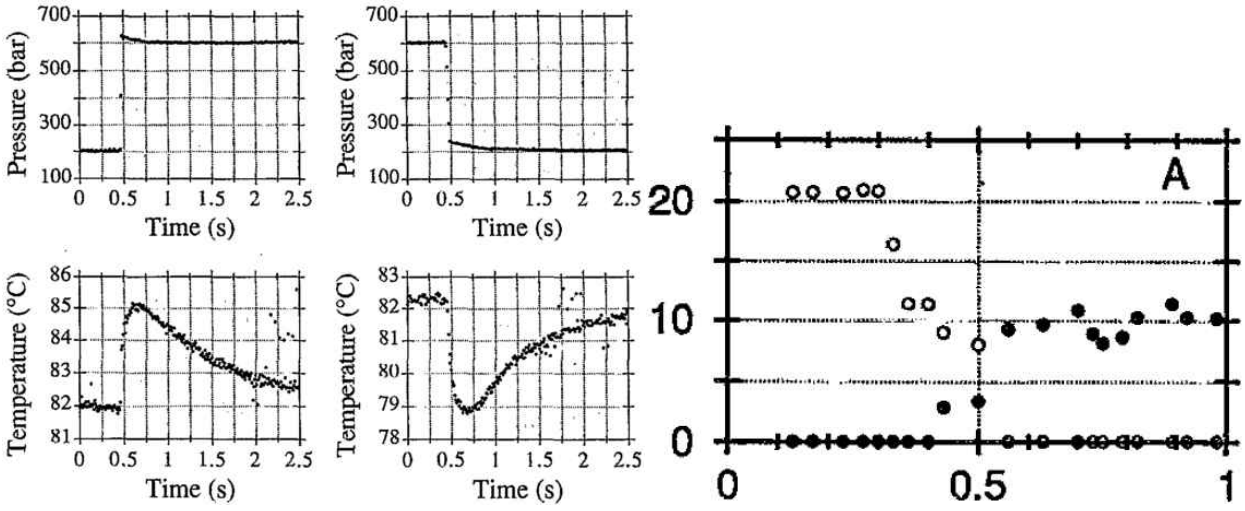
For cooling application, how can we learn from nature? There is no direct cooling example in nature. However, caloric effect may occur accompanying with structure transition. For living organism, the structure transition occurs in response to environmental change. Deep sea organisms, which are known as piezo- or

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baro-philic, have the mechanism to adapt their lipid membranes to maintain their fundamental fluid bilayer structure and mechanical properties in high pressure.[5,6] The main transition in lipid membrane is the gel/liquid crystalline transition. In the gel phase, the lipid molecule extends in the direction of membrane thickness and shrinks in the direction of membrane parallel, whereas the situation is reversed in the liquid crystalline phase.[7] Thus, the application of pressure can induce the gel/liquid crystalline transition.

A lipid is a solid crystal with a well-ordered lamellar structures.[7] When adding water to the solid crystal, the liquid crystal is produced. One typical liquid crystal is dihexadecylphosphatidylethanolamine (DHPE) in excess water. Its BC effect was measured directly by Mencke *et al*..[8] This measurement is for testing a pressure apparatus. The temperature variation and diffracted intensity by using time-resolved x-ray diffraction (TRXRD) are shown in Fig. 1. When the pressure is applied and removed, the temperature increases and decreases, respectively. It exhibits a conventional BC effect. It is attributed to the transition between the lamellar liquid crystal, L_{α}, and the lamellar gel, $L_{\beta'}$, phase.

The pressure variation is 400 bar (40 MPa) and the temperature variation is ~3 K. The pressure is much lower than the current BC material (0.1-0.5 GPa) and the temperature variation is almost the same level (1-4.5 K).[9,10] The BC strength of this liquid crystal can be up to 75 K/GPa, which is much larger than current BC materials (4-15 K/GPa).[10]



(a)(b)

Fig. 1 (a) Typical pressure variation (200-600 bar) and the accompanying temperature variations for lipid, DHPE, in excess water. The temperature variation is from the enthalpy of the lamellar liquid crystal (L_{α})/gel ($L_{\beta'}$) transition. (b) The variation of diffracted intensity shows the L_{α} (hollow)/$L_{\beta'}$ (solid) phase transition acquired simultaneously with the pressure jump.[8]

The dynamic response of DHPE to pressure change was also tested by Mencke *et al*.[8] The material is subjected to a sinusoidal pressure oscillation at 1 Hz. The dynamic TRXRD data on the phase transition is shown in Fig. 2. The diffracted intensity of two phases shows the fast response to pressure change. It provides insights into the kinetics and mechanism of the transition.[11] The liquid crystal can be used for a high-frequency cooling application. Moreover, it shows the reversibility of phase transition in a few pressure cycles.

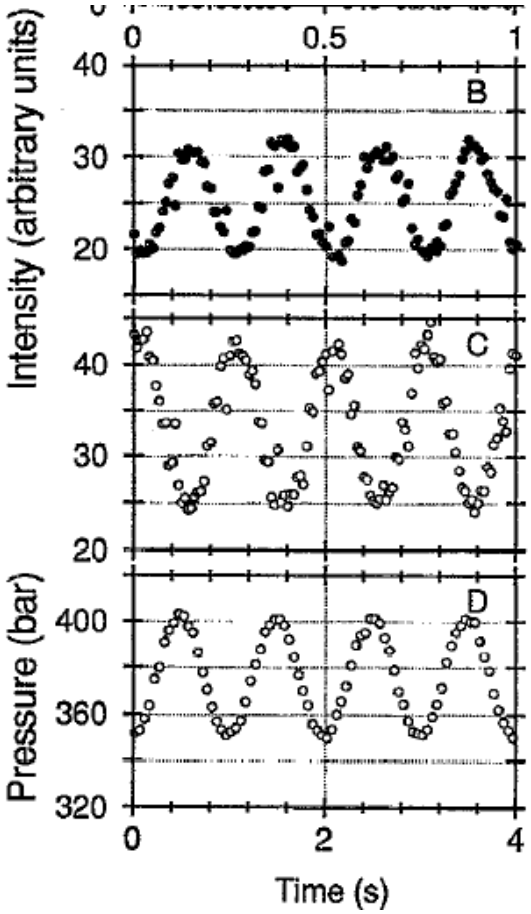


Fig. 2 TRXRD data acquired on a pressure-induced mesophase transition. The sinusoidal pressure oscillation is 1 Hz and peak-to-peak amplitude is 50 bar. It shows the reIative amounts of lamellar liquid crystal (hollow)/gel (solid) transition in response to the oscillating pressure perturbation.[8]

For DHPE, one of the problems is the high transition temperature (82 ^{o}C), which limits its near room temperature cooling application. The transition temperature locating near room temperature can be realized in other lipid materials.

Enthalpy, entropy change and transition temperature in liquid crystal

The bilayer phase-transitions of a series of 1,2-diacylphosphatidylcholines containing linear saturated acyl chain of carbons number (12, 13, 14, 15, 16, 17 and 18) was investigated by Ichimori *et al*.[12] When the carbon number of acyl chain increases from 12 to 18, the transition temperature increases from -2.1 ^{o}C to 55. 6 ^{o}C and the entropy change increases from 28 to 137 $J.K^{-1}.mol^{-1}$ (Table 1). Considering the molecular weight of ~700 g/mol, the entropy change increases from 40 $J.K^{-1}.kg^{-1}$ to 200 $J.K^{-1}.kg^{-1}$. Thus, the acyl chain length can be used to adjust both the transition temperature and entropy change.

Table 1 Thermodynamic properties of phase transition for the bilayer membranes of diacylphosphatidylcholines[12]

Lipid	Transition temperature		dT/dp	ΔH		ΔS	ΔV
	(K)	(°C)	(K MPa^{-1})	(kJ mol^{-1})	(kcal mol^{-1})	(J K^{-1} mol^{-1})	(cm^3 mol^{-1})
12:0-PC	271.1	−2.1	0.200	7.5[a]	1.8[a]	28	5.5
13:0-PC	286.8	13.6	0.210	16.0	3.8	56	11.7
14:0-PC	297.1	23.9	0.212	24.7	5.9	83	17.6
15:0-PC	307.0	33.8	0.215	30.3	7.2	99	21.2
16:0-PC	315.2	42.0	0.220	36.4	8.7	115	25.4
17:0-PC	322.1	48.9	0.224	41.4	9.9	129	28.8
18:0-PC	328.8	55.6	0.230	45.2	10.8	137	31.6

The transition temperature can also be shifted by pressure. In Fig. 3, as the pressure increases, the transition temperature increases. The pressure dependence of transition temperature, dT/dP, T is transition temperature and P is pressure, is ~ 0.2 K/MPa for different acyl chain-lengths (Table 1). This can be used to adjust the transition temperature at the hot end and cold end for a cooling system. At the cold end, a low transition temperature is needed and a low pressure can be applied. At the hot end, a high transition temperature is needed and a high pressure can be applied.

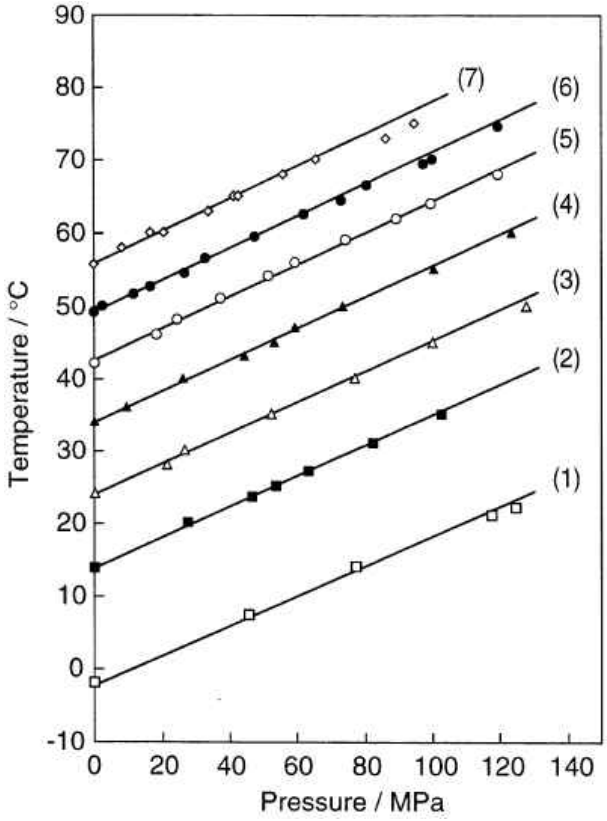


Fig. 3 Temperature—pressure phase boundaries between the ripple gel and liquid crystal phases for bilayer membranes of lipids with different acyl chain-lengths. (1) 12:0-PC, (2) 13:0-PC, (3) 14:0-PC, (4) 15:0-PC, (5) 16:0-PC, (6) 17:0-PC and (7) 18:0-PC.[12]

In Table 2, the liquid crystal is compared with other mechanocaloric materials, including Hydrochlorofluorocarbons (HCFC), shape memory alloys (SMAs), natural rubber (NR) and PVDF-based polymers. The stress of liquid crystal is the same level with PVDF-based polymers,[13] larger than HCFC[14] and natural rubber[15] while much smaller than Ni-Ti[16,17] and Cu-Zn-Al[18] alloys. The volumetric entropy change of liquid crystal is smaller than Ni-Ti but larger than other materials. The mass entropy change and enthalpy of liquid crystal are smaller than HCFC but larger than other solid materials.

Table 2 Comparison of liquid crystal with other mechanocaloric materials (all the values are estimated)

	HCFC[14]	**Ni-Ti**[16,17]	**Cu-Zn-Al**[18]	**Natural rubber**[15]	**PVDF-based polymers**[13]	**Liquid crystal**[12]
Critical stress (MPa)	1	500	>100	1	tens	tens
Volumetric entropy change ($J.K^{-1}.cm^{-3}$)	0.03	0.26	0.16	0.07	0.14	0.2
Mass entropy change ($J.K^{-1}.kg^{-1}$)	500	40	21	80	80	200
Enthalpy ($kJ.kg^{-1}$)	200	12	6	24	24	64

Conclusion

In conclusion, the barocaloric effect of liquid crystal is proposed for cooling application. It needs a low pressure (tens of MPa). Its phase transition contributes to a large entropy change of ~200 $J.K^{-1}.kg^{-1}$, which is larger than solid mechanocaloric (mC) materials, including shape memory alloys (SMAs), natural rubber (NR) and PVDF-based polymers. Moreover, its phase transition can be performed near room temperature and can be adjusted by the acyl chain length and pressure.

Comparing with other solid mC materials, the absolute advantage of liquid crystal is its liquid form and it can be used for some unique cooling application case. Moreover, the liquid crystal has no breakage problem like solid mC materials. Most importantly, the material is sustainable and non-toxic.

Further detailed research of liquid crystal towards cooling application is needed. Moreover, some liquid crystals (ferroelectric liquid crystals) has been observed to possess the electrocaloric effect. The multicoupling method may be used to improve the caloric performance (multicaloric effect) of liquid crystal.

A bold idea is the biological refrigeration. The deep-sea bacteria with lipid membranes may be employed to perform the caloric effect and refrigeration. The advantage of biological refrigeration is its self-healing mechanism.

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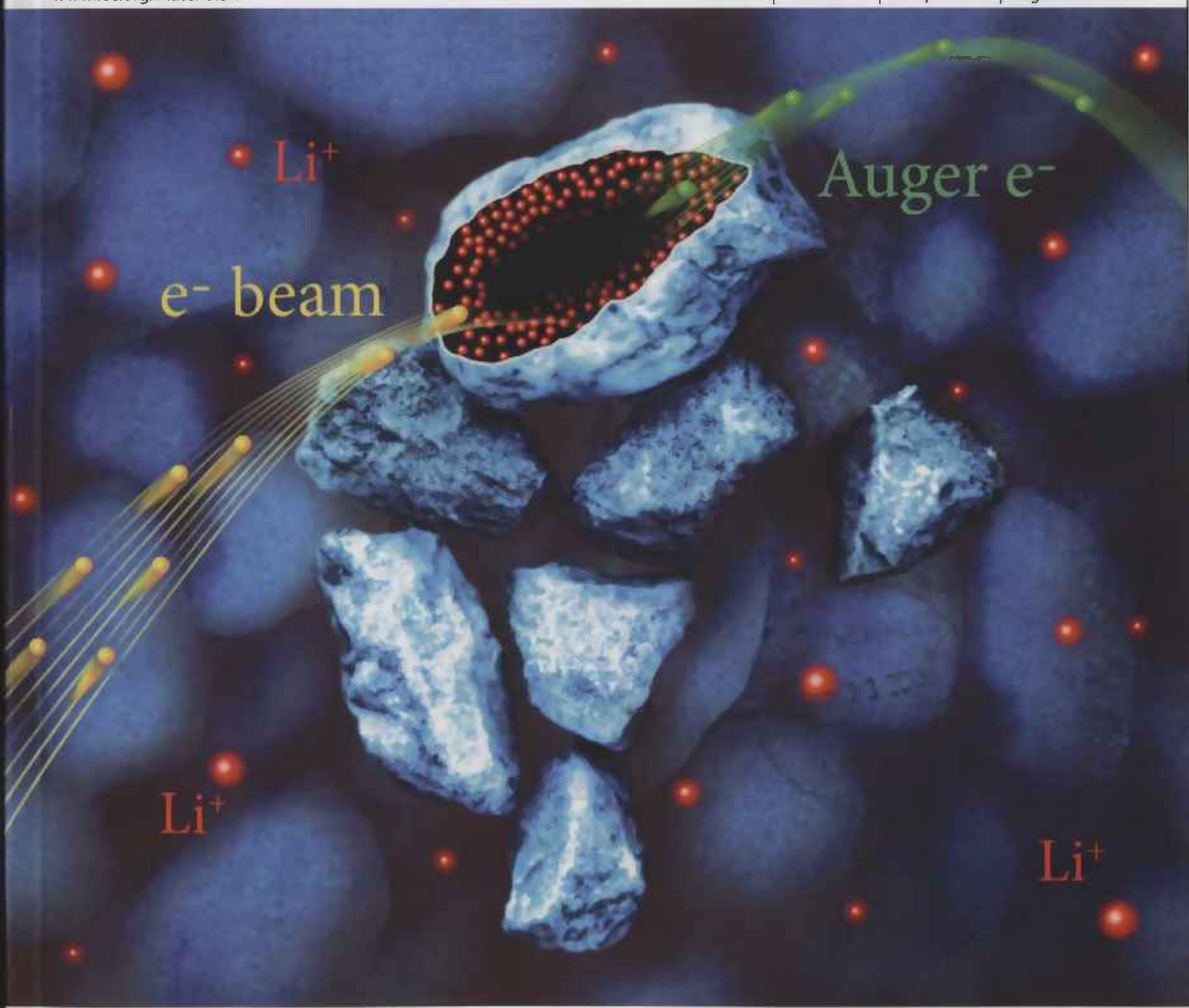
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Etienne Radvanyi *et al.*

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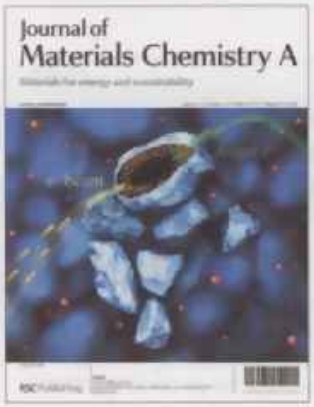
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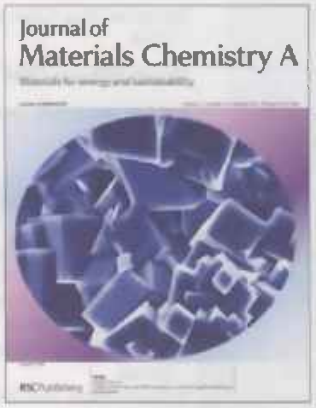
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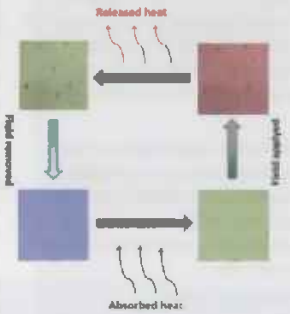
4925

Advanced materials for solid-state refrigeration

Lluís Mañosa,* Antoni Planes and Mehmet Acet

Recent progress on caloric effects are reviewed.

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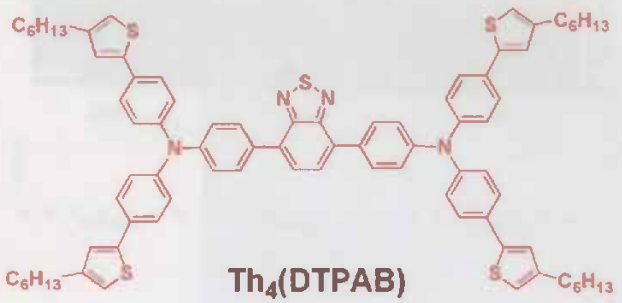
COMMUNICATIONS

4937

A triphenylamine-based four-armed molecule for solution-processed organic solar cells with high photo-voltage

Qiong Hou, Yiquan Chen, Hongyu Zhen,* Zaifei Ma, Wenbiao Hong, Guang Shi and Fengling Zhang

Solution-processed organic solar cells fabricated from a new four-armed molecule Th_4(DTPAB) and $PC_{71}BM$ demonstrate a power conversion efficiency of 3.18%.



