

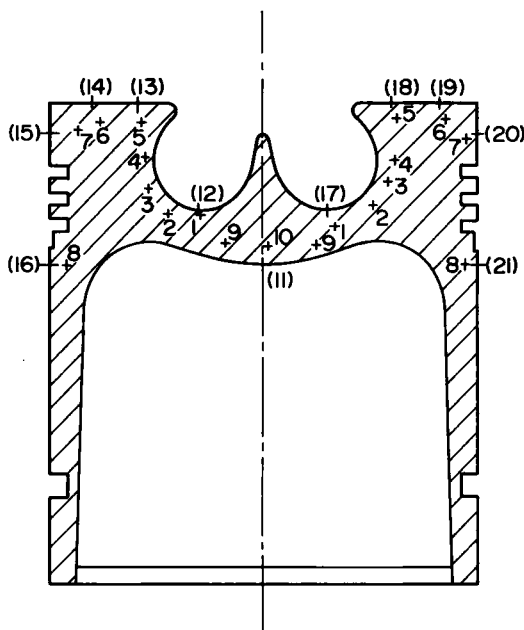


FIG. I.10. Templug positions in piston section thrust plane.

$$\frac{\partial^2 V}{\partial z^2} + \frac{1}{r} \frac{\partial V}{\partial r} + \frac{\partial^2 V}{\partial r^2} = 0.$$

Thus there is a direct analogy between T and V .

We shall illustrate the method, initially, with respect to a two-dimensional system, and then indicate how a three-dimensional system can be set up.

The two-dimensional equations for T and V in the x, y plane are

$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} = 0 \quad \text{and} \quad \frac{\partial^2 V}{\partial x^2} + \frac{\partial^2 V}{\partial y^2} = 0$$

A diagrammatic arrangement of the system is shown in Fig. I.11. A tank contains distilled water as an electrolyte. Inserted in the tank are two electrodes A and B and a probe P. The electrodes are connected to an alternating current supply (to avoid electrolysis) with resistances R_1 and R_2 forming two arms of a Wheatstone Bridge—the resistances of the electrolyte between the probe P and the electrodes A and B being the other two arms. A galvanometer D is used as a detector. The resistances R_1 and R_2 are set at fixed values to correspond to a given isothermal and the probe P moved until the detector D is zero and the current flow is balanced. To nullify polarizing effects at the probe a variable capacitor C may

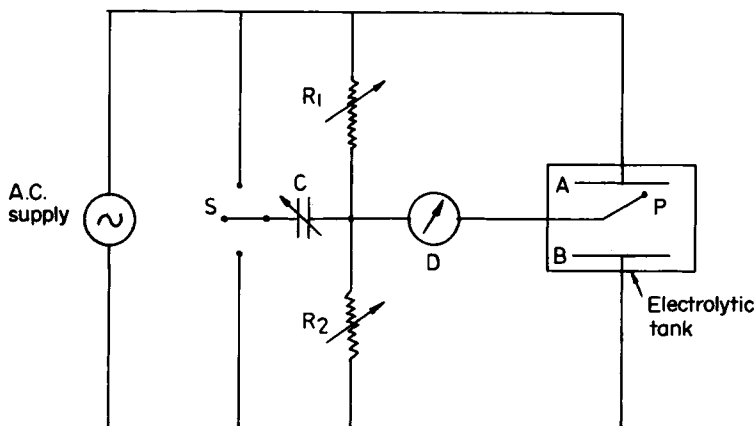


FIG. I.11. Electrical analogue system.

S, switch; C, variable capacitor;
 D, detector; R_1, R_2 , variable resistances;
 A, B, electrodes; P, probe.

be switched into either arm at S. The probe is connected by means of a pantograph to a pencil over a plotting table. When the null point is obtained a pencil mark is made on drawing paper in the plotting table. The probe traverses the tank until a reasonable number of null points are obtained for a continuous isothermal to be plotted.

Let R_a and R_b be the electrolyte resistance from A to P and B to P respectively, and let R_1 and R_2 be set at some value, then at balance

$$\frac{R_a}{R_b} = \frac{R_1}{R_2}.$$

Let X be the ratios

$$X = \frac{R_a}{R_a + R_b} = \frac{R_1}{R_1 + R_2}.$$

Now the analogue equations give:

$$V_{AB} = V_A - V_B \equiv T_A - T_B \equiv \Delta T_{AB},$$

$$V_{PA} = V_P - V_A \equiv T_P - T_A \equiv \Delta T_{PA}.$$

Then at balance for current I:

$$\frac{V_{PA}}{V_{AB}} = \frac{I R_a}{I(R_a + R_b)} = \frac{R_a}{R_a + R_b} \equiv \frac{\Delta T_{PA}}{\Delta T_{AB}},$$

$$X = \frac{R}{R_1 + R_2} = \frac{1}{1 + (R_2/R_1)} \equiv \frac{\Delta T_{PA}}{\Delta T_{AB}}.$$

Hence for a fixed ratio of R_2/R_1 we can plot an isothermal for $\Delta T_{PA}/\Delta T_{AB}$. Now if T_A and T_B are known it follows that the isothermal for T_P corresponds to the ratio R_2/R_1 . Thus the resistances R_1 and R_2 give the temperature T_P .

For an engine component the temperatures are not uniform along the surfaces so that a modification is required to the analogue system. An arrangement for a piston is shown in Fig. I.12 to illustrate the modification. The electrodes A and B shown in Fig. I.11 are replaced by the system shown in Fig. I.12. A model piston—normally made of wood—is filled with distilled water.

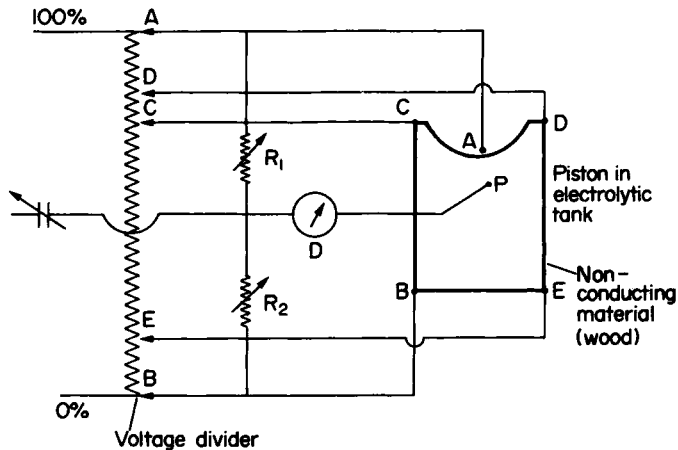


FIG. I.12. Modification to electrical analogue for non-uniform temperature boundaries.

At certain locations on the surface A, B, C, D and E the temperatures are known, say with templug. We will assume that the maximum temperature is at A and the minimum temperature at B. The points A and B are connected either end of the voltage divider such that $V_{AB} = IR_{AB} \equiv \Delta T_{AB}$. The points C, D and E are then connected to the divider such that

$$\frac{R_{CB}}{R_{AB}} \equiv \frac{\Delta T_{CB}}{\Delta T_{AB}}, \quad \frac{R_{DB}}{R_{AB}} \equiv \frac{\Delta T_{DB}}{\Delta T_{AB}}, \quad \frac{R_{EB}}{R_{AB}} \equiv \frac{\Delta T_{EB}}{\Delta T_{AB}}.$$

The plotting procedure for the isothermals follow in the same manner as before.

In practice the piston cannot be represented by a simple two-dimensional pattern due to the piston shape. We normally consider two planes—the gudgeon pin plane and the thrust plane—normal to the gudgeon pin plane. One half of each plane is represented in the model as shown in Fig. I.13.

