

*A
History
of the
Photographic Lens*

Rudolf Kingslake

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Photographic Lens*

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Rochester, New York*



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PREFACE

My interest in lens design began while I was still a schoolboy on reading a book of my father's entitled *Photographic Lenses: A Simple Treatise*, by C. Beck and H. Andrews, published about 1907. In this book were several sectional diagrams of lenses with graphs of astigmatism and field curvature, which I did not fully understand. However, the seed was sown, and when the time came to go to college I immediately chose the Imperial College of Science and Technology, in London, where there was a course of lectures on lens design given by Professor A.E. Conrady.

Later, in 1929, after holding a couple of smaller jobs in England, I was offered an assistant professorship at the newly established Institute of Applied Optics at the University of Rochester, which I immediately accepted. After another eight years an opportunity for further advancement came when I was chosen to succeed C.W. Frederick as head of the lens design department at the Eastman Kodak Company, from which I retired in 1968, 31 years later.

So, the history and design of photographic lenses has been my major interest for nearly seventy years. It is a fascinating subject, involving inevitably the greatest pioneers of lens design, Petzval, Dallmeyer, Rudolph, Taylor, Lee, Bertele, and more recently Naumann, plus numerous living designers that I have not included here. It is, of course, impossible to mention all of the thousands of different lenses that have been developed during the 150 years since photography was introduced, nor is it possible to include the hundreds of men who have worked laboriously to improve photographic objectives, but I have tried to summarize the major developments in this field, with a few minor ones as well.

It is hoped that the story given here will be of interest to those photographers who desire to know more about their equipment and how it came to be developed.

Rudolf Kingslake
June 1989

CHAPTER 1

Introduction

The science and art of photography have been thoroughly documented throughout its history. Many writers have been attracted to this subject, and innumerable photographic books and journals have flourished since the announcement of Daguerre's invention in 1839. The photographic lens has by no means been neglected; several books on this subject have been particularly useful to the historian (see Section VII). Nevertheless, it remains true that the lens is generally the most expensive and least understood part of any camera.

Of course, ordinary photographers have no difficulty in taking excellent photographs without knowing anything about the construction of their equipment. Most workers distinguish completely between the artistic and technological aspects of the subject. A similar situation exists in many other aspects of modern life. For example, how many users are familiar with the internal construction of their radio, typewriter, watch, TV set, calculator, or even ordinary motor engine? Yet these things are used all the time by people who know nothing about them, and in many cases they couldn't care less. Nevertheless, there are some who are anxious to know more about their tools and instruments. It is to these people, and to the growing number of collectors of cameras and other photographica, that this book is directed.

I. LENS DESIGN

Lens design is far from a simple matter. The function of a lens is to take a bundle of rays emanating from a single object point and bend each ray by just the right amount in just the right direction to make all the rays meet again exactly at the corresponding point in the image. As if this were not difficult enough, the image point in question must lie on a flat plane (the surface of the plate or film), and the magnification (i.e., the ratio of the image height to the object height) must be constant over the entire field of view. In addition, the rays in all colors must be made to meet together, in spite of the fact that the refractive index of all transparent substances varies from one color to another.

If a young engineer were presented with this problem in its complete form, he or she would at once declare it to be hopelessly difficult, if not insoluble. Indeed, most of the opticians existing when photography was introduced had no idea how to design a lens that would cover a wide flat field, as this problem had never arisen. Yet we know that excellent photographic lenses have been designed and manufactured for over 140 years. The explanation is, of course, that lens designers approached the problem in steps. The earliest objectives were single elements in which the shape and stop position of the lens were chosen in such a way as to optimize the image quality over the field. Then it was found necessary to achromatize the system, and cemented doublets were introduced. Next, distortion was found to be a problem, so a pair of identical elements were mounted on each side of a central stop to remove it. Astigmatism was found to be the principal remaining defect and, by 1890, means had been found to eliminate it, and so on.

Fortunately, there are several laws governing lens behavior that the designer soon learns and that are of inestimable value to him in solving what would otherwise be an impossible problem. For instance, he soon finds that symmetry about a central stop has the effect of automatically correcting three difficult aberrations (see Chapter 4, I), for which reason symmetrical lenses remained popular for nearly a hundred years. He also finds that the astigmatism in an image is controlled by a theorem named after Petzval, which will be discussed in Section B. With these and other well-known optical laws before him, a designer finds that the determination of lens structure becomes much simpler, and in due course he can produce a design that promises to be good enough to justify making up a sample for testing. Actually, very few lenses are found to be perfect at this first trial, and a continuing series of changes and new developments follow,

resulting in either a satisfactory design or a decision to abandon the attempt and try something different.