Th_4(DTPAB)

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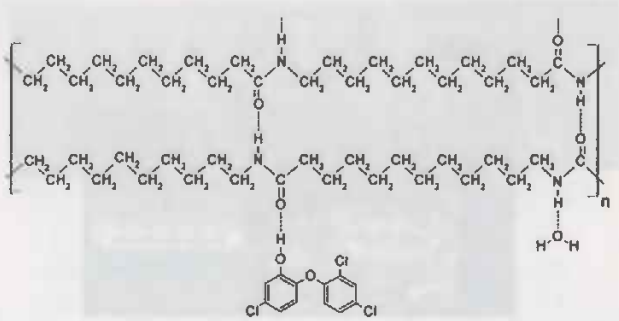
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Remarkable sorption properties of polyamide 12 microspheres for a broad-spectrum antibacterial (triclosan) in water

Jie Han,* Zhi Cao and Wei Gao

Low surface-area polyamide 12 microspheres exhibited remarkable sorption properties for triclosan, a broad-spectrum antibacterial, *via* a unique hybrid sorption mechanism.

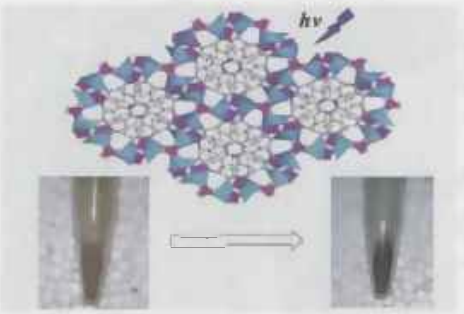


4945

A hybrid metal phosphate–phosphite material grafted with electron deficient organic components showing interesting fluorescent and photosensitive properties

Jie Zhang, Zhenguo Yao, Shijun Liao, Jingcao Dai and Zhiyong Fu*

The covalent coupling of tris (4-pyridyl) triazine and zinc phosphate–phosphite framework builds a novel fluorescent photochromic dyad system.

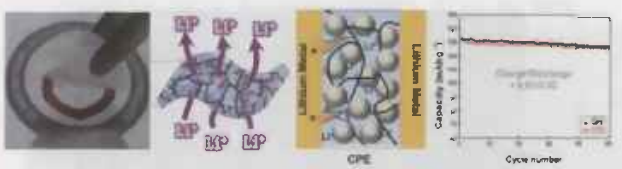


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Mechanically compliant and lithium dendrite growth-suppressing composite polymer electrolytes for flexible lithium-ion batteries

Se-Hee Kim, Keun-Ho Choi, Sung-Ju Cho, Eun-Hye Kil and Sang-Young Lee*

A mechanically compliant and lithium dendrite growth-suppressing composite polymer electrolyte for flexible lithium-ion batteries is demonstrated. Structural uniqueness featuring close-packed Al_2O_3 nanoparticles in the liquid electrolyte-swollen, UV-cured triacrylate macromer matrix provides noticeable improvement in solid electrolyte properties.

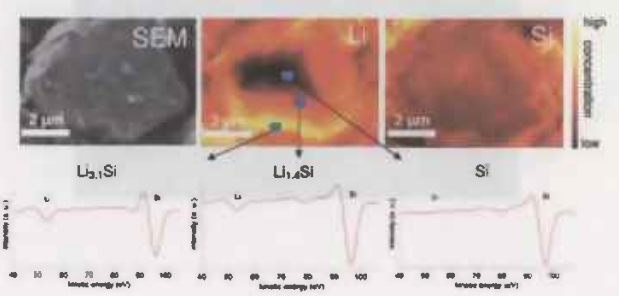


4956

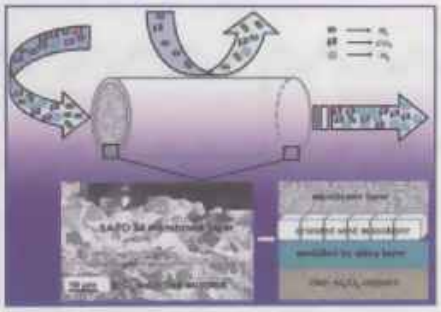
Study of lithiation mechanisms in silicon electrodes by Auger Electron Spectroscopy

Etienne Radvanyi,* Eric De Vito, Willy Porcher, Julien Danet, Philippe Desbois, Jean-François Colin and Séverine Jouanneau Si Larbi

By using a technique of surface characterization, Auger Electron Spectroscopy, the mechanisms of the first silicon lithiation are investigated.



4966



Highly oriented improved SAPO 34 membrane on low cost support for hydrogen gas separation

Jugal Kishore Das, Nandini Das* and Sibdas Bandyopadhyay

A highly oriented improved SAPO 34 membrane was prepared on a silica modified low cost clay-Al_2O_3 support for hydrogen gas separation.

4974

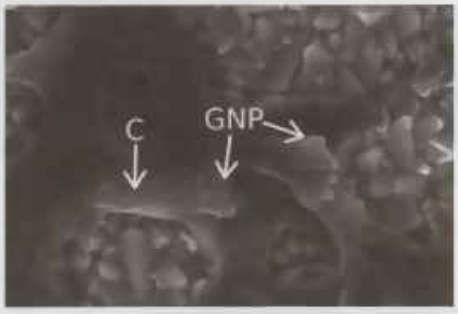


Nanoporous Ag–CeO_2 ribbons prepared by chemical dealloying and their electrocatalytic properties

Guijing Li, Feifei Lu, Xin Wei, Xiaoping Song, Zhanbo Sun,* Zhimao Yang and Shengchun Yang

Nanoporous Ag–CeO_2 ribbons with good thermal stability and enhanced electrocatalytic activity are successfully prepared by a dealloying method.

4982

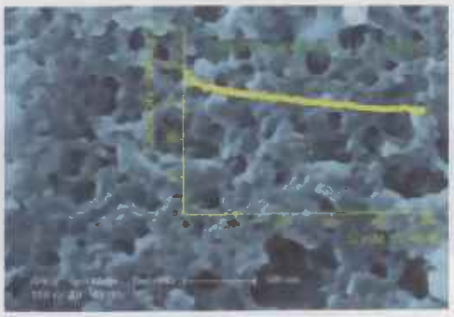


Carbon–graphene nanocomposite cathodes for improved Co(II/III) mediated dye-sensitized solar cells

Morgan Stefik,* Jun-Ho Yum, Yelin Hu and Michael Grätzel

Nanocomposite carbon–graphene cathodes offer both stable and efficient operation of cobalt based dye-sensitized solar cells.

4988



Hierarchical porous Li_2FeSiO_4/C composite with 2 Li storage capacity and long cycle stability for advanced Li-ion batteries

Zhongxue Chen, Shen Qiu, Yuliang Cao,* Jiangfeng Qian, Xinping Ai, Kai Xie, Xiaobin Hong and Hanxi Yang*

A hierarchical porous Li_2FeSiO_4/C composite demonstrates a high redox capacity of 254.3 mA h g^{-1} with stable cycling and superior rate capability.

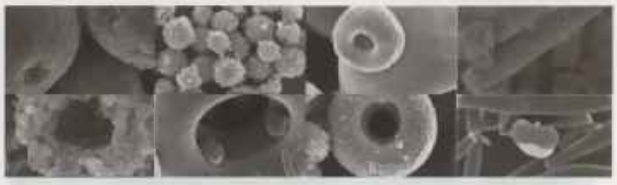
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4993

Construction of hierarchical titanium dioxide nanomaterials by tuning the structure of polyvinylpyrrolidone–titanium butoxide complexes from 2- to 3-dimensional

Baoshun Liu,* Xiujian Zhao, Kazuya Nakata* and Akira Fujishima

Various morphology of TiO_2 hierarchical materials with high photocatalytic activity were prepared by electrospray and post-hydrothermal treatment.

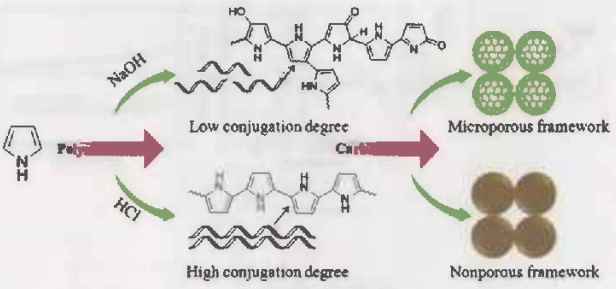


5001

A facile approach for tailoring carbon frameworks from microporous to nonporous for nanocarbons

Fei Xu, Yongjie Lai, Ruowen Fu and Dingcai Wu*

Carbon frameworks of nanocarbons can be tailored from microporous to nonporous by variation of the conjugation degree of polypyrrole chains.

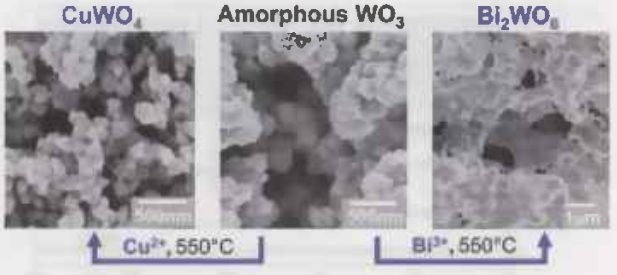


5006

Synthesis and characterization of high surface area $CuWO_4$ and Bi_2WO_6 electrodes for use as photoanodes for solar water oxidation

James C. Hill and Kyoung-Shin Choi*

Two n-type W-containing ternary oxides, $CuWO_4$ and Bi_2WO_6, were prepared as high surface area electrodes and investigated for use as photoanodes in a water-splitting photoelectrochemical cell.

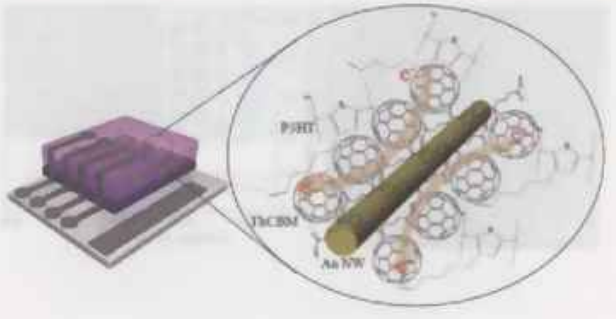


5015

Building a hybrid nanocomposite assembly of gold nanowires and thienyl-derivative fullerenes to enhance electron transfer in photovoltaics

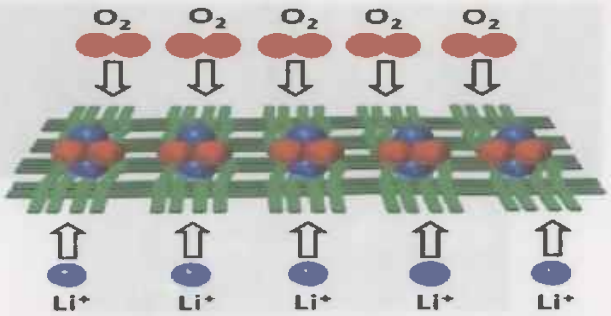
Yong Seok Kim, Byung-Kwan Yu, Jeong Won Kim, Yo-Han Suh, Dong-Yu Kim and Won Bae Kim*

We report the preparation and characterization of a novel nanocomposite assembly comprising metallic gold nanowires (Au NWs) and thienyl-C_{61}-butyric acid methyl ester (ThCBM) fabricated by adsorbing ThCBM groups, *via* coordinate bonds involving sulfur functionalities, onto the Au(111) surfaces of Au NWs.



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5021

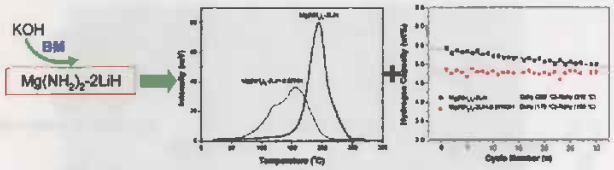


Hierarchical activated carbon microfiber (ACM) electrodes for rechargeable Li–O_2 batteries

Vinodkumar Etacheri, Daniel Sharon, Arnd Garsuch, Michal Afri, Aryeh A. Frimer and Doron Aurbach*

Hierarchical activated carbon microfiber (ACM) and ACM/α-MnO_2 nanoparticle hybrid electrodes were fabricated for rechargeable Li–O_2 batteries.

5031

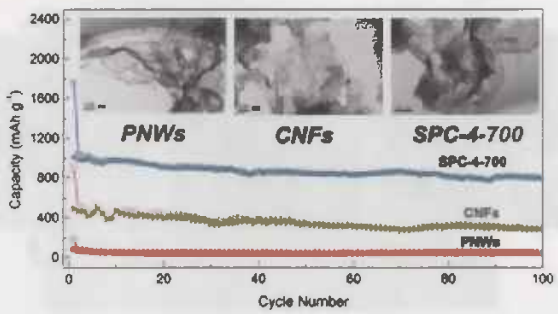


Understanding the role of K in the significantly improved hydrogen storage properties of a KOH-doped Li–Mg–N–H system

Chu Liang, Yongfeng Liu,* Mingxia Gao and Hongge Pan*

A significant decline in the operating temperatures for the de-/hydrogenation of the $Mg(NH_2)_2$–2LiH system was achieved by doping with KOH.

5037

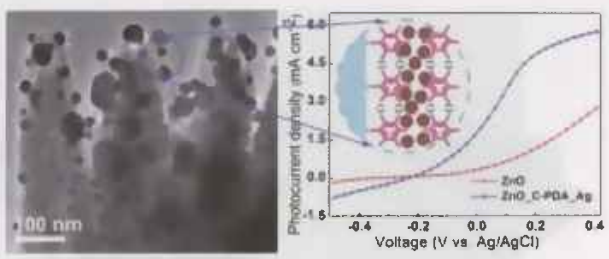


Seaweed-like porous carbon from the decomposition of polypyrrole nanowires for application in lithium ion batteries

Xiangyang Zhou, Jingjing Tang, Juan Yang,* Jing Xie and Bin Huang

High yield porous carbon nanomaterials, prepared *via* the chemical oxidative polymerization of pyrrole and subsequent decomposition of polypyrrole nanowires with KOH activation, exhibit high capacity for lithium ion battery applications.

5045



Polydopamine-assisted decoration of ZnO nanorods with Ag nanoparticles: an improved photoelectrochemical anode

Yuefan Wei, Junhua Kong, Liping Yang, Lin Ke, Hui Ru Tan, Hai Liu, Yizhong Huang, Xiao Wei Sun, Xuehong Lu* and Hejun Du*

Polydopamine, a unique biomimetic material, is firstly used to evenly and controllably anchor Ag nanoparticles onto ZnO nanorods to achieve excellent photoelectrochemical properties as a photoanode.

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5053

Cu superstructures fabricated using tree leaves and Cu–MnO_2 superstructures for high performance supercapacitors

Huan Pang,* Shaomei Wang, Guochang Li, Yahui Ma, Juan Li, Xuexue Li, Li Zhang, Jiangshan Zhang and Honghe Zheng*

Copper superstructures are synthesized in mild hydrothermal conditions with natural sapless leaves as the reducing agent, and coated with MnO_2 nanofilms for high performance supercapacitors.

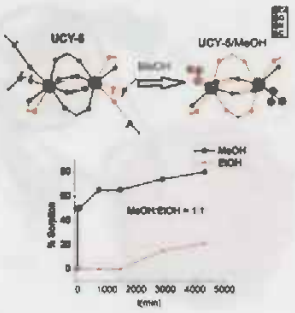


5061

Flexible lanthanide MOFs as highly selective and reusable liquid MeOH sorbents

Constantinos G. Efthymiou, Eleni J. Kyprianidou, Constantinos J. Milios, Manolis J. Manos* and Anastasios J. Tasiopoulos*

A series of flexible Ln^{3+} MOFs with three-dimensional framework structures are described, which display a remarkable capability to absorb liquid MeOH selectively and rapidly.



5070

Growth of carbon nanotubes over transition metal loaded on Co-SBA-15 and its application for high performance dye-sensitized solar cells

Jayaraman Balamurugan, Rangasamy Thangamuthu and Arumugam Pandurangan*

High quality MWCNT material based counter electrodes for dye-sensitized solar cells (DSSCs) were fabricated using a novel route and their power-conversion efficiency was studied.



5081

How a bio-based epoxy monomer enhanced the properties of diglycidyl ether of bisphenol A (DGEBA)/graphene composites

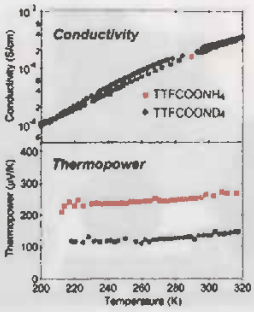
Lijun Cao, Xiaoqing Liu,* Haining Na, Yonggang Wu, Wenge Zheng and Jin Zhu*

A novel bio-based epoxy monomer was synthesized to promote the dispersion of graphene in an epoxy matrix so as to fabricate high performance composites.



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5089

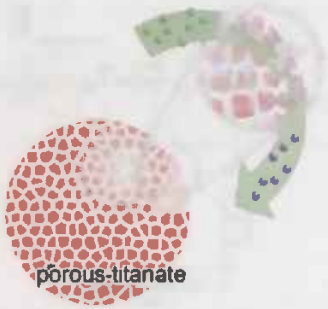


Room-temperature proton transport and its effect on thermopower in a solid ionic semiconductor, $TTFCOONH_4$

Yuka Kobayashi,* Takenori Fujii, Ichiro Terasaki, Hiori Kino, Yongcheng Jin, Takashi Hibino, Tetsuya Kobayashi, Eiji Nishibori, Hiroshi Sawa, Hideki Yoshikawa, Takeshi Terauchi and Satoshi Sumi

Ammonium proton in a solid ionic semiconductor, $TTFCOONH_4$, is shown to be mobile under anhydrous conditions at room temperature.

5097

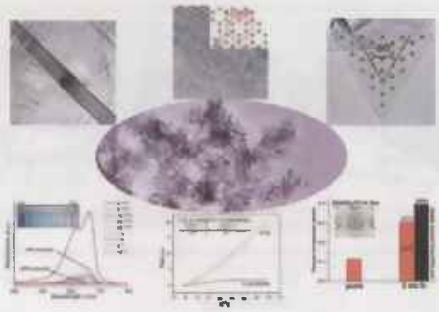


Mesoporous titanate-based cation exchanger for efficient removal of metal cations

Miaomiao Ye, Zhenda Lu, Yongxing Hu, Qiao Zhang and Yadong Yin*

A mesoporous titanate-based cation exchanger with large surface area and high adsorption capacity for metal cations has been synthesized.

5105

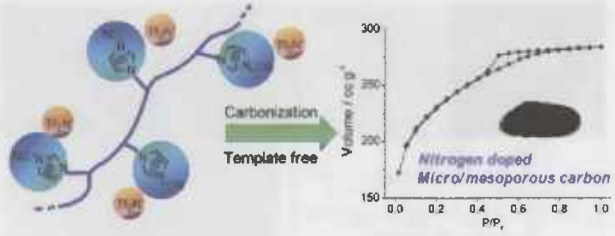


Ultrathin BN nanosheets with zigzag edge: one-step chemical synthesis, applications in wastewater treatment and preparation of highly thermal-conductive BN–polymer composites

Shunjie Zhang, Gang Lian,* Haibin Si, Jun Wang, Xiao Zhang, Qilong Wang and Deliang Cui*

Zigzag-edged ultrathin BN nanosheets with excellent adsorption properties are synthesized using a new variable-pressure one-step chemical synthesis route.

5113



A novel polymeric precursor for micro/mesoporous nitrogen-doped carbons

Qiang Zhao, Tim-Patrick Fellinger, Markus Antonietti and Jiayin Yuan*

A poly(ionic liquid) when carbonized without any template produced micro/mesoporous nitrogen-doped carbons.