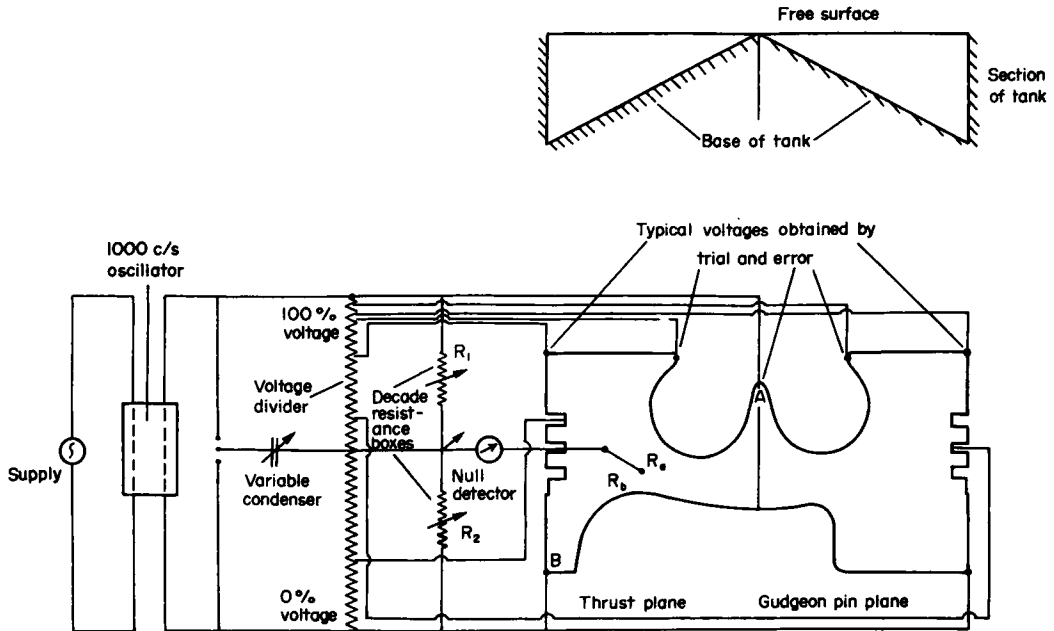


FIG. I.13. Three-dimensional electrolytic tank wiring diagram for the piston.

The axisymmetric equations are simulated by inclining the base at the tank 30° subtended from the axis (Fig. I.13). We now have a wedge of water comprising the free surface, the bottom of the tank and the piston wall. The voltage divider is connected as before on the free surface. If the templug is bedded into the component the boundary temperature must be adjusted so that the isothermals agree with the bedded temperature. Inevitably, because of the approximations in the axisymmetric assumption for a piston, it will be difficult to obtain complete agreement between the isothermals and the measured temperature, but very close agreement can be obtained as shown in Fig. I.14.

To obtain the heat flux a "heat path" is generated as shown in Fig. I.14 (broken line). Since there is no heat accumulated in the piston it is possible to calculate the width of the heat path Δl at each isothermal. The total heat flux and local heat fluxes at the surface can be computed from a knowledge of the thermal conductivity of the piston. From the heat flux, the surface temperature and the gas temperature, the heat transfer coefficients at the cylinder surface are determined. A full discussion of the electrical

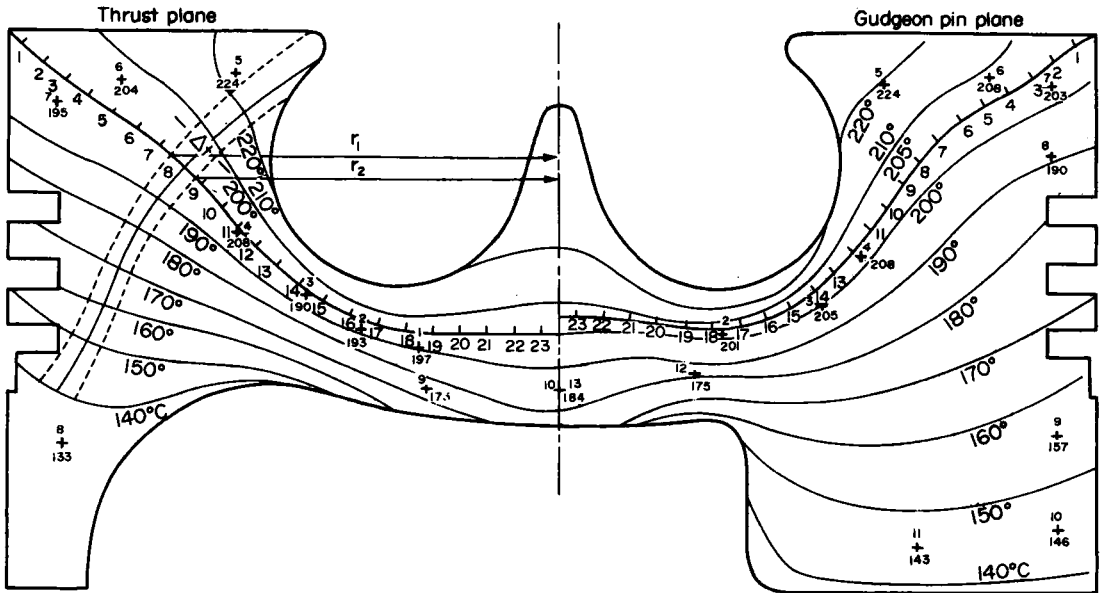


FIG. I.14. Isothermals obtained from electrical analogue.

analogue method is given by Ramchandani⁽⁶⁾ and Jamil;⁽⁷⁾ the former also describes a computer analysis of the problem.

I.2.2 Gas Temperature Measurement

The measurement of gas temperatures is extremely difficult, particularly in the cylinder. A number of methods have been developed but at the time of writing it seems that infrared or spectrographic methods are the most successful. These are both based on the same principle. For exhaust temperatures fine wire resistance thermometers have been successful, but there are practical difficulties in maintaining the integrity of the probes unless they are only used when the temperature is required and removed from the pipe when not required.

We shall first discuss the infrared method developed by Myers and Uyehara⁽⁸⁾ for cylinder temperature measurement and then describe the fine wire resistance method for exhaust gas temperature measurement.

In Fig. I.15 a diagrammatic arrangement of the infrared method developed by Myers and Uyehara is shown. It is a null method. The method is based on the principle that if infrared waves from a black body source pass through a cylinder containing gas at a temperature T , then the black body temperature T_b equals the cylinder temperature when the rate of absorption of the infrared waves by the gas in the cylinder equals the rate of emission from the gas. Water vapour is taken as the sensing element (that is the detector and

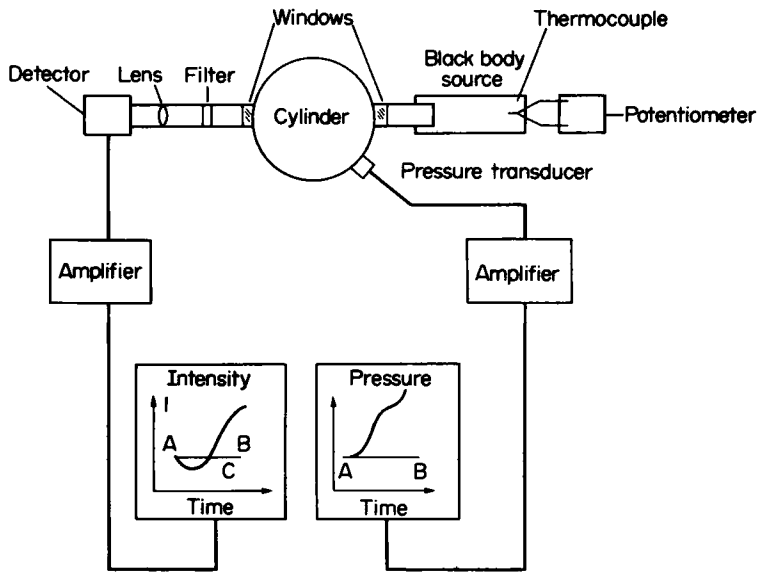


FIG. I.15. Diagrammatic arrangement of infrared method of measuring cylinder temperatures.

optical system is set to record the emissions at one of the wavelengths for water vapour— 2.6μ). A black body source is placed opposite the detector and an optical filter is placed ahead of the detector to absorb the unwanted wavelengths. The cylinder has two quartz windows so that there is a direct optical path from the infrared source to the detector. During the suction stroke there is minimum infrared absorption by the cylinder gases so that infrared waves transmitted from the black body source will pass through the cylinder with almost no change in intensity. A horizontal line AB (Fig. I.15) will be recorded. The intensity I will correspond to the black body temperature T_b measured by the thermocouple. Note this will not be the same as the gas temperature. If T_b is set above the suction temperature then at the beginning of the compression stroke as the temperature rises there will be some absorption of the infrared by the cylinder gas and the emission level will be less than from the black body. The detector will record a decrease in intensity. Further increase in temperature of the cylinder gas will produce a further decrease in recorded intensity until a minimum is reached. As the stroke continues the intensity will now increase until at C the rate of absorption of the infrared waves from the black body source equals the rate of emission from the cylinder gases. At this point the cylinder temperature equals the black body temperature T_b . The crankangle at which this occurs can be measured in the normal manner. By taking a series of black body temperatures T_b the procedure is repeated and a temperature angle diagram can be obtained. The accuracy of the method depends on the cleanliness of the quartz windows, window radiation and absorption,

homogeneity of the cylinder temperature cycle to cycle variations. A full analysis of the accuracy of the method is given by Myers and Uyehara. (8)

This method makes use of the intensity of infrared waves emitted on 2.6μ waveband corresponding to water vapour. It is a null method. If some other chemical species can be identified participating in some chemical reaction in the cylinder whose equilibrium data are known and the relationship known between light intensity and chemical concentrations at the set wavelength, then it is possible to measure local temperatures. This method will be discussed later since it is the basis of spectrograph studies of the chemical reactions in the combustion chamber.

