Module 1
Dynamics Extension

Introduction

If you took Physics 11, you were introduced to the concepts of vectors and vector arithmetic. You will recall that **vectors** are used to represent quantities that have both magnitude (how much) and direction (which way). A **scalar**, on the other hand, requires magnitude only for complete description. Scalars can be added, subtracted, multiplied and divided like ordinary numbers. However, vector arithmetic has its own rules. Recall that adding vectors involves head to tail addition and the result of adding two vectors is called the **resultant**. For example, if Jane walks 3 blocks north then turns and walks 4 blocks east, her resultant is 5 blocks 37° north of east. If you haven't taken Physics 11 or you want a refresher on vectors, review your textbook pp. 108-116.

For a refresher on acceleration due to gravity, review pages 76 - 77 of your textbook. The acceleration of gravity that we will use is -9.80 m/s^2. The negative symbol indicates that the acceleration is acting in a downward direction.

To calculate the weight or force of gravity of an object, multiply mass (in kg) by the acceleration due to gravity (no need to use the negative integer). The calculation to calculate weight is:

W = mg
W = weight of object in Newtons (N)
m = mass of object in kilograms (kg)
g = acceleration due to gravity (N/kg)

Module Outcomes

Upon completion of this module, you are expected to be able to:

- ❐ use vector analysis in two dimensions for systems involving two or more masses, relative motions, static equilibrium, and static torques

Example: An object has a mass of 60.0 kg. Find its weight.

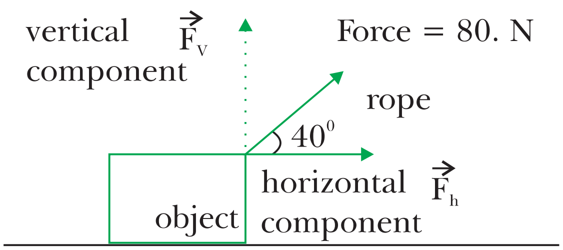
W = mg = (60.0 kg)(9.80 N/kg) = 588 N

Section 1
Components of Vectors

In physics we will often want to change a single vector into an equivalent set of two component vectors at right angles to one another. Any vector can be resolved into two component vectors, usually called the horizontal and vertical component. This process of breaking a vector into its components is very useful in simplifying the mathematics involved in solving vector problems.

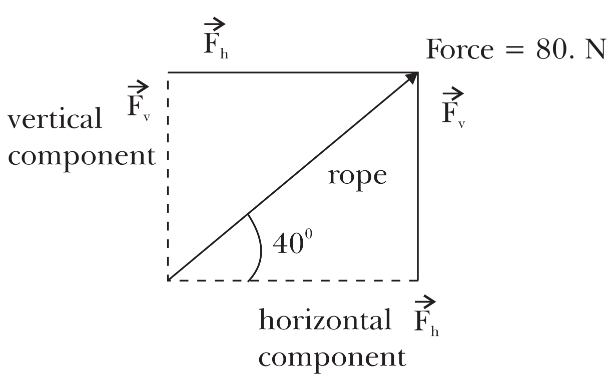
The process of determining the magnitude of a component in a specific direction for a given vector is called vector resolution. Figure 1.1 shows an object being pulled with a force of 80. N by a rope held at an angle of 40° with respect to the horizontal. The rope pulls both forward (in the horizontal direction) and upward (in the vertical direction) on the object.

Figure 1.1



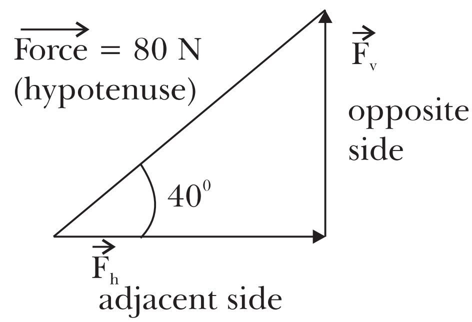
The magnitudes of the horizontal and vertical components of the 80. N force can be determined by first drawing a horizontal and vertical line of reference (set of perpendicular axes). To resolve the 80. N force into the components, F_h and F_v, draw lines perpendicularly from each axis to the tip of the 80. N force vector (Figure 1.2).

Figure 1.2



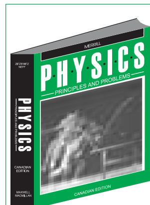
The magnitude of the horizontal component, F_h, and the vertical component, F_v, can be determined by considering the vector resolution diagram as a right-angled triangle and using trigonometry (Figure 1.3).

