156

G. W. MARR B.Sc. (Eng.), A.M.I.E.E.
Lecturer in Electrical Engineering, Cambridgeshire College of Arts and Technology

GENERAL ENGINEERING SCIENCE

Volume 2

The Commonwealth and International Library of Science, Technology, Engineering and Liberal Studies

General Engineering Science

VOLUME TWO

G. W. MARR

B.Sc. (Eng.), A.M.I.E.E.

Lecturer in the Engineering Department
Cambridgeshire College of Arts and Technology

PERGAMON PRESS

OXFORD · LONDON · EDINBURGH · PARIS · FRANKFURT

THE MACMILLAN COMPANY

NEW YORK

PERGAMON PRESS LTD.
Headington Hill Hall, Oxford
4 & 5 Fitzroy Square, London W.1

PERGAMON PRESS (SCOTLAND) LTD.
2 & 3 Teviot Place, Edinburgh 1

THE MACMILLAN COMPANY
60 Fifth Avenue, New York 11, New York

COLLIER-MACMILLAN CANADA, LTD.
132 Water Street South, Galt, Ontario, Canada

GAUTHIER-VILLARS ED.
55 Quai des Grands-Augustins, Paris 6

PERGAMON PRESS G.m.b.H.
Kaiserstrasse 75, Frankfurt am Main

Library of Congress Card No. 62-22039

Set in 11 on 12 pt Baskerville and
printed in Great Britain by Page Bros. (Norwich) Ltd.

General Engineering Science

Preface to Volume Two

THIS book is the second of two volumes written primarily to cover the Engineering Science content of the General Course in Engineering. The content of this volume corresponds in the main to the requirements of the syllabus for the second year of a two-year course. There are two exceptions to this—the sections devoted to Young's Modulus and to heat exchange in mixtures. These items were intentionally included in the first volume so as to follow other first year topics to which they are closely related.

Great care has been taken to avoid errors either in the text or in the answers to exercises. Some, however, may remain and I shall be grateful to have my attention drawn to any which have been overlooked.

Cambridge G. W. MARR

Contents

SECTION 4. POWER AND ENERGY

SECTION 5. STRENGTH OF MATERIALS

SECTION 6. HEAT

Section 7. Electricity

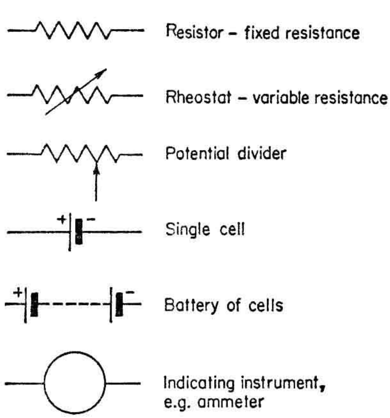
Section 8. Electromagnetism

Section 9. Electromagnetic Induction

Section 10. Ammeters and Voltmeters

Tables

Drawing Symbols



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*.

Section 1

Concurrent Forces

1.1. Introduction

The reader will recall that in volume I a distinction was drawn between quantities—such as work, area, and temperature—which could be sufficiently described by stating their magnitudes, and other quantities—such as force and displacement—which required, in addition to a statement of magnitude, an indication of direction. These kinds of quantities were termed scalar quantities and vector quantities respectively. The need for special rules which apply to the addition of vector quantities was demonstrated. In particular the use of the parallelogram and of the triangle of forces as a means of obtaining the resultant of two concurrent forces was explained and illustrated by several examples. Additional examples involving the equilibrium of three coplanar, concurrent forces were considered. Many instances occur in practice in which a larger number of forces are involved and this section will be concerned mainly with methods which are suited to such instances.

Before proceeding, however, one example involving only two applied forces will be given. In volume I only graphical methods of solution were considered. Graphical methods are, however, not always suitable, sometimes because the relative magnitudes of the vector quantities are inconvenient; sometimes because the accuracy is limited by the small scale which may have to be used. This particular example illustrates how such problems can be solved by direct calculation. The "sine rule" and the "cosine rule" provide the mathematical basis.

EXAMPLE. Two forces, $\mathbf{F_1} = 20$ lbf and $\mathbf{F_2} = 25$ lbf act at a point O as shown in Fig. 1.1a. The angle between the forces is 30°. Calculate the magnitude of the resultant force and also its direction relative to the direction of $\mathbf{F}_1$.

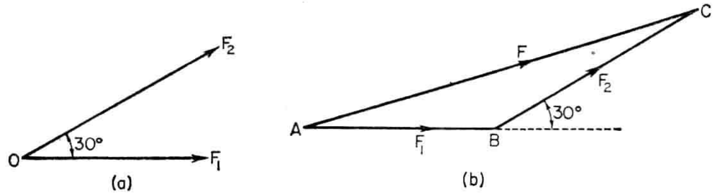


FIG. 1.1

The triangle of forces for the given system is shown in Fig. 1.1b. Forces $\mathbf{F}_1$ and $\mathbf{F}_2$ are represented by the sides AB and BC. The resultant, $\mathbf{F}$, is therefore represented by the side AC.

