

▲ Many of us think of an image like this when we think of physics. But a new driver must master the physics of driving, and a skater might understand some aspects of physics even more than the scientist.



Everything Is Physics

As students begin their study of physics, there are many thoughts about just what physics is. Some say it is challenging, and there certainly are challenging aspects of the subject. Others say that it is an advanced science; that is true regarding some fields of physics. But in reality physics is very basic. Some physicists enjoy pointing out that everything is physics. What do they mean by that?

Think about what interests you. Is it music? art? photography? sports? hiking? cooking? The list can go on. All these things, actually everything, can be explained using physics. Music is produced when a musician applies a force to his instrument to create a vibration that produces resonance in the instrument. The instrument carries energy away in the form of sound waves, which then arrive at our ear. The waves transfer energy through the mechanical linkages in the ear to our inner ear. Mechanical waves are produced in the fluid in the cochlea. The cochlea produces electrical signals that move along the auditory nerve to our brain which decodes the music. Physics can be—and is—used to describe each of the steps in this process.

Not all of us are expert musicians, but we are all skilled applied physicists. Whether we walk, run, stand up, sit down, throw something, or catch something, our actions involve physics

principles, and our mastery of these activities is evidence of our understanding of physics. So what is the purpose of this textbook? It will help you to understand the physics behind everyday tasks that are grounded in physics, such as walking, running, driving a car, playing an instrument, and playing football. You will learn the theory behind the physics and the mathematics that models the physics. You will become a *theoretical* physicist in addition to being an *applied* physicist. You will see how the Bible accounts for the possibility of physics itself.



▲ The f-stop on a camera is related to light optics—a field of physics.

Though the Bible establishes science's purpose, it is not a physics textbook or a scientific reference book. Nor would we want it to be! Physics and science change, but God's Word is the unchanging basis for a biblical worldview. In contrast, most scientists today work from within a *naturalistic worldview*. They assume that all phenomena have only natural causes and reject the existence of anything supernatural. Thus, naturalistic science is essentially atheistic, even though individual scientists may believe in a god. Do physics and the Bible relate to each other?

- Is physics incompatible with the Bible, or does physics explain the universe that God created?
- Is there a right use of physics from an ethical standpoint?
- What does physics and the Bible teach about the origins of the universe and life?
- Why should a Christian study science, in general, and more specifically, physics?

Through your study of physics, you will learn the answers to these questions.



Features of This Textbook

This textbook is for you, and we've designed it to help you learn. Flip through the following pages to see its features, which we believe will help you succeed in physics. In the back of the textbook you will see other features, including an appendix section, glossary, index, and periodic table. We've designed this textbook with you in mind. We hope that it will help you appreciate the wonders of God's creation even more.

- 1 Chapter Opener**
short articles that highlight issues and developments in physics that demonstrate how physics intersects with your life



13.1 The Zeroth and First Laws

As the sun and the thermometer readings rise in the summer, we get more and more uncomfortable. But the higher temperatures affect more than just our comfort but air travel, too. Both temperature and humidity can affect consumer and farmer health. Agriculture, the most industry, agricultural, consumer, services, computers, manufacturing, finance, and more other industries rely on cooler temperatures and low humidity to function efficiently and to protect their customers and products. Many disease vectors and spread faster in hot, humid weather. Farmers have ways to the temperatures have killed thousands of people in the United States over in recent decades. How can technology help us cope with this continuing problem?

Internal Energy

So far we have studied two forms of energy—mechanical and thermal. Mechanics of energy is a property of objects. Two aspects of mechanical energy are potential and kinetic energy. Potential energy, a result of work, can be changed to kinetic energy—energy of motion. Total mechanical energy is the sum of the kinetic and potential energy due to the motion and position of physical objects.

Just as objects can have both kinetic and potential energy, the particles within an object also have both kinetic and potential energy. The sum of the particle kinetic and potential energies of a substance is called its internal energy (U). Because the particles of a substance are constantly moving, they have kinetic energy. Their average kinetic energy is proportional to the temperature of the substance. These particles also have potential energies, but it is extremely complicated to determine the reference points for establishing these energies. As with total mechanical energy, once the internal energy of a system is established or assumed for a given state of the system, only the change in internal energy becomes important. Changes in internal energy (ΔU) are usually much easier to determine than the internal energy value at the beginning and end of a process.