Figure 1.3



Horizontal Component	Vertical Component
$\sin\theta = \dfrac{\text{opposite side}}{\text{hypotenuse}}$	$\cos\theta = \dfrac{\text{adjacent side}}{\text{hypotenuse}}$
$\sin\theta = \dfrac{F_v}{F} = \dfrac{F_v}{80\text{ N}}$	$\cos\theta = \dfrac{F_h}{F} = \dfrac{F_h}{80\text{ N}}$
$F_v = (80\text{ N})\sin 40^\circ = 51\text{ N}$	$F_h = (80\text{N})\cos 40^\circ = 61\text{ N}$

READ AND DO



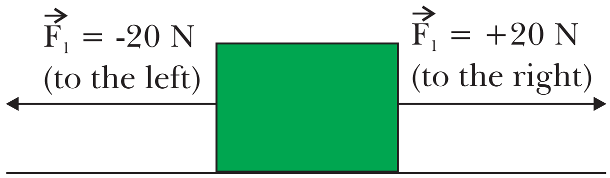
Read pp. 116-118 in your textbook.
Do Practice Problems 11, 12, 13 and 14 on p. 118 in your textbook.

Check your answers by turning to p. 664 in your textbook.

SECTION 2: THE EQUILIBRANT

When two or more forces act on an object from the same point, their vector sum may result in a net force of zero. When this occurs, the object is considered to be in a state of **equilibrium**. An example of equilibrium is the case in which two equal forces act in opposite directions as illustrated in Figure 1.4.

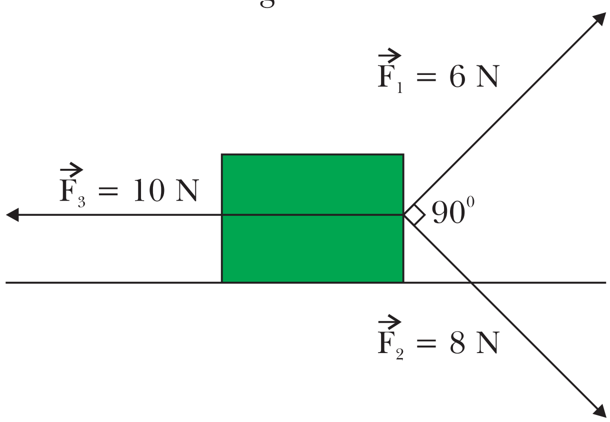
Figure 1.4



According to Newton's Laws, the object will not be accelerated because there is no net force on it. This is a simple example of equilibrium where the resultant force is zero.

For a second example, consider three forces acting on an object as illustrated in Figure 1.5.

Figure 1.5



Force (1) and Force (2) will produce a resultant force of 10 N to the right. Force (3) is a 10-N force to the left. The resultant force of these three forces is zero. Therefore, the three forces produce no net force on the object and the object is in equilibrium.

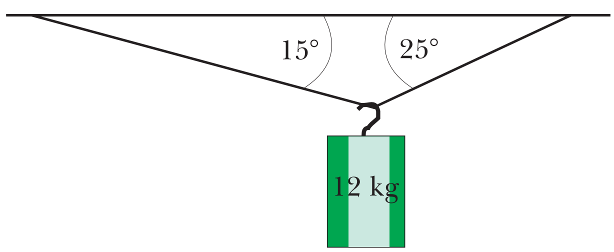
Engineers are frequently concerned with the stability of structures, such as bridges and buildings, and the forces that support frameworks must offset. To produce stability, these forces acting on the structures must be arranged in such a manner as to produce a *net force of zero*. The vector sum of these forces must be zero. A resultant force of zero is known as the condition for equilibrium.

Sometimes, when two or more forces acting on an object do not produce a net force of zero, an **equilibrant force** can be determined if equilibrium is still desired. The equilibrant force is the single additional force which, when applied at the same point as the other forces acting on the object, will produce equilibrium.

EXAMPLE PROBLEM

Figure 1.6 represents a 12.0-kg mass hanging from a clothesline.

Figure 1.6



(a) Draw a free body diagram of the situation.

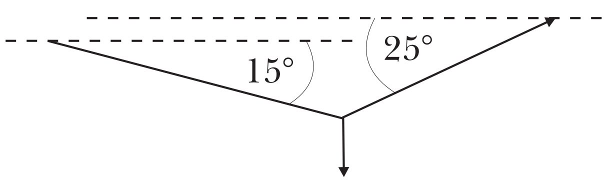
(b) Draw diagrams showing the components of the tensions in the clothesline.