In retrospect, it is hard to understand why the development of a good camera lens was such a slow process, especially between the years 1840 and 1890. The mechanical skill of some of the earlier lens manufacturers was remarkable, and many historical lenses show evidence of excellent design and construction. (Other lenses, unfortunately, are sometimes so bad that one wonders how they could have been used at all.) We are driven to the conclusion that the lens designers of the day were slow to learn and apply the theory of lenses as developed by Gauss, Petzval, von Seidel, and others. Opticians were far too willing to make empirical trials and put together a series of lens elements, hoping that a miracle would happen and that their system would turn out to be better than those currently available. There were exceptions, of course. Petzval's Portrait lens was designed on paper before fabrication was commenced, using theoretical formulae that he developed himself, while Steinheil's Aplanat of 1866 was aided by the theoretical work of von Seidel. Even these successes did not convince the optical world of the need for a good theoretical background. H. Dennis Taylor (1862–1943), the designer of the Cooke Triplet lens, made only partial use of theory, and he would often adjust a new lens in the workshop until the best image was obtained. Today a new design can be analyzed completely by computer, and it is no longer necessary to construct a sample to determine whether the lens is good enough for its intended application.

We must realize, however, that some interesting lens designs were once considered unsatisfactory because no one was willing to devote the time and patience necessary to explore the possibilities of that particular type. Some of these have returned to popularity now that electronic computers enable us to try out a multitude of possible designs in a very short time.

It is interesting to note that the earliest lens to be properly designed, the simple Wollaston Landscape lens of 1812, is still being manufactured in enormous numbers for low-cost cameras; the Petzval Portrait lens of 1840 was made and used regularly until about 1920; the Rapid Rectilinear lens of 1866 was fitted almost universally to all the better cameras for over sixty years; and the Cooke Triplet, after a few years of hesitation, has become the universal design for all cameras and projectors where an aperture of $f/3.5$ or less is adequate. Many other types of construction have come and gone, while some, such as the telephoto, have returned to popularity after a lapse of many years. Innumerable experimental lenses are constantly being developed, but most of these show no advantage over existing types, and they are soon abandoned and forgotten.

A. Lens Aberrations

During the 1850s, L. von Seidel (1821 – 1896) investigated the formation of an image by a lens and identified seven so-called primary aberrations that affect the definition. These aberrations are independent of one another, and correcting one does not imply that any of the others will be corrected. Indeed, it is generally found that we require one degree of freedom in a lens (e.g., the curvature of a surface, the thickness of an element, the airspace between two elements, or the position of the stop) to correct one aberration. Hence, if six aberrations are to be corrected there must be at least six degrees of freedom available to the designer. Actually, there must be one more degree of freedom with which to hold the focal length. This is because a lens can be constructed to any desired focal length by merely scaling all the linear dimensions; consequently, a degree of freedom is really the ratio of one variable parameter to another, so there must be one more available parameter than the number of aberrations to be corrected.

Most good lenses possess more than the minimum number of degrees of freedom. This helps the designer, because there are several important aberrations that do not have any primary value, and even the well-known Seidel aberrations have higher-order components that must be controlled separately. In the simpler types of lens, the designer has to accept whatever higher-order aberrations happen to appear, as he has no control over them. Of course, he can try the effect of a change of glass or he can even resort to the use of one or more aspheric surfaces, although this latter possibility is likely to prove very expensive to manufacture.

B. The Petzval Sum

The design of any photographic lens is dominated by a certain mathematical expression known as the Petzval sum. This sum is related to the basic field curvature that we should expect to find in any lens, from very simple considerations. In Figure 1.1, it is clear that the oblique object distance b is greater than the axial object distance a ; hence, the oblique image distance b' should be less than the axial image distance a' , leading at once to a curved image for a plane object.

Joseph Petzval (1807 – 1891), in 1839, reduced this problem to mathematical terms and showed that if all other aberrations are absent, the curvature of the image of a flat object will be given by the sum $\Sigma \phi / nn'$, ϕ being the power of a lens surface, given by $(n' - n)/r$ where r is the radius of curvature of the surface and n and n' are the refractive indices of the

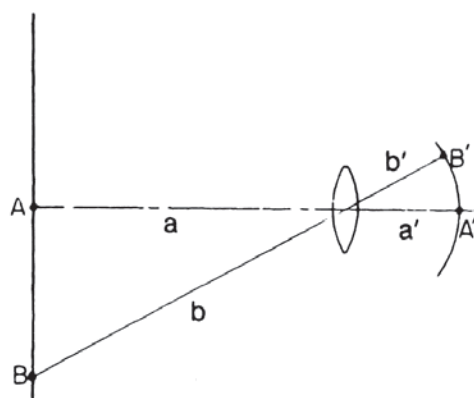


Figure 1.1. The reason why a simple lens has a curved field.

media on the two sides of that particular surface. This sum differs from all other aberrations in that it does not depend on the aperture or field of the lens nor on the stop position, airspaces, thickness of the elements, or conjugate distances. Indeed, some workers do not regard it as an aberration at all but merely an inherent property of the lens along with its focal length and other basic data.