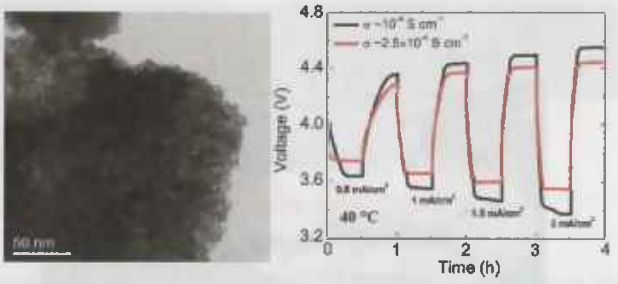
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5121

Dual-electrolyte lithium–air batteries: influence of catalyst, temperature, and solid-electrolyte conductivity on the efficiency and power density

Longjun Li and Arumugam Manthiram*

Highly efficient dual-electrolyte Li–air batteries enabled by nanocrystalline IrO_2, elevated operating temperature, and increased ionic conductivity of the solid electrolyte.

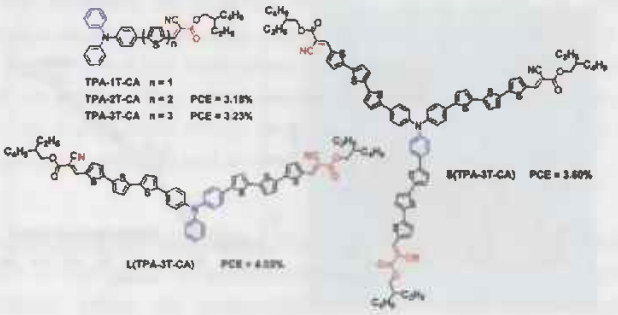


5128

One, two and three-branched triphenylamine–oligothiophene hybrids for solution-processed solar cells

Yuze Lin, Zhi-Guo Zhang, Yongfang Li, Daoben Zhu and Xiaowei Zhan*

One, two and three-branched molecules with triphenylamine–oligothiophene hybrids as donor groups and alkyl cyanoacetate as acceptor end groups were synthesized; the effects of oligothiophene bridge length and branch number on absorption, energy level, charge transport, morphology and photovoltaic properties of these molecules were studied.

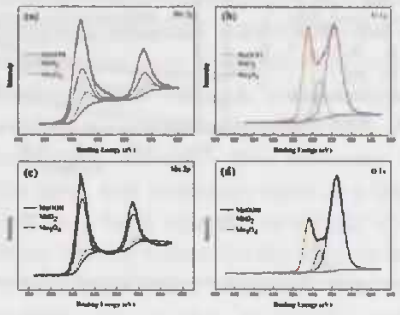


5136

Self-assembled amorphous manganese oxide/hydroxide spheres *via* multi-phase electrochemical interactions in reverse micelle electrolytes and their capacitive behavior

Liwen Hu, Wei Wang, Jiguo Tu, Jungang Hou, Hongmin Zhu and Shuqiang Jiao*

Amorphous matrices of three-dimensionally interconnected MnO_x/MnOOH nano-spheres were electrochemically assembled onto a carbon substrate by a pulse galvanostatic method (PGM) in a nonionic reverse micelle electrolyte.

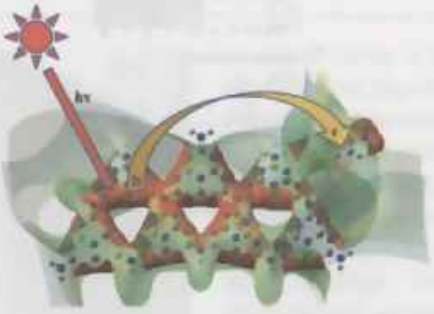


5142

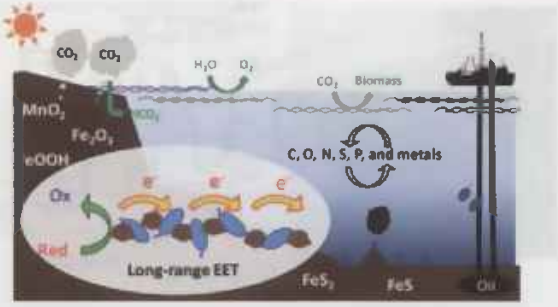
Molecule-induced gradient electronic potential distribution on a polymeric photocatalyst surface and improved photocatalytic performance

Yong Guo, Fei Kong, Cuicui Wang, Sheng Chu, Juncheng Yang, Ying Wang* and Zhigang Zou*

A polymeric photocatalyst has been synthesized based on the facile post-treatment of a graphitic carbon nitride polymer with chemical modification. Photodegradation of methyl orange under visible light irradiation shows that it has a higher photocatalytic performance than g-C_3N_4.



5148

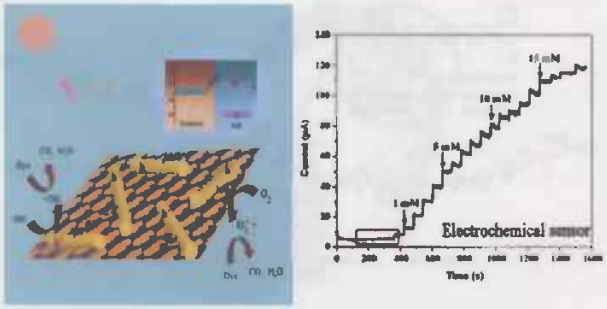


Mechanisms of long-distance extracellular electron transfer of metal-reducing bacteria mediated by nanocolloidal semiconductive iron oxides

Ryuhei Nakamura,* Fumiyoshi Kai, Akihiro Okamoto and Kazuhito Hashimoto

Semiconductive iron oxide minerals promote bacterial long distance extracellular electron transfer.

5158

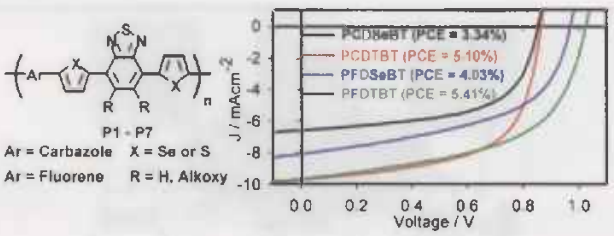


CdS nanorods/reduced graphene oxide nanocomposites for photocatalysis and electrochemical sensing

Xiaoqiang An, Xuelian Yu, Jimmy C. Yu* and Guangjin Zhang*

CdS nanorods/RGO composites with improved photocatalytic activity were fabricated through a simple one-pot reaction. The new material can also be used as an enzyme-free H_2O_2 sensor, with rapid and sensitive response.

5165

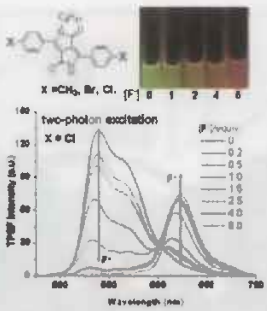


Selenophene *vs.* thiophene in benzothiadiazole-based low energy gap donor–acceptor polymers for photovoltaic applications

Abdulaziz A. B. Alghamdi, Darren C. Watters, Hunan Yi, Solyman Al-Faifi, Mohammed S. Almeataq, David Coles, James Kingsley, David G. Lidzey* and Ahmed Iraqi*

The effects of replacing thiophene with selenophene in efficient low energy gap polymers with benzothiadiazole repeat units on their optical and photovoltaic properties in plastic solar cells are investigated.

5172



***N*-Monoalkylated 1,4-diketo-3,6-diphenylpyrrolo [3,4-*c*]pyrroles as effective one- and two-photon fluorescence chemosensors for fluoride anions**

Chao Yang, Meng Zheng, Yiping Li, Baoliang Zhang, Jinfeng Li, Lingyu Bu, Wei Liu, Mingxiao Sun, Haichang Zhang, Yong Tao, Shanfeng Xue and Wenjun Yang*

These DPPs are effective one-photon and two-photon fluorescence chemosensors for F^-. The substituents could affect the ICT and the sensing performance to F^-.

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FEATURE ARTICLE

Advanced materials for solid-state refrigeration

Lluís Mañosa,*[a] Antoni Planes[a] and Mehmet Acet[b]

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www.rsc.org/MaterialsA

Recent progress on caloric effects are reviewed. The application of external stimuli such as magnetic field, hydrostatic pressure, uniaxial stress and electric field give rise respectively to magnetocaloric, barocaloric, elastocaloric and electrocaloric effects. The values of the relevant quantities such as isothermal entropy and adiabatic temperature-changes are compiled for selected materials. Large values for these quantities are found when the material is in the vicinity of a phase transition. Quite often there is coupling between different degrees of freedom, and the material can exhibit cross-response to different external fields. In this case, the material can exhibit either conventional or inverse caloric effects when a field is applied. The values reported for the many caloric effects at moderate fields are large enough to envisage future application of these materials in efficient and environmental friendly refrigeration.

1 Introduction

Every material changes its temperature when subjected to a sudden change of an external field (electric, mechanical, magnetic...). This property is generally known as the caloric effect and is related to a change in the material's entropy when the external field is isothermally modified. Generally, around room temperature, the magnitude of such a caloric effect is small and the temperature-change only becomes relatively large at very low-temperatures when the specific heat of the material is low. For this reason, refrigeration based on sweeping an external field adiabatically has been limited to low-temperatures for very long. The typical example is the attainment of cryogenic temperatures by making use of the magnetocaloric effect in paramagnetic salts when adiabatically demagnetized.[1]

The efficient use of the magnetocaloric effect for refrigeration around ambient temperature was proposed by Brown in the late seventies,[2] and a major breakthrough took place at the end of the nineties with the discovery by Pecharsky and Gschneidner of a material exhibiting large magnetic-field-induced entropy and temperature-changes around room temperature; the intermetallic Gd–Si–Ge compound, which was denoted as a giant magnetocaloric material.[3] This discovery boosted the research in the field, and nowadays there is a large variety of materials which have been reported to exhibit the giant magnetocaloric effect. The key feature for the effect to be giant is the presence of a first-order phase transition that most of these materials undergo. It is the transition entropy-change

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Lluís Mañosa received all his degrees (BSc and PhD) from the University of Barcelona in Catalonia, where he is presently Professor in Condensed Matter Physics. His research interests relate to structural and magnetic properties in solids. Recent research focuses on the study of phase transitions in solids displaying multifunctional properties.



Dr Antoni Planes is Professor of Physics in the Department d'Estructura i Constituents de la Matèria at the Universitat de Barcelona, Catalonia. His recent research is focused on the study of phase transitions in systems with interplay between the structure and magnetism, such as magnetic shape-memory and magnetocaloric materials. He is also active in the study of the influence of disorder in phase transitions, with the aim of understanding precursor phenomena and avalanche criticality in externally driven systems.

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(associated with the latent heat of a first-order phase transition) that makes the major contribution to the field-induced entropy-change of the magnetocaloric effect. As a consequence of strong interplay between magnetic and structural degrees of freedom, the phase transition also involves typically a change in the crystallographic structure.

While most of the efforts are nowadays devoted to investigation of the magnetocaloric effect, the possibility of inducing the phase transition in the solid state by fields other than magnetic opens up new routes for solid-state refrigeration using many different external stimuli. Indeed, materials showing significant changes in a certain thermodynamic quantity at the phase transition – such as volume, strain or polarization – will be extremely sensitive to the application of the corresponding thermodynamically conjugated field – pressure, stress and electric field, respectively. Hence, the possibility of inducing the transition by means of pressure, uniaxial stress and electric field will give rise to the barocaloric, elastocaloric and electrocaloric effects, respectively. A solid-state cooling cycle is illustrated in Fig. 1 based on a giant caloric effect attained by applying a generic external field.

Usually the material's entropy decreases when an external field is applied isothermally, and its temperature increases when a field is applied adiabatically. Since this is the most frequent situation, the caloric effect is known as 'conventional'. However, there are some cases for which the situation is reversed: the entropy increases on applying a field isothermally, and the material cools down. This effect is known as the 'inverse' caloric effect. Inverse caloric effects are possible in those systems with a strong coupling between different degrees of freedom, with a cross-response to the external fields, and for which the entropy contains contributions from all these degrees of freedom.

There have been detailed and comprehensive reviews dealing with magnetocaloric materials[4–11] and other caloric effects.[12–16] Also, details on the chemistry of the different materials illustrated in the present paper can be found in ref. 4, 11 and 17–19 and references therein. It is not intended to duplicate that effort here. The present paper is aimed at presenting the different caloric effects reported so far. For each of them, we select a particular material which conveniently illustrates the case.



Dr Mehmet Acet is Professor at the Physics Department of Duisburg-Essen University, Duisburg, Germany. He has been active in the study of structural and magnetic properties of solids, particularly those related to 3d metals and alloys and Heusler-based compounds. His current interest covers solid–solid phase-transition-related multifunctionality relevant to caloric effects.

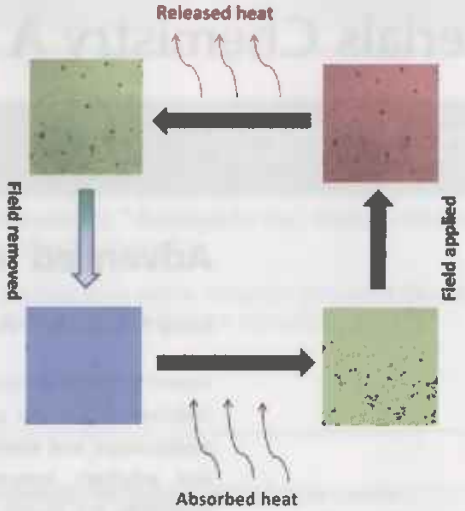


Fig. 1 Refrigerating cycle. Schematic diagram for a solid-state based refrigerating cycle based on a conventional giant caloric effect. In the first stage the field is adiabatically applied resulting in a temperature increase of the material (a forward phase transition occurs in this stage). In the second stage the material is allowed to cool down at constant field by transferring heat to a heat sink. In the third stage the field is adiabatically removed and the material cools down further (the reverse phase transition occurs in this stage). In the fourth stage, the cold material absorbs heat from the cold reservoir (which becomes colder) and recovers the initial state. The images to illustrate the cycle correspond to a magnetic shape memory alloy which undergoes a martensitic phase transition. The field can be magnetic field, hydrostatic pressure or uniaxial stress.

2 Thermodynamics of caloric effects

Let a generic system in thermodynamic equilibrium be described in terms of the generalized displacements, x_i, forces Y_i (fields) and temperature T. Both displacements and forces have the same tensorial character. However, a scalar approach is appropriate to describe most cases of interest (where only the magnitude of the external field is varied), and this will be considered in the following sections. The change in entropy reads:

$$dS = \frac{C}{T}dT + \sum_i \left(\frac{\partial x_i}{\partial T}\right)_{Y_j} dY_i, \quad (1)$$

where we have made use of the Maxwell relations $\left(\frac{\partial S}{\partial Y_i}\right)_{T,Y_{j\neq i}} = \left(\frac{\partial x_i}{\partial T}\right)_{Y_j}$, and C is the heat capacity.

For an isothermal change of a given field from 0 to Y, the field-induced entropy-change accounting for the caloric effect is given by:

$$S(T, Y) - S(T, Y = 0) = \Delta S(T, Y) = \int_0^Y \left(\frac{\partial x}{\partial T}\right)_Y dY. \quad (2)$$

When the field is applied adiabatically, the corresponding change in temperature is given by:

$$\Delta T = -\int_0^Y \frac{T}{C}\left(\frac{\partial x}{\partial T}\right)_Y dY \quad (3)$$

The above expressions quantify the magnetocaloric ($Y = H$ and $x = M$), barocaloric ($Y = -p$ and $x = V$), elastocaloric ($Y = \sigma$

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and $x = \varepsilon$) and electrocaloric ($Y = E$ and $x = P$) effects, where H is the magnetic field, M, magnetization, p, hydrostatic pressure, V, volume, σ, uniaxial stress, ε, uniaxial strain, E, electric field and P, polarization.

2.1 Experimental determination of the caloric effects

The most commonly used method for the determination of the entropy-change makes use of isothermal x *vs.* Y curves to numerically integrate eqn (2):

$$\Delta S(Y, T(k)) = \frac{1}{\Delta T_k}\left[\int_0^Y x(T_{k+1})\mathrm{d}Y - \int_0^Y x(T_k)\mathrm{d}Y\right] \quad (4)$$

where $T(k) = (T_{k+1} + T_k)/2$ and $\Delta T_k = T_{k+1} - T_k$. While this provides a fast and easy procedure to quantify a caloric effect, there has been considerable controversy on whether or not the method can be applied to first-order phase transitions.[20–24] Large spurious values[25] were shown to arise from inappropriate experimental protocols.[26] The major issue associated with this problem is the existence of a hysteresis at the first-order phase transition. However, at present, it is clear that the method gives reliable data for ΔS, provided that the experimental protocol is the appropriate one which correctly takes into account the hysteresis of the transition (details can be found in ref. 7, 27 and 28). Alternatively, ΔS can also be obtained by numerically integrating the derivatives $\left(\frac{\partial x}{\partial T}\right)_Y$ computed from measured isofield $x(T)$ curves. The latter method ensures that the sample completes the full phase transformation and consequently is free from giving spurious values.

An alternative way to obtain ΔS is from calorimetric measurements of the temperature dependence of the specific heat of the material for different constant values of the external field Y (see eqn (1)). As previously mentioned, most giant caloric materials undergo a first-order phase transition, and the best suited calorimetric technique for first-order phase transitions is differential scanning calorimetry (DSC). Purpose-built DSC operating under different external fields have been developed to study several caloric effects.[29–33] These devices provide the heat flux as a function of temperature, from which the entropy (referenced to a given state at T_0) is obtained as:

$$S(T, Y) - S(T_0, Y) = \int_{T_0}^{T} \frac{1}{T}\frac{\dot{Q}(Y)}{\dot{T}}\mathrm{d}T \quad (5)$$

where $\dot{Q}$ and $\dot{T}$ are the heat flux and the cooling (or heating) rate, respectively. The field-induced entropy-change (accounting for the caloric effect) is readily obtained by subtracting the integrated curves resulting from eqn (5).

Some of these devices can also operate at constant temperature and sweeping the external field. This method provides a direct determination of the field-induced entropy-change which is given by:

$$S(T, Y) - S(T, 0) = \frac{1}{T}\int_0^Y \frac{\dot{Q}(T)}{\dot{Y}}\mathrm{d}Y \quad (6)$$

where $\dot{Y}$ is the field rate.

For a first-order phase transition, the shift in the transition temperature with the field is governed by the Clausius–Clapeyron equation:

$$\frac{\mathrm{d}T}{\mathrm{d}Y} = -\frac{\Delta x}{\Delta S} \quad (7)$$

Since ΔS is negative (lower entropy of the low-temperature phase), the shift in the transition is determined by the sign of the generalized displacement discontinuity, Δx.

Finally, a direct determination of a caloric effect is also achieved by measuring the temperature of the sample (using an appropriate thermometer) while the external field is adiabatically modified. Although this is a quite direct method to quantify a caloric effect, adiabatic temperature-change experiments are usually difficult to implement, and the majority of studies are devoted to field-induced entropy-changes.

3 Gd–Si–Ge compounds: the prototype giant magnetocaloric material

At room temperature $Gd_5Si_2Ge_2$ is paramagnetic and exhibits a monoclinic structure (space group $P112_1/a$). On cooling it undergoes a magnetostructural transition to an orthorhombic (space group *Pnma*) structure which is ferromagnetically ordered. Since Gd_5Ge_4 is antiferromagnetic and Gd_5Si_4 is ferromagnetic, the phase diagram for off-stoichiometric $Gd_5(Ge_{1-x}Si_x)_4$ is very rich. For all x, the ground state is ferromagnetic with an orthorhombic structure (space group *Pnma*), but different structural and magnetic phases can be found depending on x. A detailed phase diagram is described in ref. 4 and 5. The giant magnetocaloric effect is observed for alloys with $0.3 \leq x \leq 0.5$. It is within this composition region that the alloy undergoes the paramagnetic to ferromagnetic first-order magnetostructural transition with a transition temperature that linearly increases with increasing Si concentration.