(c) Determine the tension in each side of the line.

SOLUTION

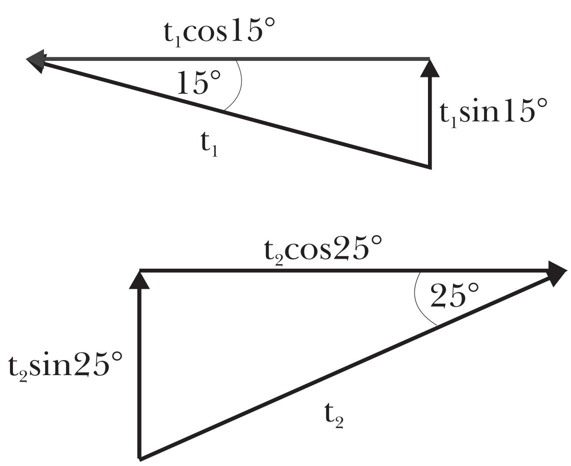
(a) Free Body Diagram

Figure 1.7



(b) Components of the Tension

Figure 1.8



(c) 177 and 166

Note that the weight of 12.0 kg is 118 N. The diagrams give us two simultaneous equations.

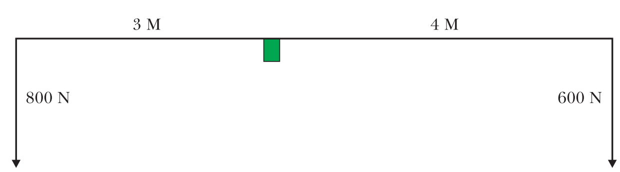
$t_1\sin15^o + t_2\sin25 = 117.7$ (vertical)

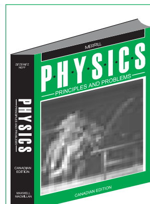
$t_1\cos15^o = t_2\cos 15^o$ (horizontal)

These equations can be solved to yield answers of approximately 175 and 164 Newtons.

Sometimes we have to deal with objects that are rotating about a pivot. Physicists define the term torque to deal with such situations. Torque is the product of the force and the perpendicular distance between the force applied and the pivot. If no rotation is to occur (rotational equilibrium) then the clockwise torque must equal the counter clockwise torque. Suppose Sally and Bob are on opporsite ends of a see-saw. Sally weighs 600 N while Bob weighs 800 N. If Bob is 3 meters away from the pivot then he is producing 2400 units of torque and Sally counter balances this by sitting 4 meters away. The result is that the see-saw does not move (Figure 1.9).

Figure 1.9



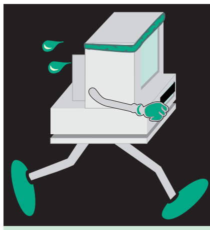


READ AND DO

Read pp. 120-122 in your textbook.

Do Practice Problems 17, 18, 19, 20, 21 and 22 on p. 123 in your textbook.

Check your answers by turning to pp. 665-666 in your textbook.



Do and Check 1: Force Components

Do the following questions.

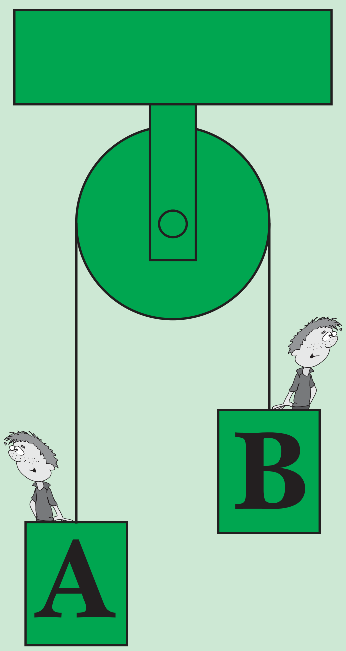
1. Buster is pushing on a broom handle, which makes an angle of 40º with the horizontal, with a force of 100 N. What are the vertical and horizontal components of this force?

2. Walt is pushing a 2000-N refrigerator up the ramp. The ramp makes an angle of 20° with the horizontal. Because the cart has a coefficient of friction of only 0.05, most of Walt's push is against the gravitational component. If Walt is pushing parallel to the ramp, what force must he exert to keep the refrigerator moving up at a constant velocity?