The Zeroth Law of Thermodynamics

We all know that when we place hot objects in contact with a cold object, the cold object becomes warmer and the hot object becomes cooler. Thermal energy flows from the hot object to the cold object. In time the two objects reach the same temperature and there is no net movement of thermal energy. That is, they are in thermal equilibrium.

If two systems are in thermal equilibrium with a third system, then they must be in thermal equilibrium with each other. This is the zeroth law of thermodynamics. This law is like the transitive property of mathematics. If $a = b$ and $b = c$, then $a = c$. The law occurred first because it is more basic than either the first or second law and is foundational to them, but scientists established it after the first two laws had already been stated.

Many power plants use steam because it is a convenient medium for transferring thermal energy, which can be transformed into other useful forms of energy. The efficient use of steam requires knowledge of thermodynamics.

2

How do work and heat relate to each other?

QUESTIONS

- How can heat be converted to work?
- What are the laws of thermodynamics?
- How can you tell if a process is reversible?
- What is a heat engine?

TERMS

Internal energy, thermal equilibrium, zeroth law of thermodynamics, heat engine, open system, closed system, isolated system, adiabatic process, isothermal process, quasistatic process, isobaric process

ConnectConcepts

As you learned in Chapter 12, the flow of thermal energy is called heat. In every case thermal energy can be used interchangeably with internal energy discussed here.

7

• Sometimes surface temperatures become extremely high.



- 2 Essential Question**
the big question that you will learn about in a section
- 3 Key Questions**
the smaller questions that you can ask along the way through a section to help you answer the essential question
- 4 Vocabulary Terms**
the key terms that will be introduced in a section

- 5 ConnectConcepts**
short text connecting the current chapter to previously learned material
- 6 Bold-Faced Terms**
vocabulary terms that you need to know
- 7 Italicized Terms**
terms that will be defined later in the textbook or that are important terms in other scientific fields

case study

FOUCAULT PENDULUM

Do you believe that the earth rotates once a day? In 1851 French physicist Leon Foucault set out to prove that it did. He hung a pendulum from the dome of the Pantheon in Paris. The pendulum consisted of a 28 kg iron ball on the end of an approximately 67 m wire. The period of its swinging pendulum was about 34.5 s—it would swing about four times each minute.

The pendulum was hung in such a way that only one force was acting on the pendulum. If the earth truly rotated, it would move under Foucault's pendulum so that the pendulum's orientation would appear to change. Foucault drew a line on the floor to mark the direction of the pendulum's initial swing and then set the pendulum in motion.

At first the pendulum seemed to follow the line, but eventually the change was noticeable. After eight hours, the pendulum was swinging perpendicular to the line. After nearly thirty-two hours, the pendulum's swing was aligned with the line on the floor again. Since only vertical forces acted on the pendulum, Foucault concluded that the pendulum's orbit rotates through 360° relative to the floor and the earth rotates around the pendulum.

Questions to Consider

1. Does the mass and length of the pendulum affect its period?
2. Why do you think Foucault selected the specific mass and length for his pendulum?
3. If Foucault's pendulum demonstrates that the earth is rotating, explain how it is why the pendulum didn't return to its original alignment in twenty-four hours.




Photo: Science 377

8 Case Studies
opportunities to investigate specific areas in physics to apply what you have learned in a chapter

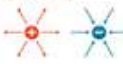
16 CHAPTER REVIEW

Chapter Summary

16.1 MODELING ELECTRIC FIELDS

TERMS
electric field
test charge
electric potential energy
electric potential
potential difference

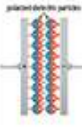
- All charged objects have an electric field that extends into the space around them. Other charged objects within the space will experience electric forces.
- The electric field strength is a vector quantity of the electric force per unit charge. Due to the convention of using a positive test charge.
- Electric fields point away from positive objects and toward negative objects.
- Electric potential energy is the work needed to move a charge to a position within an electric field.
- Electric potential is the electric potential energy per unit charge.



TERMS
capacitor
permittivity of free space
permittivity of material

16.2 CAPACITORS

- A capacitor is an electrical device for storing charge. It is typically made of two conductors separated by a vacuum or a dielectric.
- A dielectric, an insulating material, increases the charge stored on each conductor due to the induced polarization of the dielectric.
- A dielectric increases the capacitance of a capacitor. The degree to which the dielectric increases the capacitance is determined by its dielectric constant.
- Capacitance is a measure of the charge that can be stored per unit potential difference.
- The total capacitance of capacitors in parallel is the sum of their capacitances.
- The reciprocal of the total capacitance is equal to the sum of the reciprocals of the individual capacitances for capacitors in series.