Another method using the relationship between the speed of sound and temperature was developed to study end gas temperatures (9) but is not now extensively used.

For measuring rapidly fluctuating exhaust gas temperatures a thin wire resistance thermometer may be used. The smaller the size of the wire the faster the response; there is, however, a limitation to the wire size before mechanical failure in service militates against its use. A full description of the construction of a resistance probe and the factors which influence its response are given by Benson. (10, 11) A typical design is shown in Fig. I.16. The element is retracted from the exhaust pipe when not in use, thus saving the wire from destruction due to solid particles in the exhaust, particularly during starting. The tungsten wire, 6.9μ diameter and about 10 mm long, is welded to the supports after insertion in the nickel sleeves. For recording purposes the thermometer is one element of an a.c. bridge suitably offset so that the transient temperature can be measured (Fig. I.17).

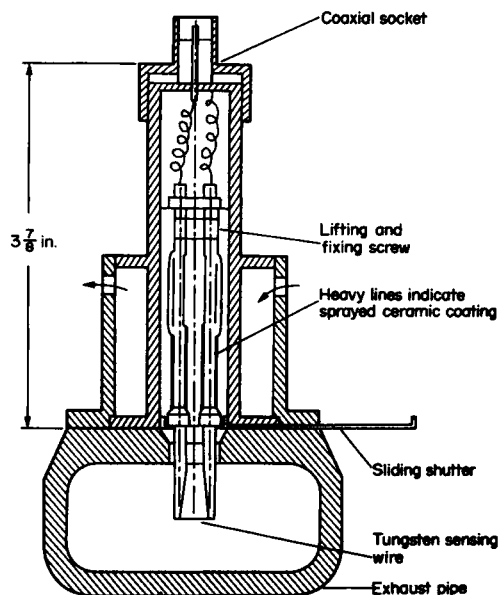


FIG. I.16. Water-cooled transient temperature probe.

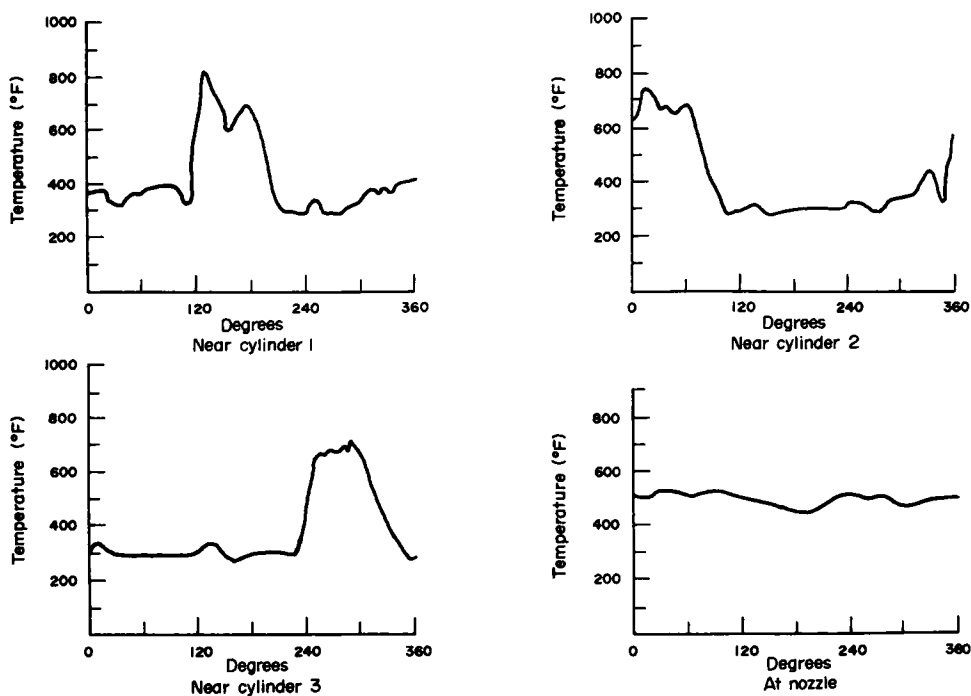


FIG. I.17. Exhaust pipe temperatures 1200 rev/min two-stroke engine. (From Benson and Pick,⁽⁴⁾ by courtesy of the Society of Automotive Engineers.)

I.3 COMBUSTION PHOTOGRAPHY AND FLAME SPEED DETECTION

For qualitative combustion studies high speed colour photography has been successfully used, notably by Ricardo.⁽¹⁾ A diagrammatic layout of the system is shown in Fig. I.18. The cylinder has either a quartz or perspex window. A high speed rotating prism camera, operating up to 16,000 frames per second, is mounted on a rigid support, and mirrors are arranged to record the combustion and crankshaft simultaneously. The fuel is normally doped with copper oleate to render low luminosity flames visible. From combustion films a better understanding of the combustion process has been obtained.⁽¹²⁾

An alternative arrangement for photographing the combustion process, Fig. I.19, has been developed in the author's laboratory for a medium speed engine, where, due to the valve gear in the cylinder head, it is not possible to obtain a good view of the combustion space. In this apparatus the piston has a perspex crown. The combustion is viewed through the piston by means of mirrors.

A direct measurement of flame location with time may be made using ionization gauges. These consist essentially of a wire in an annulus. The wire is insulated from the body of the gauge. When a flame reaches the annulus it becomes conducting as an electrical

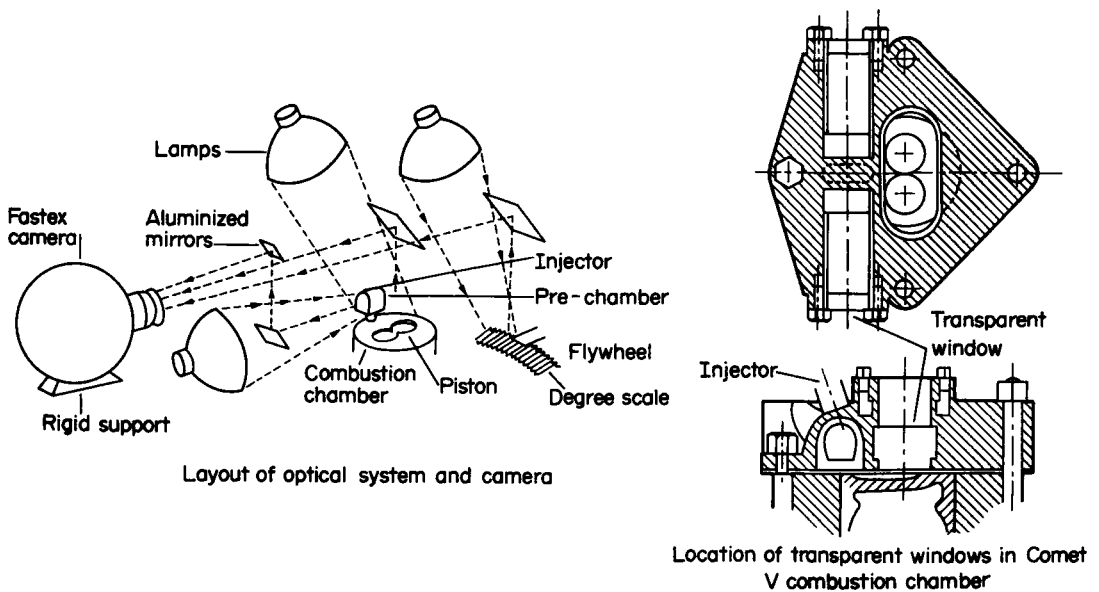


FIG. I.18. Ricardo combustion photographic rig. (From Alcock and Scott,⁽¹²⁾ by courtesy of the Institution of Mechanical Engineers.)