The structural transition involves shear displacements of atomic layers in which (Si, Ge)–(Si, Ge) dimers that are richer in Ge increase their distances. This modifies the spin-dependent hybridization between Ge 4p and Gd 5d conduction states reducing the net Gd 5d moment and the strength of the ferromagnetic RKKY exchange coupling across sheared layers.[34,35] In addition to the giant magnetocaloric effect, the magnetostructural transition is also at the origin of other technologically important properties of this alloy, such as giant magnetoresistance[36] and magnetostriction.[37]

The magnetocaloric effect in the $Gd_5(Ge_{1-x}Si_x)_4$ family has been investigated by numerous researchers by means of several experimental techniques. Depending on composition and purity of the samples, the reported entropy values range from 10 J kg^{-1} K^{-1} to 50 J kg^{-1} K^{-1}. The highest values correspond to those compositions for which the magnetostructural transition is close to the Néel temperature of the orthorhombic phase. Interestingly, the whole entropy-change associated with the magnetostructural transition has been found to scale with the transition temperature, no matter if the latter is tuned by composition or magnetic field.[22] This result is illustrated in Fig. 2 and proves that magnetovolume effects due to the

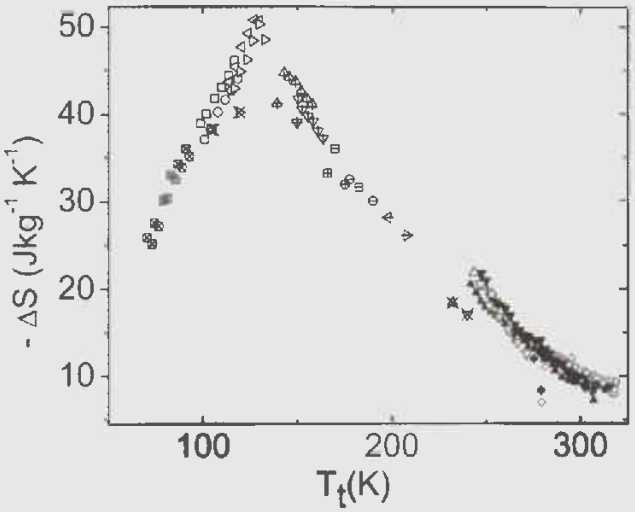


Fig. 2 Magnetocaloric effect in Gd–Si–Ge. Transition entropy-change as a function of the transition temperature for $Gd_5(Ge_{1-x}Si_x)_4$ alloys. Figure adapted from ref. 38.

magnetic field are of the same nature as the volume effects caused by substitution. Such a statement has been corroborated by later studies showing the equivalence of temperature, magnetic field, and chemical and hydrostatic pressures on the polymorphism of $Gd_5(Ge_{1-x}Si_x)_4$.[39,40]

The magnetostructural transition involves a change in the volume of the unit cell: the volume of the low-temperature monoclinic phase is larger than that of the ferromagnetic orthorhombic one. Owing to such a volume change, the transition is sensitive to external hydrostatic pressure, and therefore, it is prone to exhibit a giant barocaloric effect. Such a possibility was theoretically predicted within the framework of band theory,[42] and experimentally demonstrated by differential scanning calorimetry under hydrostatic pressure.[41] Fig. 3 shows the pressure-induced entropy-change as a function of temperature for selected values of hydrostatic pressure for stoichiometric

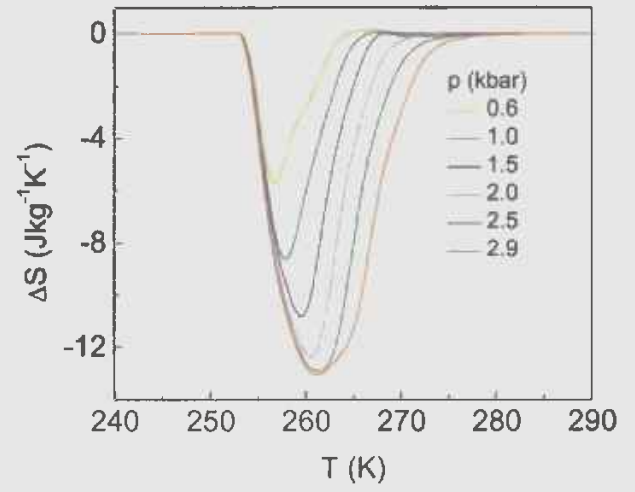


Fig. 3 Barocaloric effect in Gd–Si–Ge. Temperature dependence of the pressure induced entropy-change for $Gd_5Si_2Ge_2$. Figure adapted from ref. 41

$Gd_5Si_2Ge_2$. The values found for moderate pressures around 3 kbar are comparable to those corresponding to the magnetocaloric effect for fields around 2 T for this compound.

For $Gd_5Si_2Ge_2$, both magnetocaloric and barocaloric effects are found to be conventional, *i.e.* the entropy decreases with increasing field and pressure. This is associated with the larger magnetization and lower volume of the low-temperature ferromagnetic orthorhombic phase. The total entropy of the alloy decreases at the paramagnetic-monoclinic to ferromagnetic-orthorhombic transition, and such a decrease is due to a decrease in both magnetic and structural contributions to the entropy.

4 La–Fe–Si family and the inverse barocaloric effect

The $La(Fe_{13-x}Si_x)$ compounds have a cubic $NaZn_{13}$ structure (space group $Fm\bar{3}c$) in the concentration range $1.2 \leq x \leq 2.5$. La atoms occupy the 8a sites. The 8b site is fully occupied by Fe, and the 96i site is shared by Fe and Si atoms.[5] On cooling, the alloy orders ferromagnetically at a Curie temperature (T_C) that increases from 198 K for $x = 1.5$ to 262 K for $x = 2.5$. The saturation magnetic moment decreases from $2.08\mu_B$ to $1.85\mu_B$ in this range.[43] Above T_C, an itinerant-electron metamagnetic (IEM) transition can be induced by an external magnetic field.[44] The transition has a marked first-order character for low x, but for $x \geq 2.4$, it becomes second order.

In contrast to $Gd_5Si_2Ge_2$, the phase transition does not involve structural symmetry breaking, and the material keeps the cubic $Fm\bar{3}c$ structure above and below the transition temperature. However, a strong coupling between magnetism and the structure is evidenced by the change in the unit cell volume: the volume of the low-temperature ferromagnetic phase is ~1% larger than that of the high-temperature paramagnetic phase.[45] These large magnetization and volume changes at the phase transition suggest that this alloy might have interesting magnetocaloric and barocaloric properties.

The IEM transition originates from a magnetic-field-induced change in the density of states of the 3d electrons at the Fermi level.[44] A strong magnetovolume effect originates from the existence of a peak in the electronic density of states close to the Fermi level that yields a negative contribution from spin fluctuations to the magnetostriction, resulting in a volume increase on cooling from the paramagnetic to the ferromagnetic state.

From the point of view of potential applications, $La(Fe_{13-x}Si_x)$ is an attractive material due to its reduced hysteresis at the first-order phase transition (irreversibilities related to hysteresis reduce the cooling capacity of the alloy). It has the only drawback that the transition temperature is below room temperature. Two alternative methods have been reported to bring the transition temperature to values close to room temperature.[8] One method is to add interstitial elements (H is the most successful one) that expand the crystalline lattice and modify the exchange interaction between iron atoms. The electron band-structure is not modified but the tri-critical point is shifted to higher temperatures as a consequence of the change in the lattice parameter. Another method is to replace some Fe atoms by other magnetic transition metals (Co has been found to be the best suited

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element). Such a substitution does modify the electron band-structure and consequently the relative phase stability. As the amount of Co increases, the first-order character of the transition weakens; and for high enough Co content, the phase transition turns to the second order.[46]

The study of the magnetocaloric effect in $La(Fe_{13-x}Si_x)$ has received considerable interest.[8] Fig. 4 shows reported values for the isothermal entropy-change as a function of Si concentration. A marked decrease is observed as x increases: the first-order character of the transition diminishes and approaches a second order character. Such a decrease is overcome by tailoring the transition temperature by the concentration of interstitial hydrogen in hydrogenated $La(Fe_{13-x}Si_x)H_y$ compounds. While T_C linearly rises with increasing y, the entropy-change only exhibits a very weak dependence on the hydrogen content.[44,47]

The pressure dependence of the magnetic and magnetocaloric properties of La–Fe–Si and doped compounds has been reported by several experimental techniques, and it has also been theoretically modeled.[44,49] The barocaloric effect in $LaFe_{11.33}Co_{0.47}Si_{1.2}$ was measured by means of differential scanning calorimetry under applied hydrostatic pressure.[48] Fig. 5 shows the values obtained for the pressure-induced entropy-change as a function of temperature for selected values of the hydrostatic pressure. The barocaloric effect increases with pressure, and for pressures ~2 kbar, the barocaloric effect amounts to about 75% of the transition entropy-change. This value compares well with the magnetocaloric effect for a magnetic field of ~5 T for the same compound. The most striking feature in Fig. 5 is the positive value for the entropy-change which indicates that the barocaloric effect in this material is inverse: the entropy increases with increasing pressure. This finding is consistent with the decrease in the temperature of the magnetostructural transition with increasing pressure.

A material exhibiting the inverse barocaloric effect will have the unusual property of cooling when adiabatically compressed and warming when decompressed. Such a feature is illustrated in Fig. 6 which shows measurements of the adiabatic temperature-change when a $LaFe_{11.33}Co_{0.47}Si_{1.2}$ is rapidly decompressed. The positive values are direct evidence of the inverse nature of the barocaloric effect in this compound.

In systems with coupling between different degrees of freedom, the dominant change in entropy at the transition should be associated with a conventional caloric effect, whereas the secondary property may provide conventional or inverse effect depending on the specific feature of the coupling. In La–Fe–Si the magnetocaloric effect is conventional while the barocaloric is inverse, which reflects that the transition is essentially of magnetic nature. Indeed the major contribution to the entropy in these compounds is due to the magnetic contribution from itinerant 3d electrons. Spin fluctuations induce a larger volume of the ferromagnetic phase, and as a consequence, the barocaloric effect in this material is inverse.

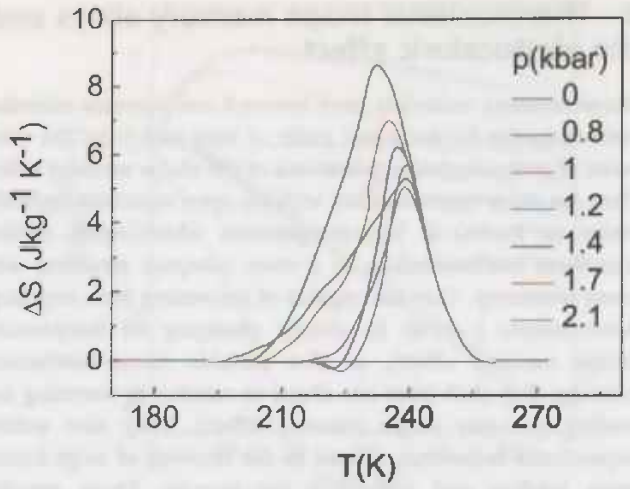


Fig. 5 Barocaloric effect in La–Fe–Si. Temperature dependence of the pressure-induced entropy-change for $LaFe_{11.33}Co_{0.47}Si_{1.2}$. Figure adapted from ref. 48.

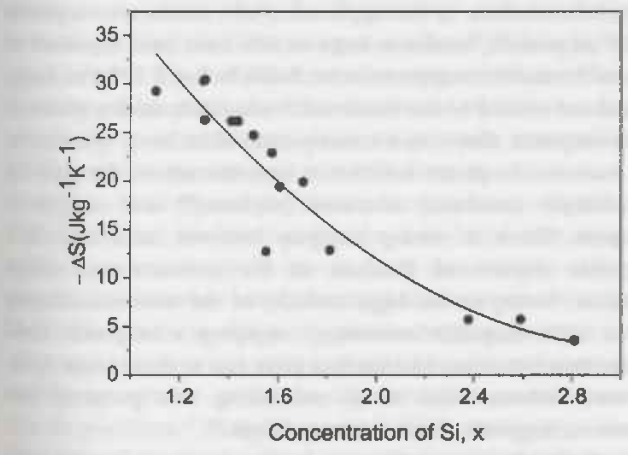


Fig. 4 Magnetocaloric effect in La–Fe–Si. Magnetic-field induced entropy-change as a function of the Si concentration for $La(Fe_{13-x}Si_x)$. Figure adapted from ref. 4. An average density of 7229 kg m^{-3} has been used for all data. The line is a guide to the eyes.

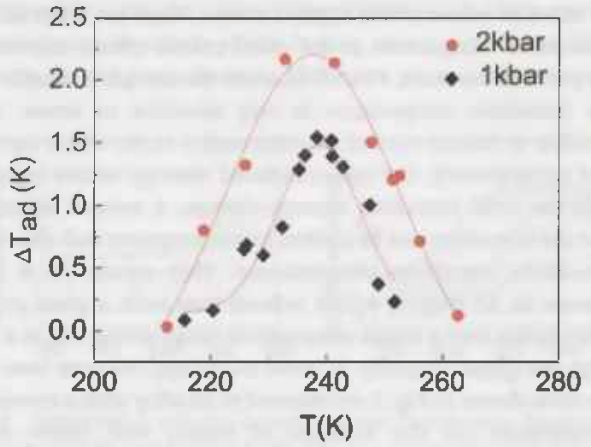


Fig. 6 Barocaloric effect in La–Fe–Si. Temperature dependence of the adiabatic temperature-change for decompression of 2 kbar (circles) and 1 kbar (diamonds) for $LaFe_{11.33}Co_{0.47}Si_{1.2}$. Figure adapted from ref. 48.

5 Thermoelastic shape memory alloys and the elastocaloric effect

Shape memory materials have received considerable attention both from the fundamental point of view and from the viewpoint of technological applications of the shape memory effect. They are cubic intermetallics with an open structure (typically *Fm*3*m* or *Pm*3*m*) at high-temperature which upon cooling transform martensitically to a more compact structure with lower symmetry. They are capable of recovering from very large deformations (~10%) by simply changing its temperature (shape memory effect), or after suitable themo-mechanical training, they shift from one shape to another by warming and cooling (two-way shape memory effect). They also exhibit superelastic behaviour, related to the recovery of large strains upon loading and unloading the sample. These peculiar mechanical properties are related to the martensitic transition that these alloys undergo. The transition is first-order from a high-temperature high-symmetry phase to a low-temperature lower symmetry phase where the lattice distortion can be mainly described by a shear mechanism. An excellent overview of these materials can be found in ref. 18.

In non-magnetic shape memory alloys, there is negligible difference in the volume of the unit cell of the martensitic and cubic phases. Nevertheless, the transformation involves a large shear distortion (typically shearing {110} planes along the $\langle 1\bar{1}0 \rangle$ directions), and therefore, it is very sensitive to the application of uniaxial stresses. Indeed the possibility of inducing martensitic transitions by the mechanical stress has been known since decades, and many of the mechanical applications of these alloys rely on such a possibility.

The entropy-change associated with the latent heat of the first-order martensitic transition gives rise to a large caloric effect when the transition is induced by the uniaxial stress: this is the elastocaloric effect. A giant elastocaloric effect was reported for a Cu–Zn–Al single crystal[50] and for Ti–Ni polycrystals.[51,52] It is also worth mentioning that the elastocaloric effect was earlier reported for non-martensitic Fe–Rh alloys.[53] The temperature-dependence of the stress-induced entropy-change (elastocaloric effect) for Cu–Zn–Al is illustrated in Fig. 7 for selected values of the applied stress. There are a few salient features in comparison to the other caloric effects referred in the previous sections. First of all, since the sample is ductile and the transition temperature is very sensitive to stress, it is possible to induce the full transformation in the whole sample, and consequently, the stress-induced entropy values coincide with the total transition entropy-change. A second feature is that the transition can be shifted to temperatures well above the zero-stress transition temperatures. This results in a large plateau in ΔS (Fig. 7) which reflects that such a giant caloric effect spans over a broad temperature range giving rise to a very large refrigerant capacity in these materials. We note here that the data shown in Fig. 7 correspond to an alloy with a transition temperature (in the absence of stress) well below room temperature ($T_M = 234$ K), and experiments carried out close to this temperature show that stresses as low as 5 MPa are enough to induce the transformation in the whole sample.

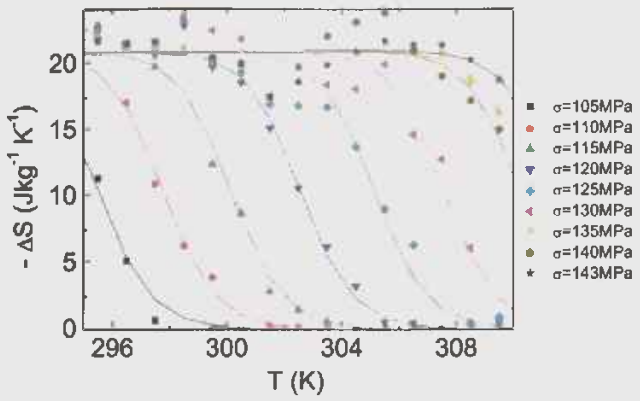


Fig. 7 Elastocaloric effect in Cu–Zn–Al. Temperature dependence of the stress-induced entropy-change for $Cu_{68.13}Zn_{15.74}Al_{16.13}$. Figure adapted from ref. 50.

The elastocaloric effect in shape memory alloys is conventional, and this is also corroborated by direct measurements of the adiabatic temperature-change.[54] Significant cooling of the sample was measured when the stress was rapidly released. Values around 10 K for Cu-based alloys[55] and around 20 K for Ti–Ni based alloys have been reported.[51]

In contrast to all other giant caloric materials, the transition entropy change is solely related to the change in the structure at the transition (contributions from other degrees of freedom are negligible). Indeed such an entropy-change is mostly vibrational and originates from low-lying transverse phonons in the TA_2 branch of the open cubic high-temperature phase (details can be found in ref. 56).

6 Magnetic Heusler alloys and the inverse magnetocaloric effect

Heusler alloys are X_2YZ intermetallics with a *Fm*3*m* structure where X atoms occupy the 8c Wyckoff positions and Y and Z atoms the 4a and 4b positions, respectively. These alloys have received considerable interest for several decades[19] which was further promoted by the report that Ni_2MnGa could exhibit large deformations by the application of a moderate magnetic field.[57] At present, strains as large as 10% have been reported in off-stoichiometric compounds for fields below 1 T.[58] The large strains are related to the martensitic transition taking place in these magnetic alloys. As a consequence of its lower symmetry, the martensitic phase exhibits a heterostructure formed by twin-related structural domains (variants)[59] and magnetic domains. There is strong interplay between structural and magnetic degrees of freedom at the mesoscale of these domains. Owing to the high mobility of the twin boundaries and a high magnetic anisotropy, applying a magnetic field causes twin boundary motion that gives rise to these large field-induced deformations. Alloys exhibiting this property are known as magnetic shape memory alloys.[60]

In the Ni–Mn-based Heusler family, Ni_2MnGa is the only ferromagnetic alloy that undergoes a martensitic transition at the stoichiometric composition, but almost any alloy of this family undergoes a martensitic transformation at appropriate

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off-stoichiometric compositions.[61] Among them, the particularly interesting ones are those exhibiting magnetic superelastic behaviour.[62,63] They also exhibit large magnetic-field-induced strains. But in this case, the strains are not due to a rearrangement of structural domains but rather to the possibility of inducing the reverse martensitic transition on applying a magnetic field. In this case, large magnetocrystalline anisotropy is not required, but there must be a significant change in the magnetic moment between the high-temperature phase and the martensitic phase.