Chapter Review Questions

RECALLING FACTS

1. What would you see for the spatial distribution and relative size of the electric field lines associated with a charge? What graphical aid can we use to represent the electric field?
2. What are lines of force?
3. What is electric field strength?
4. Describe a test charge.
5. Describe the direction of an electric field.
6. What is electric potential?
7. What does a capacitor do?
8. What does it mean that a dielectric is polarizable? What effect does that have on the electric field within a capacitor?
9. Define capacitance.

UNDERSTANDING CONCEPTS

10. What is the relationship between the charge stored in a capacitor, potential difference, and capacitance?
11. How is the capacitance of a capacitor related to the dimensions and materials within it?
12. In the diagram at right, in what region is the electric force the strongest? Why?
13. Draw the lines of force surrounding a spherical, negatively charged body.
14. How can we observe and measure an electric field?
15. An object with a charge of 2.00 nC sees the force of other charges. Write an equation that gives electric field strength at a given distance r from the charge.



818 Chapter 16

9 Chapter Summary
handy statements of the big ideas of the chapter, including vocabulary lists

10 Review Questions
questions at the end of each section and chapter that will have you recall facts, demonstrate your understanding of concepts, and cause you to use critical thinking

11 Mini Labs
short hands-on activities to get you thinking and working like a scientist

12 Career Boxes
information about careers in physics (that could be yours!) that can be followed to wisely use God's world and help people!

13 STEM Connection Boxes
descriptions of how science, technology, engineering, and mathematics (STEM) work together to solve real-world problems

MINI LAB

Changing the Harmonics of a Bottle

The notes played by a musical instrument are produced by vibrating some medium in the instrument. A soda bottle can be used as an instrument by blowing horizontally across the open top. How can we change the notes played in a bottle?

11 What affects the harmonics of a bottle?

EQUIPMENT

- soda bottles (2)
- water, varying temperatures
- marker

Procedure

- Mark each of the bottles at about 1/3, 1/2, and 2/3 the way up the bottle.
- Fill the first bottle to the 1/3 mark with room-temperature water and the other bottle to the 1/3 mark with warm water. Then blow across the open neck of each bottle to produce a note. Observe any difference in the pitch.
- Repeat step 2 but with water at both the 1/2 and the 2/3 marks.

Conclusions

- What was the effect of changing the volume of water in the bottle? Explain.
- What was the effect of changing the water temperature?

Going further

- Put an instrument and make correlations between that instrument and what you observed in the laboratory.

Standing Waves

An interesting application of constructive and destructive interference is called a standing wave, a wave that appears to stand still even though it is in fact moving. A standing wave is created by driving an oscillator, and as we learned in Section 15.1, the input is a driven oscillator here to be in phase. To generate a standing wave in a string, the wavelength of the input wave must be related to the length of the string. The relationship is

$$L = n \frac{\lambda}{2} \quad (15.8)$$

where L is the length of the string and n is an integer.

284 Chapter 15

Example 23 Finding an Image Algebraically—Diverging Lens

An object 8.00 cm high is 30.0 cm from a diverging lens with a focal length of 10.0 cm. Use the lens equation to determine (a) the position of the image, (b) the height of the image, and (c) the magnification of the image. Then (d) describe the image.

Write what you know.

$$h_o = 8.00 \text{ cm} \quad f = -10.0 \text{ cm} \quad h_i = ?$$

$$d_o = 30.0 \text{ cm} \quad d_i = ? \quad M = ?$$

a. Write the formula and solve for the unknown.

$$\frac{1}{d_i} = \frac{1}{d_o} + \frac{1}{f}$$

Plug in known values and evaluate.

$$\frac{1}{d_i} = \frac{1}{30.0 \text{ cm}} + \frac{1}{-10.0 \text{ cm}}$$

$$\frac{1}{d_i} = \frac{1}{30.0 \text{ cm}} - \frac{1}{10.0 \text{ cm}}$$

$$\frac{1}{d_i} = \frac{1 - 3}{30.0 \text{ cm}}$$

$$\frac{1}{d_i} = \frac{-2}{30.0 \text{ cm}}$$

$$d_i = -15.0 \text{ cm}$$

b. Write the formula and solve for the unknown.

$$M = \frac{h_i}{h_o} = \frac{d_i}{d_o}$$

Plug in known values and evaluate.

$$M = \left(\frac{-15.0 \text{ cm}}{30.0 \text{ cm}} \right)$$

$$M = -0.500$$

d. Describe the image.