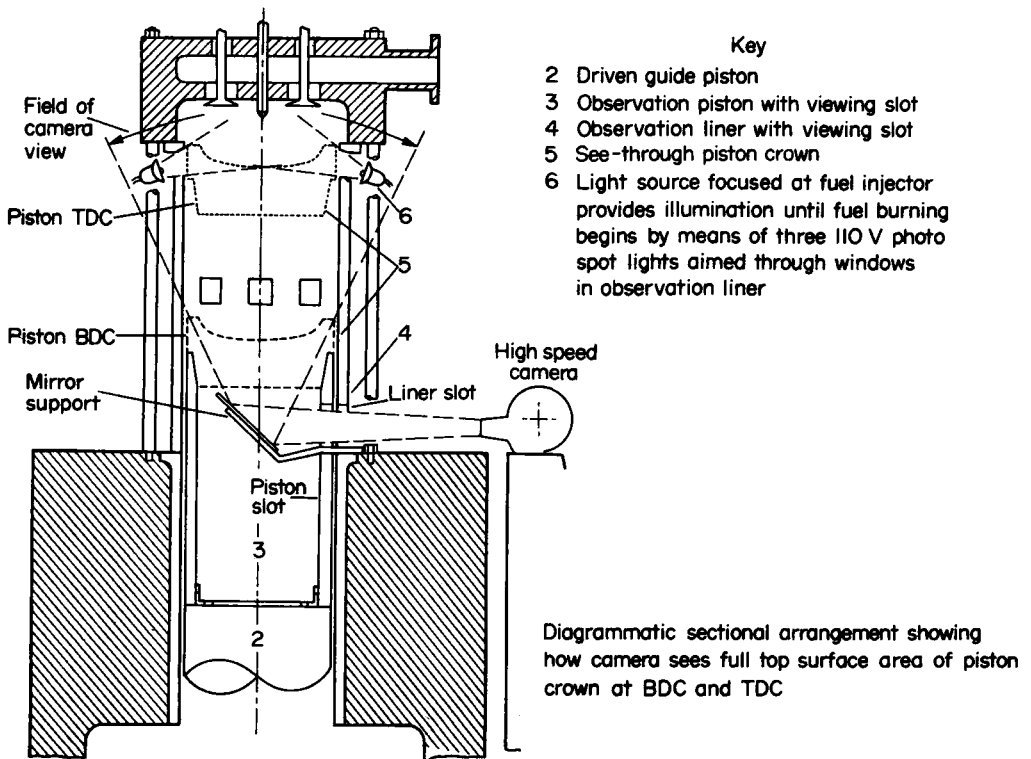


FIG. I.19. Diagrammatic arrangement for indirectly photographing combustion phenomena.

circuit is completed between the wire and the gauge body. A d.c. voltage is normally applied to the wire and an electronic timing circuit connected to the gauge body as well as some reference time location. When the flame arrives at the gauge the timing circuit is triggered and the time from the reference time measured. A full description of the technique is given by Harrow.⁽¹³⁾

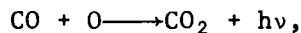
By locating a sufficient number of gauges in the combustion chamber a quantitative picture of the flame propagation may be made. In analysing the results allowance must be made for expansion of the hot gas zone which is superimposed on the flame speed. The minimum voltage to trigger the ionization gauge will vary with air/fuel ratio.

I.4 SPECTROGRAPHIC METHODS

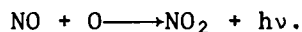
Spectrographic methods may be used for studying the chemical reactions in the cylinder as well as the local gas temperature. In these methods the light intensities associated with reacting species are measured at defined wavelengths at which the intensities are at a maximum. We will describe one method which has been successfully used to study the formation of nitric oxide during combustion.

In Fig. I.20 the rig used by Lavoie et al.^(14, 15) is shown. A number of quartz windows W are fitted in the cylinder head. The light source is 2 mm by 2 mm in the cylinder combustion chamber. The cone of light emitted from the cylinder is split into four separate beams in mirror M₂, each of which is brought to a separate focus by mirrors M₃ and M₄. Three beams (2, 3 and 4) are focused onto a photomultiplier with an interference filter to pass wavelengths 0.38 μ and 0.61 μ with a bandpass of 100 Å and a wavelength of 0.75 μ at a bandpass of 300 Å. The fourth channel is monitored with a monochromator and photomultiplier.

The light intensities I at the wave length 0.38 μ, 0.68 μ and 0.61 μ are recorded on a oscillograph relative to the crankangle as shown in Fig. I.20(c). The 0.38 μ wavelength corresponds to the reaction



where the emitted light is associated with the discreet energy packet hν. The 0.61 μ and 0.68 μ wavelengths are associated with the reaction



For the above two reactions the intensities of emitted light I associated with the energy packets hν are related to the concentrations () by

$$I_{\text{CO}} = K_1 (\text{CO}) (\text{O}),$$

$$I_{\text{NO}} = K_2 (\text{NO}) (\text{O}).$$

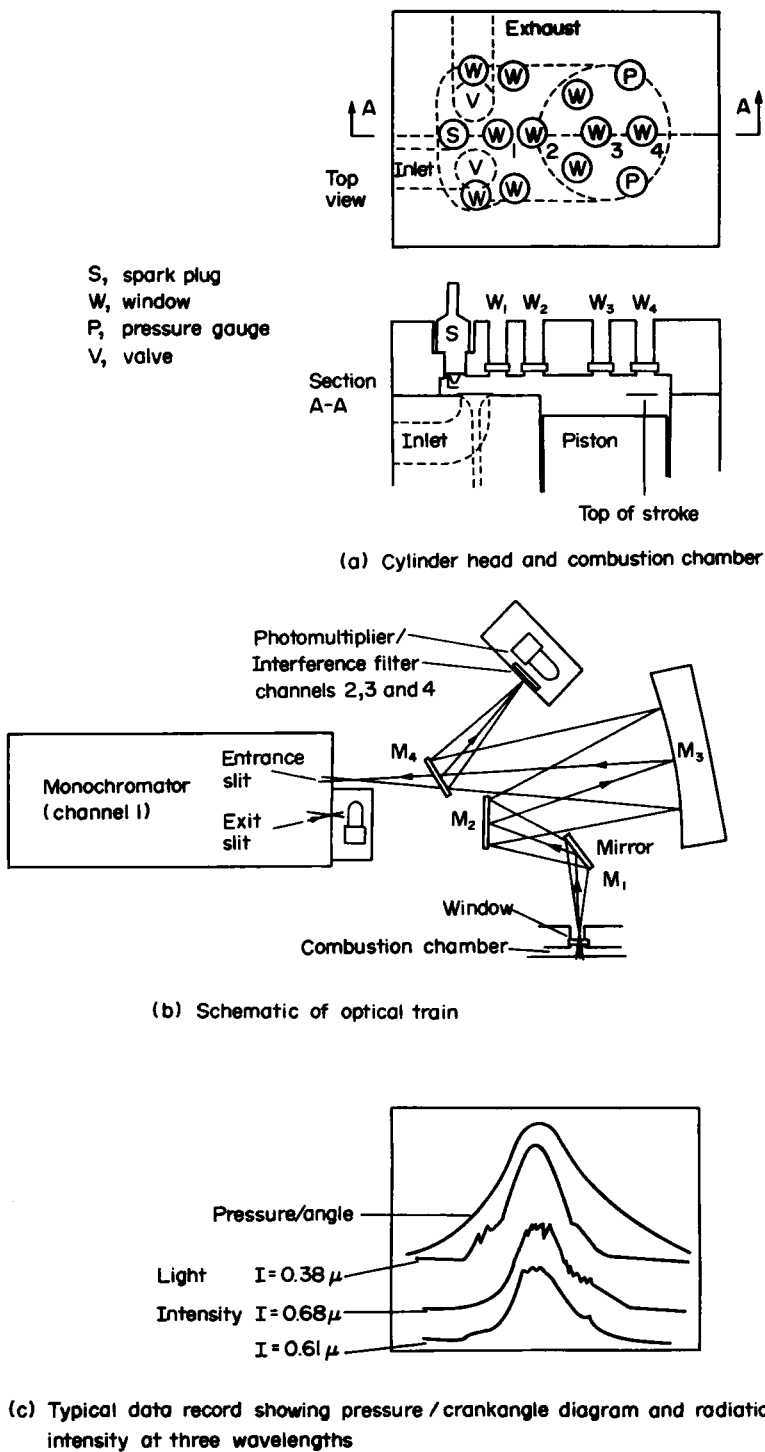


FIG. I.20. Spectrographic measurements. (From Lavoie et al.,⁽¹⁴⁾ by courtesy of the Massachusetts Institute of Technology.)

The parameters K_1 and K_2 are functions of the instantaneous temperature T and the wavelength λ .

