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COLLEGE PHYSICS

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FREDERICK J. BUECHE

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SCHAUM'S OUTLINE SERIES IN SCIENCE

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SCHAUM'S OUTLINE OF

THEORY AND PROBLEMS

of

COLLEGE PHYSICS

SEVENTH EDITION

by

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0-07-008857-8

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 SH SH 7 8

Library of Congress Cataloging in Publication Data

Bueche, Frederick, 1923–
Schaum's outline of college physics.

(Schaum's outline series)
Includes index.
1. Physics. I. Title. II. Title: Outline of college physics.
QC21.2.B842 1979 530 78-21551
ISBN 0-07-008857-8

Preface

Lord Kelvin said: "I often say that when you can measure what you are speaking about, and express it in numbers, you know something about it." Experienced teachers are aware of the wisdom in his remark, and they insist that physical understanding and problem-solving ability are firmly linked together. This book offers the student of general physics the opportunity to see clearly the principles of physics through their application to a large number of carefully selected problems.

Each chapter begins with a clear statement of the pertinent definitions, principles, and laws. This is followed by graduated sets of solved and supplementary problems. These are arranged so as to present a natural development of each topic, and they include a wide range of applications in both pure and applied physics. The solved problems illustrate and amplify the theory, provide the repetition of basic principles so vital to effective teaching, and bring into sharp focus those fine points which are often so worrisome to the student. The supplementary problems serve as a complete review of the material of each chapter. This book is no mere condensation of ordinary text material; it is a comprehensive approach to physics through problems.

Previous editions of this book have been favorably received and adopted by a multitude of colleges and technical schools. In this substantially revised seventh edition, major changes have been made to keep pace with the most recent concepts, methods, and terminology. Although the English gravitational and cgs systems are still included, so as to provide familiarity with them, the text now uses the SI as its fundamental units system. Many new problems have been included and many others have been revised in the interests of clarity and pedagogical value. The theory section of each chapter has been reexamined and revised where necessary to conform better with the needs of present-day students.

I am indebted to Daniel Schaum, the author of the original text, for the foundation upon which this revision is based. Professor J. Kepes was kind enough to recheck all problem solutions and I appreciate his help. A special thanks is due David Beckwith, of the Schaum's Outline Series, whose guidance and editorial expertise have been of considerable aid to me.

FREDERICK J. BUECHE

Contents

CONTENTS

CONTENTS

CONTENTS

Chapter 1

Introduction to Vectors

A SCALAR QUANTITY has only magnitude. Typical scalar quantities are the number of students in a class, the quantity of sugar in a jar, the cost of a house, etc.

Scalars, being simple numbers, are added like any numbers. Two candies in one box plus seven in another give nine candies total.

A VECTOR QUANTITY has both magnitude and direction. For example, a *vector displacement* might be a change in position from one point to a second point 2 cm away and in the x-direction from the first point. As another example, a cord pulling northward on a post gives rise to a *vector force* on the post of 20 lb northward. Similarly, a car moving south at 40 km/h has a *vector velocity* of 40 km/h southward.

A vector quantity can be represented by an arrow drawn to scale. The length of the arrow is proportional to the magnitude of the vector quantity (2 cm, 20 lb, 40 km/h in the above examples). The direction of the arrow represents the direction of the vector quantity.

In printed material, vectors are represented by boldface type, such as **F**. When written by hand, the designations $\vec{F}$ and $\underset{\sim}{F}$ are often used.

THE RESULTANT of a number of similar vectors, force vectors for example, is that single vector which would have the same effect as all the original vectors taken together.

GRAPHICAL ADDITION OF VECTORS (POLYGON METHOD): This method for finding the resultant of several vectors consists in beginning at any convenient point and drawing (to scale) each vector arrow in turn. They may be taken in any order of succession. The tail end of each arrow is attached to the tip end of the preceding one.

The resultant is represented by an arrow with its tail end at the starting point and its tip end at the tip of the last vector added.