In △ ABC

$$(AC)^2 = (AB)^2 + (BC)^2 - 2(AB) \cdot (BC) \cos \angle ABC.$$

Hence, to scale,

$$\begin{aligned} F^2 &= F_1^2 + F_2^2 - 2F_1F_2 \cos \angle ABC \\ &= 20^2 + 25^2 - 2.20.25 \cos 150° \\ &= 400 + 625 - 1\,000 \times (-0{\cdot}866) \\ &= 1\,025 + 866 \\ &= 1\,891 \\ F &= \sqrt{1\,891} = 43{\cdot}5 \text{ lbf.} \end{aligned}$$

Also,
$$\frac{AC}{\sin \angle ABC} = \frac{BC}{\sin \angle BAC}.$$

To scale,
$$\frac{F}{\sin \angle ABC} = \frac{F_2}{\sin \angle BAC}$$

$$\frac{43{\cdot}5}{\sin 150°} = \frac{25}{\sin \angle BAC}$$

$$\frac{43{\cdot}5}{0{\cdot}5} = \frac{25}{\sin \angle BAC}$$

$$\sin \angle BAC = 25 \times \frac{0{\cdot}5}{43{\cdot}5} = 0{\cdot}287\,5$$

$$\angle BAC = 16^\circ\ 42'.$$

The resultant force thus has a magnitude of 43·5 lbf and is inclined at an angle of 16° 42′ to the force $\mathbf{F}_1$.

1.2. Resultant of a Number of Coplanar, Concurrent Forces

Let the vectors, **P**, **Q**, **S** and **T** in Fig. 1.2a represent a group of coplanar concurrent forces, applied at a point O. Any two forces can be replaced by a single force—the resultant of the two separate forces—and this force can be determined by drawing the triangle of forces. Thus, in Fig. 1.2b, if vectors **AB** and **BC**

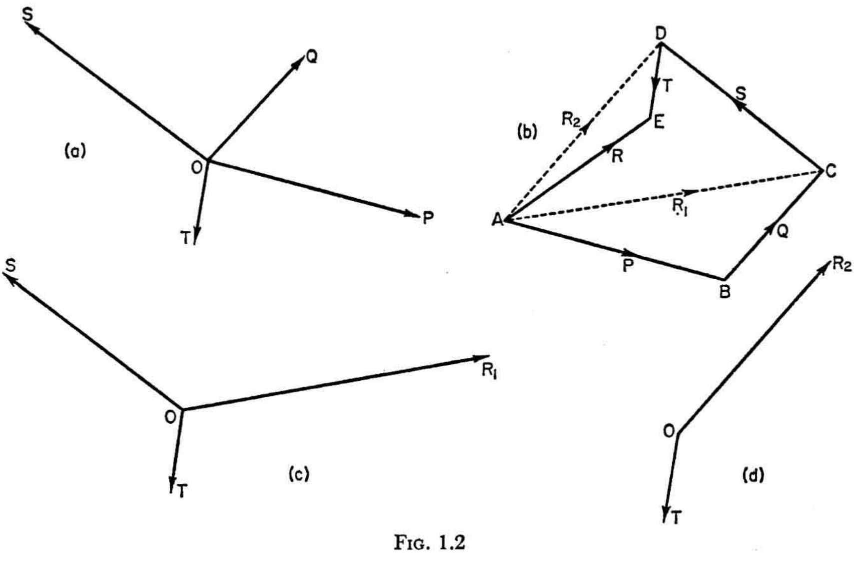


Fig. 1.2

represent the forces **P** and **Q**, then **AC** represents their resultant, $\mathbf{R}_1$. The original system of four forces can now be replaced by the system of three forces shown in Fig. 1.2c. This process can be repeated; for example forces $\mathbf{R}_1$ and **S** can be replaced by the single force $\mathbf{R}_2$ obtained from the triangle of forces ACD, thereby reducing the original system to an equivalent system involving only two forces, $\mathbf{R}_2$ and **T** (Fig. 1.2d). Finally these two forces can be replaced by a single force **R** obtained from the △ADE. The original system of four forces has now been replaced by a single equivalent force **R**; that is to say, force **R** is the resultant of the original forces **P**, **Q**, **S** and **T**.

It will be observed that there is, in fact, no need to draw the vectors **AC** and **AD** representing forces $\mathbf{R}_1$ and $\mathbf{R}_2$ respectively. The vector **AE** which represents the resultant of the original system of forces is seen to be the closing side of the polygon ABCDEA. Each of the other sides of the polygon represents, to scale, the magnitude of one of the given forces, and each side is drawn parallel to and in the same sense as the corresponding force vector in the space diagram (Fig. 1.2a). Since **AE** represents the resultant of the given forces, then **EA** must represent their equilibrant.

