

Student Solutions Manual

College

Phys- ics

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PREFACE

The Student's Solutions Manual provides solutions to select Problems & Exercises from Openstax *College Physics*. The purpose of this manual and of the Problems & Exercises is to build problem-solving skills that are critical to understanding and applying the principles of physics. The text of *College Physics* contains many features that will help you not only to solve problems, but to understand their concepts, including Problem-Solving Strategies, Examples, Section Summaries, and chapter Glossaries. Before turning to the problem solutions in this manual, you should use these features in your text to your advantage. The worst thing you can do with the solutions manual is to copy the answers directly without thinking about the problem-solving process and the concepts involved.

The text of *College Physics* is available in multiple formats (online, PDF, e-pub, and print) from <http://openstaxcollege.org/textbooks/college-physics>. While these multiple formats provide you with a wide range of options for accessing and repurposing the text, they also present some challenges for the organization of this solutions manual, since problem numbering is automated and the same problem may be numbered differently depending on the format selected by the end user.

As such, we have decided to organize the Problems & Exercises manual by chapter and section, as they are organized in the PDF and print versions of *College Physics*. See the Table of Contents on the previous page.

Problem numbering throughout the solutions manual will match the numbering in the PDF version of the product, provided that users have not modified or customized the original content of the book by adding or removing problems. Numbering of Tables, Figures, Examples, and other elements of the text throughout this manual will also coincide with the numbering in the PDF and print versions of the text.

For online and epub users of *College Physics*, we have included question stem along with the solution for each Problem order to minimize any confusion caused by discrepancies in numbering. Images, figures, and tables—which occasionally accompany or complement problems and exercises—have been omitted from the solutions manual to save space.

CHAPTER 1: INTRODUCTION: THE NATURE OF SCIENCE AND PHYSICS

1.2 PHYSICAL QUANTITIES AND UNITS

4. *American football is played on a 100-yd-long field, excluding the end zones. How long is the field in meters? (Assume that 1 meter equals 3.281 feet.)*

Solution Since 3 feet = 1 yard and 3.281 feet = 1 meter, multiply 100 yards by these conversion factors to cancel the units of yards, leaving the units of meters:

$$100 \text{ yd} = 100 \text{ yd} \times \frac{3 \text{ ft}}{1 \text{ yd}} \times \frac{1 \text{ m}}{3.281 \text{ ft}} = \underline{91.4 \text{ m}}$$

A football field is 91.4 m long.

10. *(a) Refer to Table 1.3 to determine the average distance between the Earth and the Sun. Then calculate the average speed of the Earth in its orbit in kilometers per second. (b) What is this in meters per second?*

Solution (a) The average speed of the earth's orbit around the sun is calculated by dividing the distance traveled by the time it takes to go one revolution:

$$\begin{aligned} \text{average speed} &= \frac{2\pi(\text{average dist of Earth to sun})}{1 \text{ year}} \\ &= \frac{2\pi(10^8 \text{ km})}{365.25 \text{ d}} \times \frac{1 \text{ d}}{24 \text{ h}} \times \frac{1 \text{ h}}{3600 \text{ s}} = \underline{20 \text{ km/s}} \end{aligned}$$

The earth travels at an average speed of 20 km/s around the sun.

(b) To convert the average speed into units of m/s, use the conversion factor: 1000 m

= 1 km:

$$\text{average speed} = \frac{20 \text{ km}}{\text{s}} \times \frac{1000 \text{ m}}{1 \text{ km}} = \underline{20 \times 10^3 \text{ m/s}}$$

1.3 ACCURACY, PRECISION, AND SIGNIFICANT FIGURES

15. (a) Suppose that a person has an average heart rate of 72.0 beats/min. How many beats does he or she have in 2.0 y? (b) In 2.00 y? (c) In 2.000 y?

Solution (a) To calculate the number of beats she has in 2.0 years, we need to multiply 72.0 beats/minute by 2.0 years and use conversion factors to cancel the units of time:

$$\frac{72.0 \text{ beats}}{1 \text{ min}} \times \frac{60.0 \text{ min}}{1.00 \text{ h}} \times \frac{24.0 \text{ h}}{1.00 \text{ d}} \times \frac{365.25 \text{ d}}{1.00 \text{ y}} \times 2.0 \text{ y} = 7.5738 \times 10^7 \text{ beats}$$

Since there are only 2 significant figures in 2.0 years, we must report the answer with 2 significant figures: $\underline{7.6 \times 10^7 \text{ beats}}$.

(b) Since we now have 3 significant figures in 2.00 years, we now report the answer with 3 significant figures: $\underline{7.57 \times 10^7 \text{ beats}}$.

(c) Even though we now have 4 significant figures in 2.000 years, the 72.0 beats/minute only has 3 significant figures, so we must report the answer with 3 significant figures: $\underline{7.57 \times 10^7 \text{ beats}}$.

21. A person measures his or her heart rate by counting the number of beats in 30 s. If 40 ± 1 beats are counted in 30.0 ± 0.5 s, what is the heart rate and its uncertainty in beats per minute?

Solution To calculate the heart rate, we need to divide the number of beats by the time and convert to beats per minute.

$$\frac{\text{beats}}{\text{minute}} = \frac{40 \text{ beats}}{30.0 \text{ s}} \times \frac{60.0 \text{ s}}{1.00 \text{ min}} = 80 \text{ beats/min}$$

To calculate the uncertainty, we use the method of adding percents.

$$\% \text{ unc} = \frac{1 \text{ beat}}{40 \text{ beats}} \times 100\% + \frac{0.5 \text{ s}}{30.0 \text{ s}} \times 100\% = 2.5\% + 1.7\% = 4.2\% = 4\%$$

Then calculating the uncertainty in beats per minute:

$$\delta A = \frac{\% \text{ unc}}{100\%} \times A = \frac{4.2\%}{100\%} \times 80 \text{ beats/min} = 3.3 \text{ beats/min} = 3 \text{ beats/min}$$

Notice that while doing calculations, we keep one EXTRA digit, and round to the correct number of significant figures only at the end.

So, the heart rate is $80 \pm 3 \text{ beats/min}$.

27. *The length and width of a rectangular room are measured to be $3.955 \pm 0.005 \text{ m}$ and $3.050 \pm 0.005 \text{ m}$. Calculate the area of the room and its uncertainty in square meters.*

Solution The area is $3.995 \text{ m} \times 3.050 \text{ m} = 12.06 \text{ m}^2$. Now use the method of adding percents to get uncertainty in the area.

$$\% \text{ unc length} = \frac{0.005 \text{ m}}{3.955 \text{ m}} \times 100\% = 0.13\%$$

$$\% \text{ unc width} = \frac{0.005 \text{ m}}{3.050 \text{ m}} \times 100\% = 0.16\%$$

$$\% \text{ unc area} = \% \text{ unc length} + \% \text{ unc width} = 0.13\% + 0.16\% = 0.29\% = 0.3\%$$

Finally, using the percent uncertainty for the area, we can calculate the uncertainty in

$$\text{square meters: } \delta \text{ area} = \frac{\% \text{ unc area}}{100\%} \times \text{area} = \frac{0.29\%}{100\%} \times 12.06 \text{ m}^2 = 0.035 \text{ m}^2 = 0.04 \text{ m}^2$$

The area is $12.06 \pm 0.04 \text{ m}^2$.

CHAPTER 2: KINEMATICS

2.1 DISPLACEMENT

1. Find the following for path A in *Figure 2.59*: (a) The distance traveled. (b) The magnitude of the displacement from start to finish. (c) The displacement from start to finish.

Solution (a) The total distance traveled is the length of the line from the dot to the arrow in path A, or 7 m.

(b) The distance from start to finish is the magnitude of the difference between the position of the arrows and the position of the dot in path A:

$$\Delta x = |x_2 - x_1| = |7 \text{ m} - 0 \text{ m}| = \underline{7 \text{ m}}$$

(c) The displacement is the difference between the value of the position of the arrow and the value of the position of the dot in path A: The displacement can be either positive or negative: $\Delta x = x_2 - x_1 = 7 \text{ m} - 0 \text{ m} = \underline{+7 \text{ m}}$

2.3 TIME, VELOCITY, AND SPEED

14. A football quarterback runs 15.0 m straight down the playing field in 2.50 s. He is then hit and pushed 3.00 m straight backward in 1.75 s. He breaks the tackle and runs straight forward another 21.0 m in 5.20 s. Calculate his average velocity (a) for each of the three intervals and (b) for the entire motion.

Solution (a) The average velocity for the first segment is the distance traveled downfield (the positive direction) divided by the time he traveled:

$$\bar{v}_1 = \frac{\text{displacement}}{\text{time}} = \frac{+15.0 \text{ m}}{2.50 \text{ s}} = \underline{+6.00 \text{ m/s (forward)}}$$

The average velocity for the second segment is the distance traveled (this time in the negative direction because he is traveling backward) divided by the time he

$$\text{traveled: } \bar{v}_2 = \frac{-3.00 \text{ m}}{1.75 \text{ s}} = \underline{-1.71 \text{ m/s (backward)}}$$

Finally, the average velocity for the third segment is the distance traveled (positive again because he is again traveling downfield) divided by the time he

$$\text{traveled: } \bar{v}_3 = \frac{+21.0 \text{ m}}{5.20 \text{ s}} = \underline{+4.04 \text{ m/s (forward)}}$$

(b) To calculate the average velocity for the entire motion, we add the displacement from each of the three segments (remembering the sign of the numbers), and divide by the total time for the motion:

$$\bar{v}_{\text{total}} = \frac{15.0 \text{ m} - 3.00 \text{ m} + 21.0 \text{ m}}{2.50 \text{ s} + 1.75 \text{ s} + 5.20 \text{ s}} = \underline{+3.49 \text{ m/s}}$$

Notice that the average velocity for the entire motion is not just the addition of the average velocities for the segments.