3. Half the Bobbsey twins, with a mass of 70 kg, is riding in basket A; the other half, with a mass of 60 kg is in basket B (see Figure 1.10). The two baskets each have a mass of 10 kg, and are linked together by a rope that is slung over the pulley as shown in Figure 1.10. Assume that the rope and pulley have negligible mass and that friction is negligible. How far will basket B rise in 5 s if it is initially moving upwards at a speed of 4 m/s?

   Answers:
   (a) 8.2 m
   (b) 28.2 m
   (c) 38.9 m
   (d) 36.3 m
   (e) 20.0 m

Figure 1.10



4. Explain why a long-handled wrench is better to remove a stuck bolt than a short-handled wrench.

5. The unfortunate person in Figure 1.11 has slipped off the cliff! Fortunately, a tree limb was within reach and it's providing a solution to his problem, at least temporarily. Your problem is to determine the magnitude of the torque supplied by the cliff-side to produce equilibrium. Here is some data which might be helpful:

   person's mass = 80 kg

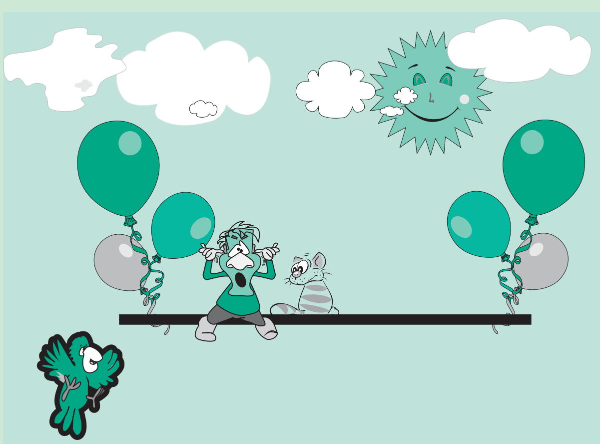
   tree limb's mass = 0 kg (it's very dry!)

   distance between cliff-side and person = 2.5 m

Figure 1.11

6. Sally Stoutheart and her cat, Shivers, have just become airborne thanks to the lift from some helium-filled balloons (see Figure 1.12). Sally, who weighs 400 N, is sitting 2 m from the left end of the 6 m pole. Shivers weighs 100 N and is sitting in the middle (3 m from either end). The pole weighs 500 N and its center of gravity is 2 m from the right end. Assume the balloons are attached to the ends of the pole and that Sally and her crew are not accelerating. How much lift are the balloons providing at each end?

Figure 1.12



Check your answers in the Solutions Appendix, p. 1 at the back of this manual.

SECTION 3: GRAVITATIONAL FORCES, FRICTION AND INCLINED PLANES

If you took Physics 11 you will recall that **friction** is the name given to the force that acts between materials that are touching as they move past one another. Friction always opposes motion and the force of friction can be found by the formula:

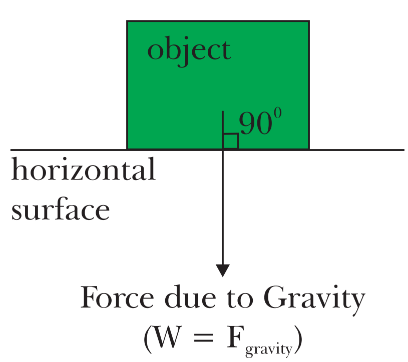
$$F_f = \mu F_n$$

where F_f is the force of friction, μ is the coefficient of friction and F_n is the normal force which acts perpendicular to the surfaces.

If you didn't take Physics 11 or you would like a refresher on friction, read pp. 96-102 in your textbook.

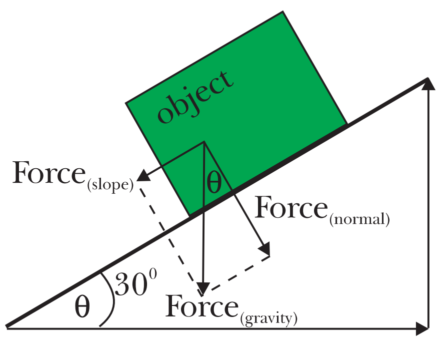
When an object is on a flat, horizontal surface, the gravitational attraction of the Earth acting on that object, its weight, is directed toward the centre of the Earth. This means that its weight ($W = F_{(gravity)}$) must act perpendicular to the surface of the Earth or perpendicular to the horizontal surface on which the object is resting. Examine Figure 1.13.

