MA = $\frac{\text{load}}{\text{effort}}$

VOLUME ONE

General Engineering Science

RELATIVE DENSITY = $\frac{\text{density of given substance}}{\text{density of water}}$

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General Engineering

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...M'S LAW

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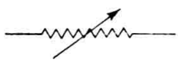
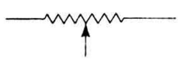
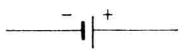
Tables

Drawing Symbols


Resistor – fixed resistance

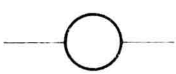

Rheostat – variable resistance


Potential divider



Single cell

Battery of cells


Indicating instrument, e.g. ammeter

Use of Distinguishing Type for Symbols

Geometrical points are represented by letters in Roman type, e.g. the point P.

Vector quantities, when both magnitude and direction are considered, are represented by letters in bold type, e.g. force **P**.

Scalar quantities, and vector quantities where only the magnitude is being considered, are represented by letters in italic type, e.g. the p.d. V, the weight W.

Authors' Preface

FOLLOWING the publication by the Government of the White Paper on "Better Opportunities in Technical Education", new General Courses in Engineering have been introduced. This book is intended to meet the requirements of the engineering science syllabus for the first (G.1) year of the course. A second volume will be devoted to the topics included in the syllabus for the second (G.2) year.

All students should be encouraged to read widely, but the young student requires some guidance in the selection of subject matter. One of the main difficulties which faces a student, who is studying a subject in which he will be examined, lies in deciding how far he should proceed with any one aspect at a particular stage in his education. Because of this, the authors have felt it preferable to present the information in two volumes. The work covered in each volume can then, in general, conform to what is required by the syllabus for each year of the course.

The need for an adequate amount of related laboratory work has been borne in mind and many experiments are described in reasonable detail. In other parts of the text the approach to particular aspects of the work is, it is hoped, such as will suggest other suitable experiments.

A considerable number of worked examples is included throughout the text wherever it was felt that to do so would assist the student to apply what he had read. In addition, most sections of the book conclude with a set of exercises which the student should work out for himself.

This preface would be incomplete if the authors did not make grateful acknowledgement of the readiness with which help was given by members of the staff of the Cambridgeshire College of Arts and Technology. The authors are also greatly indebted to their wives who willingly undertook the work of typing the manuscript.

G. W. MARR
R. C. LAYTON

Cambridge

Introduction

Many young students training to become engineers find it difficult to understand why much of what they are taught is necessary. It does not appear to be connected with their chosen branch of engineering whether it be mechanical, electrical, aeronautical or any other. This short introduction attempts to give some of the reasons why their early studies cover such a wide range of subjects.

Most young people who wish to become professional engineers seem to have been attracted to engineering because it is concerned with doing things or making things. Many say that the "science" which they studied at school did not appeal because it was too theoretical, too much concerned with "how" and "why". Quite a few admit that they disliked mathematics. To these students the list of contents of this book alone may be somewhat unexpected.

Yet the truth is that the practising engineer of today must have a sound knowledge of much of what is popularly known as "science". In addition he must be able to apply relatively advanced mathematical ideas and processes to help him solve the many problems with which he will be faced. Every year the need for this knowledge and ability becomes greater. Engineering technicians, and craftsmen too, will find that, if they are to be fully competent to perform their duties, they will have to possess an increasing background knowledge of engineering science and of mathematics.

Engineers are required to design, produce, operate, and maintain equipment which will fulfil a particular purpose. A design engineer will use many different materials. In order to choose the one best suited to a particular job, and to use it to its best advantage, he must know many things about the material. The modern world can no longer afford "rule of thumb" or "trial and error" methods. The engineer must be able to calculate, for example, the minimum size of beam which he can safely use to support a given load; to use a larger one is wasteful of space and material and adds to the cost. To do this he draws upon his knowledge of that branch of engineering science called "strength of materials" and on his knowledge of "mechanics" which enables him to decide the size and kind of forces which the load will exert. In so doing he uses his mathematical ability.

The effect of heat on a material may have to be considered. A simple example of this occurs in a steel pipe layout designed to carry steam. The pipework expands when steam passes through it, and in order to prevent buckling and possible fracture of the pipe, movement must be permitted. This is achieved by fitting special expansion joints at convenient intervals along the pipe run.

The electrical engineer designing a power transformer has many factors to consider besides the operating voltages at input and output terminals. For example, heat is produced and must be carried away to prevent damage to the insulation. The current flowing in the windings sets up mechanical forces which, under certain conditions, may be very large. He must be able to calculate how much heat will be developed and decide how it can best be removed. He must also estimate the forces which will be set up and ensure that the mechanical design will be able to withstand them.

An engineer who wishes to select a motor to drive a machine should understand the characteristics of different types of motors; for example, is the motor speed constant or does it vary as the load changes? He should also be able to calculate how powerful a motor he will require. Only in these ways can he select the type of motor best suited to his needs.