15. *The planetary model of the atom pictures electrons orbiting the atomic nucleus much as planets orbit the Sun. In this model you can view hydrogen, the simplest atom, as having a single electron in a circular orbit $1.06 \times 10^{-10} \text{ m}$ in diameter. (a) If the average speed of the electron in this orbit is known to be $2.20 \times 10^6 \text{ m/s}$, calculate the number of revolutions per second it makes about the nucleus. (b) What is the electron's average velocity?*

Solution (a) The average speed is defined as the total distance traveled divided by the elapsed

$$\text{time, so that: average speed} = \frac{\text{distance traveled}}{\text{time elapsed}} = 2.20 \times 10^6 \text{ m/s}$$

If we want to find the number of revolutions per second, we need to know how far the electron travels in one revolution.

$$\frac{\text{distance traveled}}{\text{revolution}} = \frac{2\pi}{1 \text{ rev}} = \frac{2\pi[(0.5)(1.06 \times 10^{-10} \text{ m})]}{1 \text{ rev}} = \frac{3.33 \times 10^{-10} \text{ m}}{1 \text{ rev}}$$

So to calculate the number of revolutions per second, we need to divide the average speed by the distance traveled per revolution, thus canceling the units of

$$\text{meters: } \frac{\text{rev}}{\text{s}} = \frac{\text{average speed}}{\text{distance/revolution}} = \frac{2.20 \times 10^6 \text{ m/s}}{3.33 \times 10^{-10} \text{ m/revolution}} = \underline{6.61 \times 10^{15} \text{ rev/s}}$$

- (b) The velocity is defined to be the displacement divided by the time of travel, so since there is no *net* displacement during any one revolution: $\underline{v = 0 \text{ m/s}}$.

2.5 MOTION EQUATIONS FOR CONSTANT ACCELERATION IN ONE DIMENSION

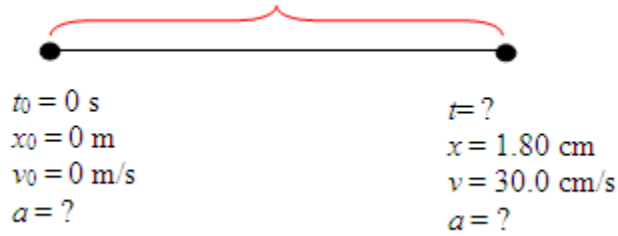
21. *A well-thrown ball is caught in a well-padded mitt. If the deceleration of the ball is $2.10 \times 10^4 \text{ m/s}^2$, and 1.85 ms ($1 \text{ ms} = 10^{-3} \text{ s}$) elapses from the time the ball first touches the mitt until it stops, what was the initial velocity of the ball?*

Solution Given: $a = -2.10 \times 10^4 \text{ m/s}^2$; $t = 1.85 \text{ ms} = 1.85 \times 10^{-3} \text{ s}$; $v = 0 \text{ m/s}$, find v_0 . We use the equation $v_0 = v - at$ because it involves only terms we know and terms we want to know. Solving for our unknown gives:

$$v_0 = v - at = 0 \text{ m/s} - (-2.10 \times 10^4 \text{ m/s}^2)(1.85 \times 10^{-3} \text{ s}) = \underline{38.9 \text{ m/s}} \text{ (about 87 miles per hour)}$$

26. **Professional Application** *Blood is accelerated from rest to 30.0 cm/s in a distance of 1.80 cm by the left ventricle of the heart. (a) Make a sketch of the situation. (b) List the knowns in this problem. (c) How long does the acceleration take? To solve this part, first identify the unknown, and then discuss how you chose the appropriate equation to solve for it. After choosing the equation, show your steps in solving for the unknown, checking your units. (d) Is the answer reasonable when compared with the time for a heartbeat?*

Solution (a)

(b) Knowns: “Accelerated from rest” $\Rightarrow v_0 = 0 \text{ m/s}$ “to 30.0 cm/s” $\Rightarrow v = 0.300 \text{ m/s}$ “in a distance of 1.80 cm” $\Rightarrow x - x_0 = \underline{0.0180 \text{ m}}$.(c) “How long” tells us to find t . To determine which equation to use, we look for an equation that has v_0 , v , $x - x_0$ and t , since those are parameters that we know orwant to know. Using the equations $x = x_0 + \bar{v}t$ and $\bar{v} = \frac{v_0 + v}{2}$ gives

$$x - x_0 = \left(\frac{v_0 + v}{2} \right) t.$$

$$\text{Solving for } t \text{ gives: } t = \frac{2(x - x_0)}{v_0 + v} = \frac{2(0.0180 \text{ m})}{(0 \text{ m/s}) + (0.300 \text{ m/s})} = \underline{0.120 \text{ s}}$$

It takes 120 ms to accelerate the blood from rest to 30.0 cm/s. Converting everything to standard units first makes it easy to see that the units of meters cancel, leaving only the units of seconds.

(d) Yes, the answer is reasonable. An entire heartbeat cycle takes about one second. The time for acceleration of blood out of the ventricle is only a fraction of the entire cycle.

32. **Professional Application** A woodpecker's brain is specially protected from large decelerations by tendon-like attachments inside the skull. While pecking on a tree, the woodpecker's head comes to a stop from an initial velocity of 0.600 m/s in a distance of only 2.00 mm . (a) Find the acceleration in m/s^2 and in multiples of g ($g = 9.80 \text{ m/s}^2$). (b) Calculate the stopping time. (c) The tendons cradling the brain stretch, making its stopping distance 4.50 mm (greater than the head and, hence, less deceleration of the brain). What is the brain's deceleration, expressed in multiples of g ?

Solution (a) Find a (which should be negative).

Given: "comes to a stop" $\Rightarrow v = 0 \text{ m/s}$.

"from an initial velocity of" $\Rightarrow v_0 = 0.600 \text{ m/s}$.

"in a distance of 2.00 m " $\Rightarrow x - x_0 = 2.00 \times 10^{-3} \text{ m}$.

So, we need an equation that involves a , v , v_0 , and $x - x_0$, or the equation

$v^2 = v_0^2 + 2a(x - x_0)$, so that

$$a = \frac{v^2 - v_0^2}{2(x - x_0)} = \frac{(0 \text{ m/s})^2 - (0.600 \text{ m/s})^2}{2(2.00 \times 10^{-3} \text{ m})} = \underline{-90.0 \text{ m/s}^2}$$

So the deceleration is 90.0 m/s^2 . To get the deceleration in multiples of g , we

divide a by g : $\frac{|a|}{|g|} = \frac{90.0 \text{ m/s}^2}{9.80 \text{ m/s}^2} = 9.18 \Rightarrow a = \underline{9.18g}$.

(b) The words "Calculate the stopping time" mean find t . Using $x - x_0 = \frac{1}{2}(v_0 + v)t$

gives $x - x_0 = \frac{1}{2}(v_0 + v)t$, so that

$$t = \frac{2(x - x_0)}{v_0 + v} = \frac{2(2.00 \times 10^{-3} \text{ m})}{(0.600 \text{ m/s}) + (0 \text{ m/s})} = \underline{6.67 \times 10^{-3} \text{ s}}$$

(c) To calculate the deceleration of the brain, use $x - x_0 = 4.50 \text{ mm} = 4.50 \times 10^{-3} \text{ m}$

instead of 2.00 mm. Again, we use $a = \frac{v^2 - v_0^2}{2(x - x_0)}$, so that:

$$a = \frac{v^2 - v_0^2}{2(x - x_0)} = \frac{(0 \text{ m/s})^2 - (0.600 \text{ m/s})^2}{2(4.50 \times 10^{-3} \text{ m})} = \underline{-40.0 \text{ m/s}^2}$$

And expressed in multiples of g gives: $\frac{|a|}{|g|} = \frac{40.0 \text{ m/s}^2}{9.80 \text{ m/s}^2} = 4.08 \Rightarrow a = 4.08g$

2.7 FALLING OBJECTS

41. Calculate the displacement and velocity at times of (a) 0.500, (b) 1.00, (c) 1.50, and (d) 2.00 s for a ball thrown straight up with an initial velocity of 15.0 m/s. Take the point of release to be $y_0 = 0$.

Solution

Knowns: $a =$ acceleration due to gravity $= g = -9.8 \text{ m/s}^2$; $y_0 = 0 \text{ m}$; $v_0 = +15.0 \text{ m/s}$

To find displacement we use $y = y_0 + v_0 t + \frac{1}{2} a t^2$, and to find velocity we use

$$v = v_0 + a t.$$

$$(a) \quad y_1 = y_0 + v_0 t_1 + \frac{1}{2} a t_1^2$$

$$= 0 \text{ m} + (15.0 \text{ m/s})(0.500 \text{ s}) + \frac{1}{2} (-9.8 \text{ m/s}^2)(0.500 \text{ s})^2 = \underline{6.28 \text{ m}}$$

$$v_1 = v_0 + a t_1 = (15.0 \text{ m/s}) + (-9.8 \text{ m/s}^2)(0.500 \text{ s}) = \underline{10.1 \text{ m/s}}$$

$$(b) \quad y_2 = y_0 + v_0 t_2 + \frac{1}{2} a t_2^2$$

$$= 0 \text{ m} + (15.0 \text{ m/s})(1.00 \text{ s}) + \frac{1}{2} (-9.8 \text{ m/s}^2)(1.00 \text{ s})^2 = \underline{10.1 \text{ m}}$$

$$v_2 = v_0 + a t_2 = (15.0 \text{ m/s}) + (-9.8 \text{ m/s}^2)(1.00 \text{ s}) = \underline{5.20 \text{ m/s}}$$

$$\begin{aligned}
 \text{(c) } y_3 &= y_0 + v_0 t_3 + \frac{1}{2} a t_3^2 \\
 &= 0 \text{ m} + (15.0 \text{ m/s})(1.50 \text{ s}) + \frac{1}{2} (-9.8 \text{ m/s}^2)(1.50 \text{ s})^2 = \underline{11.5 \text{ m}} \\
 v_3 &= v_0 + a t_3 = (15.0 \text{ m/s}) + (-9.8 \text{ m/s}^2)(1.50 \text{ s}) = \underline{0.300 \text{ m/s}}
 \end{aligned}$$

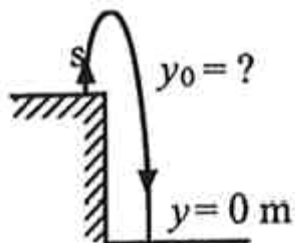
The ball is almost at the top.

$$\begin{aligned}
 \text{(d) } y_4 &= y_0 + v_0 t_4 + \frac{1}{2} a t_4^2 \\
 &= 0 \text{ m} + (15.0 \text{ m/s})(2.00 \text{ s}) + \frac{1}{2} (-9.8 \text{ m/s}^2)(2.00 \text{ s})^2 = \underline{10.4 \text{ m}} \\
 v_4 &= v_0 + a t_4 = (15.0 \text{ m/s}) + (-9.8 \text{ m/s}^2)(2.00 \text{ s}) = \underline{-4.60 \text{ m/s}}
 \end{aligned}$$

The ball has begun to drop.