PARALLELOGRAM METHOD for adding two vectors: The resultant of two vectors acting at any angle may be represented by the diagonal of a parallelogram. The two vectors are drawn as the sides of the parallelogram and the resultant is its diagonal, as shown in Fig. 1-1. The direction of the resultant is away from the origin of the two vectors.

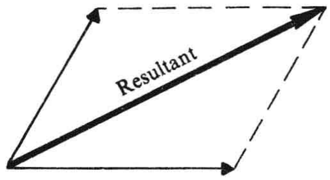

Fig. 1-1

SUBTRACTION OF VECTORS: To subtract a vector **B** from a vector **A**, reverse the direction of **B** and add it vectorially to vector **A**, i.e. $\mathbf{A} - \mathbf{B} = \mathbf{A} + (-\mathbf{B})$.

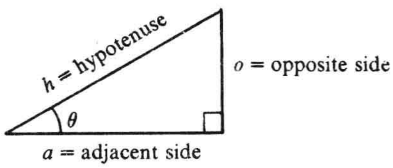

Fig. 1-2

THE TRIGONOMETRIC FUNCTIONS are defined in relation to a right triangle. For the right triangle shown in Fig. 1-2, by definition

$$\sin\theta = \frac{o}{h} \qquad \cos\theta = \frac{a}{h} \qquad \tan\theta = \frac{o}{a}$$

We often use these in the forms

$$o = h\sin\theta \qquad a = h\cos\theta \qquad o = a\tan\theta$$

A COMPONENT OF A VECTOR is its effective value in a given direction. For example, the x-component of a displacement is the displacement parallel to the x-axis caused by the given displacement. A vector may be considered as the resultant of its component vectors along the specified directions. It is customary, and useful, to resolve a vector into components along *mutually perpendicular* directions (*rectangular components*).

COMPONENT METHOD FOR ADDING VECTORS: Each vector is resolved into its x-, y-, and z-components, with negatively directed components taken as negative. The x-component of the resultant, R_x, is the algebraic sum of all the x-components. The y- and z-components of the resultant are found in a similar way. Knowing the components, the magnitude of the resultant is given by

$$R = \sqrt{R_x^2 + R_y^2 + R_z^2}$$

In two dimensions, the angle of the resultant with the x-axis can be found from the relation

$$\tan\theta = \frac{R_y}{R_x}$$

Solved Problems

1.1. Using the graphical method, find the resultant of the following two displacements: 2 m at 40° and 4 m at 127°, the angles being taken relative to the $+x$-axis.

Choose (x,y)-axes as shown in Fig. 1-3 and lay out the displacements to scale tip to tail from the origin. Notice that all angles are measured from the $+x$-axis. The resultant vector, **R**, points from starting point to end point as shown. We measure its length on the scale diagram to find its magnitude, 4.6 m. Using a protractor, we measure its angle θ to be 101°. The resultant displacement is therefore 4.6 m at 101°.

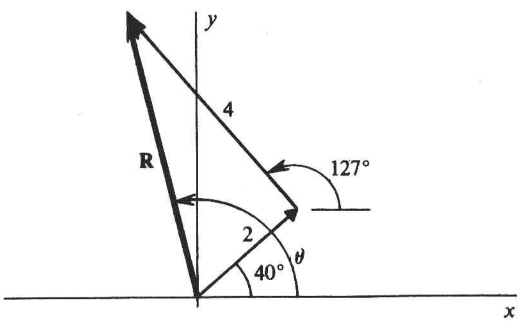

Fig. 1-3

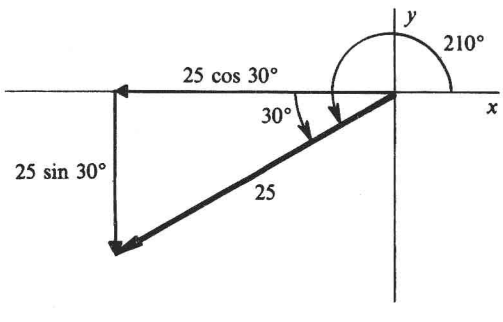

Fig. 1-4

1.2. Find the x- and y-components of a 25 m displacement at an angle of 210°.

The vector displacement and its components are shown in Fig. 1-4. The components are

$$x\text{-component} = -25\cos 30° = -21.7\text{ m}$$
$$y\text{-component} = -25\sin 30° = -12.5\text{ m}$$

Notice in particular that each component points in the negative coordinate direction and must therefore be taken as negative.