Lavoie assumed that the carbon-hydrogen-oxygen reactions were in equilibrium. Thus for each temperature T there is a known value for (CO) (O) from the equilibrium constant. Furthermore, for each temperature and wavelength there is a known value for K_1 . It follows therefore that at a given wavelength

$$K_1 (CO) (O) = f(T).$$

When this function equals the numerical value of the emitted light I_{CO} we know the temperature and the oxygen concentration. Thus by measuring the intensity I_{CO} at the wavelength 0.38μ we can determine the local temperature T .

For the nitric oxide reaction, if I_{NO} is known at the appropriate wavelength, then since we know the temperature T and the oxygen concentration (O) and K_2 is a known function of the wavelength and temperature, the nitric oxide concentration can be calculated from

$$(NO) = \frac{I_{NO}}{K_2 (O)}.$$

For a full discussion of the technique the reader is referred to the original papers^(14, 15).

I.5 CHEMICAL ANALYSIS TECHNIQUES

Spectrographic techniques require sophisticated equipment and are limited to studying the combustion in fix positions associated with the location of the quartz windows. These windows must be kept clean and the spectrograph must be a rigid structure to cope with the optics. A more rugged method of analysis is to use a sampling valve. If this is located in a probe, then provided there is adequate clearance in the combustion space a reasonable area of the combustion chamber can be studied. With a sampling valve the chemical analysis can be carried out at some distance from the engine with fairly standard equipment which has been specifically developed for engine exhaust emissions. In this section we will describe a sampling valve and five methods of chemical analysis which are now standard equipment in engine laboratories.

I.5.1 Sampling Valve

A sampling valve should be capable of opening at a defined time and should remain open for as short a time as possible to allow an adequate sample to be drawn for analysis. There should be no chemical changes in the sample from the sample point to the point of analysis. The experiments by Downs and Wheeler referred to in Chapter 5 were carried out using a sampling valve in the end gas. A sampling valve designed in the authors' laboratories is shown in Fig. I.21. This valve is fitted in a 300 mm bore engine and opens

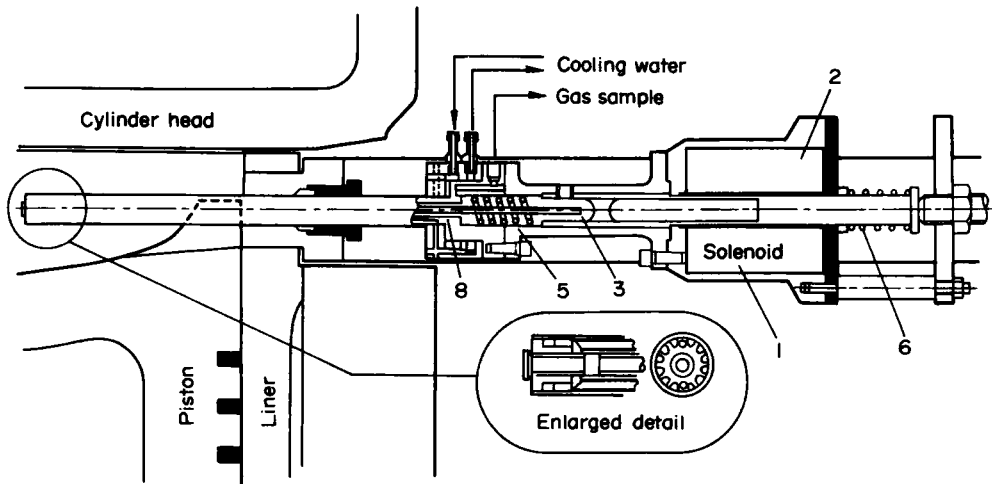


FIG. I.21. Sampling valve.

for a period of about 3 crankangle degrees at 500 rev/min with a sample withdrawal rate of some 2 l/min. The timing of the valve is controlled by a crankshaft driven optical encoder which initiates current flow to the solenoid (2). This causes the steel striker (1) to be accelerated. After travelling a predetermined distance the striker hits the cap (3) on the head of the spindle (8) and rapidly opens the valve to its maximum position. The valve and the striker are returned to their original positions by the springs (5) and (6). During the opening period the gas flows from the engine cylinder through the valve annulus into a pair of hyperdermic tubes and then out of the valve body through drilled passages. The rapid expansion of the gas and the water-cooled passages provide conditions for freezing the gas composition. The sampling valve can be moved into various positions in the cylinder so that a broad spatial-temporal study of the cylinder reactions can be made. The gas samples can be analysed by the methods outlined below.

I.5.2 Orsat Apparatus

The conventional method of gas analysis is the Orsat apparatus. It is primarily used for exhaust gas analysis. If it is handled correctly it can give excellent results but cannot measure extremely small quantities or concentrations.

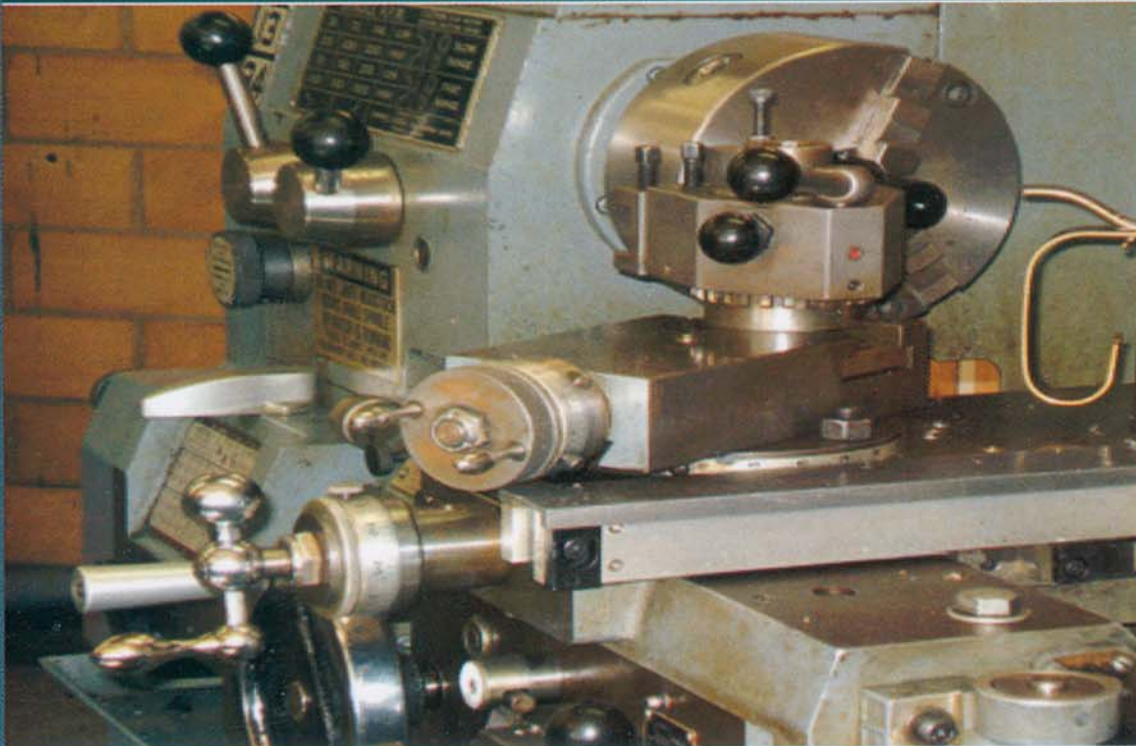
100 c.c. of exhaust gas is withdrawn from the pipe directly into a water-jacketed measuring burette. The sample gas is then successively passed into a solution of caustic potash to absorb carbon dioxide, a solution of pyrogallol acid in caustic potash and water to absorb oxygen and finally, a solution of cuprous chloride to absorb carbon monoxide. At each step the reduction in volume of the 100 c.c. sample corresponds to the percentage of the constituent in the exhaust gas. Accurate exhaust gas analysis will enable the air flow to an engine to be calculated from the fuel flow.

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ALNICOS – Alnicos materials are composed mainly of aluminium, nickel, cobalt and iron. Some include additions of copper and titanium. They are high-coercive force, high magnetic energy alloys.

ALOXITE – Artificial abrasive material used in the manufacture of grinding wheels. Essentially it consists of alumina, or aluminium oxide, the chemical symbol for which is Al_2O_3 .

ALPHA IRON – The body centered cubic form of pure iron, stable below 1025°C.

ALUMEL – A nickel base alloy containing about 2.5% Mn, 2% Al, and 1 % Si, used chiefly as a component of pyrometric thermocouples.