47. (a) Calculate the height of a cliff if it takes 2.35 s for a rock to hit the ground when it is thrown straight up from the cliff with an initial velocity of 8.00 m/s. (b) How long would it take to reach the ground if it is thrown straight down with the same speed?

Solution



(a) Knowns: $t = 2.35 \text{ s}$; $y = 0 \text{ m}$; $v_0 = +8.00 \text{ m/s}$; $a = -9.8 \text{ m/s}^2$

Since we know t , y , v_0 , and a and want to find y_0 , we can use the equation

$$y = y_0 + v_0 t + \frac{1}{2} a t^2.$$

$$y = (0 \text{ m}) + (+8.00 \text{ m/s})(2.35 \text{ s}) + \frac{1}{2} (-9.80 \text{ m/s}^2)(2.35 \text{ s})^2 = -8.26 \text{ m}, \text{ so the cliff is } \underline{8.26 \text{ m}} \text{ high.}$$

(b) Knowns: $y = 0 \text{ m}$; $y_0 = 8.26 \text{ m}$; $v_0 = -8.00 \text{ m/s}$; $a = -9.80 \text{ m/s}^2$

Now we know y , y_0 , v_0 , and a and want to find t , so we use the equation

$y = y_0 + v_0t + \frac{1}{2}at^2$ again. Rearranging,

$$t = \frac{-v_0 \pm \sqrt{v_0^2 - 4(0.5a)(y_0 - y)}}{2(0.5a)}$$

$$t = \frac{-(-8.00 \text{ m/s}) \pm \sqrt{(-8.00 \text{ m/s})^2 + 2(9.80 \text{ m/s}^2)(8.26 \text{ m} - 0 \text{ m})}}{(-9.80 \text{ m/s}^2)}$$

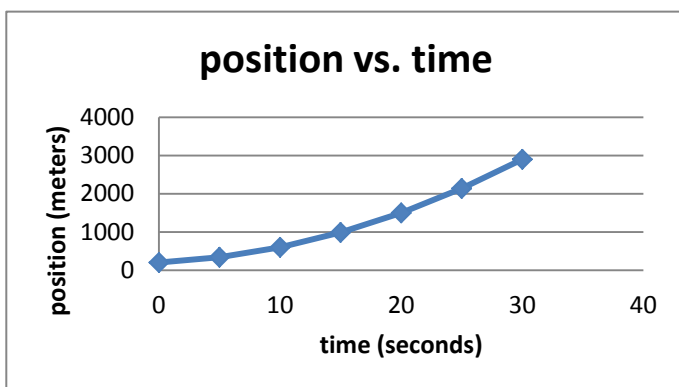
$$= \frac{8.00 \text{ m/s} \pm 15.03 \text{ m/s}}{-9.80 \text{ m/s}^2}$$

$$t = 0.717 \text{ s or } -2.35 \text{ s} \Rightarrow t = \underline{0.717 \text{ s}}$$

2.8 GRAPHICAL ANALYSIS OF ONE-DIMENSIONAL MOTION

59. (a) By taking the slope of the curve in *Figure 2.60*, verify that the velocity of the jet car is 115 m/s at $t = 20 \text{ s}$. (b) By taking the slope of the curve at any point in *Figure 2.61*, verify that the jet car's acceleration is 5.0 m/s^2 .

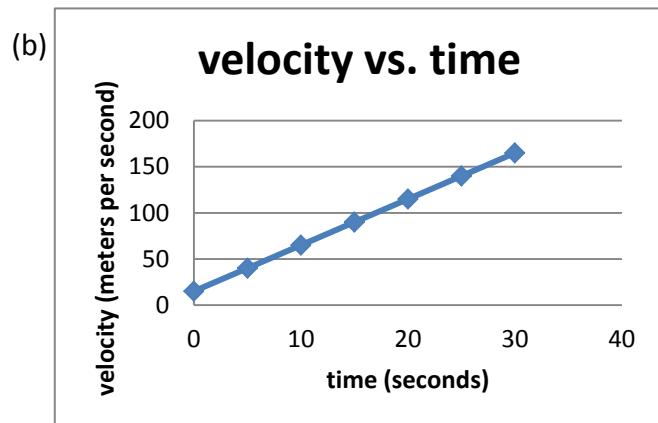
Solution (a)



In the position vs. time graph, if we draw a tangent to the curve at $t = 20 \text{ s}$, we can identify two points: $x = 0 \text{ m}, t = 5 \text{ s}$ and $x = 1500 \text{ m}, t = 20 \text{ s}$ so we can

calculate an approximate slope: $v = \frac{\text{rise}}{\text{run}} = \frac{(2138 - 988) \text{ m}}{(25 - 15) \text{ s}} = 115 \text{ m/s}$

So, the slope of the displacement vs. time curve is the velocity curve.



In the velocity vs. time graph, we can identify two points: $v = 65 \text{ m/s}, t = 10 \text{ s}$ and $v = 140 \text{ m/s}, t = 25 \text{ s}$. Therefore, the slope is $a = \frac{\text{rise}}{\text{run}} = \frac{(140 - 65) \text{ m/s}}{(25 - 10) \text{ s}} = 5.0 \text{ m/s}^2$

The slope of the velocity vs. time curve is the acceleration curve.

CHAPTER 3: TWO-DIMENSIONAL KINEMATICS

3.2 VECTOR ADDITION AND SUBTRACTION: GRAPHICAL METHODS

1. Find the following for path A in *Figure 3.54*: (a) the total distance traveled, and (b) the magnitude and direction of the displacement from start to finish.

Solution (a) To measure the total distance traveled, we take a ruler and measure the length of Path A to the north, and add to it to the length of Path A to the east. Path A travels 3 blocks north and 1 block east, for a total of four blocks. Each block is 120 m, so the distance traveled is $d = (4 \times 120 \text{ m}) = \underline{480 \text{ m}}$

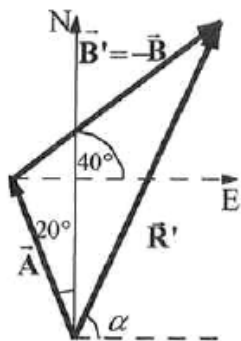
(b) Graphically, measure the length and angle of the line from the start to the arrow of Path A. Use a protractor to measure the angle, with the center of the protractor at the start, measure the angle to where the arrow is at the end of Path A. In order to do this, it may be necessary to extend the line from the start to the arrow of Path A, using a ruler. The length of the displacement vector, measured from the start to the arrow of Path A, along the line you just drew.

$$\underline{\mathbf{S} = 379 \text{ m}, 18.4^\circ \text{ E of N}}$$

7. Repeat the problem two problems prior, but for the second leg you walk 20.0 m in a direction 40.0° north of east (which is equivalent to subtracting \mathbf{B} from \mathbf{A} —that is, to finding $\mathbf{R}' = \mathbf{A} - \mathbf{B}$). (b) Repeat the problem two problems prior, but now you first walk 20.0 m in a direction 40.0° south of west and then 12.0 m in a direction 20.0° east of south (which is equivalent to subtracting \mathbf{A} from \mathbf{B} —that is, to finding $\mathbf{R}'' = \mathbf{B} - \mathbf{A} = -\mathbf{R}'$). Show that this is the case.

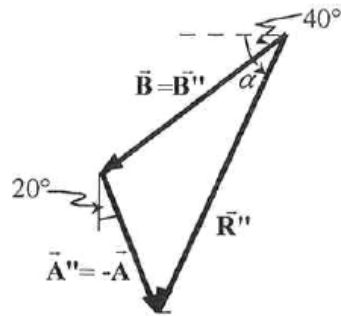
- Solution (a) To do this problem, draw the two vectors \mathbf{A} and $\mathbf{B}' = -\mathbf{B}$ tip to tail as shown below. The vector \mathbf{A} should be 12.0 units long and at an angle of 20° to the left of the y -axis. Then at the arrow of vector \mathbf{A} , draw the vector $\mathbf{B}' = -\mathbf{B}$, which should be 20.0 units long and at an angle of 40° above the x -axis. The resultant vector, \mathbf{R}' , goes from the tail of vector \mathbf{A} to the tip of vector \mathbf{B}' , and therefore has an angle of α above the x -axis. Measure the length of the resultant vector using your ruler, and use a protractor with center at the tail of the resultant vector to get the angle.

$$\underline{R' = 26.6 \text{ m, and } \alpha = 65.1^\circ \text{ N of E}}$$



- (b) To do this problem, draw the two vectors \mathbf{B} and $\mathbf{A}'' = -\mathbf{A}$ tip to tail as shown below. The vector \mathbf{B} should be 20.0 units long and at an angle of 40° below the x -axis. Then at the arrow of vector \mathbf{B} , draw the vector $\mathbf{A}'' = -\mathbf{A}$, which should be 12.0 units long and at an angle of 20° to the right of the negative y -axis. The resultant vector, \mathbf{R}'' , goes from the tail of vector \mathbf{B} to the tip of vector \mathbf{A}'' , and therefore has an angle of α below the x -axis. Measure the length of the resultant vector using your ruler, and use a protractor with center at the tail of the resultant vector to get the angle.

$$\underline{R'' = 26.6 \text{ m, and } \alpha = 65.1^\circ \text{ S of W}}$$



So the length is the same, but the direction is reversed from part (a).