It is hoped that these simple illustrations will show to the student the large extent to which the engineer must draw on his so-called "theoretical" knowledge, as well as on his practical experience. They may also have helped to make the student aware of the extent to which various branches of engineering overlap. The work of the electrical engineer, for example, calls for a basic knowledge of other branches such as heat and mechanics. This is required not so much that he will be able to deal with problems relating to these other branches, but that he will know when and where to expect them, and have some idea of their consequences.

The purpose of this book and its companion volume is to introduce to the student some of the basic ideas from which the science of engineering has been developed, and to point to the ways in which these ideas are applied in practice.

Contents

SECTION 4. ELASTIC PROPERTIES OF MATERIALS

SECTION 5. FRICTION

SECTION 6. WORK AND ENERGY

SECTION 7. MATTER, MOLECULES AND ATOMS

SECTION 8. HEAT

SECTION 9. ELECTRICITY

SECTION 10. EFFECTS OF AN ELECTRIC CURRENT

SECTION 11. ELECTRIC CIRCUIT THEORY

SECTION 12. ELECTROLYSIS

Section 1

Engineering Units and Quantities

1.1. Introductory

The development of any branch of science depends on accurate observation of events and on a reliable means of measuring what is observed. This requires a well defined system of units in which to express the results of these measurements. Without such a system of units, no calculations relating the results of these measurements can be made.

All quantities and events which are observed and measured must be clearly defined so as to leave no doubt as to the exact meaning of any word or phrase, for without this there would be endless confusion. Such words as force and pressure are often used in everyday speech to describe the same quantity, but in science they have each a distinct and precise meaning.

Before a proper study of any science can be undertaken it is necessary, therefore, to learn the meanings of some of the terms which are used, and to gain a working knowledge of the units employed. The first section of this book is therefore devoted to these basic topics.

1.2. Fundamental Quantities

Even if only mechanical and electrical sciences are considered, the large number of apparently unrelated quantities or concepts which are involved (such as force, magnetic flux, friction, and electric charge) might suggest that a correspondingly large number of units would be required. Surprisingly, this is not so. All aspects of mechanical science to be considered require that units be provided for only three quantities; the addition of one further suitable unit is sufficient for the inclusion of electrical science. More units are used in practice because it is convenient to do so, not because it is necessary.

The basic quantities for which separate, distinct units are essential are called *fundamental quantities*. Another name for these is *fundamental dimensions*.

In mechanical science the quantities usually chosen are *length*, *mass*, and *time*, but other selections such as length, force, and time, or force, work, and time, could be used. The dimensions length, mass, and time, were preferred because they appeared to be the simplest to understand. Even primitive people can sense, for example, the passage of time and have found the need to be able to measure it.

1.3. Standards

Measurement of any quantity requires in the first place some standard of that quantity which is unvarying. The quantity is then measured by comparing it with the standard to find out how many times as great as the standard the quantity is. The standard is the unit in which the quantity is measured, and the number representing "how many times as great" is called the measure number. A standard should be permanent. This is most conveniently achieved if the standard is related to some unvarying natural occurrence. Thus the length of a day suggests itself as a unit of time.

The unit should be of convenient size for everyday use; that is, the measure number should neither be too large nor too small. No fundamental unit is likely to be satisfactory in this respect, and multiples and sub-multiples of the basic unit are employed. For example the yard is the British unit of length, but this is inconvenient for the surveyor measuring very large distances and the instrument maker dealing with small instrument parts. Other units, the mile and the inch respectively, are more convenient.

1.4. Fundamental Units

The units in which fundamental dimensions are measured are called fundamental units. There are two principal systems of units used in mechanics. One is the British system, used mainly in the British Commonwealth and in the United States of America. It is based on the foot as the unit of length, the pound as the unit of mass, and the second as the unit of time, and is commonly called the *foot-pound-second system.*

The other system is used in almost all countries of the world. It is a metric system based on the metre, kilogram, and second as units of length, mass, and time respectively. It is called the *metre-kilogram-second system*, usually abbreviated to M.K.S. system.

1.5. Length

The British unit of length is the *Imperial Standard Yard.* This length is the distance between two lines engraved on two gold plugs inserted in a certain bronze bar which is kept in London.

A smaller unit, the *foot* ($= \frac{1}{3}$ yard) was considered more convenient for use as a basic unit in mechanical science. Other units are the inch ($= \frac{1}{36}$ yard) and the mile (= 1 760 yards).

The *metre* is the metric unit of length. It is defined as the distance between two lines engraved on the polished surface of a certain platinum–iridium bar which is kept at the International Bureau of Weights and Measures at Sèvres, near Paris. Other related units are the centimetre ($= \frac{1}{100}$ metre) and the millimetre ($= \frac{1}{1000}$ metre).

It is interesting to note that, to ensure a permanent standard, the distance marked on the bar was meant to be exactly one-ten-millionth part of a quadrant of the earth (or more simply a quarter of the circumference of the earth drawn through the poles). Later more accurate measurements showed that this had not been achieved. It is now also known that the circumference of the earth is gradually changing and cannot be used as a standard. Because of this the actual length marked on the bar is now the standard.

A length of 1 foot is equivalent to 0·305 metre.

1.6. Mass

Mass is frequently defined as being the quantity of matter contained in a body, and this definition is sufficient for the present. In Volume 2 another way of explaining what is meant by mass will be considered.