ALUMINIUM – Grayish white metal, very light in weight, and having in its pure form low mechanical strength, frequently alloyed with other elements to improve its physical characteristics.

ALUMINIUM ALLOY – Aluminium which is alloyed with other metals to give it strength and desirable properties.

ALUMINIUM BRONZE – Alloy containing 90% copper and 10% aluminium, extensively used for diecasting.

ANTIFREEZE – A chemical added to the coolant in order to lower its freezing point.

ANTIFRICTION BEARINGS – Ball, roller and needle bearings exhibit very low friction and are suitable for very high speeds, and high loading.

ANTIMONY – Brittle, bluish white metallic element designated Sb. Melting point 630°C. Used as a constituent in some alloys, for instance, bearings and storage battery plates.

ARGON – An inert gas used in certain welding and heat treatment processes.

ARSENIC – A brittle, grayish metallic element designated As. Melting point 814°C. Used as a constituent in some alloys, and in the manufacture of lead shot.

ASBESTOS – A fibrous organic mineral that is non-combustible, non-conducting and acid resistant.

ATOM – The smallest particle of an element.

AUSTENITE – A solid solution of iron and carbon and sometimes other elements in which gamma iron, characterized by a face centered crystal

CHILL – (1) A metal insert embedded in the surface of a sand mould or core or placed in a mould cavity to increase cooling rate at that point. (2) White iron occurring on a gray iron casting such as the chill in the wedge test.

CHINESE SCRIPT – An angular microstructural form with the constituents alpha (Al-Fe-Si) and alpha (Al-Fe-Mn-Si) in cast aluminium alloys. A similar microstructure is found in cast magnesium alloys containing silicon as Mg_2Si .

CHROMEL – (1) 90% Ni, 10% Cr alloy used in thermocouples. (2) A series of Nickel chromium alloys, some with iron, used for heat resistant applications.

CHROMIUM – Grayish white metallic element obtained from chromite, chemical symbol is Cr and melting point $1830^{\circ}C$, used in alloying steels and corrosion resisting plating.

CLAD METAL – A composite material containing two or three layers that have been bonded together. The bonding may have been accomplished by rolling, welding, casting, heavy chemical deposition or heavy electroplating.

COAL TAR – Also called crude oil, when subjected to fractional distillation and purification, yields a variety of useful products-neutral, acidic, and base oils.

COBALT-60 – A radio isotope with a half-life of 5.2 years and dominant characteristic gamma radiation energies of 1.17 and 1.33 MeV. It is used as a gamma radiation source in industrial radiography and therapy.

COLD FINISHED STEEL – Steel bar which has been cold drawn/cold rolled, centerless ground or turned smooth to improve surface finish, accuracy or mechanical properties.

COLD ROLLED STEEL – Steel which has been passed through rollers at the steel mill to size it accurately and smoothly.

COLLOIDS – Finely divided material, less than 0.5 micron in size, gelatinous, highly absorbent and sticky when moistened.

COLUMNAR STRUCTURE – A coarse structure of parallel columns of grains having the long axis perpendicular to the casting surface.

COMBINED CARBON – The part of the total carbon in steel or cast iron that is present as other than FREE CARBON.

COMPOSITE FIBRES – The strands of material used as reinforcement extending through a resin or other matrix in a composite material. An example is carbon fibres in an epoxy matrix. Loads applied to the structure are carried by the fibres.

COMPOSITE MATERIAL – Materials exhibiting a much higher strength than the matrix or base material because of reinforcement fibres.

CONDUCTORS (electrical) – Materials in which an electromotive force causes appreciable drift of electrons, called **CURRENT**.

CONSTANTAN – A group of copper nickel alloys containing 45-60% copper with minor amounts of iron and manganese and characterized by relatively constant electrical resistivity irrespective of temperature used in resistors and thermocouples.

CONVERSION COATING – A coating consists of a compound of the surface metal produced by chemical or electro-chemical treatments of the metal.

COPPER – A reddish, soft, ductile metal with very good heat and electrical conductivity and is the basic element in brass and bronze.

CORE – (1) In a metal casting, the hollow parts (which cannot be shaped as easily by the pattern) that are made by using formed sand shapes, that are strengthened by baking or by using epoxy. (2) In a ferrous alloy, the inner portion that is softer than the outer portion or case.

CORE SAND – Variety of silica sand. Rock sand, river bed and sea shore sand, commonly known as sharp sand, used for making of cores in the foundry because they are capable of withstanding high temperatures, and resisting the penetrating action of the molten metal.

CORUNDUM – Natural abrasive of the aluminium oxide type that has higher purity than emery.

ROCUS CLOTH – A very fine abrasive polishing cloth.

CHROMIUM BRONZE – It is a precipitation hardening alloy of copper with upto 1 per cent chromium. It has high electrical conductivity and high temperature resistance.

CRUCIBLE – A vessel or pot, made of refractory substance or of a metal with a high melting point, used for melting metals or other substances.

CRUCIBLE STEEL – A high grade steel made by melting iron in a crucible and adding charcoal, pig iron and some substance rich in carbon so that

SLOTTING MACHINE – Machine whose mechanical principles are much the same as those of the shaping machine, but with the difference that the ram on which the slotting tool is mounted moves vertically, as in a vertical shaping machine. Also called **SLOTTER**.

SOLENOID – An electrically operated magnetic device used to do work.

SPOT WELDING MACHINE – Fixture in which sheets of metal to be welded together are clamped between two electrodes through which an electric current is passed.

SUPERCHARGER – An air pump driven by an engine, which fills the cylinders with air at a higher pressure than atmospheric pressure.

SURFACE GRINDER – It is a general purpose machine tool used to finish machine a plane surface. There are two types—horizontal and vertical.

TAPE CONTROLLED MACHINES – Machines which have partial automation in which the movements of a machine tool and cutters are automatically controlled by a magnetic tape or cards which have been punched to indicate data previously planned for the sequence of each operation to be performed.

TAPPING MACHINE – Machine designed to cut threads in holes in nuts and other parts.

TESTING MACHINE – Machine designed to apply accurately measured loads to a test piece and, in many cases, to measure the resulting extension, compression or deflection, in order to ascertain the physical properties of materials.

THYRISTOR – A type of semiconductor device that acts as a switch. It turns on when a certain voltage is applied to the gate, and it turns off when the current flowing between the other two terminals stops or reverses.

TOOL GRINDER – Special machine for the grinding of turning, planing and other tools.

THREAD MILLER – A machine that cuts threads by using a rotating milling cutter.

TROCHOID PUMP – An oil pump consisting primarily of a pair of rotors of special shape.

TURBO CHARGER – An exhaust gas driven turbine directly coupled to a compressor wheel.

DUAL SERVO BRAKES – A drum brake assembly with both front and rear shoes, self energized during forward and rearward wheel rotations.

DUMMY AXLE – provided in some vehicles increases the load carrying capacity of the vehicle. Wheels on the dummy axle can rotate freely.

DUNY BUGGY – Off road vehicle set up to run on sand.

ELLIOT TYPE AXLE – Solid bar front axle on which ends span or straddle steering knuckle.

EMERGENCY BRAKE – is the hand brake, operated by a lever, is used when the vehicle is left parked and prevents the vehicle from moving. The hand brake can be applied to stop the vehicle when the service brake fails.

EPICYCLIC GEAR – In the epicyclic gearing, at least one gear not only rotates about its own axis, but also rotates about some other axis.

EQUALIZER LINK – A common connector in the parking brake system that causes both rear brakes to be applied with the same cable tension.

EVASIVE MANEUVER – Rapid steering changes to avoid obstacles in the path of the vehicle.

EXPANSION TANK – A tank at the top of an automobile radiator which provides room for heated coolant to expand and give off any air that may be trapped in the coolant. Also used in some fuel tanks to prevent fuel from spilling from the tank because of expansion.

FADE (brake) – A condition that occurs when there is little braking effect with full brake pedal force.

FIFTH WHEEL – is the swivelling type arrangement at the rear of a tractor unit. The fifth wheel carries the front part of the semitrailer.

FINAL DRIVE – The final gear reduction between the engine and the drive wheels.

FIXED CALIPER DISC BRAKES – Disc brakes using a caliper which is fixed in position and cannot move.

FLOATING CALIPER DISC BRAKES – Disc brakes using a caliper mounted through rubber bushings which permit the caliper to float, or move, when the brakes are applied.

FLUID FLY WHEEL – A liquid coupling used to transmit the engine effort (torque) to a clutch and transmission. This coupling is always a major part of the engine flywheel.