3.3 VECTOR ADDITION AND SUBTRACTION: ANALYTICAL METHODS

13. Find the following for path C in *Figure 3.58*: (a) the total distance traveled and (b) the magnitude and direction of the displacement from start to finish. In this part of the problem, explicitly show how you follow the steps of the analytical method of vector addition.

Solution (a) To solve this problem analytically, add up the distance by counting the blocks traveled along the line that is Path C:

$$d = (1 \times 120 \text{ m}) + (5 \times 120 \text{ m}) + (2 \times 120 \text{ m}) + (1 \times 120 \text{ m}) + (1 \times 120 \text{ m}) + (3 \times 120 \text{ m}) \\ = \underline{1.56 \times 10^3 \text{ m}}$$

- (b) To get the displacement, calculate the displacements in the x- and y- directions separately, then use the formulas for adding vectors. The displacement in the x-direction is calculated by adding the x-distance traveled in each leg, being careful to subtract values when they are negative:

$$s_x = (0 + 600 + 0 - 120 + 0 - 360)\text{m} = 120 \text{ m}$$

Using the same method, calculate the displacement in the y-direction:

$$s_y = (120 + 0 - 240 + 0 + 120 + 0)\text{m} = 0 \text{ m}$$

Now using the equations $R = \sqrt{R_x^2 + R_y^2}$ and $\theta = \tan^{-1}\left(\frac{R_x}{R_y}\right)$, calculate the total displacement vectors:

$$s = \sqrt{s_x^2 + s_y^2} = \sqrt{(120 \text{ m})^2 + (0 \text{ m})^2} = 120 \text{ m}$$

$$\theta = \tan^{-1}\left(\frac{S_y}{S_x}\right) = \tan^{-1}\left(\frac{0 \text{ m}}{120 \text{ m}}\right)$$

$0^\circ \Rightarrow$ east, so that **S = 120 m, east**

19. Do **Problem 3.16** again using analytical techniques and change the second leg of the walk to 25.0 m straight south. (This is equivalent to subtracting **B** from **A**—that is, finding $\mathbf{R}' = \mathbf{A} - \mathbf{B}$) (b) Repeat again, but now you first walk 25.0 m north and then 18.0 m east. (This is equivalent to subtract **A** from **B**—that is, to find $\mathbf{A} = \mathbf{B} + \mathbf{C}$. Is that consistent with your result?)

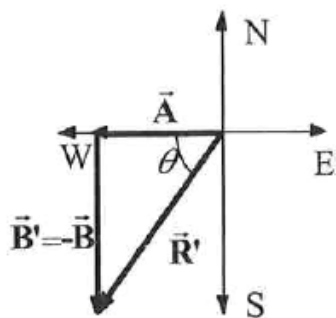
Solution (a) We want to calculate the displacement for walk 18.0 m to the west, followed by 25.0 m to the south. First, calculate the displacement in the x- and y-directions, using the equations $R_x = A_x + B_x$ and $R_y = A_y + B_y$: (the angles are measured from due east).

$$R_x = -18.0 \text{ m}, R_y = -25.0 \text{ m}$$

Then, using the equations $R = \sqrt{R_x^2 + R_y^2}$ and $\theta = \tan^{-1}\left(\frac{R_x}{R_y}\right)$, calculate the total displacement vectors:

$$R' = \sqrt{R_x^2 + R_y^2} = \sqrt{(18.0 \text{ m})^2 + (25.0 \text{ m})^2} = \underline{30.8 \text{ m}}$$

$$\theta = \tan^{-1} \frac{\text{opp}}{\text{adj}} = \tan^{-1}\left(\frac{25.0 \text{ m}}{18.0 \text{ m}}\right) = \underline{54.2^\circ \text{ S of W}}$$



(b) Now do the same calculation, except walk 25.0 m to the north, followed by 18.0 m to the east. Use the equations $R_x = A_x + B_x$ and $R_y = A_y + B_y$:

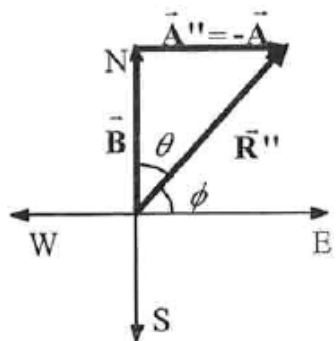
$$R_x = 18.0 \text{ m}, R_y = 25.0 \text{ m}$$

Then, use the equations $R = \sqrt{R_x^2 + R_y^2}$ and $\theta = \tan^{-1}\left(\frac{R_x}{R_y}\right)$.

$$R'' = \sqrt{R_x^2 + R_y^2} = \sqrt{(18.0 \text{ m})^2 + (25.0 \text{ m})^2} = \underline{30.8 \text{ m}}$$

$$\theta = \tan^{-1} \frac{\text{opp}}{\text{adj}} = \tan^{-1}\left(\frac{25.0 \text{ m}}{18.0 \text{ m}}\right) = \underline{54.2^\circ \text{ N of E}}$$

which is consistent with part (a).



3.4 PROJECTILE MOTION

30. *A rugby player passes the ball 7.00 m across the field, where it is caught at the same height as it left his hand. (a) At what angle was the ball thrown if its initial speed was 12.0 m/s, assuming that the smaller of the two possible angles was used? (b) What other angle gives the same range, and why would it not be used? (c) How long did this pass take?*

Solution (a) Find the range of a projectile on level ground for which air resistance is negligible:

$$R = \frac{v_0^2 \sin 2\theta_0}{g}, \text{ where } v_0 \text{ is the initial speed and } \theta_0 \text{ is the initial angle relative to}$$

the horizontal. Solving for initial angle gives:

$$\theta_0 = \frac{1}{2} \sin^{-1} \left(\frac{gR}{v_0^2} \right), \text{ where: } R = 7.0 \text{ m, } v_0 = 12.0 \text{ m/s, and } g = 9.8 \text{ m/s}^2.$$

$$\text{Therefore, } \theta_0 = \frac{1}{2} \sin^{-1} \left(\frac{(9.80 \text{ m/s}^2)(7.0 \text{ m})}{(12.0 \text{ m/s})^2} \right) = \underline{14.2^\circ}$$

- (b) Looking at the equation $R = \frac{v_0^2 \sin 2\theta_0}{g}$, we see that range will be same for another angle, θ_0' , where $\theta_0 + \theta_0' = 90^\circ$ or $\theta_0' = 90^\circ - 14.2^\circ = \underline{75.8^\circ}$.

This angle is not used as often, because the time of flight will be longer. In rugby that means the defense would have a greater time to get into position to knock down or intercept the pass that has the larger angle of release.

40. *An eagle is flying horizontally at a speed of 3.00 m/s when the fish in her talons wiggles loose and falls into the lake 5.00 m below. Calculate the velocity of the fish relative to the water when it hits the water.*

Solution x-direction (horizontal)

$$\text{Given: } v_{0,x} = 3.00 \text{ m/s, } a_x = 0 \text{ m/s}^2.$$

Calculate v_x .

$$v_x = v_{0,x} = \text{constant} = 3.00 \text{ m/s}$$

y-direction (vertical)

Given: $v_{0,y} = 0.00 \text{ m/s}$, $a_y = -g = -9.80 \text{ m/s}^2$, $\Delta y = (y - y_0) = -5.00 \text{ m}$

Calculate v_y .

$$v_y^2 = v_{0,y}^2 - 2g(y - y_0)$$

$$v_y = \sqrt{(0 \text{ m/s})^2 - 2(9.80 \text{ m/s}^2)(-5.00 \text{ m})} = -9.90 \text{ m/s}$$

Now we can calculate the final velocity:

$$v = \sqrt{v_x^2 + v_y^2} = \sqrt{(3.00 \text{ m/s})^2 + (-9.90 \text{ m/s})^2} = 10.3 \text{ m/s}$$

$$\text{and } \theta = \tan^{-1}\left(\frac{v_y}{v_x}\right) = \tan^{-1}\left(\frac{-9.90 \text{ m/s}}{3.00 \text{ m/s}}\right) = -73.1^\circ$$

so that $v = \underline{10.3 \text{ m/s}, 73.1^\circ \text{ below the horizontal}}$

46. *A basketball player is running at 5.00 m/s directly toward the basket when he jumps into the air to dunk the ball. He maintains his horizontal velocity. (a) What vertical velocity does he need to rise 0.750 m above the floor? (b) How far from the basket (measured in the horizontal direction) must he start his jump to reach his maximum height at the same time as he reaches the basket?*

Solution (a) Given: $v_x = 5.00 \text{ m/s}$, $y - y_0 = 0.75 \text{ m}$, $v_y = 0 \text{ m/s}$, $a_y = -g = -9.80 \text{ m/s}^2$.

Find: $v_{0,y}$.

Using the equation $v_y^2 = v_{0,y}^2 - 2g(y - y_0)$ gives:

$$v_{0,y} = \sqrt{v_y^2 + 2g(y - y_0)} = \sqrt{(0 \text{ m/s})^2 + 2(9.80 \text{ m/s}^2)(0.75 \text{ m})} = \underline{3.83 \text{ m/s}}$$

- (b) To calculate the x-direction information, remember that the time is the same in the x- and y-directions. Calculate the time from the y-direction information, then use it to calculate the x-direction information:

Calculate the time:

$$v_y = v_{0,y} - gt, \text{ so that}$$

$$t = \frac{v_{0,y} - v_y}{g} = \frac{(3.83 \text{ m/s}) - (0 \text{ m/s})}{9.80 \text{ m/s}^2} = 0.391 \text{ s}$$

Now, calculate the horizontal distance he travels to the basket:

$$x = x_0 + v_x t, \text{ so that } (x - x_0) = v_x t = (5.00 \text{ m/s})(0.391 \text{ s}) = \underline{1.96 \text{ m}}$$

So, he must leave the ground 1.96 m before the basket to be at his maximum height when he reaches the basket.