If the system consists of a series of separated thin elements, the Petzval sum becomes merely $\Sigma \phi/n$, where ϕ is the lens power and n is the refractive index of the material from which it is made. The Petzval sum of a thin lens of ordinary crown glass is about 0.66 for a focal length of unity or 0.066 for a focal length of 10.

In practically every lens made prior to about 1885, this natural inward field curvature was deliberately offset by the introduction of some degree of overcorrected astigmatism, which served to flatten the field artificially by opposing the inward field caused by the Petzval sum. Thus, the designers of these early lenses traded astigmatism for field curvature, or as Piazz Smyth remarked in 1874¹, they “relieved us of a blunder by substituting a sin.” At apertures as low as $f/15$ the astigmatism so introduced did not become serious until about 25° from the lens axis, but in a portrait lens with an aperture of $f/3.5$ the astigmatism was liable to become serious at perhaps 10° out. In all the early lenses it was the increasing astigmatism that set a limit to the useful field, leading to the well-established idea that a high aperture and a wide angular field were incompatible.

In some early portrait lenses a considerable amount of inward field curvature was deliberately left in the lens by the use of less overcorrected

¹ *Brit. J. Phot. Almanac*, 1874, p. 44.

astigmatism. This improved the sharpness of definition out in the field, but projecting the flat film plane out into the object space led to a curved object field. For this reason, a row of people would be seated on a curve rather than in a straight row. Photographs were often taken in the corner of a room or looking down a street, so that the objects of principal interest would be sharply imaged on the plate.

There are three principal ways by which the Petzval sum of a lens can be reduced:

- (a) By the use of a thick meniscus construction, the two outer lens surfaces having about the same radius of curvature.
- (b) By the use of a series of positive and negative lens elements widely spaced. Achromatizing such a system requires that the negative elements be considerably strengthened, which immediately reduces the Petzval sum.
- (c) By the use of a crown glass of high refractive index combined with a flint glass of lower refractive index.

All these methods have been used in lenses, but oddly it was the third that was tried first. By 1886 Abbe and Schott in Jena had developed barium crown glasses having just the required property to reduce the Petzval sum, and these glasses were immediately adopted by Schroeder in 1888 in his Ross Concentric lens.² Soon the other methods were tried by almost every designer, resulting in the development of numerous anastigmat lenses. A few nonanastigmats are still used, provided that the aperture or field are low enough so that the inevitable astigmatism is not serious or where the field is deliberately made inward-curving so that the image lies on the Petzval surface and the astigmatism automatically disappears.

C. Remounting a Lens

If an occasion arises to remount the two halves of a photographic objective in a new barrel or shutter, it is essential to ensure that the optical axes of the two halves are coincident and that there is the correct separation between the two components. Some lenses are highly sensitive to the space between the halves, and an error of as little as 0.5% of the focal length can often be quite serious, while in other lenses the central airspace may be insensitive. For instance, in a lens of the Dagor type, a small error in the separation by as little as 0.4% has a considerable effect on the field curvature, and also a lesser effect on the coma, an increase in the airspace

² U.S. Pat. 404,506 (1888).

leading to an inward-curving field. On the other hand, in a lens of the Rapid Rectilinear type, an error as large as 1.0% has only a negligible effect on the field curvature and almost no effect on the coma, an increase in the airspace leading to a backward-curving field. In general, it is usually found that the better the lens the greater is the effect of an error in the central airspace.

II. A BRIEF HISTORICAL SURVEY

Any attempt to develop a strictly chronological approach to the history of the photographic objective is invariably confused by a hopeless mass of crosscurrents. It would be easier if each type of lens had been invented, developed, perfected, and then abandoned in a limited period of time, after which another type had appeared and been similarly treated. Unfortunately for the historian, but fortunately for the working photographer, the lenses available at any one time cover a wide range of constructional types, some being suitable for use at high apertures, some covering a wide angular field, some being usable over a broad range of magnifications, some being simple and cheap, while some are complicated and expensive. It is, in fact, only recently that a high aperture and a wide angular field have become possible simultaneously in the same lens, and it is only in the last forty years that lenses with a variable focal length have become available. Consequently, in this book it has been decided to follow the rise and decline of each type separately, starting with its first introduction and continuing its development to the present day, or until it was abandoned.