EXHIBIT 1030

Meaning of **apparatus** in English



apparatus

noun

UK  /,æp.ə'reɪ.təs/ US  /,æp.ə'ræɪ.təs/

plural **apparatuses**

apparatus *noun* (EQUIPMENT)

Add to word list 

[U or C]

a set of equipment or tools or a machine that is used for a particular purpose:

- *a **piece of** apparatus*
- *The divers checked their breathing apparatus.*

— SMART Vocabulary: related words and phrases

Things needed for a task

accoutrements

armoury

could use something *idiom*

equipment

gadgetry

gear

kit

material

matériel

necessaries

tackle

thing

tool

tool (something/someone) up *phrasal verb*

use

apparatus *noun* (ORGANIZATION)



[C usually singular]

an organization or system, especially a political one:

- *The whole apparatus of communism was already falling apart.*

+ SMART Vocabulary: related words and phrases

(Definition of **apparatus** from the [Cambridge Advanced Learner's Dictionary & Thesaurus](#) © Cambridge University Press)

apparatus | AMERICAN DICTIONARY

apparatus

noun

US  / ,æp·əˈræt·əs /

plural **apparatuses** or **apparatus**

apparatus *noun* (EQUIPMENT)

Add to word list 

[C/U]

a set of equipment, tools, or a machine that is used for a particular purpose:

- [C] *The garage had an apparatus to lift cars up.*

apparatus *noun* (SYSTEM)



[C]

a system or organization:



(Definition of **apparatus** from the [Cambridge Academic Content Dictionary](#) © Cambridge University Press)

EXAMPLES of **apparatus**

apparatus

The source of statehood remained extraverted, limiting the impact of the colonial state and its apparatuses.

From the [Cambridge English Corpus](#)



Indeed, the healthcare system seems to be primarily devoted to increasing the use of a variety of artefacts: synthetic drugs, diagnostics, a whole range of biomedical apparatuses.

From the [Cambridge English Corpus](#)



288 development of the outer and middle ear apparatuses.

From the [Cambridge English Corpus](#)



The book's strength lies in its detailed discussion of military and security apparatuses and capabilities, which will be of significant interest to defense and policy analysts.

From the [Cambridge English Corpus](#)



Cruz does not directly address this concern, for the book says little about differences among the countries that concern their socioeconomic conditions and the organisation of their state apparatuses.

From the [Cambridge English Corpus](#)



The 1930s proved to be a decade of relative prosperity for most chicleiros, partly because state apparatuses initially compensated for the fall in price on the world market.

From the [Cambridge English Corpus](#)



One such option taken by the new leaders combined constitutional amendments, the multiplication of restrictive political statutes (for example, censorship laws), and the creation of elaborate security apparatuses.

From the [Cambridge English Corpus](#)



Of course, these apparatuses are being provided in the maternity hospitals as quickly as they can be made available and midwives trained to use them.

From the [Hansard archive](#)



From the [Hansard archive](#)



He was responsible for dealing with these diathermic apparatuses because they were, in effect, transmitting stations.

From the [Hansard archive](#)



The apparatuses—so long as they are used within those prescribed limits, the police themselves are protected.

From the [Hansard archive](#)



The limits of these two apparatuses in many respects appear to be the same.

From the [Hansard archive](#)



Are you going to forbid the pubs and clubs and hotels in a certain area to turn on their apparatuses on a certain occasion or between certain hours?

From the [Hansard archive](#)



The *apparatus* is shown in figure 7(a).

From the [Cambridge English Corpus](#)



Two kinds of *apparatus* were used in this study.

From the [Cambridge English Corpus](#)



See all examples of apparatus

These examples are from corpora and from sources on the web. Any opinions in the examples do not represent the opinion of the Cambridge Dictionary editors or of Cambridge University Press or its licensors.

COLLOCATIONS with **apparatus**

apparatus

These are words often used in combination with *apparatus*.

Click on a collocation to see more examples of it.

administrative apparatus

- First, union participation in the administrative apparatus of the welfare state provides them with a potentially important voice in relevant decision-making.

From the [Cambridge English Corpus](#)



and considered as lying elsewhere.

From the [Cambridge English Corpus](#)



complex apparatus

- In oligodendrocytes, recent studies provided evidence of a complex apparatus of molecules, which might coordinate trafficking of proteins and lipids.

From the [Cambridge English Corpus](#)



These examples are from corpora and from sources on the web. Any opinions in the examples do not represent the opinion of the Cambridge Dictionary editors or of Cambridge University Press or its licensors.

See all collocations with apparatus

What is the pronunciation of *apparatus*?



Translations of **apparatus**

in Chinese (Traditional)

設備, 儀器, 裝置...

[See more](#)

in Chinese (Simplified)

设备, 仪器, 装置...

[See more](#)

in Spanish

equipo, aparato, aparato [masculine]...

[See more](#)

in Portuguese

aparelhagem, aparato, instrumento [masculine]...

[See more](#)

in more languages



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Browse

appalled
appalling
appallingly
apparatchik
apparatus
apparatuses
apparel
apparent
apparent damage



couple

noun

UK  /'kʌp.əl/ US  /'kʌp.əl/

couple *noun* (SOME)

Add to word list 

B1 [S]

two or a few things that are similar or the same, or two or a few people who are in some way connected:

- **a couple of** *The doctor said my leg should be better in a couple of days.*
- *A couple of people objected to the proposal, but the vast majority approved of it.*
- **another couple of** *We'll have to wait another couple of hours for the paint to dry.*
- **a couple more** *She'll be retiring in a couple more years.*
- **the last couple of** *The weather's been terrible for the last couple of days.*
- **the next couple of** *Many economists expect unemployment to fall over the next couple of months.*
- **the past couple of** *I'm sorry I didn't call you, but I've been very busy over the past couple of weeks.*

— Fewer examples

- *Take a couple of steps backwards.*
- *She lived in Rome for a couple of years, where she taught English.*
- *Take a couple of weeks off - you need a break.*

- *There's not much in the way of entertainment in this town - just the cinema and a couple of pubs.*

+ SMART Vocabulary: related words and phrases

couple *noun* (TWO PEOPLE)



B1 [C, + sing/pl verb]

two people who are married or in a romantic or sexual relationship, or two people who are together for a particular purpose:

- **married couple** *We sit in our armchairs watching TV like an old married couple.*
- **elderly couple** *An elderly couple live next door.*
- **young couple** *Should the government do more to help young couples buy their own homes?*
- *The couple skated spectacularly throughout the competition.*

+ More examples

+ SMART Vocabulary: related words and phrases



couple

verb

UK  /'kʌp.əl/ US  /'kʌp.əl/

couple *verb* (JOIN)



[T usually passive, usually + adv/prep]

to join or combine:

- **be coupled together** *The sleeping car and restaurant car were coupled together.*



- **couple something with something** *The government has promoted the use of public transport, but has not coupled it with adequate investment in the network.*

+ **SMART Vocabulary:** related words and phrases

couple *verb* (HAVE SEX)



[I] formal

When two people or two animals couple, they have sex.

(Definition of **couple** from the Cambridge Advanced Learner's Dictionary & Thesaurus © Cambridge University Press)

couple | AMERICAN DICTIONARY

couple

noun

US  /'kʌp·əl/

couple *noun* (SOME)

Add to word list 

[U]

two or a few things that are similar or the same, or two or a few people who are in some way connected:

- *I'm packing a couple of sweaters in case it gets cold.*



couple noun (TWO PEOPLE)



[C]

two people who are married or who spend a lot of time together esp. in a romantic relationship:

- *We're having two couples over for dinner.*

(Definition of **couple** from the Cambridge Academic Content Dictionary © Cambridge University Press)

What is the pronunciation of *couple*?



Translations of **couple**

in Chinese (Traditional)

一些, (相似或相同事物的) 一對 , 一雙 , 幾個, (有某種聯繫之人的) 一對 , 幾個...

[See more](#)

in Chinese (Simplified)

一些, (相似或相同事物的) 一对, 一双, 几个, (有某种联系之人的) 一对, 几个...

[See more](#)

in Spanish

par, pareja, pareja [feminine]...

[See more](#)

in Portuguese

alguns, casal, casal [masculine]...