In the above computation the components should properly have been written

$$-(25\text{ m})\cos 30° \qquad -(25\text{ m})\sin 30°$$

We shall often omit units in situations such as this to save space.

1.3. Solve Problem 1.1 by use of rectangular components.

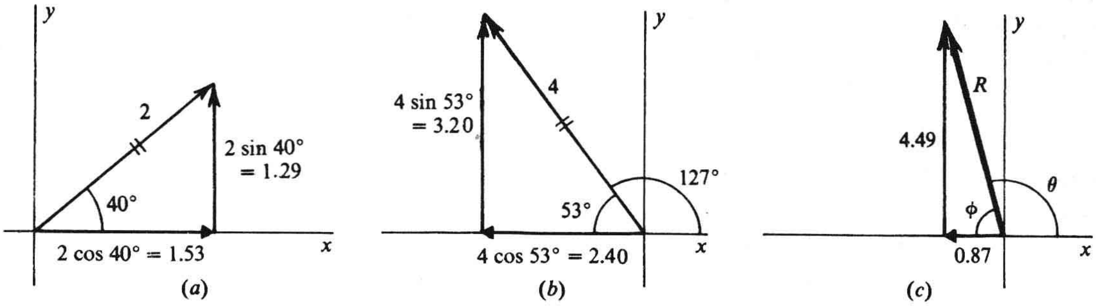

Fig. 1-5

We resolve each vector into rectangular components as shown in Fig. 1-5(*a*) and (*b*). (We place a cross hatch symbol on the original vector to show that it is replaced by its components.) The resultant has the components

$$R_x = 1.53 - 2.40 = -0.87 \text{ m} \qquad R_y = 1.29 + 3.20 = 4.49 \text{ m}$$

Notice that components pointing in the negative direction must be assigned a negative value.

The resultant is shown in Fig. 1-5(*c*); we see that

$$R = \sqrt{(0.87)^2 + (4.49)^2} = 4.57 \text{ m} \qquad \tan\phi = \frac{4.49}{0.87}$$

Hence, $\phi = 79°$, from which $\theta = 180° - \phi = 101°$.

1.4. Add the following two force vectors by use of the parallelogram method: 30 pounds at 30° and 20 pounds at 140°. (A *pound of force* is chosen such that a 1 kg object weighs 2.21 lb on earth. One pound is equivalent to a force of 4.45 newtons, 4.45 N.)

The force vectors are shown in Fig. 1-6(*a*). We construct a parallelogram using them as sides, as shown in Fig. 1-6(*b*). The resultant, **R**, is then shown as the diagonal. By measurement, we find that **R** is 30 lb at 72°.

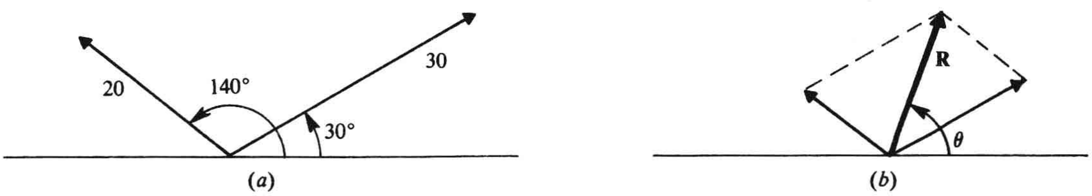

Fig. 1-6

1.5. Four coplanar forces act on a body at point *O* as shown in Fig. 1-7(*a*). Find their resultant graphically. (In Fig. 1-7, the force unit N is newtons. A 1 kg object weighs 9.8 N on earth. A force of 1 N is equivalent to a force of 0.225 pounds.)