Figure 1.13



When an object is on an inclined plane, the gravitational force, weight of the object, continues to act toward the centre of the Earth but is no longer perpendicular to the surface on which it is resting. Examine Figure 1.14.

Figure 1.14



The inclined plane prevents the weight (**force of gravity**) of the object from accelerating in the vertical direction. Instead, the inclined plane causes the weight, the force of gravity, to be resolved into two components. One component is called the **Force$_{(slope)}$** and acts parallel to and down the sloped inclined plane. The second component is called the **Force$_{(normal)}$** and acts perpendicular to the surface of the inclined plane.

The right-triangle formed by the inclined plane and the right-triangle formed by the forces, $W(F_g)$, F_s and F_N, are similar triangles (corresponding sides are mutually perpendicular). If θ and $W(F_g)$ are both known, a vector diagram similar to that illustrated in Figure 1.14 may be drawn and the $W(F_g)$ resolved into the two components, Force$_{(slope)}$ and Force$_{(normal)}$, by using the trigonometric functions of right-angled triangles.

EXAMPLE PROBLEM 1

Consider the situation above, given that the object on the inclined plane weighs 400 N and the angle θ is equal to 30°. Determine the Force$_{(slope)}$ and the Force$_{(normal)}$.

SOLUTION

(a) $\sin\theta = \text{Force}_{(slope)}/\text{Force}_{(gravity)}$

$\text{Force}_{(slope)} = \text{Force}_{(gravity)} \times \sin\theta$

$\text{Force}_{(slope)} = (400\ \text{N}) \times \sin 30^{o}$

$\text{Force}_{(slope)} = (400\ \text{N}) \times 0.500 = 200\ \text{N}$

(b) $\cos\theta = \text{Force}_{(normal)}/\text{Force}_{(gravity)}$

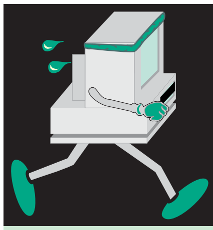
$\text{Force}_{(normal)} = \text{Force}_{(gravity)} \times \cos\theta$

$\text{Force}_{(normal)} = (400\ \text{N}) \times \cos 30^{o}$

$\text{Force}_{(normal)} = (400\ \text{N}) \times 0.866 = 346\ \text{N}$

PHUN ACTIVITY

Read over the Example Problem on p. 126 in your textbook. It shows you how to find the coefficient of static friction between a coin and your textbook cover. Find the coefficient of static friction between a Canadian “twonie” and the textbook cover. Compare it with the coefficient of static friction between a “loonie” and the same book cover. Be careful: you need to find the spot where the coin just begins to slide down at constant speed. I suggest you find the angle, by using the ratio of the height over the length of the plane, in conjunction with the sine function.



DO AND CHECK 2: FORCE AND INCLINES

Do the following questions.

1. Suppose you are pushing a 325-N crate up a 20° inclined plane at a steady speed.

   (a) What is the downward component of the crate's weight?

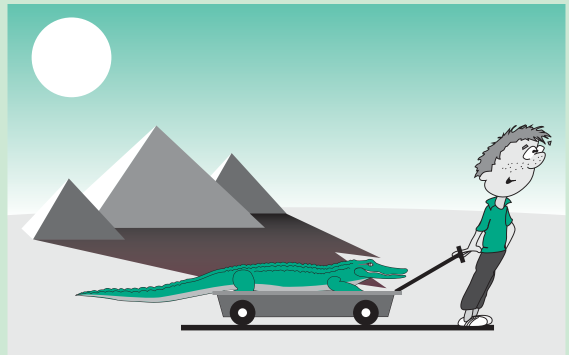
   (b) What is the net force on the crate?

   (c) If the force of friction present is 100 N, find the coefficient of friction between the crate and the plane.

   (d) What force are you actually exerting in order to slide the crate up the ramp at a constant speed?

2. Andy and his pet alligator are strolling at a constant velocity on the sands of the Sahara Desert (see Figure 1.15). Andy is pulling on the handle of the wagon with a force of 90 N, and the handle makes an angle of 30° with the horizontal. If the wagon weighs 60 N, the alligator weighs 220 N, Andy weighs 500 N, the Earth is round, and the desert is hot, what is the magnitude of the force of friction between the wagon and the hot desert sands?