The image is 7.50 cm from the lens on the same side as the object and is 2.00 cm high. It is a virtual, upright, reduced image.

12 CAREERS

SERVING AS AN OPTOMETRIST: RESTORING SIGHT

In a world of 7.2 billion people, a condition that affects 2.2 billion of them would seem like a global issue. The World Health Organization estimates that 2.2 billion people around the world suffer some form of vision disability. People living in the United States may assume

that these issues are all resolved through regular doctor visits and the use of eyeglasses, but the WHO estimates that one billion of the cases worldwide either could have been prevented or have yet to be addressed.

Optometrists around the world work to alleviate the suffering of those with vision deficiencies. The field of optometry was initially focused on prescribing and providing corrective lenses. Over time the field has expanded to study many aspects of vision, the eyes, and conditions that reduce how well people can see. The Fellowship of Canadian Optometrists focuses on the aspect of medical necessary work to meet the needs of others.

Optometrists hold a Doctor of Optometry degree, and each of these studies involves the optics of the eye as well as the harmonics optical instruments that they use in the diagnosis and treatment of eye ailments. Optometrists use their knowledge of optics to serve others and glorify God.

314 Chapter 15

STEM Connection

science • technology • engineering • mathematics

13

EYEGASSES

The human eye is amazing! God designed it with an adjustable lens so that it can focus both near and far images. As many of us know firsthand, one consequence of the fact that not everybody's eyes are able to properly focus both near and far images. Thankfully, our country has allowed us to use lenses to correct defects in near and far vision, as well as other vision deficiencies.

A person who is nearsighted can clearly see objects that are close to him but is unable to focus the image of objects that are farther away. His eye lenses are unable to reduce their curvature sufficiently so the images of distant objects are focused in front of his retina. A vision specialist, or optometrist, can prescribe glasses containing diverging lenses that will slightly spread the rays of light from distant objects. This slight diverging of the rays allows each eye's lens to focus these rays on the retina.

Another person may need reading glasses because he can't clearly see objects that are distant but can focus the image of objects that are nearby. The images of nearby objects are focused behind his retina because his eye lenses are unable to curve enough to converge the light quickly enough. In this case, a doctor prescribes glasses containing converging lenses, which start the converging of light so that the eye's lenses can focus these rays on the retina.

correcting nearsightedness

correcting farsightedness

Reflection 371



worldview investigation

SMART GRIDS

Imagine that you are working on your homework when the power goes out. You discover that your entire neighborhood is out, but the happiness of the town. You use the internet to check your favorite social media site. By noon, you find out you see that the outage is affecting your entire town. Then you hear that it is the entire state. Over the course of the next few hours, it is evident that the outage covers your state as well as all other states. News agencies are saying that some customers will be without power for two to three days.

How does this happen, and how can we prevent it? One way is by developing a smart grid of electricity. What is a smart grid and what can it possibly do?

Task

Months after the outage that interrupted your homework, the U.S. House of Representatives is preparing to debate the funding of a smart grid initiative. Your legislator is seeking input from constituents. Since you were directly impacted by a major power outage, you decide to do some research. Once you have finished, you will write a letter to your legislator fact-checking your support for or opposition to the proposed initiative.

Procedure

1. Research smart grids by doing an internet search using the keywords "developing a smart grid" and "why do we want a smart grid?" Also research any negative aspects of a smart grid by doing a keyword search for "downside to a smart grid."
2. Prepare your letter, including both positive and negative aspects of a smart grid. Explain from a biblical perspective whether your legislator should vote for or against the measure and why.
3. Share your letter with a classmate or family member and ask for feedback.
4. Revise your letter on the basis of the feedback received and turn in your letter.

Conclusion

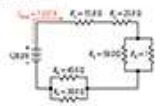
Our technology (if done well) depends on reliable electricity. Smart grids may be the answer to provide the electricity we need for our ever-growing demand.

114 Chapter 10

14 Worldview Investigation Boxes inquiry-based investigations that help you think through controversial areas of physics through the lens of Scripture

26. How many grams of water could you heat from 0 °C to 100 °C with the electrical equivalent of the energy used by a 100-W light bulb that runs for 300 s?