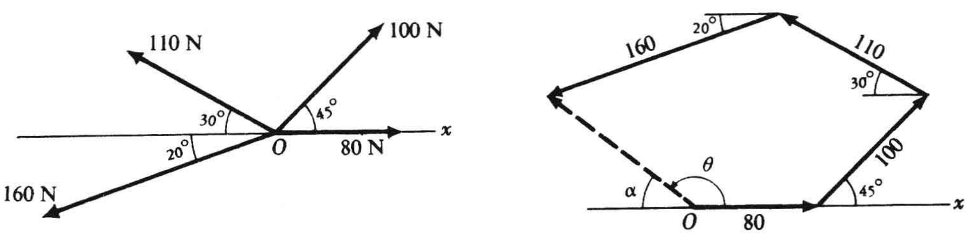

Fig. 1-7

Starting from O, the four vectors are plotted in turn as shown in Fig. 1-7(b). We place the tail end of one vector at the tip end of the preceding one. The arrow from O to the tip of the last vector represents the resultant of the vectors.

We measure R from the scale drawing in Fig. 1-7(b) and find it to be 119 N. Angle α is measured by protractor and is found to be 37°. Hence the resultant makes an angle $\theta = 180° - 37° = 143°$ with the positive x-axis. The resultant is 119 N at 143°.

1.6. Solve Problem 1.5 by use of the rectangular component method.

The vectors and their components are:

Vector	x-Component	y-Component
80	80	0
100	$100 \cos 45° = 71$	$100 \sin 45° = 71$
110	$-110 \cos 30° = -95$	$110 \sin 30° = 55$
160	$-160 \cos 20° = -150$	$-160 \sin 20° = -55$

Notice the sign of each component. To find the resultant, we have

$$R_x = 80 + 71 - 95 - 150 = -94 \text{ N}$$

$$R_y = 0 + 71 + 55 - 55 = 71 \text{ N}$$

The resultant is shown in Fig. 1-8; we see that

$$R = \sqrt{(94)^2 + (71)^2} = 118 \text{ N}$$

Further, $\tan \alpha = 71/94$, from which $\alpha = 37°$. Therefore the resultant is 118 N at $180 - 37 = 143°$.

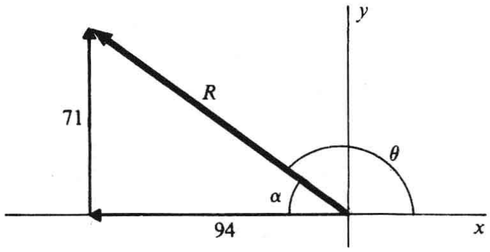

Fig. 1-8

1.7. Perform graphically the following vector additions and subtractions, where **A**, **B**, and **C** are the vectors shown in Fig. 1-9: (a) **A** + **B**; (b) **A** + **B** + **C**; (c) **A** − **B**; (d) **A** + **B** − **C**.

See Fig. 1-9(a) through (d). In (c), **A** − **B** = **A** + (−**B**); i.e. to subtract **B** from **A**, reverse the direction of **B** and add it vectorially to **A**. Similarly, in (d), **A** + **B** − **C** = **A** + **B** + (−**C**), where −**C** is equal in magnitude but opposite in direction to **C**.

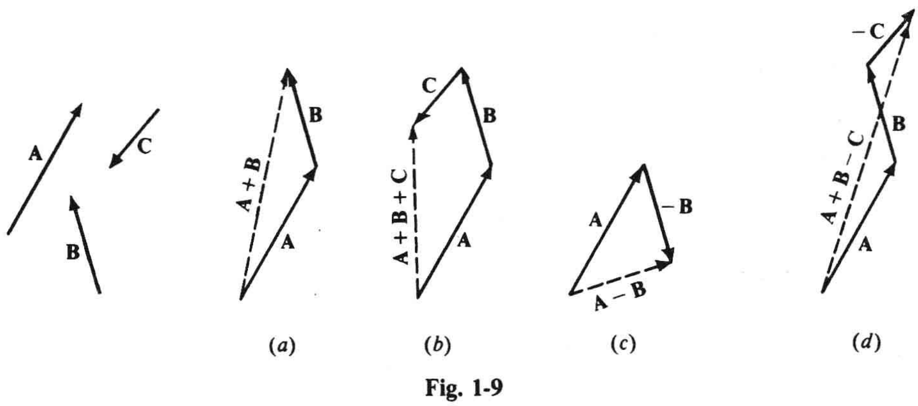

Fig. 1-9

1.8. A force of 100 N makes an angle of θ with the x-axis and has a y-component of 30 N. Find both the x-component of the force and the angle θ.