3.5 ADDITION OF VELOCITIES

54. *Near the end of a marathon race, the first two runners are separated by a distance of 45.0 m. The front runner has a velocity of 3.50 m/s, and the second a velocity of 4.20 m/s. (a) What is the velocity of the second runner relative to the first? (b) If the front runner is 250 m from the finish line, who will win the race, assuming they run at constant velocity? (c) What distance ahead will the winner be when she crosses the finish line?*

Solution (a) To keep track of the runners, let's label F for the first runner and S for the second runner. Then we are given: $v_F = 3.50 \text{ m/s}$, $v_S = 4.20 \text{ m/s}$. To calculate the velocity of the second runner relative to the first, subtract the velocities:

$$v_{SF} = v_S - v_F = 4.20 \text{ m/s} - 3.50 \text{ m/s} = \underline{0.70 \text{ m/s}} \text{ faster than first runner}$$

- (b) Use the definition of velocity to calculate the time for each runner separately. For

the first runner, she runs 250 m at a velocity of 3.50 m/s:

$$t_F = \frac{x_F}{v_F} = \frac{250 \text{ m}}{3.50 \text{ m/s}} = 71.43 \text{ s}$$

For the second runner, she runs 45 m farther than the first runner at a velocity of

$$4.20 \text{ m/s: } t_S = \frac{x_S}{v_S} = \frac{250 + 45 \text{ m}}{4.20 \text{ m/s}} = 70.24 \text{ s}$$

So, since $t_S < t_F$, the second runner will win.

- (c) We can calculate their relative position, using their relative velocity and time of travel. Initially, the second runner is 45 m behind, the relative velocity was found in part (a), and the time is the time for the second runner, so:

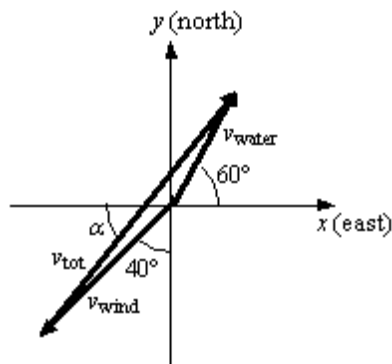
$$x_{SF} = x_{O,SF} + v_{SF}t_S = -45.0 \text{ m} + (0.70 \text{ m/s})(70.24 \text{ s}) = \underline{4.17 \text{ m}}$$

62. *The velocity of the wind relative to the water is crucial to sailboats. Suppose a sailboat is in an ocean current that has a velocity of 2.20 m/s in a direction 30.0° east of north relative to the Earth. It encounters a wind that has a velocity of 4.50 m/s in a direction of 50.0° south of west relative to the Earth. What is the velocity of the wind relative to the water?*

Solution In order to calculate the velocity of the wind relative to the ocean, we need to add the vectors for the wind and the ocean together, being careful to use vector addition. The velocity of the wind relative to the ocean is equal to the velocity of the wind relative to the earth plus the velocity of the earth relative to the ocean. Now,

$$\mathbf{v}_{WO} = \mathbf{v}_{WE} + \mathbf{v}_{EO} = \mathbf{v}_{WE} - \mathbf{v}_{OE}.$$

The first subscript is the object, the second is what it is relative to. In other words the velocity of the earth relative to the ocean is the opposite of the velocity of the ocean relative to the earth.



To solve this vector equation, we need to add the x - and y -components separately.

$$v_{WOx} = v_{WEx} - v_{OEx} = (-4.50 \text{ m/s})\cos 50^\circ - (2.20 \text{ m/s})\cos 60^\circ = -3.993 \text{ m/s}$$

$$v_{WOy} = v_{WEy} - v_{OEy} = (-4.50 \text{ m/s})\sin 50^\circ - (2.20 \text{ m/s})\sin 60^\circ = -5.352 \text{ m/s}$$

Finally, we can use the equations below to calculate the velocity of the water relative to the ocean:

$$v = \sqrt{v_x^2 + v_y^2} = \sqrt{(-3.993 \text{ m/s})^2 + (-5.352 \text{ m/s})^2} = \underline{6.68 \text{ m/s}}$$

$$\alpha = \tan^{-1} \frac{|v_y|}{|v_x|} = \tan^{-1} \left(\frac{5.352 \text{ m/s}}{3.993 \text{ m/s}} \right) = \underline{53.3^\circ \text{ S of W}}$$

66. *A ship sailing in the Gulf Stream is heading 25.0° west of north at a speed of 4.00 m/s relative to the water. Its velocity relative to the Earth is 4.80 m/s 5.00° west of north. What is the velocity of the Gulf Stream? (The velocity obtained is typical for the Gulf Stream a few hundred kilometers off the east coast of the United States.)*

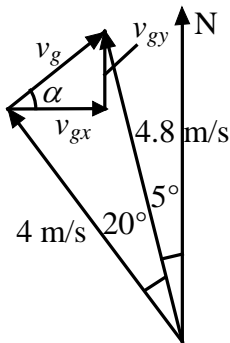
Solution To calculate the velocity of the water relative to the earth, we need to add the vectors. The velocity of the water relative to the earth is equal to the velocity of the water relative to the ship plus the velocity of the ship relative to the earth.

$$\mathbf{v}_{WE} = \mathbf{v}_{WS} + \mathbf{v}_{SE} = -\mathbf{v}_{SW} + \mathbf{v}_{SE}$$

Now, we need to calculate the x - and y -components separately:

$$v_{WE,x} = -v_{SW,x} + v_{SE,x} = -(4.00 \text{ m/s})\cos 115^\circ + (4.80 \text{ m/s})\cos 95^\circ = 1.272 \text{ m/s}$$

$$v_{WE,y} = -v_{SW,y} + v_{SE,y} = -(4.00 \text{ m/s})\sin 115^\circ + (4.80 \text{ m/s})\sin 95^\circ = 1.157 \text{ m/s}$$



Finally, we use the equations below to calculate the velocity of the water relative to the earth:

$$v_{WE} = \sqrt{v_{WE,x}^2 + v_{WE,y}^2} = \sqrt{(1.272 \text{ m/s})^2 + (1.157 \text{ m/s})^2} = \underline{1.72 \text{ m/s}}$$

$$\alpha = \tan^{-1}\left(\frac{v_{WE,y}}{v_{WE,x}}\right) = \tan^{-1}\frac{1.157 \text{ m/s}}{1.272 \text{ m/s}} = \underline{42.3^\circ \text{ N of E.}}$$

CHAPTER 4: DYNAMICS: FORCE AND NEWTON'S LAWS OF MOTION

4.3 NEWTON'S SECOND LAW OF MOTION: CONCEPT OF A SYSTEM

1. *A 63.0-kg sprinter starts a race with an acceleration of 4.20 m/s^2 . What is the net external force on him?*

Solution The net force acting on the sprinter is given by
 $\text{net } F = ma = (63.0 \text{ kg})(4.20 \text{ m/s}^2) = \underline{265 \text{ N}}$

7. *(a) If the rocket sled shown in Figure 4.31 starts with only one rocket burning, what is its acceleration? Assume that the mass of the system is 2100 kg, and the force of friction opposing the motion is known to be 650 N. (b) Why is the acceleration not one-fourth of what it is with all rockets burning?*

Solution (a) Use the thrust given for the rocket sled in Figure 4.8, $T = 2.59 \times 10^4 \text{ N}$. With only one rocket burning, $\text{net } F = T - f$ so that Newton's second law gives:

$$a = \frac{\text{net } F}{m} = \frac{T - f}{m} = \frac{2.59 \times 10^4 \text{ N} - 650 \text{ N}}{2100 \text{ kg}} = \underline{12.0 \text{ m/s}^2}$$

(b) The acceleration is not one-fourth of what it was with all rockets burning because the frictional force is still as large as it was with all rockets burning.

13. *The weight of an astronaut plus his space suit on the Moon is only 250 N. How much do they weigh on Earth? What is the mass on the Moon? On Earth?*

Solution

$$w_{\text{Moon}} = mg_{\text{Moon}}$$

$$m = \frac{w_{\text{Moon}}}{g_{\text{Moon}}} = \frac{250 \text{ N}}{1.67 \text{ m/s}^2} = 150 \text{ kg}$$

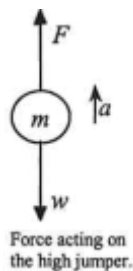
$$w_{\text{Earth}} = mg_{\text{Earth}} = (150 \text{ kg})(9.8 \text{ m/s}^2) = 1470 \text{ N} = \underline{1.5 \times 10^3 \text{ N}}$$

Mass does not change. The astronaut's mass on both Earth and the Moon is 150 kg.

4.6 PROBLEM-SOLVING STRATEGIES

25. Calculate the force a 70.0-kg high jumper must exert on the ground to produce an upward acceleration 4.00 times the acceleration due to gravity. Explicitly show how you follow the steps in the Problem-Solving Strategy for Newton's laws of motion.

Solution Step 1. Use Newton's Laws of Motion.



Step 2. Given: $a = 4.00 g = (4.00)(9.80 \text{ m/s}^2) = 39.2 \text{ m/s}^2$; $m = 70.0 \text{ kg}$

Find F .

Step 3. $\sum F = +F - w = ma$, so that $F = ma + w = ma + mg = m(a + g)$

$$F = (70.0 \text{ kg})[(39.2 \text{ m/s}^2) + (9.80 \text{ m/s}^2)] = \underline{3.43 \times 10^3 \text{ N}}$$

The force exerted by the high-jumper is actually down on the ground, but \mathbf{F} is up from the ground to help him jump.