27. Consider the circuit below. What is the value of the unknown resistor?



Use the ethics box at right to answer Question 28.

28. How do you respond to the contractor? Write a four-paragraph response to this proposal from a biblical perspective.

ethics

ELECTRICAL CODES

Electricity is essential to our daily lives, but it can also be dangerous. Each year, hundreds of people die and thousands are injured by electric shock. Additional deaths and injuries are caused by fires started by electrical malfunctions. Over the years, local, state, and federal agencies have implemented safety standards to address these issues. Each new round of safety codes costs hundreds of millions of dollars. That cost is passed on to customers.

Imagine that you are having a house built and your contractor has suggested that there are some building codes that are costly to comply with but not very effective at protecting people. He has asked you whether you want to save some money by having the electrician circumvent some of those codes. He tells you that it is your house and that noncompliance won't affect anyone else.

General Education 401

15 Ethics Boxes opportunities to apply a biblical worldview to ethical issues in physics

4 Motion in Two Dimensions

- 4.1 Kinematics of Two-Dimensional Motion 87
- 4.2 Projections 92



4.1 Kinematics of Two-Dimensional Motion

Areas inhabited by people with the greatest needs are often the most inaccessible. Populated locales devastated and isolated by war or large-scale natural disasters quickly become uninhabitable. Homes are destroyed and utility networks are disrupted. Electricity and clean water supplies are in short supply, and sewage can't be disposed of properly. Roads, bridges, and airfields may be inaccessible, cutting off areas from the outside world. Governmental authority wanes, and local medical establishments may be overwhelmed with patients. The fabric of civilized living unravels. People surviving in such circumstances urgently need water, food, shelter, and medical care. The lack of transportation and communication amplifies these problems. How can humanitarian aid be delivered to such isolated and needy people? As we'll see later in this chapter, physics can help answer that question.

Position Vectors in Two Dimensions

Analyzing position and motion in two dimensions is only slightly more complicated than analyzing one-dimensional motion. Positions, displacements, velocities, and accelerations in two dimensions are all vector quantities that can be resolved into their components. Components can be analyzed using the equations of motion derived in Chapter 2.

In straight-line motion, we located an object by its position on a one-dimensional number line using coordinates. In two-dimensional motion position is typically determined using the rectangular Cartesian coordinate system. By convention, the x -axis is horizontal and the y -axis is vertical.

Position in two dimensions is determined by the position vector (\mathbf{r}). The tail of the position vector is at the origin of the coordinate system, and the head is at the object's location. The diagram at right shows the path of a fly on a window pane. At time t_0 , the fly is at the tip of \mathbf{r}_0 ; at time t_1 , the fly is at the tip of \mathbf{r}_1 ; at time t_2 , the fly is at the tip of \mathbf{r}_2 . The origin is at the lower left corner of the window. The next figure shows the same path of the fly, but now the origin is at the center of the window. Although the positions of the fly are identical, the position vectors are different when measured from the different reference points. Recall from Chapter 2 that a frame of reference is simply the coordinate system within which motion is measured or observed. In theory, an infinite number of reference frames is possible.

Displacement in Two Dimensions

The displacement of an object is its change in position represented by the difference vector $\Delta\mathbf{r}$. The displacement for an interval of time is

$$\Delta\mathbf{r} = \mathbf{r}_f - \mathbf{r}_i$$

where \mathbf{r}_f is the final position vector and \mathbf{r}_i is the initial position vector. For instance, the fly's displacement ($\Delta\mathbf{r}_1$) for the interval t_0 to t_1 in the first figure is

$$\Delta\mathbf{r}_1 = \mathbf{r}_1 - \mathbf{r}_0;$$

for the second it is

$$\Delta\mathbf{R}_1 = \mathbf{R}_1 - \mathbf{R}_0.$$

How does a pilot correct for the wind?

QUESTIONS

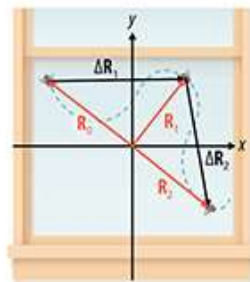
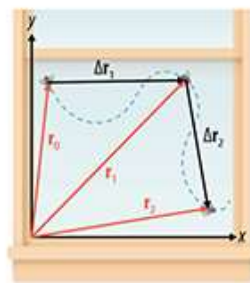
- » How can we identify the positions of objects?
- » How are vectors used to solve problems in kinematics?