The data are sketched roughly in Fig. 1-10. We wish to find F_x and θ. We know that

$$\sin \theta = \frac{o}{h} = \frac{30}{100} = 0.30$$

from which $\theta = 17.5°$. Then, since $a = h \cos \theta$, we have

$$F_x = 100 \cos 17.5° = 95.4 \text{ N}$$

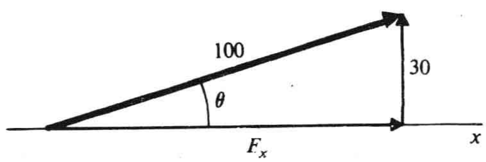

Fig. 1-10

1.9. A boat can travel at a speed of 8 km/h in still water on a lake. In the flowing water of a stream, it can move at 8 km/h relative to the water in the stream. If the stream speed is 3 km/h, how fast can the boat move past a tree on the shore in traveling (*a*) upstream? (*b*) downstream?

(*a*) If the water were standing still, the boat's speed past the tree would be 8 km/h. But the stream is carrying it in the opposite direction at 3 km/h. Therefore the boat's speed relative to the tree is $8 - 3 = 5$ km/h.

(*b*) In this case, the stream is carrying the boat in the same direction the boat is trying to move. Hence its speed past the tree is $8 + 3 = 11$ km/h.

1.10. A plane is traveling eastward at an airspeed of 500 km/h. But a 90 km/h wind is blowing southward. What are the direction and speed of the plane relative to the ground?

The plane's resultant velocity is the sum of two velocities, 500 km/h eastward and 90 km/h southward. These component velocities are shown in Fig. 1-11. The plane's resultant velocity is found by use of

$$R = \sqrt{(500)^2 + (90)^2} = 508 \text{ km/h}$$

The angle α is given by

$$\tan \alpha = \frac{90}{500} = 0.180$$

from which $\alpha = 10.2°$. The plane's velocity relative to the ground is 508 km/h at 10.2° south of east.

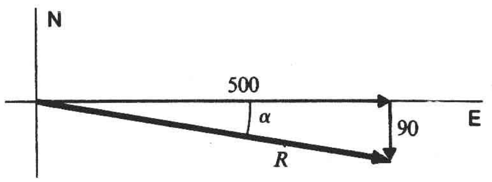

Fig. 1-11

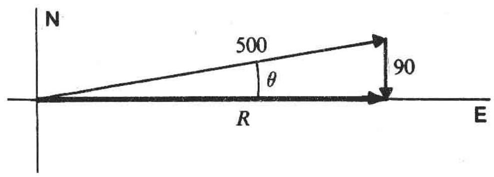

Fig. 1-12

1.11. With the same airspeed as in Problem 1.10, in what direction must the plane head in order to move due east relative to the earth?

The sum of the plane's velocity through the air and the velocity of the wind will be the resultant velocity of the plane relative to the earth. This is shown in the vector diagram of Fig. 1-12. Notice that, as required, the resultant velocity is eastward. It is seen that $\sin \theta = 90/500$, from which $\theta = 10.4°$. The plane should head 10.4° north of east if it is to move eastward on the earth.

If we wish to find the plane's eastward speed, the figure tells us that $R = 500 \cos \theta = 492$ km/h.

1.12. A child pulls a rope attached to a sled with a force of 60 N. The rope makes an angle of 40° to the ground. (*a*) Compute the effective value of the pull tending to move the sled along the ground. (*b*) Compute the force tending to lift the sled vertically.