A. 1840 to 1866

Photography was invented by L. J. M. Daguerre (1789–1851) in 1839, and the first lens to be used on a camera was the achromatic landscape lens of C. Chevalier (1804–1859). The aperture of this lens was only $f/15$, and the need for a much faster lens was immediately obvious. This requirement was soon met by J. M. Petzval in his famous Portrait lens of 1840. A few high-aperture objectives were developed by other workers but they were not good enough for practical portraiture.

Partly because of the slowness of the original daguerreotype process, many photographers were in the habit of photographing inanimate objects such as fine buildings; the appearance of barrel distortion in landscape lenses became evident by the curvature of straight lines in the outer parts of the field. So a demand arose for distortionless lenses, and a number of symmetrical systems were developed empirically by such workers as Cun-

dell, Ross, Davidson, Sutton, and others. The first symmetrical objectives to be properly designed were the 1859 Panoramic lens of T. Sutton (1819–1875), the 1865 Periskop of C. A. Steinheil (1801–1870), and the 1860 Globe lens of Harrison and Schnitzer in New York.

A few unsymmetrical distortionless lenses appeared on the market. In 1859, when the cry for distortionless lenses was at its height, the Petzval Orthoskop appeared. This lens was hailed as the solution for all the photographer's problems, but careful investigation showed that it was not perfectly distortionless and the field was somewhat curved, so the new lens was soon forgotten.

B. 1866 to 1890

In 1866 the Dallmeyer Rapid Rectilinear and the identical Steinheil Aplanat were produced. At that time there were four types of lens available to the working photographer, namely, the Landscape lens, the Portrait lens, the wide-angle Globe lens, and the intermediate Rapid Rectilinear, which together met most of their needs. However, all these lenses suffered from overcorrected astigmatism in the outer parts of the field, which was serious in lenses of high aperture but scarcely significant in lenses of very low aperture.

C. 1890 to 1914

The correction of astigmatism and the development of the Anastigmat lens of 1890 were made possible by the introduction of barium crown glasses by E. Abbe (1840–1905) and O. Schott (1851–1935) of the Zeiss Company, in 1885. Now for the first time it was possible to eliminate the astigmatism that had bedevilled all previous lenses, leading to the design of such well-known objectives as the Tessar, Dagor, and many others. Nevertheless, old favorites such as the Petzval Portrait and Rapid Rectilinear lenses took a long time to disappear. They were still being made and used extensively by 1930. The year 1890 also saw the introduction of telephoto lenses by Dallmeyer and others and, on the whole, it was a period of steady improvement in lenses of many new types.

D. The Interwar Period, 1918 to 1940

By 1920 lenses of $f/2$ aperture were becoming available, and the period around 1930 was particularly active in the development of new lenses. Reversed telephotos were appearing, at first for close-up projection and then for use in the Technicolor three-strip camera, where a long back

focus clearance was needed to house the beam-splitting prism. Some primitive zoom lenses were being developed for professional 35 mm movie cameras, and the use of anamorphic compression in motion pictures was being proposed by Chrétien. During this period, 16 mm and 8 mm movies were being developed for the amateur photographer, requiring the design of many new lenses. Toward the end of the period, some very large lenses were being developed for use in aerial cameras.

E. The Post World War II Period

As soon as World War II ended, there was a great rush of pent-up activity in the design of new photographic lenses. Practical zoom lenses for 35 mm motion pictures soon appeared, and these were followed by lenses for the new field of television. The CinemaScope system of 1952 gave the cinema a much-needed boost; this involved the use of anamorphic compression in both the camera and the projector. New lenses of high quality were required for the new film formats of the 126, 110, and Disc cameras.

Starting in the early 1950s, Japanese camera and lens manufacturers began to take over the amateur camera market and soon outstripped European countries in the low cost and high quality of their products. Eventually, even the German manufacturers could no longer compete, and today Japan has a virtual monopoly in the 35 mm still-camera market.

As an example of Japanese enterprise, we may consider the offering of a single company, Nikon, which currently makes over fifty lenses for 35 mm SLR cameras. They have three fish-eye lenses from 6 mm to 16 mm focal length; eleven reversed telephoto wide-angle lenses from 13 mm to 35 mm; three normal lenses of 50 mm focal length; twenty-three telephotos from 80 mm to 1200 mm; three mirror lenses from 500 mm to 2000 mm; and eleven zoom lenses ranging from 28–85 mm to 180–600 mm. Several other companies are manufacturing similar lines of first-quality lenses, all reasonably priced and readily available in this country.

These developments have been made possible by the introduction of the high-speed digital computer (see Section VC). Other contributing factors are efficient antireflection coatings and the introduction of new types of high-index optical glass.

III. LENS MARKINGS

At first very few lenses carried any indication of the maker or the structure of the lens. There were exceptions, of course, but often the lens would be housed in a polished brass barrel and that was it. The user had to fit the