Any body can be used as a standard mass.

In Britain the standard or unit of mass is a certain lump of platinum kept in London. It is said to have a mass of *one pound.*

The basic unit in the metric system is the *kilogram.* This is the mass of a certain piece of platinum kept at Sèvres. Originally the unit was the gram (1 kilogram = 1 000 grams) and this was intended to be the mass of 1 cubic centimetre of pure water when its temperature was 3·93°C. (The reason for selecting this particular temperature will become apparent at a later stage—Section 8.)

1.7. Time

Both systems employ the *second* as the basic unit of time. The second is defined as $\frac{1}{86400}$th part of the mean solar day. (Note 86 400 = 24×60×60.)

The mean solar day may be simply described as the average time which elapses during a year between two successive passages of the sun across any one straight line drawn from pole to pole on the earth's surface.

1.8. Derived Units

All quantities in mechanics, other than length, mass, and time, are found to be related in some manner to the basic quantities. It is thus possible to measure such quantities using units related to the basic units. These related units are called derived units. A few examples are now given.

1.9. Area

Basically an area is measured as the product of two lengths. In the simple case of a rectangle of length l "units of length" and breadth b "units of length", the area is $b \times l$ (units of length)^2. For other shapes the formula connecting the area and certain lengths characteristic of the shape may be more complicated. In every case the area involves (units of length)^2.

If the radius of a circle measured in absolute units is 4 ft, then its area will be $\pi \times (4\text{ ft})^2 = 16\pi\text{ ft}^2$. The derived unit of area is thus the "foot-squared" or *square foot.* Other units are used where more convenient, e.g. the square yard (= 9 square feet), or the acre (= 4 840 square yards).

In the M.K.S. system, the derived unit of area is the *square metre*. Other units are the square centimetre ($\frac{1}{10000}$th of a square metre), and the square millimetre ($\frac{1}{1000000}$th of a square metre).

The formula quoted for the area of a rectangle is that $A = b \times l$. This formula is correct if both b and l are measured in the same units and A is to be measured in the units derived directly from those of b and l. This was done in the above example. Suppose, however, we required the area to be expressed in square inches, but that b and l should be measured in feet. Then $A = (12b) \times (12l)$, since the length and breadth in inches will be $12l$ and $12b$ respectively. Hence $A = 144 \times b \times l$. Similarly, if A be required in square yards, when b and l are still measured in feet, then $A = \frac{1}{3}b \times \frac{1}{3}l = \frac{1}{9} \times b \times l$ square yards.

The general formula for the area of a rectangle is thus $A = \mathrm{k} \times b \times l$, where k is a constant chosen to suit the units. The simplest formula is obtained if units for all the quantities are chosen to make $\mathrm{k} = 1$.

1.10. Volume

When volumes are considered it is found that, basically, they are all measured as the product of three lengths. Hence, in the British system, a volume involves (feet) × (feet) × (feet), that is $(\text{feet})^3$. Volumes are thus measured in feet-cubed, or cubic feet, and the basic derived unit of volume is the *cubic foot*.

The corresponding basic M.K.S. unit is the *cubic metre*.

1.11. Force

All students will feel quite familiar with the term "force". Suppose, however, that an answer to the question "What is a force?" has to be given. One answer might state that a force is what we exert when lifting an object or when moving it from place to place. Another might be that force is the thing which must be applied in order to slow down, or speed up, a moving body, or to change its direction. Yet another might be that force is what is used to bend or to break an object.

When these answers are read over carefully, we see that each of them describes a force by naming some of the effects which it produces. No other kind of answer can, in fact, be given. The only way in which we can tell when a force is being exerted is by being able to observe whether or not certain effects are being produced.

The scientific definition also describes force in this way, but is carefully worded so as to include all the effects which force is considered to produce. Hence *force is defined as anything which changes, or attempts to change, either the condition of rest of a body, or its state of constant (or uniform) motion in a straight line.*

This may appear at first to be rather a vague statement. If some time is spent in thinking over examples of events in which force is considered to be involved, it should become clear that this definition is quite precise and that it covers all the cases which may be considered.

It will be more convenient to deal with the units in which force is measured when weight — a quantity closely related to force — has been considered.

1.12. Weight

Common experience tells us that effort is required to throw a stone upwards. We also know that it will soon return to earth. In order to lift a stone, we exert a force. All this we explain by saying that the earth exerts a force on the stone which attracts or pulls it back to the earth. Our experience also indicates that more effort is required to lift, or throw upwards, a large stone than a small one. We know, moreover, that it is easier to throw a rubber ball than a stone of the same size. We conclude from this that the force depends not simply on the size of the object, but also on the substance or type of matter from which it is made.

The quantity which we have called mass involves just these two aspects, size and type of substance. It is the mass of the body which decides how much effort will be required to lift the body, or throw it upwards to a particular height.

Although it is commonly recognized that the earth exerts a force of attraction on other bodies on or near its surface, it is not always realized that these bodies exert an equal pull on the earth.

A basic property of all masses is that they exert forces of attraction on each other. Why they are able to do so we do not know, but we do know how these forces act. This knowledge has