As shown in Fig. 1-13, the components of the 60 N force are 39 N and 46 N. (*a*) The pull along the ground is the horizontal component, 46 N. (*b*) The lifting force is the vertical component, 39 N.

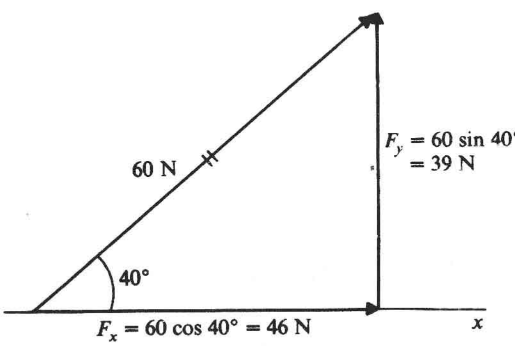

Fig. 1-13

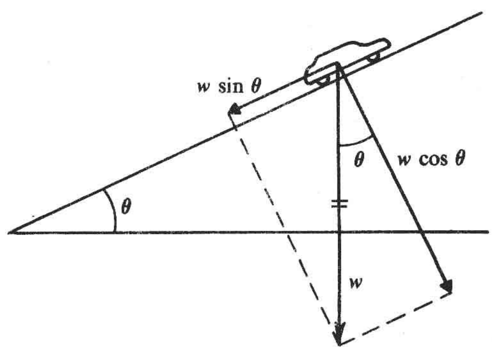

Fig. 1-14

1.13. A car whose weight is w is on a ramp which makes an angle θ to the horizontal. How large a perpendicular force must the ramp withstand if it is not to break under the car's weight?

As shown in Fig. 1-14, the car's weight is a force **w** that pulls straight down on the car. We take components of **w** along the incline and perpendicular to it. The ramp must balance the force component $w \cos \theta$ if the car is not to crash through the ramp.

1.14. The five coplanar forces shown in Fig. 1-15(*a*) act on an object. Find the resultant force due to them.

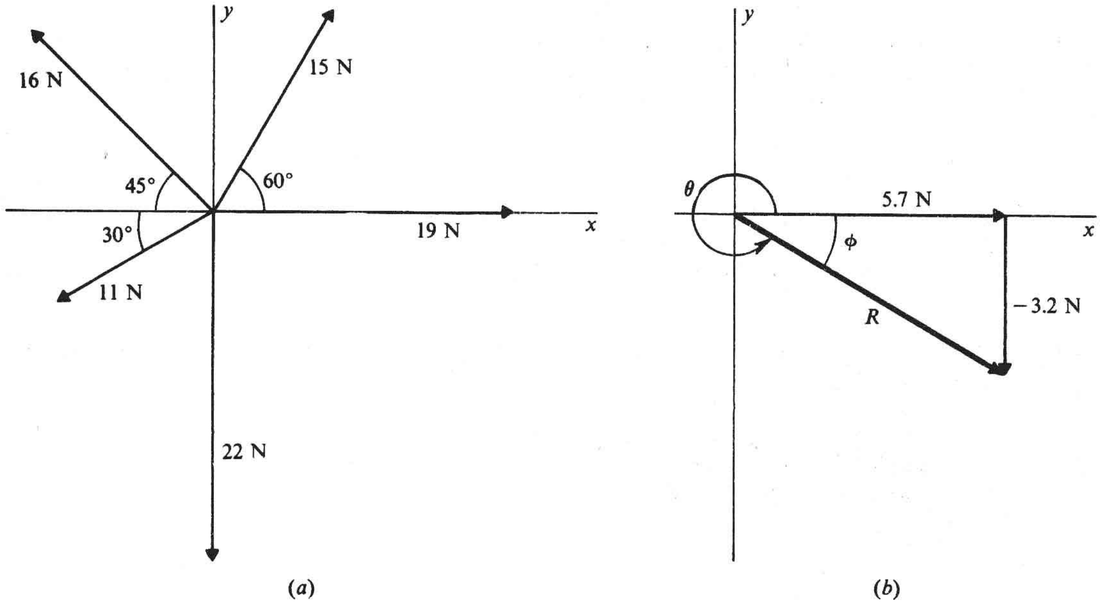

Fig. 1-15

(1) Find the x- and y-components of each force. These components are as follows:

Force	x-Component	y-Component
19 N	19.0	0
15 N	$15 \cos 60° = 7.5$	$15 \sin 60° = 13.0$
16 N	$-16 \cos 45° = -11.3$	$16 \sin 45° = 11.3$
11 N	$-11 \cos 30° = -9.5$	$-11 \sin 30° = -5.5$
22 N	0	-22.0

Notice the signs to indicate + and − directions.