TERMS

none

ConnectConcepts

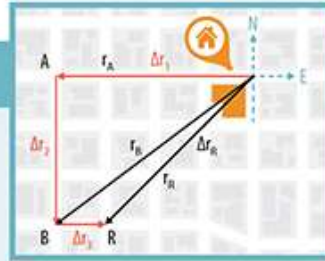
In this chapter we will be connecting the concepts of kinematics from Chapter 2 with the vector operations from Chapter 3.



The displacement is the same no matter which reference frame is used. Recall from Chapter 3 that we can also calculate a resultant vector by doing vector addition with the individual vectors. So a total displacement may be found by finding the change in position or adding the displacement vectors. The approach we take will depend on the problem.

Example 4-1 Determining Two-Dimensional Displacement

A jogger starts from home and jogs 400 m west to corner A, turns and jogs 300 m south to corner B, and then turns east and jogs for another 100 m before stopping to rest at point R. Using the jogger's home as the origin of the coordinate system, we draw the jogger's complete path and the position vectors to A, B, and R.



- What is the jogger's displacement from corner A to corner B?
- What is his displacement from home to the resting spot?
- What is the total distance that he jogged?

Write what you know.

Refer to the figure above.

Write the formula and solve for the unknown.

- $$\Delta \mathbf{r}_2 = \mathbf{r}_B - \mathbf{r}_A$$

$$= \langle -400, -300 \rangle \text{ m} - \langle -400, 0 \rangle \text{ m} = \langle 0, -300 \rangle \text{ m}$$

$$= 300 \text{ m south}$$
- $$\Delta \mathbf{r}_3 = \mathbf{r}_R - \mathbf{0} = \mathbf{r}_R$$

(A zero vector ($\mathbf{0}$) is any vector with zero magnitude. The position vector of the origin,

which is required when determining any displacement from the origin, is $\mathbf{0}$.)

Determine the components of \mathbf{r}_R .

$$\mathbf{r}_{R_x} = -300 \text{ m (west)}$$

$$\mathbf{r}_{R_y} = -300 \text{ m (south)}$$

$$|\mathbf{r}_R| = \sqrt{(-300 \text{ m})^2 + (-300 \text{ m})^2} = \sqrt{180\,000 \text{ m}^2}$$

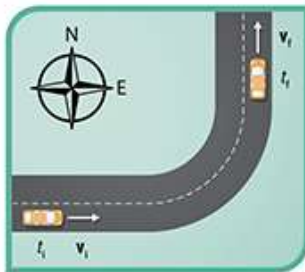
$$= 424 \text{ m}$$

$$\alpha = \tan^{-1} \frac{|\mathbf{r}_{R_y}|}{|\mathbf{r}_{R_x}|} = \tan^{-1} \left(\frac{300 \text{ m}}{300 \text{ m}} \right) = 45^\circ$$

The displacement is 424 m at 45° south of west.

- $$d_{\text{total}} = (400 \text{ m} + 300 \text{ m} + 100 \text{ m})$$

$$= 800 \text{ m}$$



Velocity and Speed in Two Dimensions

Average velocity and average speed between two positions in a Cartesian plane are determined as they are in one dimension. Use vector notation when describing average velocity in two dimensions.

$$\text{average velocity: } \bar{\mathbf{v}} = \frac{\Delta \mathbf{r}}{\Delta t}$$

$$\text{average speed: } \text{speed} = \frac{\text{distance}}{\Delta t}$$

The instantaneous velocity vector, which is the velocity of an object at any given moment, has a magnitude equal to the object's speed at that instant and points in the direction that the object is moving at that time. The diagram at left shows the instantaneous velocity of a car traveling around a curve. At time t_i the vector points east, but at time t_f the vector points north. In two- or three-dimensional motion we must include information about the direction of the motion.

The instantaneous speed is equal to the magnitude of the instantaneous velocity, $v = |\mathbf{v}|$. For instance, in the diagram on the previous page, if $|\mathbf{v}_x|$ equals $|\mathbf{v}_y|$ and $|\mathbf{v}|$ remains constant through the curve, the speed of the car is constant. Depending on the object's motion, the average speed and the magnitude of the average velocity may be quite different. These quantities are equal only if the distance equals the magnitude of the displacement, which can occur only in one-dimensional motion.