Step 4. This result is reasonable, since it is quite possible for a person to exert a force

of the magnitude of 10^3 N.

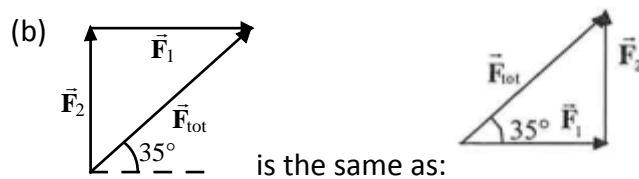
30. (a) Find the magnitudes of the forces \mathbf{F}_1 and \mathbf{F}_2 that add to give the total force \mathbf{F}_{tot} shown in **Figure 4.35**. This may be done either graphically or by using trigonometry. (b) Show graphically that the same total force is obtained independent of the order of addition of \mathbf{F}_1 and \mathbf{F}_2 . (c) Find the direction and magnitude of some other pair of vectors that add to give \mathbf{F}_{tot} . Draw these to scale on the same drawing used in part (b) or a similar picture.

Solution (a) Since F_2 is the y -component of the total force:

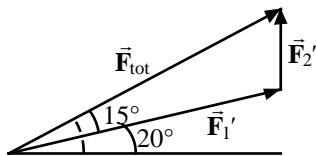
$$F_2 = F_{\text{tot}} \sin 35^\circ = (20 \text{ N})\sin 35^\circ = 11.47 \text{ N} = \underline{11 \text{ N}}.$$

And F_1 is the x -component of the total force:

$$F_1 = F_{\text{tot}} \cos 35^\circ = (20 \text{ N})\cos 35^\circ = 16.38 \text{ N} = \underline{16 \text{ N}}.$$



(c) For example, use vectors as shown in the figure.



F_1' is at an angle of 20° from the horizontal, with a magnitude of $F_1' \cos 20^\circ = F_1$

$$F_1' = \frac{F_1}{\cos 20^\circ} = \frac{16.38 \text{ N}}{\cos 20^\circ} = 17.4 \text{ N} = \underline{17 \text{ N}}$$

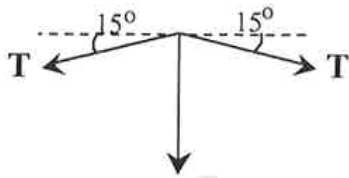
F_2' is at an angle of 90° from the horizontal, with a magnitude of

$$F_2' = F_2 - F_1' \sin 20^\circ = \underline{5.2 \text{ N}}$$

33. What force is exerted on the tooth in *Figure 4.38* if the tension in the wire is 25.0 N? Note that the force applied to the tooth is smaller than the tension in the wire, but this is necessitated by practical considerations of how force can be applied in the mouth. Explicitly show how you follow steps in the Problem-Solving Strategy for Newton's laws of motion.

Solution Step 1: Use Newton's laws since we are looking for forces.

Step 2: Draw a free body diagram:



Step 3: Given $T = 25.0 \text{ N}$, find F_{app} . Using Newton's laws gives $\Sigma F_y = 0$, so that the applied force is due to the y -components of the two tensions:

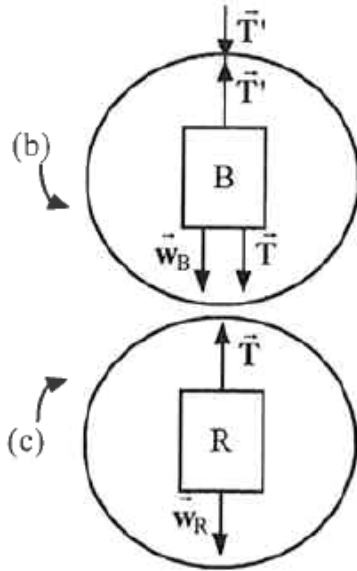
$$F_{\text{app}} = 2T \sin \theta = 2(25.0 \text{ N}) \sin 15^\circ = \underline{12.9 \text{ N}}$$

The x -components of the tension cancel. $\Sigma F_x = 0$

Step 4: This seems reasonable, since the applied tensions should be greater than the force applied to the tooth.

34. *Figure 4.39* shows Superhero and Trusty Sidekick hanging motionless from a rope. Superhero's mass is 90.0 kg, while Trusty Sidekick's is 55.0 kg, and the mass of the rope is negligible. (a) Draw a free-body diagram of the situation showing all forces acting on Superhero, Trusty Sidekick, and the rope. (b) Find the tension in the rope above Superhero. (c) Find the tension in the rope between Superhero and Trusty Sidekick. Indicate on your free-body diagram the system of interest used to solve each part.

Solution (a)



(b) Using the upper circle of the diagram, $\sum F_y = 0$, so that $T' - T - w_B = 0$.

Using the lower circle of the diagram, $\sum F_y = 0$, giving $T - w_R = 0$.

Next, write the weights in terms of masses: $w_B = m_B g$, $w_R = m_R g$.

Solving for the tension in the upper rope gives:

$$T' = T + w_B = w_R + w_B = m_R g + m_B g = g(m_R + m_B)$$

Plugging in the numbers gives: $T' = (9.80 \text{ m/s}^2)(55.0 \text{ kg} + 90.0 \text{ kg}) = \underline{1.42 \times 10^3 \text{ N}}$

Using the lower circle of the diagram, net $\sum F_y = 0$, so that $T - w_R = 0$. Again, write the weight in terms of mass: $w_R = m_R g$. Solving for the tension in the lower rope gives: $T = m_R g = (55.0 \text{ kg})(9.80 \text{ m/s}^2) = \underline{539 \text{ N}}$

4.7 FURTHER APPLICATIONS OF NEWTON'S LAWS OF MOTION

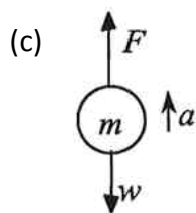
46. **Integrated Concepts** A basketball player jumps straight up for a ball. To do this, he lowers his body 0.300 m and then accelerates through this distance by forcefully straightening his legs. This player leaves the floor with a vertical velocity sufficient to carry him 0.900 m above the floor. (a) Calculate his velocity when he leaves the floor. (b) Calculate his acceleration while he is straightening his legs. He goes from zero to the velocity found in part (a) in a distance of 0.300 m. (c) Calculate the force he exerts on the floor to do this, given that his mass is 110 kg.

Solution (a) After he leaves the ground, the basketball player is like a projectile. Since he reaches a maximum height of 0.900 m, $v^2 = v_0^2 - 2g(y - y_0)$, with $y - y_0 = 0.900$ m, and $v = 0$ m/s. Solving for the initial velocity gives:

$$v_0 = [2g(y - y_0)]^{1/2} = [2(9.80 \text{ m/s}^2)(0.900 \text{ m})]^{1/2} = \underline{4.20 \text{ m/s}}$$

(b) Since we want to calculate his acceleration, use $v^2 = v_0^2 + 2a(y - y_0)$, where $y - y_0 = 0.300$ m, and since he starts from rest, $v_0 = 0$ m/s. Solving for the

acceleration gives: $a = \frac{v^2}{2(y - y_0)} = \frac{(4.20 \text{ m/s})^2}{(2)(0.300 \text{ m})} = \underline{29.4 \text{ m/s}^2}$



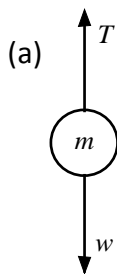
Now, we must draw a free body diagram in order to calculate the force exerted by the basketball player to jump. The net force is equal to the mass times the acceleration: net $F = ma = F - w = F - mg$

So, solving for the force gives:

$$F = ma + mg = m(a + g) = 110 \text{ kg}(29.4 \text{ m/s}^2 + 9.80 \text{ m/s}^2) = \underline{4.31 \times 10^3 \text{ N}}$$

49. **Integrated Concepts** An elevator filled with passengers has a mass of 1700 kg. (a) The elevator accelerates upward from rest at a rate of 1.20 m/s^2 for 1.50 s. Calculate the tension in the cable supporting the elevator. (b) The elevator continues upward at constant velocity for 8.50 s. What is the tension in the cable during this time? (c) The elevator decelerates at a rate of 0.600 m/s^2 for 3.00 s. What is the tension in the cable during deceleration? (d) How high has the elevator moved above its original starting point, and what is its final velocity?

Solution



The net force is due to the tension and the weight:

$$\text{net } F = ma = T - w = T - mg, \text{ and } m = 1700 \text{ kg}.$$

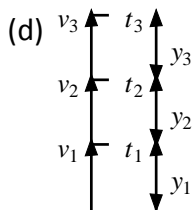
$a = 1.20 \text{ m/s}^2$, so the tension is :

$$T = m(a + g) = (1700 \text{ kg})(1.20 \text{ m/s}^2 + 9.80 \text{ m/s}^2) = \underline{1.87 \times 10^4 \text{ N}}$$

(b) $a = 0 \text{ m/s}^2$, so the tension is: $T = w = mg = (1700 \text{ kg})(9.80 \text{ m/s}^2) = \underline{1.67 \times 10^4 \text{ N}}$

(c) $a = 0.600 \text{ m/s}^2$, but down :

$$T = m(g - a) = (1700 \text{ kg})(9.80 \text{ m/s}^2 - 0.600 \text{ m/s}^2) = \underline{1.56 \times 10^4 \text{ N}}$$



$$\text{Use } y - y_0 = v_0 t + \frac{1}{2} a t^2 \text{ and } v = v_0 + a t.$$

For part (a), $v_0 = 0 \text{ m/s}$, $a = 1.20 \text{ m/s}^2$, $t = 150 \text{ s}$, given

$$y_1 = \frac{1}{2} a_1 t_1^2 = \frac{1}{2} (1.20 \text{ m/s}^2)(150 \text{ s})^2 = 1.35 \text{ m} \text{ and}$$

$$v_1 = a_1 t_1 = (1.20 \text{ m/s}^2)(150 \text{ s}) = 1.80 \text{ m/s}.$$

For part (b), $v_0 = v = 1.80 \text{ m/s}$, $a = 0 \text{ m/s}$, $t = 8.50 \text{ s}$, so

$$y_1 = v_1 t_2 = (1.80 \text{ m/s})(8.50 \text{ s}) = 15.3 \text{ m}.$$

For part (c), $v_0 = 1.80 \text{ m/s}$, $a = -0.600 \text{ m/s}^2$, $t = 3.00 \text{ s}$, so that:

$$y_3 = v_2 t + a_3 t_3^2 = (1.80 \text{ m/s})(3.00 \text{ s}) + 0.5(-0.600 \text{ m/s}^2)(3.00 \text{ s})^2 = 2.70 \text{ m}$$