In general, Ni–Mn-based Heusler materials show a rich variety of magnetic behaviour[64] with associated multifunctional properties, which include, in addition to the aforementioned magnetic shape memory, giant magneto-resistance, exchange bias, and giant caloric effects which will be discussed below.

The magnetocaloric effect in Ni–Mn–Ga was first reported by Hu *et al.*[65] who observed an increase in the entropy by applying a 1 T magnetic field. Soon after, the same authors reported in a sample with a slightly different composition an entropy decrease for fields above 1 T.[66] Such puzzling behaviour was explained by Marcos *et al.*[38,67] who showed that it arises from the different length scales of the magnetostructural coupling. The inverse effect at low fields (entropy increase with the magnetic field) is related to a magnetostructural coupling on the length scale of magnetic domains and martensitic variants: the strong uniaxial magnetocrystalline anisotropy of the martensitic phase results in a magnetic domain configuration with a lower magnetization than that of the high-temperature cubic phase, thus giving rise to an inverse magnetocaloric effect. At high fields, the coupling at a microscopic scale becomes dominant. Since for Ni–Mn–Ga the intrinsic magnetic moment in the martensite is larger than in the cubic phase, the magnetization increases at the transition and the magnetocaloric effect becomes conventional. Interestingly, when the composition is varied in such a way that the martensitic transition temperature approaches the Curie point, the magnetic anisotropy weakens with a corresponding decrease of the inverse contribution, and the conventional magnetocaloric effect becomes dominant. Actually, for Ni–Mn–Ga alloys, optimum magnetocaloric properties occur when both the martensitic and ferromagnetic transitions take place close to one another.[68] This behaviour is illustrated in Fig. 8 which shows the magnetocaloric effect as a function of magnetic field for a series of Ni–Mn–Ga alloys in which the martensitic transition temperature approaches the Curie point as the Mn concentration decreases.

Ni–Mn–Z alloys with Z different from Ga behave significantly different from Ni–Mn–Ga. On the one hand, the magnetocrystalline anisotropy is low in both martensitic and cubic phases. On the other hand, the magnetic moment of martensite is smaller than in the cubic phase. Such a decrease in the magnetic moment is a consequence of an enhancement of the antiferromagnetic correlations between Mn-atoms located at the 4b positions.[69] Such a decrease is illustrated in Fig. 9 for Ni–Mn–Sn and Ni–Mn–In alloys. Consistent with the decrease in the magnetization, the martensitic transition shifts to lower temperatures with the applied magnetic field, and consequently, the magnetocaloric effect is inverse in the vicinity of

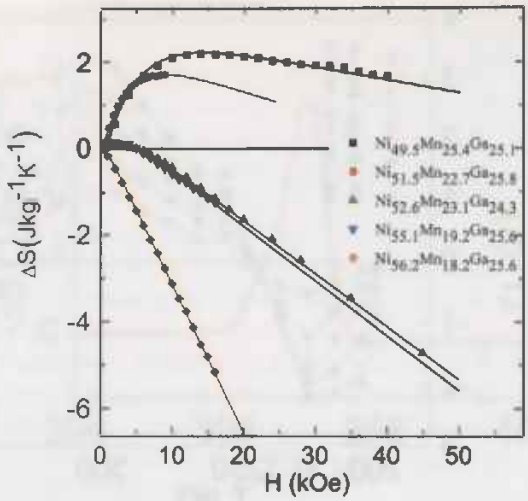


Fig. 8 Magnetocaloric effect in Ni–Mn–Ga. Average magnetic field induced entropy-change as a function of magnetic field for a family of composition related Ni–Mn–Ga alloys. Figure adapted from ref. 30.

the martensitic transition, as firstly reported for Ni–Mn–Sn.[70] Later, other alloys from the Ni–Mn–Z family (with Z as In and Sb, and related quaternary alloys) were also reported to exhibit an inverse magnetocaloric effect.[71–74] At the Curie point, the alloys exhibit a conventional magnetocaloric effect where the entropy-change is solely due to a magnetic contribution. The inverse character of the magnetocaloric effect was confirmed by direct measurements of the adiabatic temperature-change.[71,75] An example is shown in Fig. 10, which displays the measured adiabatic temperature change for Ni–Mn–In around the martensitic and magnetic transitions.

It is worth remarking that in Ni–Mn based Heusler alloys, the physical mechanism of the magnetocaloric effect is the same as that leading to their unique magnetic-field induced strain. On the one hand, the magnetostructural coupling at the mesoscale is responsible for the magnetic-shape memory and the low field inverse magnetocaloric effect in Ni–Mn–Ga alloys. Both effects require a large magnetocrystalline anisotropy in the martensitic state. On the other hand, the magnetostructural coupling at a microscopic scale gives rise to magnetic superelasticity and the inverse magnetocaloric effect. In this case a significant difference in the magnetic moment of the two phases is necessary in

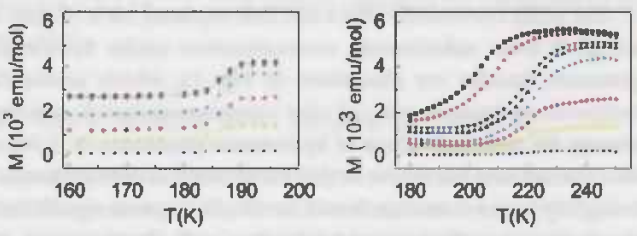


Fig. 9 Magnetization in Ni–Mn–Z magnetic shape memory alloys. Temperature dependence of the magnetization for $Ni_{50}Mn_{35}Sn_{15}$ (left panel) and $Ni_{50}Mn_{34}In_{16}$ (right panel) for selected magnetic fields. From bottom to top: $H = 0.1, 0.2, 0.5, 1, 2, 10, 50$ kOe (left panel) and $H = 0.1, 0.5, 2, 5, 10, 20, 30, 40, 50$ kOe (right panel). Figure adapted from ref. 7.

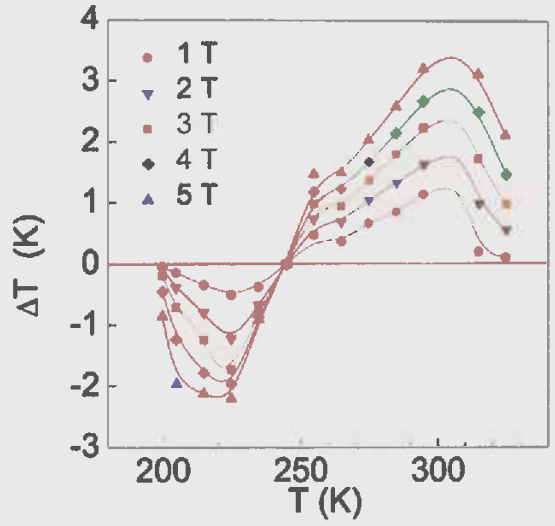


Fig. 10 Magnetocaloric effect in Ni–Mn–In. Temperature dependence of the adiabatic temperature-change for $Ni_{50}Mn_{34}In_{16}$. Figure adapted from ref. 75.

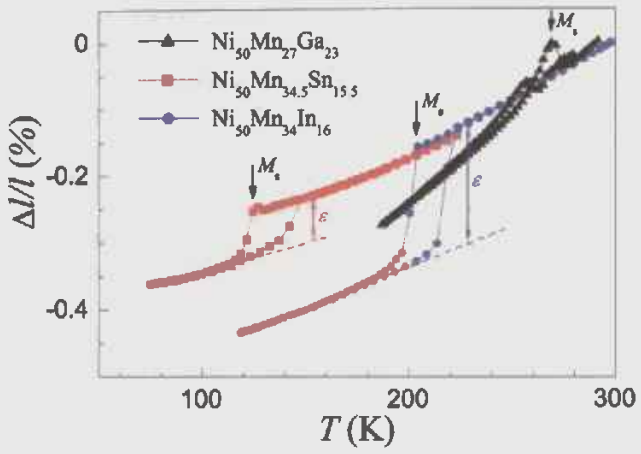


Fig. 11 Length change in magnetic shape memory alloys. Temperature dependence of the relative length change for $Ni_{50}Mn_{34}In_{16}$, $Ni_{50}Mn_{34.5}Sn_{15.5}$ and $Ni_{50}Mn_{27}Ga_{23}$ polycrystalline alloys. Figure adapted from ref. 77.

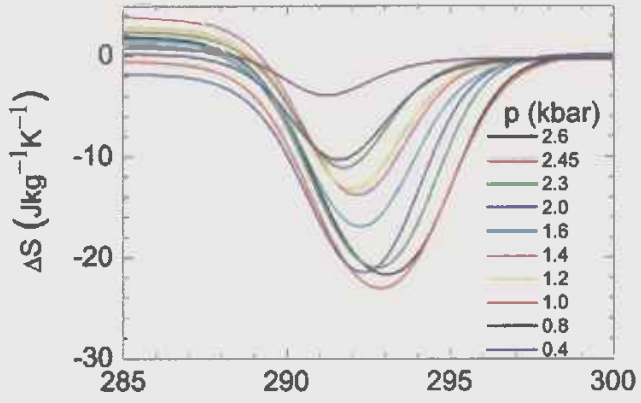


Fig. 12 Barocaloric effect in Ni–Mn–In. Temperature dependence of the pressure-induced entropy-change for $Ni_{49.26}Mn_{36.08}In_{14.66}$. Figure adapted from ref. 79.

such a way that the martensitic transition can be driven by applying a magnetic field. The decrease in the magnetic moment is a consequence of a decrease in the distance between excess Mn-atoms in the martensitic unit cell compared to the cubic one which results in an enhancement of antiferromagnetic exchange.[76]

Typically, the volume change at the martensitic transition in shape memory alloys is negligibly small. Nevertheless, for some alloys of the Ni–Mn–Z family (Z different from Ga), a consequence of the strong interaction between magnetic and structural degrees of freedom is a difference between the unit cell volume of the martensitic phase and that of the cubic one. A first indication for such a volume change is evidenced by the relative length change at the temperature-induced martensitic transition (in the absence of any external magnetic field or stress) shown in Fig. 11 for several polycrystalline alloys.[77] To a good approximation, the relative volume-change amounts to three times the relative length-change. While for Ni–Mn–Ga the coupling at a microscopic level is small, and consequently the volume change at the transition is negligible, there is a noticeable volume change for the rest of alloys of the family with strong coupling. The martensitic transition in these alloys will be influenced by hydrostatic pressure[78] and they will be prone to exhibit a giant barocaloric effect.

The giant barocaloric effect was first reported for a Ni–Mn–In sample[79] from calorimetric measurements under hydrostatic pressure. Results are illustrated in Fig. 12, which shows the temperature-dependence of the pressure-induced entropy-change for selected values of hydrostatic pressures. It is found that the barocaloric effect in this compound is conventional. It is slightly larger than that found for $Gd_5Si_2Ge_2$ and significantly larger than the effect found for La–Fe–Co–Si. Furthermore, the values measured for moderated pressures are larger than the corresponding magnetocaloric values for fields around 1 T.

As previously mentioned, the martensitic transition is mainly accomplished by a shear distortion, and consequently, it is very sensitive to the applied uniaxial strain. A stress-induced first-order transition gives rise to an associated elastocaloric effect. The conventional elastocaloric effect has been found in magnetic shape-memory alloys.[80,81] Nevertheless the strong brittleness of these alloys precludes the application of large stresses, and consequently, the associated elastocaloric effect remains at lower values.

Ni–Mn-based magnetic shape memory alloys exhibit conventional barocaloric and elastocaloric effects while the magnetocaloric effect is inverse (with the exception of Ni–Mn–Ga). This indicates that the main contribution to the transition entropy-change in these alloys is associated with the structural degrees of freedom. Actually, the origins are the same as in nonmagnetic martensitic materials: the cubic high-temperature phase has a larger vibrational entropy than the close-packed phase as a consequence of the low energy TA_2 phonon branch.[82] On the other hand, the total transition entropy, which contains a structural and a magnetic contribution, decreases as the martensitic transition is pushed below the Curie point either by tuning composition[83] or by applying a magnetic field.[84] This

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reflects that the magnetic contribution becomes more and more important and eventually can compensate the structural contribution resulting in a vanishing total entropy-change. This has been suggested to be at the origin of the interesting phenomenon of kinetic arrest[85,86] in magnetic shape memory alloys.

7 $BaTiO_3$ and the electrocaloric effect

The electrocaloric effect refers to the temperature and entropy-changes occurring in polar materials when an electric field is applied. The effect has been known for many decades[87] but it received little attention due to its small magnitude. Paralleling the development in other caloric effects, the research was triggered on realizing that giant effects were expected close to a paraelectric–ferroelectric phase transition. This was shown to occur in ceramic films[88] and later in ferroelectric copolymers and ferroelectric relaxors.[89]

Although thin films exhibit large electrocaloric effects since they can support large driving fields, their performance is significantly lower than that of bulk oxides for which the temperature and entropy-changes per unit of applied field are an order of magnitude higher.[15,33]

The prototype ferroelectric material is $BaTiO_3$. At high-temperatures, it crystallizes in a cubic (perovskite) structure (space group $Pm3m$). On cooling, it undergoes a structural transition to a tetragonal structure (space group $P4/mmm$). On further cooling, the material transforms to an orthorhombic phase (space group $Amm2$) at around $T = 270$ K and to a rhombohedral phase (space group $R3m$) around $T = 200$ K.[90] At the cubic to tetragonal transition, the Ti^{4+} ions move relatively to the O^{-2} octahedra resulting in spontaneous polarization along the c-axis. Such an electrostructural paraelectric–ferroelectric phase transition is responsible for the significant electrocaloric effect in this oxide.

The electrocaloric effect measured using calorimetry under electric field in a $BaTiO_3$ single crystal is illustrated in Fig. 13 for an electric field of 3 kV cm^{-1}. The peak value of the entropy-change coincides within experimental errors with the transition entropy-change which indicates that for this sample low values of the applied field are enough to achieve the total transition entropy-change. The electrocaloric effect is conventional, which is in agreement with the larger polarization of the tetragonal phase. Direct measurements of the adiabatic temperature-change, shown in Fig. 14, confirm this issue: the sample heats up on applying an electric field. It is interesting to note that above a certain temperature (labeled T_{h2} in the figure), the measured adiabatic temperature-change values are reversible. This behaviour is intimately related to the hysteresis of the first-order electrostructural transition in this sample.[33]

The cubic to tetragonal phase transition encompasses a change in the volume of the unit cell of around 0.037 cm^3 mol^{-1}.[91] The volume of the low-temperature tetragonal ferroelectric phase is larger than that of the cubic phase and therefore an inverse barocaloric effect is expected for this compound. Preliminary calorimetric measurements under hydrostatic pressure[92] do evidence such an inverse barocaloric effect. Interestingly, the maximum value for the entropy-change (around 2.5 J kg^{-1} K^{-1}) is already obtained for pressures as low as 1 kbar.

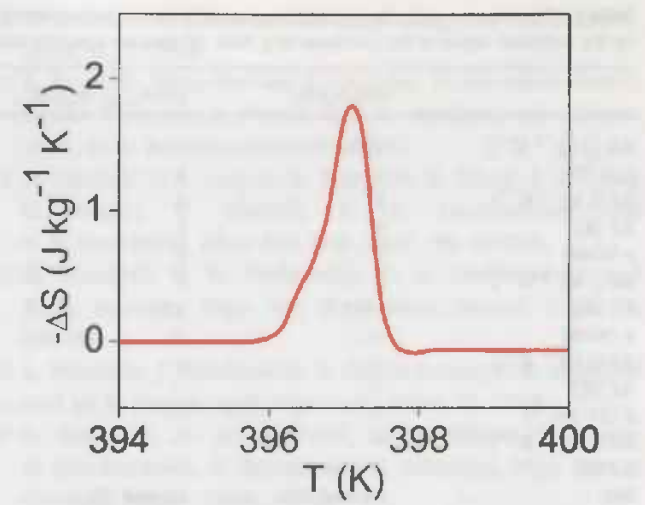


Fig. 13 Electrocaloric effect in $BaTiO_3$. Temperature dependence of the electric field induced entropy-change for $BaTiO_3$. Figure adapted from ref. 33.

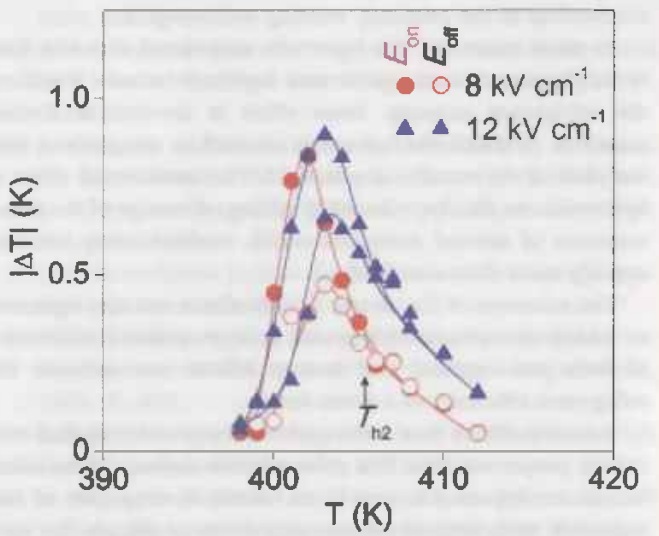


Fig. 14 Electrocaloric effect in $BaTiO_3$. Temperature dependence of the adiabatic temperature-change for electric fields of 8 kV cm^{-1} (circles) and 12 kV cm^{-1} (triangles). Solid symbols correspond to the application of the field and open symbols, to the removal of the field. Figure adapted from ref. 33.

8 Conclusions and future prospects

In general, the different thermodynamic degrees of freedom can lead to several caloric effects. The key point for these effects to be large enough for potential practical applications is the occurrence of a phase transition. We have illustrated the effects reported so far in a variety of materials. The relevant quantities for fields readily accessible in practical applications are summarized in Table 1.

Table 1 Transition entropy change (ΔS_t), measured field-induced isothermal entropy (ΔS) and adiabatic temperature (ΔT) changes for several caloric effects obtained for the indicated values of the corresponding field. All data are absolute values. (a) ref. 4, (b) ref. 41, (c) ref. 48, (d) ref. 50, (e) ref. 71, (f) ref. 79 and (g) ref. 33

	$Gd_5Si_2Ge_2$	$LaFe_{11.33}Co_{0.47}Si_{1.2}$	$Cu_{68.13}Zn_{15.74}Al_{16.13}$	$Ni_{49.26}Mn_{36.08}In_{14.66}$	$BaTiO_3$
ΔS_t (J kg^{-1} K^{-1})	21.0	11.4	21.0	27.0	2.2
$\mu_0 H$ (T)	1	1	—	1	—
ΔS (J kg^{-1} K^{-1})	8	2	—	10	—
ΔT (K)	4	1	—	0.5	—
p (kbar)	1	1	—	1	—
ΔS (J kg^{-1} K^{-1})	8	5	—	11	—
ΔT (K)	~0.5	1.5	—	—	—
σ (MPa)	—	—	5	—	—
ΔS (J kg^{-1} K^{-1})	—	—	21	—	—
ΔT (K)	—	—	10	—	—
E (kV cm^{-1})	—	—	—	—	~10
ΔS (J kg^{-1} K^{-1})	—	—	—	—	2.2
ΔT (K)	—	—	—	—	1
Ref.	(a) and (b)	(c) and (d)	(e)	(f)	(g)

The magnitude of all these caloric effects opens up new perspectives for designing solid-state refrigeration devices as alternatives to the presently existing technologies.