Figure 1.15

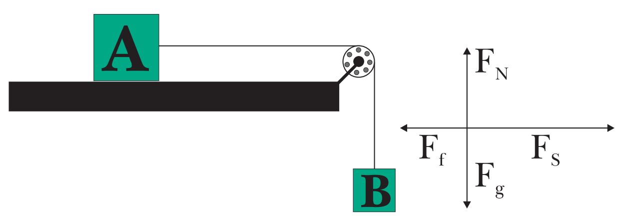


Check your answers in the Solutions Appendix, p. 2 at the back of this manual.

EXAMPLE PROBLEM 2

Suppose two boxes, A and B, are connected by a string running through a pulley, as shown in the Figure 1.16. The coefficient of friction between the box and table is 0.200. Box A has a mass of 5.0 kg and box B has a mass of 2.0 kg. Find the acceleration of the system.

Figure 1.16



SOLUTION

Note that the acceleration of both boxes will be the same since they are tied together and we assume that the string does not stretch. Also we assume that the string is massless and friction is not a factor. Consider the free body diagram of box A in Figure 1.16.

The force of the string on box A is the weight of box B, which equals 19.6 N.

The normal force on box A is equal to the weight of box A, 49 N.

The force of friction, $F_f = \mu F_n$, is equal to 0.200 x 49 N = 9.8 N

So, the net force is
$F_{net} = 19.6 - 9.8 = 9.8$ N

And, $F_{net} = \mu A$

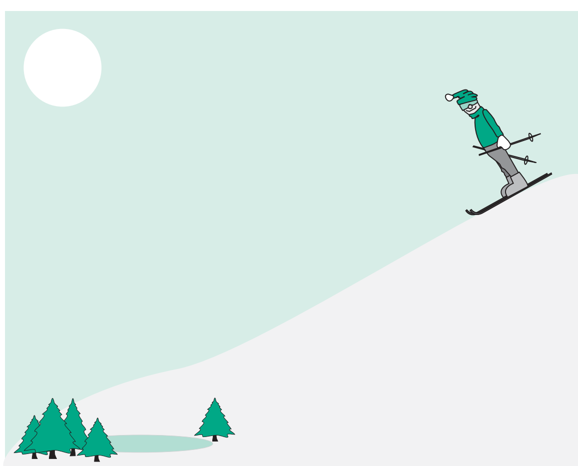
9.8 N = (5.0+2.0) kg x A

$A = 1.4 \text{ m/s}^2$

EXAMPLE PROBLEM 3

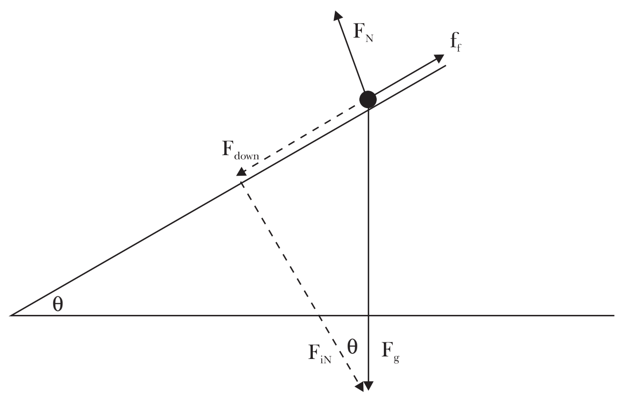
A skier (Figure 1.17) is descending down a 30° slope. Assuming the coefficient of friction is 0.10 calculate her acceleration down the slope.

Figure 1.17



SOLUTION

Figure 1.18



Notice that the net force will be

$$F_{net} = F_{down} - F_f$$

Where

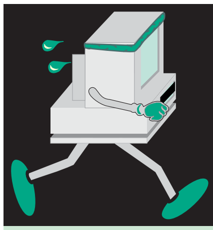
$$F_{down} = F_g \sin\theta = mg \sin 30^o = 0.5 \text{ mg}$$

$$F_f = \mu F_n = \mu F_{in} = (0.1)(0.866) \text{ mg} = 0.087 \text{ mg}$$

So $F_{net} = 0.413$ mg

And since F = mA, then .413mg = mA

And $A = 0.413(9.8\text{m/s}^2) = 4.0 \text{ m/s}^2$



DO AND CHECK 3: EQUILLIBRIUM PROBLEMS

Do the following questions.

1. Can an object in equilibrium be moving? Explain.

2. What is the sum of three vectors that form a triangle? Assuming that the vectors are forces, what does this imply about the object on which the forces act?