(2) The resultant **R** has components $R_x = \sum F_x$ and $R_y = \sum F_y$, where we read $\sum F_x$ as "the sum of all the x-force components." We then have

$$R_x = 19.0 + 7.5 - 11.3 - 9.5 + 0 = +5.7 \text{ N}$$

$$R_y = 0 + 13.0 + 11.3 - 5.5 - 22.0 = -3.2 \text{ N}$$

(3) Find the magnitude of the resultant from

$$R = \sqrt{R_x^2 + R_y^2} = 6.5 \text{ N}$$

(4) Sketch the resultant as shown in Fig. 1-15(*b*) and find its angle. We see that

$$\tan \phi = \frac{3.2}{5.7} = 0.56$$

from which $\phi = 29°$. Then we have that $\theta = 360° - 29° = 331°$. The resultant is 6.5 N at 331° (or −29°).

Supplementary Problems

1.15. A car goes 5.0 km east, 3.0 km south, 2.0 km west, and 1.0 km north. (*a*) Determine how far north and how far east it has been displaced. (*b*) Find the displacement vector both graphically and algebraically.
Ans. (*a*) 3 km east, −2 km north; (*b*) 3.6 km at 34° south of east

1.16. Find the x- and y-components of a 400 N force at an angle of 125° to the x-axis.
Ans. −229 N, 328 N

1.17. Find the vector sum of the following four displacements on a map: 60 mm north; 30 mm west; 40 mm at 60° west of north; 50 mm at 30° west of south. Solve graphically and also algebraically. (mm stands for millimeter, 0.001 meter.) *Ans.* 97 mm at 67.7° west of north

1.18. Two forces, 80 N and 100 N acting at an angle of 60° with each other, pull on an object. (*a*) What single force would replace the two forces? (*b*) What single force (called the *equilibrant*) would balance the two forces? Solve algebraically.
Ans. (*a*) **R**: 156 N at 34° with the 80 N force; (*b*) −**R**: 156 N at 214° with the 80 N force

1.19. Two forces act on a point object as follows: 100 N at 170° and 100 N at 50°. Find their resultant.
Ans. 100 N at 110°

1.20. Find graphically the resultant of each of the three coplanar force systems shown in Fig. 1-16.
Ans. (*a*) 35 lb at 34°; (*b*) 59 lb at 236°; (*c*) 172 lb at 315°

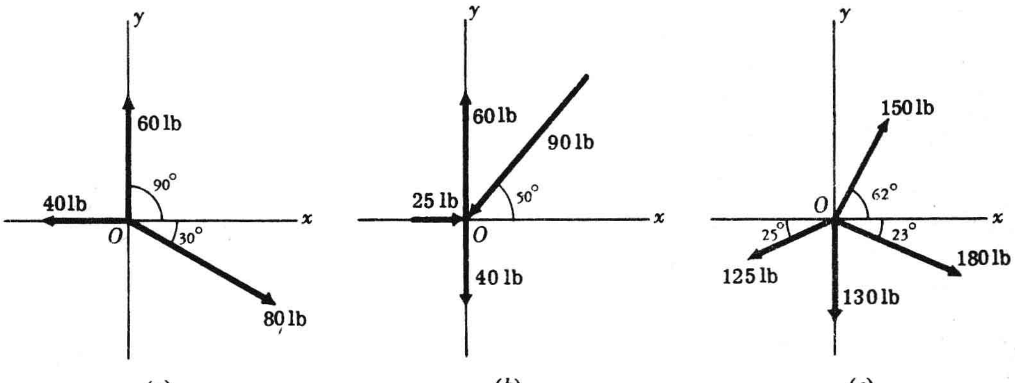

Fig. 1-16

1.21. Find algebraically the (*a*) resultant and (*b*) equilibrant (see Problem 1.18) of the following coplanar forces: 300 N at 0°, 400 N at 30°, and 400 N at 150°. *Ans.* (*a*) 500 N at 53°; (*b*) 500 N at 233°