[See more](#)

in more languages



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Translator tool



coup de grace

coup de grâce to something

coup de théâtre

coupe

couple

couple something together

couple something with something

coupled

couplet

operate

verb

UK  /'ɒp.əreɪt/ US  /'ɑː.pəreɪt/

operate verb (WORK)

Add to word list 

B2 [I or T]

to (cause to) work, be in action or have an effect:

- *How do you operate the remote control unit?*
- *Does the company operate a pension scheme?*
- *For several years she operated a dating agency from her basement.*
- *Changes are being introduced to make the department operate more efficiently.*
- *Specially equipped troops are operating in the hills.*
- *We have representatives operating in most countries.*
- *Exchange rates are currently operating to the advantage of exporters.*

— Fewer examples

- *The video provides instruction on how to operate the computer.*
- *This sewing machine is operated by a foot pedal.*
- *The legal system operates very differently in the US and Britain.*
- *Terrorists have been operating covertly in England for several years.*

+ SMART Vocabulary: related words and phrases

operate *verb* (MEDICAL PROCESS)



B1 [I]

to cut a body open for medical reasons in order to repair, remove, or replace an unhealthy or damaged part:

- *If the growth gets any bigger they'll have to operate.*
- *Are they going to operate **on** him?*

+ SMART Vocabulary: related words and phrases

(Definition of **operate** from the Cambridge Advanced Learner's Dictionary & Thesaurus © Cambridge University Press)

operate | AMERICAN DICTIONARY

operate

verb

US  /'ɑp·ə'reɪt/

operate *verb* (WORK)

Add to word list 

[I/T]

to work or cause something to work, be in action, or have an effect:

- [T] *How do you operate the remote control unit?*
- [I] *Changes are being introduced to make the department operate more efficiently.*

operate *verb* (USE MEDICAL PROCESS)



[I]

to cut a body open in order to repair, remove, or replace an unhealthy or damaged part:



operate | BUSINESS ENGLISH

operate

verb

UK  / ˈɒpəreɪt/ US 

Add to word list 

[T]

to use or control equipment or a machine or to make something work:

- *Older people are returning to classrooms for instruction in everything from operating a mouse to mastering spreadsheets.*

+ 

[I]

if a business, system, etc. operates in a particular way, it works or is used in that way:

- *Changes are being introduced to make the department operate more profitably.*
- *Exchange rates are currently operating to the advantage of exporters.*
- **operate as sth** *The company operates as an international delivery service for produce trading companies.*
- **operate through sb/sth** *Centralized lenders operate through mortgage brokers and insurance companies.*
- **operate at sth** *The plant is operating at barely 30% of capacity.*

+ 

[I]

to do business in or from a particular place:

- **operate across/in/from sth** *We operate in 50 countries around the world.*
- *We have representatives operating in most countries.*
- **operate out of sth** *The organization operates out of a small office in the centre of town.*





[T]

to manage a business, service, etc. and make it work:

- *The company operated 156 fewer stores this year.*
- *We began operating a pilot service earlier this year.*
- *Does the company operate a pension plan?*

(Definition of **operate** from the [Cambridge Business English Dictionary](#). © Cambridge University Press)

EXAMPLES of **operate**

operate

In the procedure of calculation above, it can be easily seen that the next step is being operated with the remainder of the former step.

From the [Cambridge English Corpus](#)



They have a vested interest in teaching it just as surgeons have a vested interest in operating on people.

From the [Cambridge English Corpus](#)



I observed and took notes of each interaction from a distance and operated the tape-recorder myself.

From the [Cambridge English Corpus](#)



But if both processes are operating, what explanation provides a synthesis?



These systems operate delivery over many repeated hearings.

From the [Cambridge English Corpus](#)



In section 3.1 we discuss how to represent tables and how to *operate* on tables.

From the [Cambridge English Corpus](#)



Developmentalists show that these schemas *operate* between language and perception, thereby facilitating semantic development.

From the [Cambridge English Corpus](#)



Further, structural conditions may affect how the processes identified here *operate*.

From the [Cambridge English Corpus](#)



They favored the creation of strong central bureaucratic authorities to ensure that the new agglomerations of private power operated ultimately in the public interest.

From the [Cambridge English Corpus](#)



It is also the case that historic preservation virtually never operates this way either.

From the [Cambridge English Corpus](#)



This suggests that any scaffolding provided by previous utterances operates at a highly lexically-specific level at this stage in development.

From the [Cambridge English Corpus](#)



A heavy-duty mobile manipulator while carrying a load, experiencing a force, or operating on uneven terrain needs to maintain its balance.

From the [Cambridge English Corpus](#)



This was in part because it wanted to keep on good terms with the government that was operating in its interests.

From the [Cambridge English Corpus](#)



In fact, a change of pressure is the practical way to optimize a given machine (fixed geometry) to *operate* in a certain regime.

From the [Cambridge English Corpus](#)



Modulation of the oil flow in the main valves is presently controlled by the pilot oil pressure through manually operated pilot control valves.

From the [Cambridge English Corpus](#)



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What is the pronunciation of *operate*?



Translations of **operate**

in Chinese (Traditional)

工作, (使)工作 · (使)運行, 運作...

[See more](#)

in Chinese (Simplified)

工作, (使)工作, (使)运行, 运作...

[See more](#)

in Spanish

operar, funcionar, manejar...

[See more](#)

in Portuguese

operar, acionar, funcionar...

[See more](#)

in more languages



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Translator tool

Browse

[operagoer](#)

[operand](#)

[operant](#)

[operant conditioning](#) BETA



operatic
operatically
operating

together

adverb

UK  /tə'geð.ə/ US  /tə'geð.ə/

together *adverb* (WITH EACH OTHER)

Add to word list 

A1

with each other:

- *We used to go to yoga together.*
- *We worked together on a project a couple of years back.*
- *Could you add these numbers together for me?*
- *You mix all the dry ingredients together before you add the milk.*
- *I like both flavours separately but I don't like them together.*
- *You could stick that back together (= join the separate parts to each other) with some glue.*
- **close together** *She said, "Never trust a man whose eyes are so close together!"*
- **all together** *The waiter asked if we were all together, so I explained that we were two separate parties.*
- **get together** *We should get together (= meet each other socially) some time and have a drink.*

See also

altogether *adverb*



- *Mira and Ellis have been together now for almost five years.*

▶ **get together** informal (UK also **get it together**)



If two people get together or get it together, they start a sexual relationship with each other:

- *We'd seen each other a few times as part of a group, but we didn't really get it together till Rachel's party.*

See more

— Fewer examples

- *I cherish the memories of the time we spent together.*
- *When you've finished your work sheets, clip them together and hand them in to me.*
- *It was when we started living together that we found we just weren't compatible.*
- *If you two don't talk out the differences between you, it'll be very difficult for you to continue working together.*
- *The bride and groom walked down the aisle together.*

+ SMART Vocabulary: related words and phrases

together *adverb* (AT THE SAME TIME)



B1

at the same time:

- *The packages were sent separately, but they all came together.*
- *We can deal with the next two items on the list together.*

+ More examples

+ SMART Vocabulary: related words and phrases

B2

combined:

- *Together they must earn over \$300,000 a year.*
- **put together** *She's got more sense than the rest of you put together.*

+ More examples

+ SMART Vocabulary: related words and phrases

together *adverb* (IN ONE PLACE)



B2

in one place:

- *I'll just gather my stuff together, and then we can go.*

+ More examples

+ SMART Vocabulary: related words and phrases

together *adverb* (AND ALSO)



B2 mainly UK

in addition to; and also:

- *The money that I owe you for the phone together with the rent equals £300.*

[See more](#)

Grammar

Altogether or all together?

Altogether means 'completely' or 'in total': ...

Altogether

Altogether means 'completely' or 'in total': ...

All together

All together means 'with each other', and is similar to together: ...

together

adjective • informal approving

UK  /tə'geð.ə/ US  /tə'geð.ə-/

+ 

organized, confident of your abilities, and able to use them to achieve what you want:

- *For a sixteen-year-old, he seems pretty together.*

▶ get it together

+ 

to get something organized:

- *We were going to go skiing over Christmas but we never got it together.*

[See more](#)

+ SMART Vocabulary: related words and phrases

(Definition of **together** from the Cambridge Advanced Learner's Dictionary & Thesaurus © Cambridge University Press)

What is the pronunciation of *together*? 

Translations of **together**

in Chinese (Traditional)

一起, 共同, 在一起 · 關係親密...

[See more](#)

in Chinese (Simplified)

一起, 共同, 在一起, 关系亲密...

[See more](#)

in Spanish

juntos, a la vez, juntos/as...

[See more](#)

in Portuguese

juntos, ao mesmo tempo, juntos/-tas...

[See more](#)

in more languages 

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Translator tool

Browse

toffee-nosed

tofu

tog

toga

together

together with *phrase*

togetherness

toggle

toggled