3. What is the net force that acts on an object when it is in equilibrium?

4. The weight of a book sliding down a frictionless inclined plane can be broken into two vector components: one acting parallel to the plane, and the other acting perpendicular to the plane.

   (a) At what angle are these two components equal?

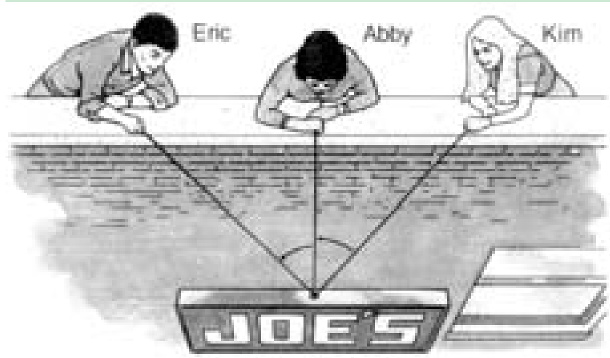
   (b) At what angle is the component parallel to the plane equal to zero?

   (c) At what angle is the component parallel to the plane equal to the weight?

5. Dan applies a force of 92 N on a heavy box by using a rope held at an angle of 45° with the horizontal. What are the vertical and horizontal components of the 92-N force?

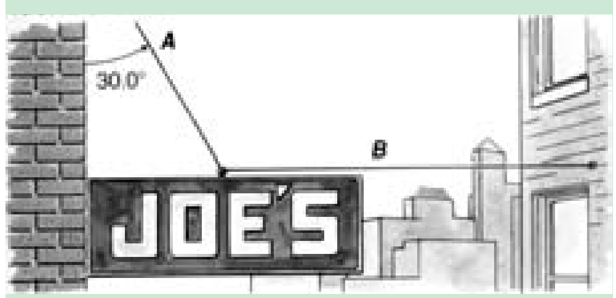
6. Three people attempt to haul a heavy sign to the roof of a building by using three ropes attached to the sign. Abby stands directly above the sign and pulls straight up on a rope. Eric and Kim stand on either side of Abby. Their ropes form 30° angles with Abby's rope. A force of 102 N is applied on each rope. What is the net upward force acting on the sign? See Figure 1.19.

Figure 1.19



7. Joe wishes to hang a sign weighing 750 N so that cable A attached to the store makes a 30° angle as shown in Figure 1.20. Cable B is attached to an adjoining building. Calculate the necessary tension in cable B.

Figure 1.20



8. A 2.5-kg block slides down a 25° inclined plane with constant acceleration. The block starts from rest at the top. At the bottom, its velocity reaches 0.65 m/s. The length of the incline is 1.6 m.

   (a) What is the acceleration of the block?

   (b) What is the coefficient of friction between the plane and block?

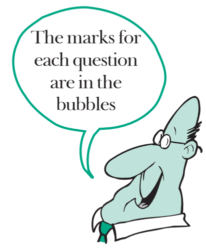
   (c) Does the result of either (a) or (b) depend on the mass of the block?

Check your answers in the Solutions Appendix, p. 2 at the back of this manual.

At this point you should begin to keep a journal that you will maintain throughout the rest of this course. Your journal is a place to write personal reflections as you progress. It is also a good place to record things you need to clarify so that you can look back at a later date and ensure you have resolved your problem. You should write a new journal entry at least once a week. At the end of the course, you will be required to send your completed journal to your marker. Your journal will be evaluated and incorporated into your mark for unit 11.

Reflect upon the first module. Your first journal entry could be to distinguish between net forces that cause motion and situations in which all forces are in static equilibrium.

Before you begin this assignment read the review summary on p. 127 in your textbook.



Do the following questions and **send** them to your marker.

When completing the Do and Send questions for **ALL** modules, show **ALL** work and logical reasoning used, including formulas. Also ensure that you draw vector diagrams for any questions that require them. For example, this module requires vector diagrams for all of the problem solving questions (except for #5) in order to receive full marks.

1. Rachel pulls her 18-kg suitcase at a constant speed by pulling on a handle that makes an angle θ with the horizontal. The frictional force on the suitcase is 27 N and Rachel exerts a 43-N force on the handle. (10)

   (a) What angle does the handle make with the horizontal?

   (b) What is the normal force exerted on the suitcase?