Example 4-2 Determining Two-Dimensional Velocity

A pilot flies a crop dusting helicopter above a field of sugar beets. She is flying 15.00 kph, aiming the copter due north (\mathbf{v}_h), but a 5.00 kph wind blowing due east (\mathbf{v}_w) also affects her copter. (a) What is the copter's resultant velocity vector? (b) How could she correct the copter's heading so that it is able to fly due north?

Write what you know.

$$\mathbf{v}_w = 5.00 \text{ km/h east} = \langle 5.00, 0 \rangle \text{ km/h}$$

$$\mathbf{v}_h = 15.00 \text{ km/h north} = \langle 0, 15.00 \rangle \text{ km/h}$$

Write the formula and solve for the unknown.

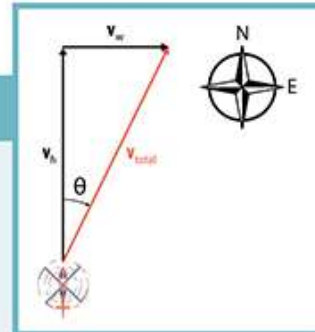
$$\mathbf{v}_{\text{total}} = \mathbf{v}_w + \mathbf{v}_h$$

Plug in known values and evaluate.

$$\begin{aligned} \text{a. } \mathbf{v}_{\text{total}} &= \langle 5.00, 0 \rangle \text{ km/h} + \langle 0, 15.00 \rangle \text{ km/h} \\ &= \langle 5.00, 15.00 \rangle \text{ km/h} \end{aligned}$$

total speed:

$$\begin{aligned} |\mathbf{v}_{\text{total}}| &= \sqrt{(\mathbf{v}_x)^2 + (\mathbf{v}_y)^2} \\ &= \sqrt{(5.00 \text{ km/h})^2 + (15.00 \text{ km/h})^2} \end{aligned}$$



$$\begin{aligned} &= \sqrt{25.0 \text{ km}^2/\text{h}^2 + 225.0 \text{ km}^2/\text{h}^2} \\ &= 15.8 \text{ km/h} \end{aligned}$$

copter's direction:

$$\begin{aligned} \theta &= \tan^{-1}\left(\frac{\mathbf{v}_x}{\mathbf{v}_y}\right) \\ &= \tan^{-1}\left(\frac{5.00 \text{ km/h}}{15.00 \text{ km/h}}\right) \\ &= 18.4^\circ \end{aligned}$$

The vector $\mathbf{v}_{\text{total}}$ is 15.8 kph at 18.4° east of north.

b. She will have to fly her copter at 15.8 kph and pointed to 18.4° to the west of north to fly due north.

Acceleration in Two Dimensions

A vector can change in any of three ways: magnitude only, direction only, or both magnitude and direction. Most real motion involves the third kind. Recall from Chapter 2 that acceleration is the rate of change of the velocity vector. The average acceleration vector ($\mathbf{\bar{a}}$) is equal to the change in velocity divided by the time interval.

$$\mathbf{\bar{a}} = \frac{\Delta \mathbf{v}}{\Delta t} = \frac{\mathbf{v}_f - \mathbf{v}_i}{\Delta t} \quad (4.1)$$

The direction of the average acceleration is always the same direction as the velocity difference vector, regardless of the direction of motion. For example, as a car slows to a stop at a traffic light, the magnitude of its final velocity is less than the magnitude of its initial velocity, so $\Delta \mathbf{v}$ points in the direction opposite the car's motion. Therefore, as the car



▲ Acceleration in two dimensions. The velocity of the ball changes as it bounces up and down and slows down while moving left to right.

slows, \vec{a} points in the opposite direction from \vec{v} . But when a moving object changes *direction*, its acceleration vector is always at an angle to its path. As with velocity, acceleration direction is indicated by a vector angle.

The instantaneous acceleration of an object is its acceleration at a particular moment. Its vector also points in the direction of the instantaneous velocity difference vector. In two-dimensional motion, determining the instantaneous change in velocity can be fairly complicated without the use of calculus. We will limit the discussion of acceleration to problems where either direction or speed vary but not both. As with one-dimensional acceleration, if the acceleration is uniform, then the average and instantaneous accelerations are the same.

Example 4-3 Determining Two-Dimensional Acceleration

A car heading due east at 90.0 kph enters a curve in the road. The curve ends with the car heading due north at 90.0 kph. Determine the car's average acceleration if the turn took 5.0 s.

Write what you know.