The polygon drawn in the manner described is called a *polygon of forces*. Although the sides of the polygon were drawn in the same order as the cyclic order, taken clockwise, of the vectors in Fig. 1.2a, this is not essential. Providing that they are drawn "head to tail" the vectors may be selected in any order. One such alternative arrangement is shown in Fig. 1.3.

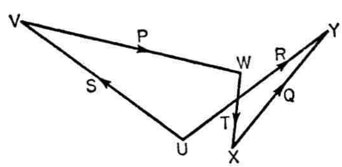


FIG. 1.3

1.3. Equilibrium of a System of Coplanar, Concurrent Forces

The polygon of forces provides a useful means of determining whether or not a system of forces is in equilibrium. All that is necessary is to draw, in the way illustrated in Fig. 1.2 and 1.3, vectors representing the given forces. If these vectors form a closed polygon, then their equilibrant is zero (since there is no "closing side" left to be drawn) and the system must therefore be in equilibrium. If, however, the vectors do not form a closed polygon, then the system is not in equilibrium. The equilibrant is the closing side of the polygon. Each of these conditions is represented in Fig. 1.4. The system of forces represented in Fig. 1.4a is in equilibrium; the system represented in Fig. 1.4b is not.

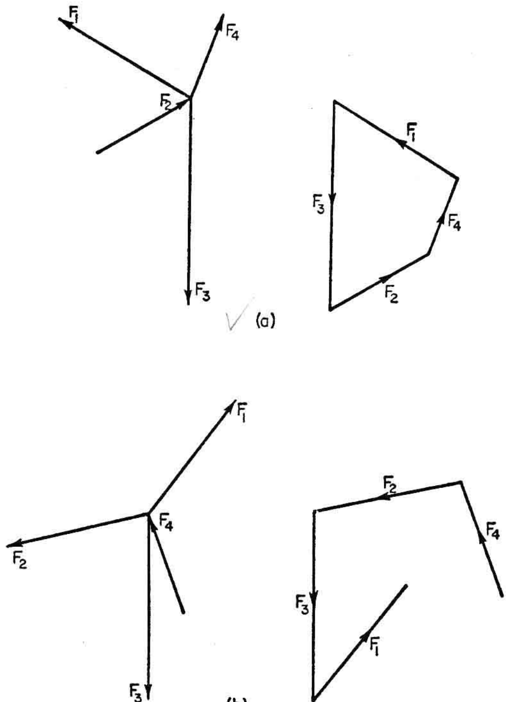


FIG. 1.4

EXAMPLE. Four horizontal concurrent forces pull on a body. One of these forces has a magnitude of 20 lbf. The remaining forces are 15 lbf at 30°, 25 lbf at 115° and 10 lbf at 200°, the angle in each case being measured counterclockwise round from the direction of the force of 20 lbf.

Determine, in magnitude and direction, the resultant pull on the body. What pull would have to be exerted to maintain the body in equilibrium?

Choose a suitable scale, say 1 in. to represent 10 lbf. Although it is not essential to do so, the reader may find it helpful, until he gains experience, to start by drawing the space diagram for the system of forces. This is shown in Fig. 1.5a, in which the solid lines represent the given forces.

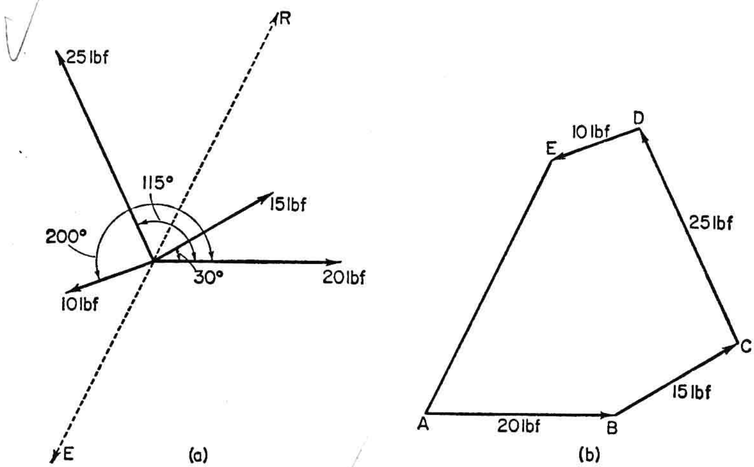


FIG. 1.5

The polygon of forces is then constructed by redrawing the force vectors "head to tail", each of the correct length and in the appropriate direction, allowing for the sense. This has been done in Fig. 1.5b, the polygon being completed by joining A to E.

The length of **AE** is measured. In this case the length is found to be $2\frac{31}{32}$ in., that is 2·97 in. which corresponds to a force of $2{\cdot}97 \times 10$ lbf $= 29{\cdot}7$ lbf. The angle BAE was measured as 64°.

Hence the resultant pull on the body is a force of 29·7 lbf