2. You slide a 325-N trunk up a 20.0° inclined plane with a constant velocity by exerting a force of 211 N parallel to the inclined plane. (10)

(a) What is the component of the trunk's weight parallel to the plane?

(b) What is the sum of your applied force, friction, and the parallel component of the trunk's weight? Why?

(c) What is the size and direction of the friction force?

(d) What is the coefficient of friction?

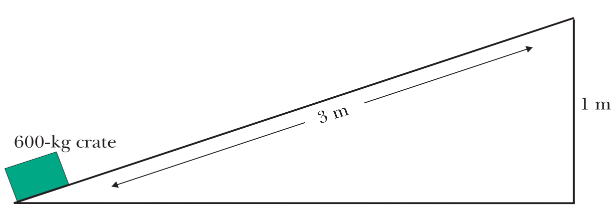
10 3. A 50-kg crate is pulled across a warehouse floor with a rope. A force of 120 N is applied to the rope which is at an angle of 30° with the horizontal. Neglecting friction, determine:

(a) the acceleration of the crate.

(b) the upward force that the warehouse floor exerts on the crate as it is being pulled across the floor.

10 4. A ramp leading up to a loading platform is 3 m long and 1 m high at its highest point (see Figure 1.21). If the friction is ignored, what work is needed to slide a 600-kg crate up the ramp at a constant speed?

Figure 1.21



(a) 2.00×10^2 J

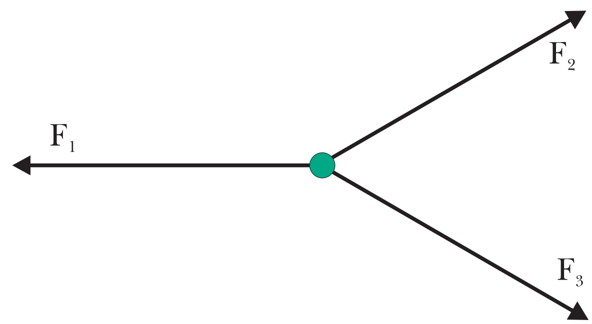
(b) 5.89×10^2 J

(c) 1.80×10^3 J

(d) 5.88×10^3 J

5. Forces F_1, F_2 and F_3 act in different directions on the same point (see Figure 1.22). Which statement is a correct description of these forces? 10

Figure 1.22



(a) The forces will always produce equilibrium.

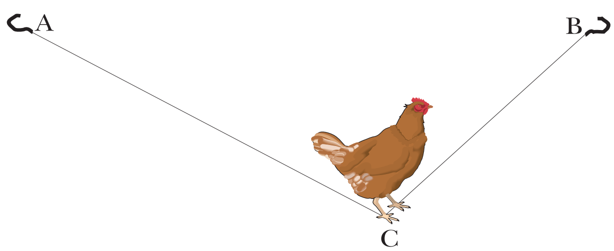
(b) The vector sum of the forces must be zero.

(c) If the vector sum of the forces is zero, the forces produce equilibrium.

(d) If the vector sum of the forces is zero, the forces can't produce equilibrium.

10 6. A 2-kg chicken rests at point C on a slack clothesline ACB as shown in Figure 1.23. C stands for chicken, not centre; CA and CB slope up from the horizontal at 30° and 45° respectively, as shown. What minimum breaking strength must the line have to ensure the continuing support of the bird? Answer in newtons.

Figure 1.23



(a) 2

(b) 9

(c) 18

(d) 20

(e) 27

10 7. A traffic light weighs 260 N. It is supported equally by two cables that form an angle of 130° with each other.

(a) Determine the tension (force) in each of the two cables.

(b) As the angle between the two cables decreases, what happens to the tension (force) in each of the two cables?

10 8. You slide a 500-N trunk up a 30° inclined plane with a constant velocity by exerting a force of 400 N parallel to the inclined plane.

(a) What is the component of the trunk's weight parallel to the inclined plane?

(b) What is the magnitude and direction of the frictional force?

(c) What is the magnitude of the $Force_{(normal)}$, the force perpendicular to the surface of the inclined plane?

(d) What is the coefficient of sliding friction?

9. We have to design an entrance ramp for the new MegaMart in downtown Halifax. The maximum force customers will exert without complaint is 20 N. Ignoring friction, at what maximum angle should the ramp be built assuming a full 20-kg grocery cart? 10

10. Consider Figure 1.24. Find the force of tension in the chain. Determine the force of compression in the support bar. Be sure to include a free body diagram as part of your solution. 10

Figure 1.24