1.22. Compute algebraically the (*a*) resultant and (*b*) equilibrant of the following coplanar forces: 100 lb at 30°, 141.4 lb at 45°, and 100 lb at 240°. Check your result graphically.
Ans. (*a*) 151 lb at 25°; (*b*) 151 lb at 205°

1.23. Compute algebraically the resultant of the following displacements: 20 m at 30°, 40 m at 120°, 25 m at 180°, 42 m at 270°, and 12 m at 315°. Check your answer by a graphical solution.
Ans. 20 m at 197°

1.24. Refer to Fig. 1-17. In terms of vectors **A** and **B**, express the vectors (*a*) **P**; (*b*) **R**; (*c*) **S**; (*d*) **Q**. *Ans.* (*a*) **A** + **B**; (*b*) **B**; (*c*) −**A**; (*d*) **A** − **B**

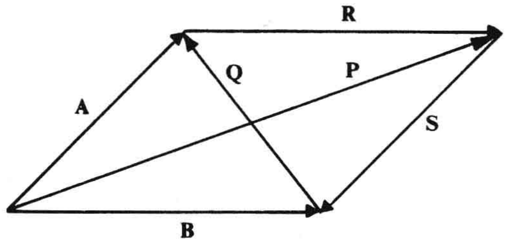

Fig. 1-17

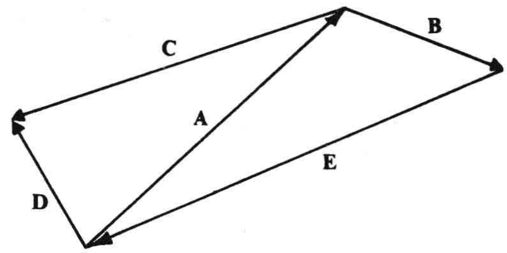

Fig. 1-18

1.25. Refer to Fig. 1-18. In terms of vectors **A** and **B**, express the vectors (*a*) **E**; (*b*) **D** − **C**; (*c*) **E** + **D** − **C**. *Ans.* (*a*) −**A** − **B** or −(**A** + **B**); (*b*) **A**; (*c*) −**B**

1.26. A reckless drunk is playing with a gun in an airplane that is going directly east at 500 km/h. The drunk shoots the gun straight up at the ceiling of the plane. The bullet leaves the gun at a speed of 1000 km/h. According to someone standing on the earth, what angle does the bullet make to the vertical? *Ans.* 26.6°

1.27. A truck is moving north at a speed of 70 km/h. The exhaust pipe above the truck cab sends out a trail of smoke that makes an angle of 20° east of south behind the truck. If the wind is blowing directly toward the east, what is the wind speed at that location? *Ans.* 25 km/h

1.28. A ship is traveling due east at 10 km/h. What must be the speed of a second ship heading 30° east of north if it is always due north from the first ship? *Ans.* 20 km/h

1.29. A boat, propelled so as to travel with a speed of 0.50 m/s in still water, moves directly across a river that is 60 m wide. The river flows with a speed of 0.30 m/s. (*a*) At what angle, relative to the straight-across direction, must the boat be pointed? (*b*) How long does it take the boat to cross the river? *Ans.* (*a*) 37° upstream; (*b*) 150 s

1.30. A child is holding a wagon from rolling straight back down a driveway that is inclined at 20° to the horizontal. If the wagon weighs 150 N, how hard must the child pull on the handle if the handle is parallel to the incline? *Ans.* 51 N

1.31. Repeat Problem 1.30 if the handle is at an angle of 30° above the incline. *Ans.* 59 N