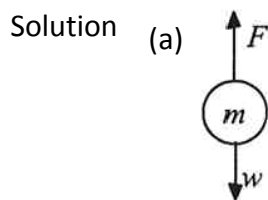
$$v_3 = v_2 + a_3 t_3 = 1.80 \text{ m/s} + (-0.600 \text{ m/s}^2)(3.00 \text{ s}) = 0 \text{ m/s}$$

Finally, the total distance traveled is

$$y_1 + y_2 + y_3 = 1.35 \text{ m} + 15.3 \text{ m} + 2.70 \text{ m} = 19.35 \text{ m} = \underline{19.4 \text{ m}}$$

And the final velocity will be the velocity at the end of part (c), or $v_{\text{final}} = \underline{0 \text{ m/s}}$.

51. **Unreasonable Results** A 75.0-kg man stands on a bathroom scale in an elevator that accelerates from rest to 30.0 m/s in 2.00 s. (a) Calculate the scale reading in newtons and compare it with his weight. (The scale exerts an upward force on him equal to its reading.) (b) What is unreasonable about the result? (c) Which premise is unreasonable, or which premises are inconsistent?



$$\text{Using } v = v_o + at \text{ gives: } a = \frac{v - v_o}{t} = \frac{30.0 \text{ m/s} - 0 \text{ m/s}}{2.00 \text{ s}} = 15.0 \text{ m/s}^2.$$

Now, using Newton's laws gives net $F = F - w = ma$, so that

$$F = m(a + g) = 75.0 \text{ kg}(15.0 \text{ m/s}^2 + 9.80 \text{ m/s}^2) = \underline{1860 \text{ N}} .$$

The ratio of the force to the weight is then:

$$\frac{F}{w} = \frac{m(a + g)}{mg} = \frac{15.0 \text{ m/s}^2 + 9.80 \text{ m/s}^2}{9.80 \text{ m/s}^2} = \underline{2.53}$$

- (b) The value (1860 N) is more force than you expect to experience on an elevator.
- (c) The acceleration $a = 15.0 \text{ m/s}^2 = 1.53g$ is much higher than any standard elevator. The final speed is too large (30.0 m/s is VERY fast)! The time of 2.00s is not unreasonable for an elevator.

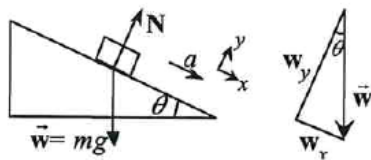
CHAPTER 5: FURTHER APPLICATION OF NEWTON'S LAWS: FRICTION, DRAG, AND ELASTICITY

5.1 FRICTION

8. Show that the acceleration of any object down a frictionless incline that makes an angle θ with the horizontal is $a = g \sin \theta$. (Note that this acceleration is independent of mass.)

Solution The component of w down the incline leads to the acceleration:

$$w_x = \text{net } F_x = ma = mg \sin \theta \text{ so that } \underline{a = g \sin \theta}$$

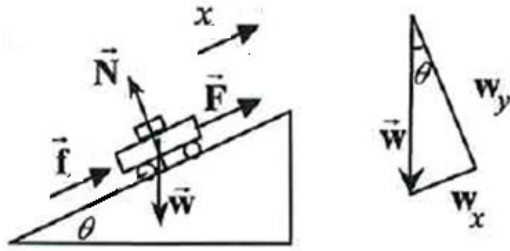


The component of w perpendicular to the incline equals the normal force.

$$w_y = \text{net } F_y = 0 = N - mg \sin \theta$$

14. Calculate the maximum acceleration of a car that is heading up a 4° slope (one that makes an angle of 4° with the horizontal) under the following road conditions. Assume that only half the weight of the car is supported by the two drive wheels and that the coefficient of static friction is involved—that is, the tires are not allowed to slip during the acceleration. (Ignore rolling.) (a) On dry concrete. (b) On wet concrete. (c) On ice, assuming that $\mu_s = 0.100$, the same as for shoes on ice.

Solution



Take the positive x -direction as up the slope. For max acceleration,

$$\text{net } F_x = ma = f - w_x = \frac{1}{2} \mu_s mg \cos \theta - mg \sin \theta$$

$$\text{So the maximum acceleration is: } a = g \left(\frac{1}{2} \mu_s \cos \theta - \sin \theta \right)$$

$$(a) \mu_s = 1.00, a = (9.80 \text{ m/s}^2) \left[\frac{1}{2} (1.00) \cos 4^\circ - \sin 4^\circ \right] = \underline{4.20 \text{ m/s}^2}$$

$$(b) \mu_s = 0.700, a = (9.80 \text{ m/s}^2) \left[\frac{1}{2} (0.700) \cos 4^\circ - \sin 4^\circ \right] = \underline{2.74 \text{ m/s}^2}$$

$$(c) \mu_s = 0.100, a = (9.80 \text{ m/s}^2) \left[\frac{1}{2} (0.100) \cos 4^\circ - \sin 4^\circ \right] = \underline{-0.195 \text{ m/s}^2}$$

The negative sign indicates downwards acceleration, so the car cannot make it up the grade.

5.3 ELASTICITY: STRESS AND STRAIN

29. During a circus act, one performer swings upside down hanging from a trapeze holding another, also upside-down, performer by the legs. If the upward force on the lower performer is three times her weight, how much do the bones (the femurs) in her upper legs stretch? You may assume each is equivalent to a uniform rod 35.0 cm long and 1.80 cm in radius. Her mass is 60.0 kg.

Solution Use the equation $\Delta L = \frac{1}{Y} \frac{F}{A} L_0$, where $Y = 1.6 \times 10^{10} \text{ N/m}^2$ (from Table 5.3),

$$L_0 = 0.350 \text{ m}, A = \pi r^2 = \pi (0.0180 \text{ m})^2 = 1.018 \times 10^{-3} \text{ m}^2, \text{ and}$$

$F_{\text{tot}} = 3w = 3(60.0 \text{ kg})(9.80 \text{ m/s}^2) = 1764 \text{ N}$, so that the force on each leg is
 $F_{\text{leg}} = F_{\text{tot}} / 2 = 882 \text{ N}$. Substituting in the value gives:

$$\Delta L = \frac{1}{1.6 \times 10^{10} \text{ N/m}^2} \frac{(882 \text{ N})}{(1.018 \times 10^{-3} \text{ m}^2)} (0.350 \text{ m}) = 1.90 \times 10^{-5} \text{ m}.$$

So each leg is stretched by $1.90 \times 10^{-3} \text{ cm}$.

35. *As an oil well is drilled, each new section of drill pipe supports its own weight and that of the pipe and drill bit beneath it. Calculate the stretch in a new 6.00 m length of steel pipe that supports 3.00 km of pipe having a mass of 20.0 kg/m and a 100-kg drill bit. The pipe is equivalent in strength to a solid cylinder 5.00 cm in diameter.*

Solution Use the equation $\Delta L = \frac{1}{Y} \frac{F}{A} L_0$, where $L_0 = 6.00 \text{ m}$, $Y = 1.6 \times 10^{10} \text{ N/m}^2$. To calculate the mass supported by the pipe, we need to add the mass of the new pipe to the mass of the 3.00 km piece of pipe and the mass of the drill bit:

$$m = m_p + m_{3 \text{ km}} + m_{\text{bit}} \\ = (6.00 \text{ m})(20.0 \text{ kg/m}) + (3.00 \times 10^3 \text{ m})(20.0 \text{ kg/m}) + 100 \text{ kg} = 6.022 \times 10^4 \text{ kg}$$

So that the force on the pipe is:

$$F = w = mg = (6.022 \times 10^4 \text{ kg})(9.80 \text{ m/s}^2) = 5.902 \times 10^5 \text{ N}$$

Finally the cross sectional area is given by: $A = \pi r^2 = \pi \left(\frac{0.0500 \text{ m}}{2} \right)^2 = 1.963 \times 10^{-3} \text{ m}^2$

Substituting in the values gives:

$$\Delta L = \frac{1}{2.10 \times 10^{11} \text{ N/m}^2} \frac{(5.902 \times 10^5 \text{ N})}{(1.963 \times 10^{-3} \text{ m}^2)} (6.00 \text{ m}) = 8.59 \times 10^{-3} \text{ m} = \underline{8.59 \text{ mm}}$$

41. *A farmer making grape juice fills a glass bottle to the brim and caps it tightly. The juice expands more than the glass when it warms up, in such a way that the volume increases by 0.2% (that is, $\Delta V / V_0 = 2 \times 10^{-3}$) relative to the space available. Calculate the force exerted by the juice per square centimeter if its bulk modulus is $1.8 \times 10^9 \text{ N/m}^2$, assuming the bottle does not break. In view of your answer, do you think the bottle will survive?*

Solution Using the equation $\Delta V = \frac{1}{B} \frac{F}{A} V_0$ gives:

$$\frac{F}{A} = B \frac{\Delta V}{V_0} = (1.8 \times 10^9 \text{ N/m}^2) (2 \times 10^{-3}) = 3.6 \times 10^6 \text{ N/m}^2 = \underline{4 \times 10^6 \text{ N/m}^2} = \underline{4 \times 10^2 \text{ N/cm}^2}$$

Since $1 \text{ atm} = 1.013 \times 10^5 \text{ N/m}^2$, the pressure is about 36 atmospheres, far greater than the average jar is designed to withstand.