In most materials, the hysteresis associated with the first-order phase transition represents a drawback because it reduces the refrigerant capacity. Most effort is devoted at finding materials in which the hysteresis is small in comparison with the shift of the transition with field. The detrimental effect of hysteresis can also be reduced by taking advantage of the cross-response of several materials which enables using simultaneously more than one field.

The existence of the inverse caloric effects can also represent an added value, since devices with an appropriate combination of both conventional and inverse effects can enhance the refrigerant efficiency of a given device.

Recently efforts have been undertaken in order to deal with caloric properties from first principle calculation. These calculations are expected to give hints for the development of new materials with desired caloric properties or simply for optimizing caloric properties of already known materials. The validity of this point of view is supported by the fact that they have proved to be able to nicely reproduce caloric behaviour of given materials.[93] These investigations are approached with the idea of finding materials undergoing a phase transition involving a large change of the properties giving rise to the caloric effects of interest. There are, however, still few works with predictive character. By combining density functional modelling and Monte Carlo simulations Siewert *et al.*[94] suggested that Pt-doping in Ni–Mn-based Heusler alloys improves the performance of these alloys, in particular their magnetocaloric properties.[95] Furthermore, in recent works, models based on first principles have been used to predict a giant electrocaloric effect in $LiNbO_3$ (ref. 96) and both, electrocaloric[97] and elastocaloric[98] effects in $Ba_{0.55}Sr_{0.5}TiO_3$. Computational discovery of new caloric and multicaloric materials not only represents an important step towards the understanding of these properties but also opens up a new route in relation to the development of this class of materials. While this certainly could yield to more efficient solid-state refrigeration devices, care must be taken since by using these numerical techniques it is not easy to have a reasonable estimation of hysteresis effects related to dissipative non-equilibrium aspects which reduce the refrigerant capacity.

Prototype refrigerators are, to a larger extent, based on the thermodynamic Brayton cycle, and the degree of field maturity is different for the several caloric effects: a significant number of prototypes using permanent magnets have already been developed in the case of the magnetocaloric effect (a good compilation can be found in ref. 99), and very recently a refrigerator based on the electrocaloric effect has been reported[100] which uses multilayer capacitors of $BaTiO_3$.[101] With regards to barocaloric and elastocaloric effects the research is still on the early stages.

While recent progress in the development and understanding of multicaloric materials have resulted in significant advances that suggest that solid-state refrigeration can become a reality in a near future, there are still important challenges to overcome both in the basic understanding and design of new materials and in the engineering of prototypes before these technologies become commercially competitive.

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Elastocaloric and barocaloric effects in polyvinylidene di-fluoride-based polymers

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Polyvinylidene di-fluoride-based polymers were investigated for elastocaloric and barocaloric effects. Bulk samples were subjected to uniaxial tensile and hydrostatic loading. Resulting strain profile (function of temperature) was used to predict the temperature change. A peak elastocaloric effect of 1.8 K was observed at 298 K (15 MPa). Alternately, a large barocaloric effect of ~6 K was observed at 300 K (200 MPa). This was further improved to an astounding ~19 K near 368 K (200 MPa). The results of this study are expected to greatly benefit the field of ferroelectric solid-state refrigeration and open another horizon for future exploration of multicaloric effects in ferroelectric polymers. © *2016 AIP Publishing LLC*. [http://dx.doi.org/10.1063/1.4942000]

Micro/nano scale refrigerators are posed to be the next generation cooling/heat pump devices.[1–4] Conventional mechanical refrigeration systems suffer from severe performance degradation upon downscaling from macro-scale.[5,6] Foremost, compressors cannot be scaled down to nano/micro scales. Therefore, there is a dire need to develop suitable alternatives for integrated cooling. Solid state refrigeration could be a prominent solution for on-board cooling as these are compressor free systems.[1,4–6] These work on material's entropy change under an external field. Thermal response is registered in a material (heating/cooling) when subjected to a sudden change of an external field (electric, mechanical, magnetic). This phenomenon is known as the caloric effect (electrocaloric (EC), elastocaloric (eC), magnetocaloric (MC)).[4–6] Some of these techniques (such as MC and thermoelectric) have been well explored by researchers and various designs have been proposed for specialized commercial applications.[7] However, devices based on thermoelectric/magnetocaloric effects have relatively poor coefficient of performance (COP).[1,2,5,6] In order to improve their performance, researchers are now interested in novel materials/efficient design phenomenon which possess either a high COP or the ability to demonstrate multiple or coupled caloric effects to enhance the cooling capacity. In this direction, materials which can demonstrate more than one caloric effect are expected to perform with higher COP when individual caloric effects can be coupled or are made to operate in a crossover.[2,4–6] Multicaloric effect entails coupling of EC, MC, eC, and barocaloric (BC) effects. These caloric effects have been extensively investigated (except BC) in their respective class of materials.[1,6–9] At the forefront of this field, shape-memory alloys have been used to demonstrate eC and MC effects in separate instances.[8–13] However, other classes of materials have not been well explored for multicaloric effects. Recently, few interesting articles have attempted demonstration of eC effects in ferroelectric materials, conventionally reported for EC effects.[8,14–18] In this regards, ceramics such as $PbTiO_3$,[15] $BaTiO_3$,[16] $Ba_xSr_{1-x}TiO_3$,[14] $(Ba_xCa_{1-x})(Zr_yTi_{1-y})O_3$ (BCZTO),[18–20] and $xPb(Mg_{1/3}Nb_{2/3})O_3$–1-$xPbTiO_3$[17] have been studied for stress driven caloric effects. This has sparked interest in the field of ferroelectric solid-state refrigeration through enhanced cooling of coupled caloric effects. However, research in this field is still at its preliminary stage and possibility exists for obtaining rapid improvement in terms of multicaloric cooling capacity. We have previously demonstrated that some classes of ferroelectric materials produce significantly larger temperature drops when subjected to ferroelastic depolarization.[17,18] This effect can easily surpass even the maximum EC cooling capacity within the same material,[18] hence suggesting the existence of large untapped potential of ferroelectric materials for eC cooling applications.

Polyvinylidene di-fluoride (PVDF) and its co-polymers are another important ferroelectric materials reported for giant EC in a wide temperature range.[3] Additionally, PVDF has other advantages such as ease of fabrication (shape), low cost, and low processing temperatures.[3,21] Further, PVDF being a cross-linked polymer (with high crystallinity) promises high potential for eC and BC refrigeration applications. Through this study, we have made an attempt to demonstrate eC and BC effects in PVDF. Such studies have not been reported so far. At this point, it becomes imperative to mention that BC effect has not been thoroughly examined for many material classes. BC effect has an analogy similar to vapor compression cycle, where heating and cooling effects are obtained using fluid compression and expansion. Giant barocaloric effect has been reported in various classes of magnetic materials including shape memory alloys and in one instance for $BaTiO_3$ single crystal.[8–12,22] By general extension, other ferroelectric materials are also anticipated to produce significant BC effect due to polarization change, which is the major component in material's entropy change.[15,22] However, there is a lack of any additional literature reported. Hence, present study also tries to account for estimation of BC cooling effect in ferroelectric PVDF.

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Some modern calorimeters exist which allow simultaneous measurement of thermal parameters under the influence of external stimuli.[3,5,6] This allows for direct and *in situ* measurement of the caloric effects. However, such systems are few, and most predictions are based on results derived from either mean-field theory or Maxwell's relations.[3,5,6] The choice of method for predicting the caloric effects is generally decided by considering two factors: (a) nature of material and (b) availability of experimental data.[23] Indirect assessment has been corroborated with those obtained directly and found to be in good agreement.[23] A few anomalies as recorded resulted often due to incorporation of anhysteretic second order phase transition. Hence in this study, we proceed by using Maxwell's relations as their use is justifiable. Magnitude of eC effect produced can be determined by using the Maxwell's relation for entropy change in ferroelastic (ΔS_{eC}) materials as follows:[16,24]

$$\Delta S_{eC} = -\frac{1}{\rho}\int_{\sigma_1}^{\sigma_2}\left(\frac{\partial \epsilon}{\partial T}\right)_{\sigma} d\sigma. \tag{1}$$

Here, the symbols σ, ϵ, and ρ represent the conventional values of stress, strain, and density, respectively. By determining the isothermal entropy change of the material at any given temperature, the equivalent adiabatic temperature change obtainable (at the said temperature) can be determined by modifying Equation (1)[16,24]

$$\Delta T_{eC} = -\frac{T}{\rho * c_p}\int_{\sigma_1}^{\sigma_2}\left(\frac{\partial \epsilon}{\partial T}\right)_{\sigma} d\sigma, \tag{2}$$

where the symbols T and c_p are used to denote the material's initial temperature and heat capacity, respectively. Equation (2) indicates that a material possessing a large strain gradient with respect to temperature will exhibit a large eC effect. Indeed, some of the largest eC effects have been demonstrated in ferroelastic materials including shape memory alloys and other cross-linked polymers.[2,4,10] The theory behind the origin for eC effects in ferroelectric and other classes of materials has been well reported in the literature.[2,4,16–19,24] Polarization and structural transitions are closely coupled in ferroelectric materials, and hence, it is to be expected that ferroelectric materials will possess elastocaloric effect.[2,4,17,18] On the other hand, reports concerning BC abilities of different material classes are far and few. The Maxwell's relation for estimating BC temperature change in a given material is described as[15,16]

$$\Delta T_{BC} = -\frac{T}{\rho * c_p}\int_{\sigma_1}^{\sigma_2}\left(\frac{\partial \epsilon_v}{\partial T}\right)_{\sigma} d\sigma_v. \tag{3}$$

In Equation (3), all symbols carry their usual meanings and the subscript v stands for volumetric parameters. Most reports concerning BC effects have been documented for magnetic shape memory alloys only,[8–13] with the exception of $BaTiO_3$ single crystal[22] and $PbTiO_3$.[25] However, preliminary results have yielded promising results indicating high cooling capacity near room temperature. This study aims to expand such study to include cooling capacity for PVDF.

In order to prepare the PVDF for mechanical testing, the PVDF granules (MW 530 000) supplied by Sigma Aldrich were melt mixed in Brabender plasticorder (Model: PLE 331) for 15 min at 448 K and then hot pressed at this temperature to obtain a sheet of area 150 mm^2 with 0.3 mm thickness. Hounsfield tensile testing machine (50KN) was used to load the films and obtain the necessary stress-strain data. Temperature was varied using an integrated cryo-chamber. The results for the same are plotted in Figure 1 (0–35 MPa and 298–373 K). To obtain the necessary data for eC measurement, strain was plotted as a function of temperature and tensile stress (0–15 MPa), represented as inset in Figure 1. 15 MPa was selected as the upper limit for the strain data corresponding to the highest elastic limit of the material under the selected parameters. XRD patterns of the PVDF polymer before and after load application are shown in Figure 2(a).

Figure 2(b) describes the strain gradient ($\frac{\partial \epsilon}{\partial T}$) as a function of stress and operating temperature. It can be clearly depicted from the figure that there exists an abrupt change in strain gradient at a temperature of 323 K. This phenomenon is seemingly unaffected by the loading conditions and is common to all stress values. The plot of specific heat as a function of temperature is shown in inset of Fig. 2(b) and has been adopted from a previous publication as reported by Roland *et al.*[26] These data were used in conjunction with Equation (2) to evaluate the eC temperature change profile and the same is depicted in Figure 2(c), while the corresponding entropy change is depicted in Figure 2(d). The ΔT_{eC} appears to increase with the intensity of loading. As the applied stress moves from 7.5 MPa to 15 MPa, the amount of cooling produced more than doubled from 0.7 K to 1.8 K, at 298 K. This stress induced large temperature change is due to significant entropy variation. In PVDF polymer, there could be a number of factors which could contribute towards entropy changes. PVDF can be elastically stretched to several percent which could be a major factor in contributing entropy change due to orientation of polymeric chains. Such a phenomenon is reported in natural rubber where significant elastocaloric effect is reported.[27] It is well documented that PVDF commonly crystallizes in non-polar crystalline α and γ phase[26] which is also evident from Figure 2(a). However, polar phase (β phase) is responsible for ferroelectric behavior. β phase can be induced via mechanical stretching of polymer as depicted in Figure 2(a). From Figure 2(a), it is clear that β phase is formed (along with small fraction of α phase) after elongation. In present study, tensile stretching will be responsible for orientation of polymeric chains and α to β phase transformation. Hence, elastocaloric effect in PVDF is due to change in free volume and structural transformation as well. However, their contribution is not quantified in this study. It is important to note that structural transformation (α/γ to β) can only contribute in caloric applications when it is a reversible transformation. It is only possible when this transformation occurs in the elastic region of PVDF polymer. The cooling capacity decreases with increase in operating temperature and a drastic reduction is observed at the phase transition temperature of 323 K. The prediction is in accordance to the original stress strain curves where this temperature marks a stark decrease in the mechanical strength of the polymer. The reported values are indicative of a large improvement in terms of cooling efficiency of bulk ferroelectric materials. Not only is the

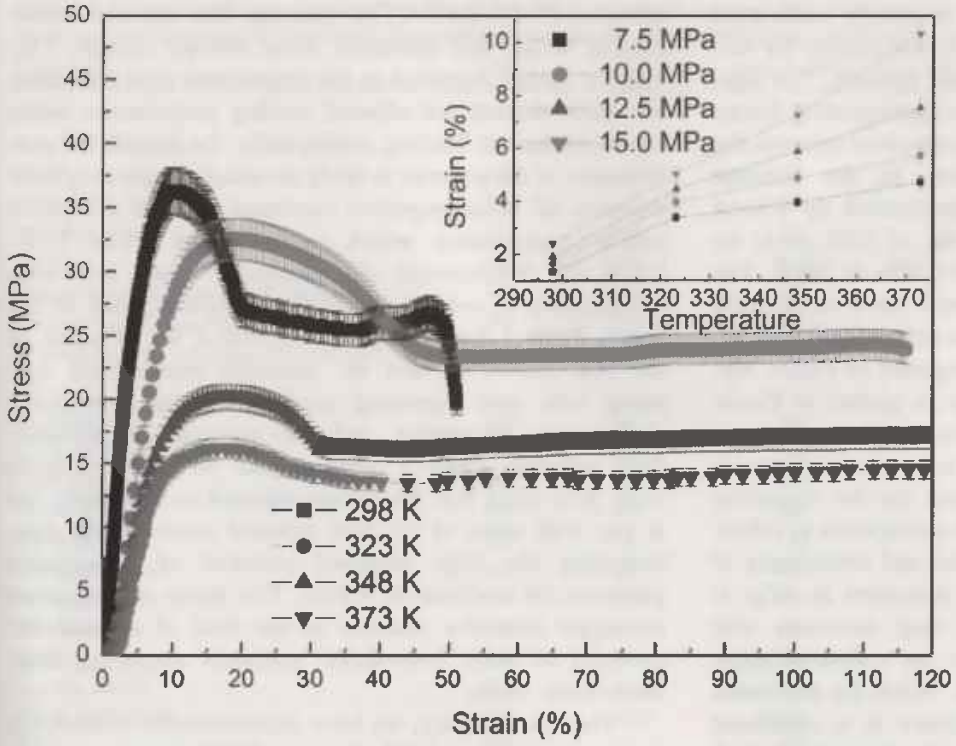


FIG. 1. Stress-strain for PVDF at different temperature. Inset shows stain versus temperature plots.

temperature drop (1.8 K) among the largest eC ever reported in bulk ferroelectric materials, but it has been obtained at a substantially lower value of applied stress (15 MPa) as opposed to 1.5 K reported for BCZTO composition for an applied stress of 250 MPa.[18] Further, the peak temperature change has been achieved closer to room temperature and is relatively insensitive to temperature variation (albeit in a small window of operation). All these results are indicative of a substantial improvement in performance and would help expedite the realization of a practical multicaloric cooling system based on ferroelectric materials. As the value of stress required is small, relatively smaller loading cells can be readily deployed for the purpose. Further, this combined with the already enhanced EC cooling capacity of the polymer will give it definitive edge over other contending materials.

In order to further evaluate the mechanical cooling capacity of PVDF-TrFE-CTFE (trifluoroethylene-chlorotrifluoroethylene), the volumetric stress-strain data were also utilized. Data for the same have been adopted from a previous publication as reported by Roland *et al.*[26] The volumetric strain as a function of stress and temperature so acquired has

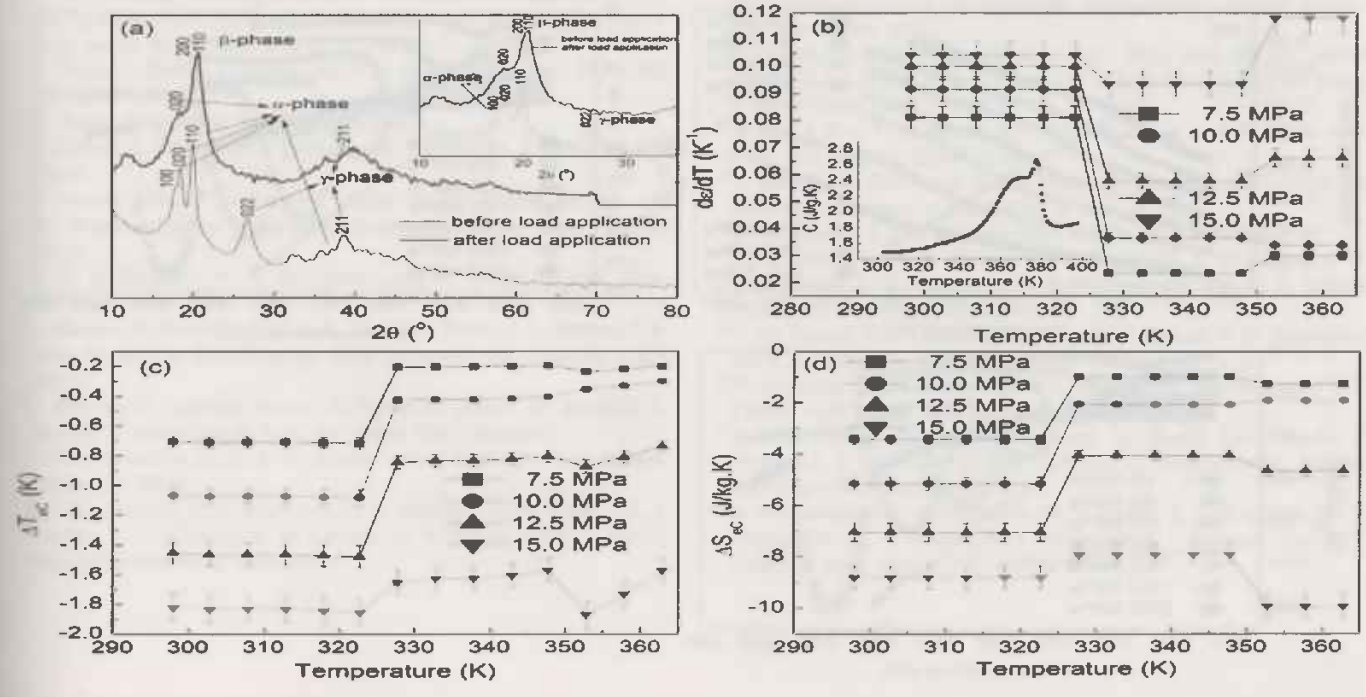


FIG. 2. (a) XRD, (b) dε/dT (inset shows heat capacity c_p), (c) elastocaloric (ΔT_{eC}), and (d) corresponding entropy change (ΔS_{eC}) as a function of temperature at different loading.

been depicted in Figure 3(a). It can be clearly understood from the figure that thermal expansion acts to counter the volumetric strain resulting from hydrostatic pressure. The relationship between the two appears to be approximately linear, as is expected. Further, a small peak is observed between the pressure-volume graphs corresponding to the pressure induced α to β phase change, as documented by Roland *et al.*[26] A maximum volumetric strain of 0.03 could be obtained for an applied pressure of 200 MPa at 298 K. The mass specific heat capacity of the sample has been depicted in Figure 2(b). These data were used to estimate ΔT_{BC} by utilizing Equation (3) and the same is reported in Figure 3(b) and the corresponding entropy change is plotted in Figure 3(c). From Figures 3(a) and 3(b), it can be observed that a small peak corresponding to a large temperature change is observed near the phase transformation for the respective applied pressures. The phase transition corresponds to a drastic change in the mechanical properties and crystallinity of the polymer, and hence, this sudden increment in ΔT_{BC} is expected. Further, the temperature drop increases with increasing pressure, corresponding to the enhanced upper limit of the pressure in Equation (3). While the maximum temperature change for 10 MPa pressure is a significant 1.8 K, the highlight of the result lies at the staggeringly high temperature drop of ~19 K expected near 368 K for an applied pressure of 200 MPa. This value represents an order of magnitude improvement over the other results reported for bulk ferroelectric samples till date. Furthermore, mass specific entropy change also receives a corresponding increment. Even if the peak temperature change is excluded, the polymer, under 200 MPa pressure, can still boast of a substantial temperature drop of 6 K near 300 K (room temperature). Roland *et al.* have reported pressure induced phase transformation (α to β) in PVDF-TrFE-CTFE polymer.[26] It has been documented that hydrostatic pressure can drastically influence PVDF-TrFE-CTFE structure like uniaxial tensile loading which will ultimately boost entropy change. This value is further improved as the temperature rises indicating the much desired self-adjusted cooling performance under enhanced thermal loading. Additionally, the overall BC performance of the polymer is fairly invariant of operating temperature. All these properties combined boast of a superior caloric performance which could propel PVDF-TrFE-CTFE for development of ferroelectric based solid-state refrigerators. In order to highlight the ramifications of the result, Table I has been provided with a list of some of the best known eC and BC materials reported till date along with their operating conditions, input normalized performance parameters, and the maximum temperature drop reported. Table I contains data for bulk materials only. It is clear that the values reported in this study are at par with some of the best reported materials till date, indicating the huge untapped potential of ferroelectric polymers for multicaloric effects. This study is also aimed to trigger extensive research in the field of eC and BC potential of other ferroelectric polymers displaying large recoverable strain.

Thus in summary, we have experimentally (indirectly) demonstrated eC and BC effects in PVDF-based polymers. Remarkably large elastocaloric response (ΔT_{eC} of 1.8 K) was observed under a tensile loading of 15 MPa at room temperature (298 K). Alternately, a large BC temperature change of ~6 K was observed near room temperature for an applied hydrostatic pressure of 200 MPa. This value was improved by an order of magnitude to an astounding ~19 K near the phase transition temperature of 368 K. The results of this study are expected to benefit greatly the field of ferroelectric solid-state refrigeration and open another horizon for future exploration of the regime of multicaloric effects in ferroelectric polymers.

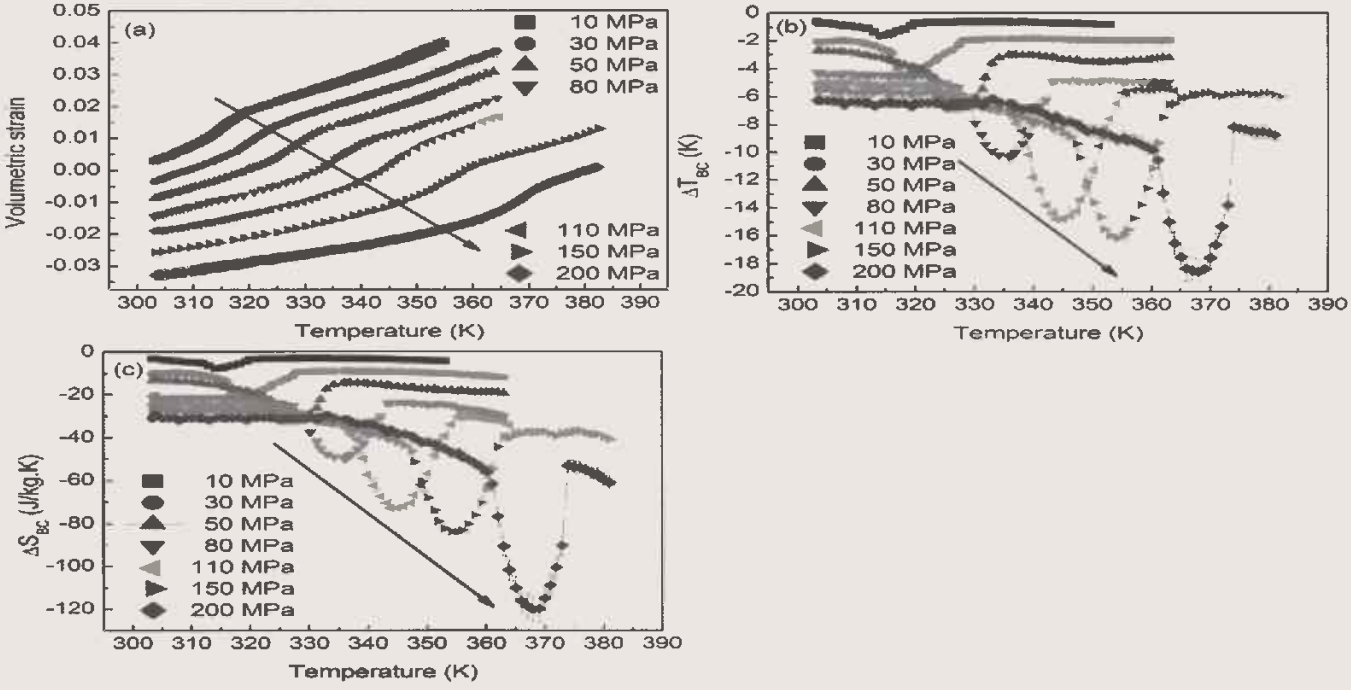


FIG. 3. (a) Volumetric strain, (b) barocaloric (ΔT_{BC}), and (c) corresponding entropy change (ΔS_{BC}) as a function of temperature under different hydrostatic pressure level.

TABLE I. Comparison of elastocaloric (eC) and barocaloric (BC) properties for various class of materials.

Compound	T (K)	ΔT (K)	$\sigma/p(\sigma_v)$ (MPa)	$(\Delta T/d\sigma)/(\Delta T/dp)$ (mK MPa^{-1})	References
eC					
$Ba_{0.5}Sr_{0.5}TiO_3$	250	9	1000	9	14
PVDF	298	~1.8	15	120	Present work
PMN-32PT	323	0.36	28	12.8	17
$BaTiO_3$	401	3.2	200	16	16
$PbTiO_3$	750	20	1000	20	15
$(Ba_{0.85}Ca_{0.15})(Zr_{0.1}Ti_{0.9})O_3$ (at 2MV m^{-1})	340	1.5	250	6	18
$(Ba_{0.865}Ca_{0.135}Zr_{0.1089}Ti_{0.8811}Fe_{0.01})O_3$	298	1.4	200	7	19
$(Ba_{0.865}Ca_{0.135}Zr_{0.1078}Ti_{0.8722}Fe_{0.01}Nb_{0.01})O_3$	298	1.17	200	5.85	20
BC					
$Rb_2KMoO_3F_3$	200	16	500	32.00	12
La-Fe-Co-Si	230	2.2	210	10.48	9
$Gd_5Si_2Ge_2$	267	1.2	200	6.00	13
Ni-Mn-In	291	4.5	260	17.31	10
MnAs (at 1 T)	300	20	150	133.33	11
$Li(Fe_{0.89}Si_{0.11})_{13}$	150	16	450	35.56	8
$Li(Fe_{0.89}Si_{0.11})_{13}$ (at 5 T)	170	13.8	450	30.67	8
Ni–Mn–In	350	3-4	250	14.00	28
$BaTiO_3$	305	3	2000	1.50	22
$La_{0.7}Pb_{0.3}MnO_3$	339	1.1	400	2.75	29
PVDF-TrFE-CTFE	368	~18.6	200	93	Present work
$PbTiO_3$	758	2.2	30	73.33	25

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Thermodynamic Study of Some Neopentane Derivated by Thermobarometric Analysis

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By using a metabolemeter, the phase behaviour under pressure of five plastic crystals derivated from Neopentane have been studied. The analysed compounds have been: 2,2-dimethyl, 1,3 propanediol (NPG), 2-hydroxymethyl-2 methyl, 1,3 propanediol (PG), 2-amino, 2-methyl, 1,3 propanediol (AMP), tris(hydroxymethyl-aminomethane (TRIS) and 2-methyl, 2-nitro, 1-propanol (MNP). The pressure–temperature phase diagrams have been established. The molar volume changes for both solid to plastic and plastic to liquid first order phase transitions have been determined.

1. INTRODUCTION

There are very few data relating to the molar volume changes at atmospheric pressure and pressure-temperature dependence for the phase transitions of compounds formed by tetrahedral molecules characterized by orientationally disordered phases (ODIC) or plastic phases [1]. Such disorder is most readly observed with globular compounds (as tetrahedral molecules) or cyclic compounds—so-called "Plastic Crystals"—, because of their relative ease of reorientational motion. In the last decade an extensive and systematic work has been developed over basically the cyclic compounds by A. Würflinger and G. M. Schneider [2–12] in order to characterize thermodynamically the compounds and to study the dielectric behaviour, both as a function of temperature and pressure parameters.

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In the present work we report on the pressure dependence of the phase behaviour of some Plastic Crystals established with the aid of a thermobarometric method, which has been recently used to study the phase behaviour under pressure of "Liquid Crystals" i.e., disk-like mesogens [13], pyramidic mesogens [14] and rodlike mesogens (pures [15,16] or in binary mixtures [17]).

For compounds derived from Neopentane $C(CH_3)_4$, (plastic crystals studied in this work), the high symmetry of the molecular shape enables an interesting comparison with other related compounds for which some pressure-temperature data have been given recently [18–21].

The molar volume change associated to the first order phase transitions determined by the thermobarometric method will be compared to the calculated values by the extrapolation of the volume expected for the related phases at the transition temperature, from X-ray diffraction measurements, when available literature data are known.

2. EXPERIMENTAL DEVICE

The thermobarometric measurements have been performed by means of an automatic metabolemeter [22]. The details of the method (simultaneous recording of pressure of a small sample enclosed in a metallic cell as a function of temperature) interpretation and exploitation of thermobarograms and experimental procedures have been described elsewhere [15, 23].

The first order phase transitions are accompanied by a sudden increase in pressure as a function of the temperature; the slope $(dP/dT)_e$ at the transition given by the Clausius–Clapeyron relation

$$\left(\frac{dP}{dT}\right)_e = \frac{\Delta H}{T \cdot \Delta V}$$

enables us to calculate the associated molar volume change ΔV at atmospheric pressure, where the enthalpy variation ΔH and the temperature T of the transformation are well established. Outside of the transition domain, the slope of the thermobarogram $(dP/dT)_v$ is [23]

$$\left(\frac{dP}{dT}\right)_v = \frac{\alpha}{\chi}$$

where α is the isobaric thermal expansion coefficient and χ is the isothermal compressibility coefficient of the analysed phase.

The working range of the equipment used is 273–490 K and 0–120 MPa in temperature and pressure respectively. The heating and cooling rates used in this work have been $2\,K \cdot min^{-1}$. The extrapolated temperatures of the phase transitions at atmospheric pressure, match up within the experimental (± 2 K) error with those determined previously by thermal analysis.

3. SUBSTANCES

The studied compounds have been some members of the Neopentane ($C(CH_3)_4$) derivated series. From this compound, four series are typically well known, giving plastic crystal compounds. The first series can be obtained from the substitution of $-CH_3$ group by $-CH_2OH$ group. That is to say, $(CH_3)_{4-n1}C(CH_2OH)_{n1}$. For this series, the members $n_1 = 2$, NPG (2,2-dimethyl, 1,3 propanediol) and $n_1 = 3$, PG (2-hydroxymethyl-2 methyl, 1,3 propanediol) have been studied and will be compared to the compound $n_1 = 1$, NPA (2,2-dimethyl, 1-propanol) studied previously [24]. The temperatures of transition and melting processes of the last member of this series $n_1 = 4$, PE (2,2-Bis(hydroxymethyl), 1,3-propanediol) are outside of the working range. All members of this series show a plastic (face centered cubic [25]) phase before the melting process.

The second series is obtained from the substitution of a $-CH_3$ group by the $-NH_2$ group, and the successive substitution of methyl groups by hydroxymethyl group. Then, the series is $(NH_2)(CH_3)_{3-n2}C(CH_2OH)_{n2}$; the two first members, $n_2 = 0$ and $n_2 = 1$, do not show a plastic phase [26]. The two next members studied in this work, are $n_2 = 2$, AMP (2-Amino, 2-methyl, 1,3 propanediol) and $n_2 = 3$, TRIS (Tris(hydroxymethyl-aminomethane), which plastic phases are known to be body centered cubic [25, 27].

The next series is generated in a similar way, but by the substitution of a $-NO_2$ group, giving $(NO_2)(CH_3)_{3-n3}(CH_2OH)_{n3}$ series; in this case the compound studied has been $n_3 = 1$, MNP (2-methyl,2-nitro,1-propanol), and can be compared to the compound corresponding to $n_3 = 0$, MN (2-methyl, 2-nitro propane), which phase behaviour under pressure has been described previously [18]. The last series can be obtained by the introduction of a carboxyl group (COOH), i.e., $(COOH)(CH_3)_{3-n4}C(CH_2OH)_{n4}$. Any member of this series has been analysed, but the results obtained by Chihara and co. [19] for the compound corresponding to $n_4 = 0$, PA (2,2-dimethyl propanoic acid), will be used in order to include more information.

Obviously, additional substitutions of the $-CH_3$ group can be performed using other different groups as $-C_2H_5$ (e.g., Neohexanol $(C_2H_5)(CH_3)_2C(CH_2OH)$ [28] or 1,1,1 Tris(hydroxymethyl)propane $(C_2H_5)C(CH_2OH)_3$, [29]. Only in some cases [28] the thermodynamic PVT data are reported in the literature.

The compounds have been purchased from Aldrich Chemical Company with purities of NPG 99%, PG 99%, MNP 99%, AMP 99% and TRIS 99,9 + %. In order to eliminate the residual humidity, the compounds have been dried by vacuum sublimation at different temperatures.

4. RESULTS

4.1. Thermobarograms

In Figures 1a and 1b are given examples of thermobarograms obtained for the solid II (monoclinic structure [30]) to plastic I (fcc lattice [31]) and for the plastic I to liquid L phase transitions, respectively, for NPG compound. Figure 1a shows clearly the

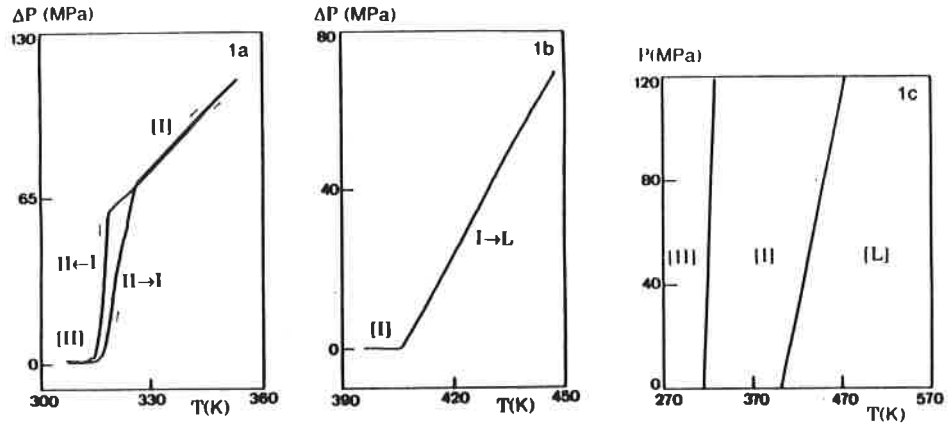


FIGURE 1 Experimental thermobarograms showing for NPG, $n_1 = 2$, $(CH_3)_2C(CH_2OH)_2$ the solid II to plastic I phase transition (on heating and cooling (a)) and the plastic I to liquid L process (b) and Pressure–Temperature phase diagram (c).

reversibility of the solid state transformation but with a weak undercooling under pressure. In both cases, very clear pressure changes (characteristic of the first order phase transitions [23]) are shown.

Figures 2a and 2b show two typical thermobarograms obtained for PG and corresponding respectively to the solid II (body centered tetragonal [32] to plastic *I* (fcc lattice [33]) and I to L transitions.

For AMP, three characteristic thermobarograms obtained experimentally are presented in Figures 3a (solid–plastic phase transition on heating and cooling) and 3b (melting process). From Figure 3a, on heating, the solid state transformation is clearly

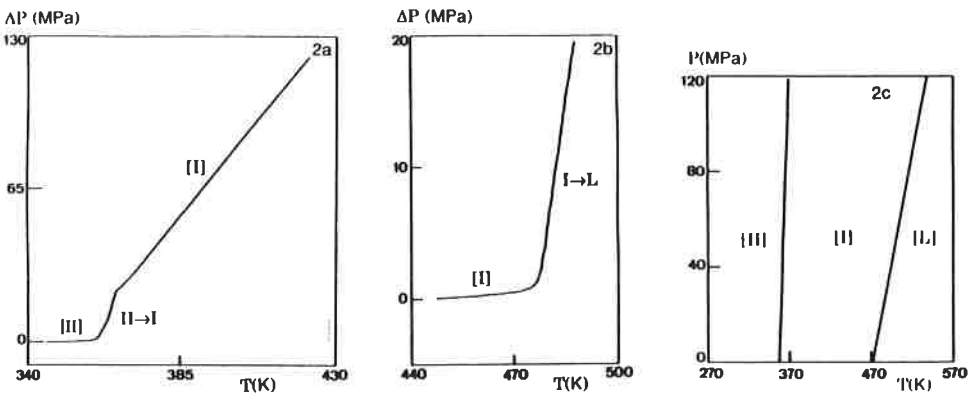


FIGURE 2 Experimental thermobarograms showing for PG, $n_1 = 3(CH_3)C(CH_2OH)_3$ the solid II to plastic I phase transition (a) and the plastic I to liquid L process (b) and Pressure–Temperature phase diagram (c).