CHAPTER 6: UNIFORM CIRCULAR MOTION AND GRAVITATION

6.1 ROTATION ANGLE AND ANGULAR VELOCITY

1. *Semi-trailer trucks have an odometer on one hub of a trailer wheel. The hub is weighted so that it does not rotate, but it contains gears to count the number of wheel revolutions—it then calculates the distance traveled. If the wheel has a 1.15 m diameter and goes through 200,000 rotations, how many kilometers should the odometer read?*

Solution Given:

$$d = 1.15 \text{ m} \Rightarrow r = \frac{1.15 \text{ m}}{2} = 0.575 \text{ m}, \Delta\theta = 200,000 \text{ rot} \times \frac{2\pi \text{ rad}}{1 \text{ rot}} = 1.257 \times 10^6 \text{ rad}$$

Find Δs using $\Delta\theta = \frac{\Delta s}{r}$, so that

$$\begin{aligned}\Delta s &= \Delta\theta \times r = (1.257 \times 10^6 \text{ rad})(0.575 \text{ m}) \\ &= 7.226 \times 10^5 \text{ m} = \underline{723 \text{ km}}\end{aligned}$$

7. *A truck with 0.420 m radius tires travels at 32.0 m/s. What is the angular velocity of the rotating tires in radians per second? What is this in rev/min?*

Solution Given: $r = 0.420 \text{ m}, v = 32.0 \text{ m/s}$.

$$\text{Use } \omega = \frac{v}{r} = \frac{32.0 \text{ m/s}}{0.420 \text{ m}} = \underline{76.2 \text{ rad/s}}.$$

Convert to rpm by using the conversion factor:

$$1 \text{ rev} = 2\pi \text{ rad},$$

$$\begin{aligned}\omega &= 76.2 \text{ rad/s} \times \frac{1 \text{ rev}}{2\pi \text{ rad}} \times \frac{60 \text{ s}}{1 \text{ min}} \\ &= 728 \text{ rev/s} = \underline{728 \text{ rpm}}\end{aligned}$$

6.2 CENTRIPETAL ACCELERATION

18. Verify that the linear speed of an ultracentrifuge is about 0.50 km/s, and Earth in its orbit is about 30 km/s by calculating: (a) The linear speed of a point on an ultracentrifuge 0.100 m from its center, rotating at 50,000 rev/min. (b) The linear speed of Earth in its orbit about the Sun (use data from the text on the radius of Earth's orbit and approximate it as being circular).

Solution (a) Use $v = r\omega$ to find the linear velocity:

$$v = r\omega = (0.100 \text{ m}) \left(50,000 \text{ rev/min} \times \frac{2\pi \text{ rad}}{1 \text{ rev}} \times \frac{1 \text{ min}}{60 \text{ s}} \right) = 524 \text{ m/s} = \underline{0.524 \text{ km/s}}$$

(b) Given: $\omega = 2\pi \frac{\text{rad}}{\text{y}} \times \frac{1 \text{ y}}{3.16 \times 10^7 \text{ s}} = 1.988 \times 10^{-7} \text{ rad/s}$; $r = 1.496 \times 10^{11} \text{ m}$

Use $v = r\omega$ to find the linear velocity:

$$v = r\omega = (1.496 \times 10^{11} \text{ m}) (1.988 \times 10^{-7} \text{ rad/s}) = 2.975 \times 10^4 \text{ m/s} = \underline{29.7 \text{ km/s}}$$

6.3 CENTRIPETAL FORCE

26. What is the ideal speed to take a 100 m radius curve banked at a 20.0° angle?

Solution Using $\tan \theta = \frac{v^2}{rg}$ gives:

$$\tan \theta = \frac{v^2}{rg} \Rightarrow v = \sqrt{rg \tan \theta} = \sqrt{(100 \text{ m})(9.8 \text{ m/s}^2) \tan 20.0^\circ} = \underline{18.9 \text{ m/s}}$$

6.5 NEWTON'S UNIVERSAL LAW OF GRAVITATION

33. (a) Calculate Earth's mass given the acceleration due to gravity at the North Pole is 9.830 m/s^2 and the radius of the Earth is 6371 km from pole to pole. (b) Compare this with the accepted value of $5.979 \times 10^{24} \text{ kg}$.

Solution (a) Using the equation $g = \frac{GM}{r^2}$ gives:

$$g = \frac{GM}{r^2} \Rightarrow M = \frac{r^2 g}{G} = \frac{(6371 \times 10^3 \text{ m})^2 (9.830 \text{ m/s}^2)}{6.673 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2} = \underline{5.979 \times 10^{24} \text{ kg}}$$

(b) This is identical to the best value to three significant figures.

39. *Astrology, that unlikely and vague pseudoscience, makes much of the position of the planets at the moment of one's birth. The only known force a planet exerts on Earth is gravitational. (a) Calculate the gravitational force exerted on a 4.20 kg baby by a 100 kg father 0.200 m away at birth (he is assisting, so he is close to the child). (b) Calculate the force on the baby due to Jupiter if it is at its closest distance to Earth, some $6.29 \times 10^{11} \text{ m}$ away. How does the force of Jupiter on the baby compare to the force of the father on the baby? Other objects in the room and the hospital building also exert similar gravitational forces. (Of course, there could be an unknown force acting, but scientists first need to be convinced that there is even an effect, much less that an unknown force causes it.)*

Solution (a) Use $F = \frac{GMm}{r^2}$ to calculate the force:

$$F_f = \frac{GMm}{r^2} = \frac{(6.673 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2)(100 \text{ kg})(4.20 \text{ kg})}{(0.200 \text{ m})^2} = \underline{7.01 \times 10^{-7} \text{ N}}$$

(b) The mass of Jupiter is:

$$m_j = 1.90 \times 10^{27} \text{ kg}$$

$$F_j = \frac{(6.673 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2)(1.90 \times 10^{27} \text{ kg})(4.20 \text{ kg})}{(6.29 \times 10^{11} \text{ m})^2} = \underline{1.35 \times 10^{-6} \text{ N}}$$

$$\frac{F_f}{F_j} = \frac{7.01 \times 10^{-7} \text{ N}}{1.35 \times 10^{-6} \text{ N}} = \underline{0.521}$$

6.6 SATELLITES AND KEPLER'S LAWS: AN ARGUMENT FOR SIMPLICITY

45. Find the mass of Jupiter based on data for the orbit of one of its moons, and compare your result with its actual mass.

Solution Using $\frac{r^3}{T^2} = \frac{G}{4\pi^2} M$, we can solve the mass of Jupiter:

$$M_j = \frac{4\pi^2}{G} \times \frac{r^3}{T^2} \\ = \frac{4\pi^2}{6.673 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2} \times \frac{(4.22 \times 10^8 \text{ m})^3}{[(0.00485 \text{ y})(3.16 \times 10^7 \text{ s/y})]^2} = \underline{1.89 \times 10^{27} \text{ kg}}$$

This result matches the value for Jupiter's mass given by NASA.

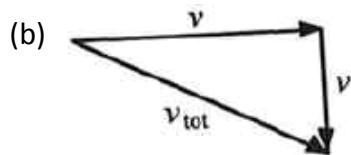
48. **Integrated Concepts** Space debris left from old satellites and their launchers is becoming a hazard to other satellites. (a) Calculate the speed of a satellite in an orbit 900 km above Earth's surface. (b) Suppose a loose rivet is in an orbit of the same

radius that intersects the satellite's orbit at an angle of 90° relative to Earth. What is the velocity of the rivet relative to the satellite just before striking it? (c) Given the rivet is 3.00 mm in size, how long will its collision with the satellite last? (d) If its mass is 0.500 g, what is the average force it exerts on the satellite? (e) How much energy in joules is generated by the collision? (The satellite's velocity does not change appreciably, because its mass is much greater than the rivet's.)

Solution (a) Use $F_c = ma_c$, then substitute using $a = \frac{v^2}{r}$ and $F = \frac{GmM}{r^2}$.

$$\frac{GmM}{r^2} = \frac{mv^2}{r}$$

$$v = \sqrt{\frac{GM_E}{r_S}} = \sqrt{\frac{(6.673 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2)(5.979 \times 10^{24} \text{ kg})}{900 \times 10^3 \text{ m}}} = \underline{2.11 \times 10^4 \text{ m/s}}$$



In the satellite's frame of reference, the rivet has two perpendicular velocity components equal to v from part (a):

$$v_{\text{tot}} = \sqrt{v^2 + v^2} = \sqrt{2v^2} = \sqrt{2}(2.105 \times 10^4 \text{ m/s}) = \underline{2.98 \times 10^4 \text{ m/s}}$$

(c) Using kinematics: $d = v_{\text{tot}} t \Rightarrow t = \frac{d}{v_{\text{tot}}} = \frac{3.00 \times 10^{-3} \text{ m}}{2.98 \times 10^4 \text{ m/s}} = \underline{1.01 \times 10^{-7} \text{ s}}$

(d) $\bar{F} = \frac{\Delta p}{\Delta t} = \frac{mv_{\text{tot}}}{t} = \frac{(0.500 \times 10^{-3} \text{ kg})(2.98 \times 10^4 \text{ m/s})}{1.01 \times 10^{-7} \text{ s}} = \underline{1.48 \times 10^8 \text{ N}}$

(e) The energy is generated from the rivet. In the satellite's frame of reference, $v_i = v_{\text{tot}}$, and $v_f = 0$. So, the change in the kinetic energy of the rivet is:

$$\Delta \text{KE} = \frac{1}{2}mv_{\text{tot}}^2 - \frac{1}{2}mv_i^2 = \frac{1}{2}(0.500 \times 10^{-3} \text{ kg})(2.98 \times 10^4 \text{ m/s})^2 - 0 \text{ J} = \underline{2.22 \times 10^5 \text{ J}}$$