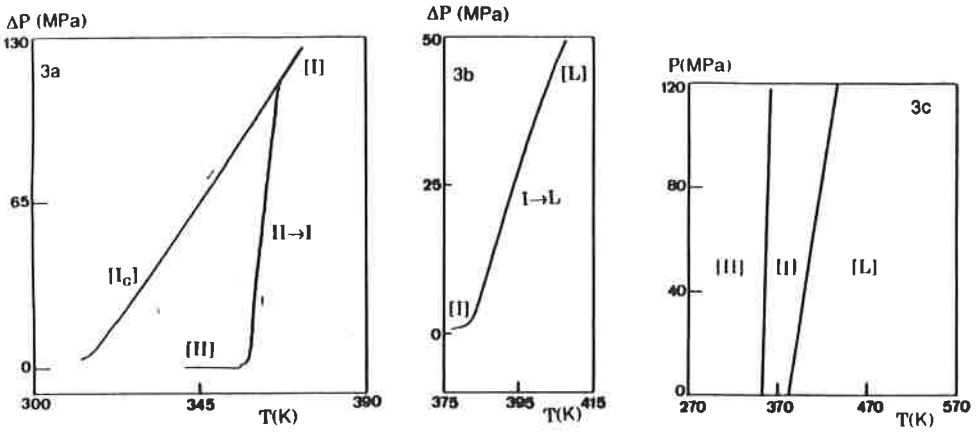


FIGURE 3 Experimental thermobarograms for AMP, $n_2 = 2$, $(NH_2)(CH_3)C(CH_2OH)_2$ on heating (solid II to plastic I phase transition) and cooling (the reversible transition is absent in the range of temperature studied) (a) and the plastic I to liquid L process (b) and Pressure–Temperature phase diagram (c).

of first order. However, on cooling, no reversible transition is obtained. This fact is due to undercooling of the plastic phase that leads to a glassy plastic phase I at low temperatures [34, 35]. More work (outside of the scope of this paper) must be performed in order to determine the glassy temperature transition at different pressures.

Figures 4a and 4b are representative of typical thermobarograms for TRIS in the solid state transition (orthorhombic to bcc) and in the melting process.

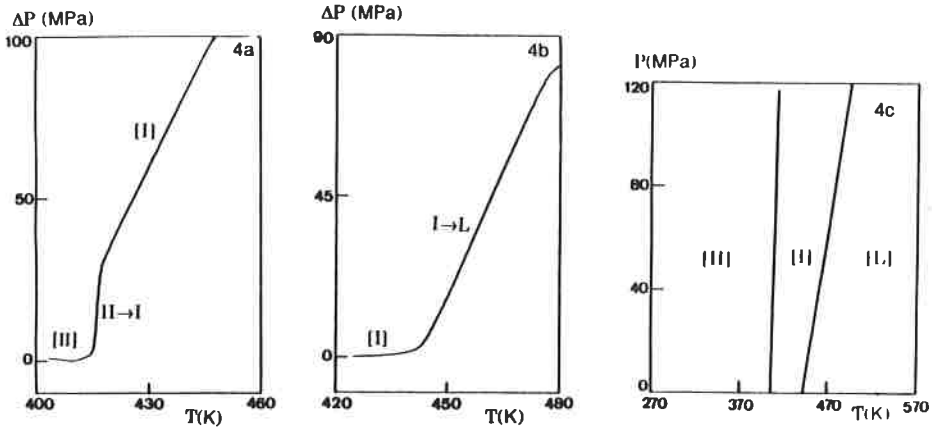


FIGURE 4 Experimental thermobarograms showing for TRIS, $n_2 = 3$, $(NH_2)C(CH_2OH)_3$ the solid II to plastic I phase transition (a) and the plastic I to liquid L process (b) and Pressure–Temperature phase diagram (c).

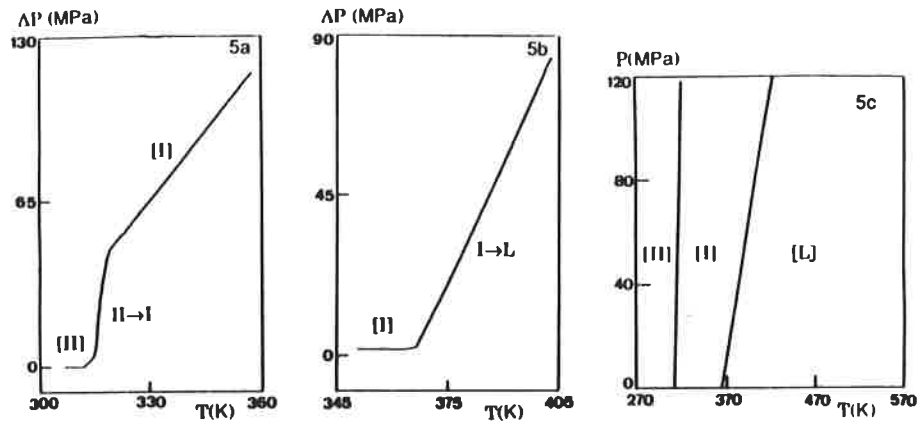


FIGURE 5 Experimental thermobarograms showing for MNP, $n_3 = 1$, $(NO_2)(CH_3)_2C(CH_2OH)$ the solid II to plastic I phase transition (a) and the plastic I to liquid L process (b) and Pressure–Temperature phase diagram (c).

Characteristic curves related to the solid–plastic transition and to the melting process for MNP compound are given in Figures 5a and 5b respectively.

4.2. Phase Diagrams

For each studied compound, the pressure-temperature phase diagram, deduced from the thermobarograms, has been given. It is interesting to note that, for all the compounds, the application of pressure displaces the region of the existence of the plastic phase to a higher and a wider temperature range, because of the difference between the data of the slopes of the P–T phase diagram for the solid–plastic and plastic–liquid equilibria. On the other hand, in not one of the studied compounds, an additional intermediate phase generated by the pressure (as in other plastic compounds [2, 9, 20, 21, 28]) has been found.

4.3. Thermodynamic Data

Literature data for the temperature, entropy and enthalpy changes at the II–I and I–L transitions are reported in Table 1 for the studied compounds, i.e., NPG, PG, AMP, TRIS and MNP and for the compounds used for comparison, i.e., NPA, MN and PA. Experimental data for the equilibrium curves $(dP/dT)_e$ of the P–T phase diagrams and molar volume changes for both transitions (calculated from Clausius–Clapeyron relation) are given in Table 1.

From the slope of the thermobarogram in the plastic domain, the ratio (α/χ) can be deduced (see Table 2). Using literature data of the isobaric thermal expansion coefficient, the isothermal compressibility coefficient (χ) has been calculated and is given in Table 2.

TABLE I

Literature data for the temperature T(K), enthalpy $\Delta H(kJ \cdot mol^{-1})$ and entropy variations $\Delta S(J \cdot mol^{-1} \cdot K^{-1})$ at the solid–plastic (II–I) and plastic–liquid (I–L) phase transitions measured by thermal analysis; experimental data for the equilibrium curves (dP/dT) $(MPa \cdot K^{-1})$ of the pressure–temperature phase diagrams and molar volume changes $(cm^3 \cdot mol^{-1})$ for the transitions calculated from Clausius Clapeyron relation (ΔV) and from X-Ray diffraction literature data extrapolated at the transition temperature (ΔV^+)

NPA ($n_1 = 1$)	II–I	I–L	Reference
T(K)	236.5	331.4	[24]
$\Delta H(kJ \cdot mol^{-1})$	4.0	3.9	[24]
$\Delta S(J \cdot mol^{-1} \cdot K^{-1})$	16.9	11.8	[24]
$(dP/dT)_\theta$ $(MPa \cdot K^{-1})$	4.22	1.49	[24]
$\Delta V(cm^3 \cdot mol^{-1})$	4.01	7.90	[24]
NPG ($n_1 = 2$)	**II–I**	**I–L**	**Reference**
T(K)	314.6	401.3	[25]
$\Delta H(kJ \cdot mol^{-1})$	12.8	4.4	[25]
$\Delta S(J \cdot mol^{-1} \cdot K^{-1})$	40.6	10.8	[25]
$(dP/dT)_\theta$ $(MPa \cdot K^{-1})$	8.36	1.63	
$\Delta V(cm^3 \cdot mol^{-1})$	4.86	6.63	
$\Delta V^+(cm^3 \cdot mol^{-1})$	4.89	–	
PG ($n_1 = 3$)	**II–I**	**I–L**	**Reference**
T(K)	357.5	471.7	[36]
$\Delta H(kJ \cdot mol^{-1})$	21.3	5.1	[36]
$\Delta S(J \cdot mol^{-1} \cdot K^{-1})$	59.5	10.8	[36]
$(dP/dT)_\theta$ $(MPa \cdot K^{-1})$	9.71	1.79	
ΔV $(cm^3 \cdot mol^{-1})$	6.13	6.03	
$\Delta V^+(cm^3 \cdot mol^{-1})$	6.09	–	
AMP ($n_2 = 2$)	**II–I**	**I–L**	**Reference**
T(K)	352.6	382.4	[25]
$\Delta H(kJ \cdot mol^{-1})$	23.3	2.83	[25]
$\Delta S(J \cdot mol^{-1} \cdot K^{-1})$	66.2	7.40	[25]
$(dP/dT)_\theta$ $(MPa \cdot K^{-1})$	13.08	2.18	
ΔV $(cm^3 \cdot mol^{-1})$	5.06	3.39	
$\Delta V^+(cm^3 \cdot mol^{-1})$	4.87	–	
TRIS ($n_2 = 3$)	**II–I**	**I–L**	**Reference**
T(K)	406.8	442.7	[36]
$\Delta H(kJ \cdot mol^{-1})$	34.0	3.15	[36]
$\Delta S(J \cdot mol^{-1} \cdot K^{-1})$	83.7	7.12	[36]
$(dP/dT)_\theta$ $(MPa \cdot K^{-1})$	16.50	2.27	
$\Delta V(cm^3 \cdot mol^{-1})$	5.07	3.14	
$\Delta V^+(cm^3 \cdot mol^{-1})$	4.47	–	[27]
MN ($n_3 = 0$)	**II–I**	**I–L**	**Reference**
T(K)	260.1	299.2	[18]
$\Delta H(kJ \cdot mol^{-1})$	4.66	2.59	[18]
$\Delta S(J \cdot mol^{-1} \cdot K^{-1})$	17.9	8.66	[18]
$(dP/dT)_\theta$ $(MPa \cdot K^{-1})$	7.65	2.5	[18]
ΔV $(cm^3 \cdot mol^{-1})$	2.34	3.46	[18]
MNP ($n_3 = 1$)	**II–I**	**I–L**	**Reference**
T(K)	312.0	364.1	[25]
$\Delta H(kJ \cdot mol^{-1})$	15.0	3.28	[25]
$\Delta S(J \cdot mol^{-1} \cdot K^{-1})$	48.1	9.00	[25]
$(dP/dT)_\theta$ $(MPa \cdot K^{-1})$	12.30	2.02	
$\Delta V(cm^3 \cdot mol^{-1})$	3.90	4.46	

TABLE I (*Continued*)

PA ($n_4 = 0$)	II–I	I–L	Reference
T(K)	≈279	309.7	[19]
ΔH(kJ·mol^{-1})	–	2.0	[19]
ΔS(J·mol^{-1}·K^{-1})	25.5	6.5	[19]
$(dP/dT)_e$ (MPa·K^{-1})	3.26	2.22	[19]
ΔV (cm^3·mol^{-1})	7.82	2.93	[19]

TABLE II

Literature Data of the Isobaric Thermal Expansion Coefficient (α), (a:[37], b:[25], c:[27]) Experimental Ratio (α/χ) and Calculated Isothermal Compressibility Coefficient (χ) in the Plastic Phase.

Compound	$\alpha(10^3\,K^{-1})$	(α/χ) (MPa·K^{-1})	$\chi(10^9\,Pa^{-1})$
NPG ($n_1 = 2$)	1.91[a]	1.51	1.265
PG ($n_1 = 3$)	1.50[b]	1.65	0.91
AMP ($n_2 = 2$)	1.28[b]	2.06	0.62
TRIS ($n_2 = 3$)	1.23[c]	2.13	0.58
MNP ($n_3 = 1$)	0.975[b]	1.65	0.59

5. DISCUSSION

5.1 $(CH_3)_{4-m}C(CH_2OH)_m$ Series.

For NPG the knowledge of the structure at the low temperature solid phase [25] and the mentioned thermal expansion of the high temperature plastic phase [37], enables us to calculate the molar volume change at the solid to plastic phase transition (at atmospheric pressure) by extrapolation of the lattice volume at the transformation temperature. As we can see in Table 1, this extrapolated value and the corresponding to the thermobarometric method used in this work match up satisfactorily.

For the PG ($n_1 = 3$) the solid (body centered tetragonal [32]) and the plastic (fcc lattice [33]) phases of PG have been studied by X-ray powder diffraction at different temperatures by Barrio [25], and then, the molar volume change at the transition temperatures can be easily calculated. The agreement between this extrapolated value at the transition temperature and the calculated from the Clausius–Clapeyron relation in this work is again very good.

The literature values of NPA ($n_1 = 1$) compound [24] are included in Table 1 in order to compare to the other compounds of this series. As we can easily observe from that table, the values of the temperature, enthalpy, entropy and volume variations, and the equilibrium slopes $(dP/dT)_e$ increase when the methyl (—CH_3) groups are substituted by the hydroxyl (—CH_2OH) group. The increasing of the temperature and ΔH values (and consequently ΔS) are explained taking into account that the solid low temperature phase is characterized by a hydrogen bonded network produced by the —CH_2OH groups [38]. Then, the higher number of n_1, i.e., the number of the hydrogen bonds, the higher energy and temperature is required to enable the reorientational motion in the high temperature plastic phase. Moreover, for the next member PE ($n_1 = 4$) which

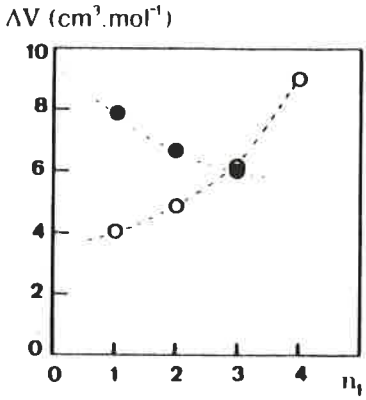


FIGURE 6 Volume change ΔV values for the solid to plastic phase transition (○) and plastic to liquid process (●) versus the number of hydroxyl —CH_2OH groups (n_1) corresponding to the $(CH_3)_{4-n1}C(CH_2OH)_{n1}$ series.

transition temperatures are outside of the working range, the molar volume change at the solid to plastic phase transition, can be obtained from the available X-ray powder diffraction reported data [25]. The calculated value is about $9.0\,cm^3 \cdot mol^{-1}$. For this series the volume changes at the solid state transition and at the melting process are plotted versus of the number of hydroxyl groups (n_1) in Figure 6. As we can clearly see, the similarity between the molar volume of the plastic and liquid phases increases when n_1 does; on the contrary, the molar volumes of the solid and plastic phases are, when n_1 increases, more different.

On the basis of the extended Pople and Karasz theory [39, 40] by Amzel and Becka [41] for rotational phase transitions and fusion of molecular crystals with orientational degrees of freedom, the volume changes on melting and for the solid–solid transition can be discussed as a function of the key parameter v. This parameter is a measure of the relative energy barriers for the rotation of the molecule and for its diffusion to an interestitial site. According to the preceding theory, the relative volume change on melting decreases, whereas for the solid–solid transition increases with v. Moreover, another interesting feature of the extended theory is that the volume changes at the solid–solid transition become larger than that on melting when $v > 0.28$. For the present series, a similar behaviour (see Figure 6) is found when analysing the volume changes as a function of n_1. Thus, on the basis of the same behaviour, n_1 may be correlated with v, and then the barrier to reorientation increases more than the barrier to diffusion for an increase in n_1. This assumption would yield high values of the reorientation barrier of the molecules with a higher number of groups with possibility of the formation of the hydrogen bond (CH_2OH group). Unfortunately, nuclear magnetic resonance studies, yielding experimental values for the energies of the reorientation and for the self-diffusion barriers, have not been performed in this series. However, we want to point out that in the case of the pivalic acid PA ($n_4 = 0$), the high values of the volume and the enthalpy of activation for molecular reorientation have been rationalized by the assumption of the formation of dimers (by hydrogen bond) in the plastic phase [19].

5.2. $(NH_2)(CH_3)_{3-n2}C(CH_2OH)_{n2}$ Series

For AMP ($n_2 = 2$), the lattice structure of the low temperature phase II was earlier determined as monoclinic [34]. The parameters at different temperatures of this phase, together with those of the high temperature bcc plastic phase have been also determined [25]. These results allow to calculate, by extrapolation, the molar volume change at the transition temperature and at atmospheric pressure; the obtained value ($4.87\,cm^3 \cdot mol^{-1}$) approaches the value obtained by the thermobarometric method in this work ($5.06 cm^3 \cdot mol^{-1}$).

For TRIS ($n_2 = 3$), the high values of the entropy change and the slope of the low temperature (orthorhombic [27]) phase and plastic equilibrium curve (the higher of the studied compounds), provide a value of the molar volume change ($5.07\,cm^3 \cdot mol^{-1}$) very similar to the previous compound of this series (AMP). The lattice parameter-temperature dependence has been well determined by X-ray single crystal diffraction by Elierman and co. [27]. The same authors have calculated, also by extrapolation at the transition temperature, the volume change associated, reporting a value of $4.47\,cm^3 \cdot mol^{-1}$ (see Table 1). In this case, a disagreement (12%) is found between this reported value and the determined here. However, the same authors [27] pointed out that in order to obtain reliable values of ΔV, using X-ray diffraction techniques, by extrapolation to the values expected at the transition temperature, more measurements should be performed; so that, the reported values has to be considered with a 30% of uncertainty.

In this series, a similar behaviour with the previous one is found when the temperatures, enthalpy changes and slope equilibria are compared. However, the volume changes are very close, being nearly independent of the hydroxyl group number (n_2).

As Table 2 presents, the values of (α/χ), α and χ are very similar for the compounds of this amino series, although in this case the lattice of the plastic phases are bcc, with regard to the previous one where are know to be fcc.

5.3. $(NO_2)(CH_3)_{3-n3}C(CH_2OH)_{n3}$ Series

For MNP, the structure of the low temperature solid phase is not known and, then the molar volume change at the solid to plastic phase transition determined in the present work can not be compared.

The literature reported values of MN ($n_3 = 0$) (see Table 1), when compared with those obtained for MNP, show a similiar behaviour that in the other series. However, the molar volume changes associated to the II–I phase transition are lower. Different crystal interactions in the two solid phases of MN and MNP must be reflected in the latter difference of the molar volume change.

5.4. $(COOH)(CH_3)_{3-n4}C(CH_2OH)_{n4}$ Series

Although any member of this series has been studied here, the previously reported values for the PA compound ($n_4 = 0$) [19] have been included in order to compare them with our results. The characteristic thermodynamic values for PA, which are included in Table 1, show that the slope of the equilibrium transition is low as compared to the

previously given for the other compounds. This fact also produces a very high volume change at the transition ($7.82\,cm^3 \cdot mol^{-1}$, i.e., about 8.4% of the molar volume of the low temperature phase). On the contrary, the slope at the melting equilibrium is not so different from the others, although the associated volume change in this process is low.

6. CONCLUSION

The metabolèmeter, previously used to determine phase changes under pressure on liquid crystals, has been used, for the first time, to study the first order phase transformations on plastic crystals.

Five compounds belonging to three series derivated from the Neopentane have been studied. The extrapolation at atmospheric pressure of the phase transition temperatures (solid to plastic and plastic to liquid) gives satisfactory values when compared to the determined values by thermal analysis.

Data for the isothermal compressibility coefficients have been calculated for the plastic phases. Values ranged from 1.265 to $0.58\,(GPa)^{-1}$ have been found. Similar values have been previously reported for other plastic phases [18, 42, 43].

The molar volume changes of the transitions at atmospheric pressure have been calculated by means of the Clausius Clapeyron relation. When the literature reported values of the lattice volumes for both solid and plastic phases are known, the calculation by extrapolation at the transition temperature of the volume change and our results agree, in general, satisfactorily. We would like to emphasize the point that in order to obtain reliable values of volume change by means X-ray diffraction techniques, one should know the molecular volume at several temperatures and with a good accuracy, in order to be able to extrapolate to the volumes expected at the transformation point.

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