A diagram of the car on the curve is given at right. Note the orientation of the initial and final velocity vectors.

$$\vec{v}_i = 90.0 \text{ km/h east} = \langle 90.0, 0.0 \rangle \text{ km/h}$$

$$\vec{v}_f = 90.0 \text{ km/h north} = \langle 0.0, 90.0 \rangle \text{ km/h}$$

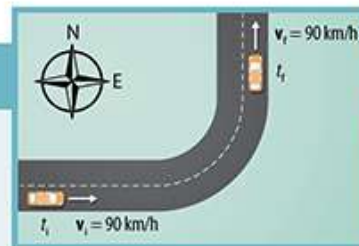
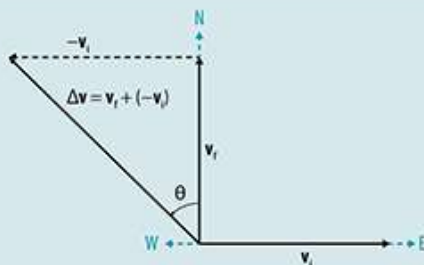
$$\Delta t = 5.0 \text{ s}$$

$$\vec{a} = ?$$

Write the formula and solve for the unknown.

$$\Delta \vec{v} = \vec{v}_f - \vec{v}_i = \vec{v}_f + (-\vec{v}_i)$$

$$\vec{a} = \frac{\Delta \vec{v}}{\Delta t}$$



Plug in known values and evaluate.

$$-\vec{v}_i = \langle -90.0, 0.0 \rangle \text{ km/h}$$

$$\Delta \vec{v} = \langle 0.0, 90.0 \rangle \text{ km/h} + \langle -90.0, 0.0 \rangle \text{ km/h} \\ = \langle -90.0, 90.0 \rangle \text{ km/h}$$

$$\Delta v = \sqrt{(\Delta v_x)^2 + (\Delta v_y)^2} \\ = \sqrt{(-90.0 \text{ km/h})^2 + (90.0 \text{ km/h})^2} \\ = 127.27 \text{ km/h}$$

Determine the direction of $\Delta \vec{v}$.

$$\theta = \tan^{-1} \left(\frac{\Delta v_x}{\Delta v_y} \right)$$

$$= \tan^{-1} \left(\frac{90.0 \text{ km/h}}{90.0 \text{ km/h}} \right)$$

$$= 45.0^\circ$$

$$\vec{a} = \frac{\Delta \vec{v}}{\Delta t} = \frac{127.27 \frac{\text{km}}{\text{h}} \left(\frac{1000 \text{ m}}{1 \text{ km}} \right) \left(\frac{1 \text{ h}}{3600 \text{ s}} \right)}{5.0 \text{ s}} \\ = 7.1 \text{ m/s}^2$$

The average acceleration of the car 7.1 m/s^2 at 45° west of north.

4.1 SECTION REVIEW

1. In physics, a location in two dimensions is most efficiently represented by what quantity?
2. Describe how displacement is calculated in two-dimensional motion. In your answer include the formula that you would use.
3. How is the direction of the average acceleration vector determined if you are given the initial and final velocities?
4. A visitor walks directly from the White House 1.83 km in the direction 20° south of east. Then he turns left and walks due east for an additional 0.67 km. He turns and walks 0.25 km due south to the US Capitol Building. What is his displacement from the White House?
5. A quarterback is attempting to run toward his goal line at 4.6 m/s. A linebacker hits him and their combined final velocity is 3.7 m/s at an angle of 120° back and to the left of the quarterback's original direction. The time to change direction was 0.20 s. Calculate the average acceleration of the quarterback during the tackle.
6. An athlete sprints a circular 400.0 m track in 50.0 s. Assume that he runs at a constant speed.
 - a. What is his speed over the entire course?
 - b. What is the magnitude of his instantaneous velocity at any point along the circuit?
 - c. If he starts facing west, what is his instantaneous velocity halfway around the circle?
 - d. What is the average acceleration for one-half lap of the track?

Use the careers box below to answer Questions 7–8.

7. Describe a challenge that a humanitarian engineer working with a remote people group might face that would not be an issue for an engineer working in an urban environment.
8. Why might a Christian consider a career as a humanitarian engineer?

careers

SERVING AS A HUMANITARIAN ENGINEER: HELPING WHERE IT IS MOST NEEDED

In 2000 engineering professor Dr. Bernard Amadei visited a Mayan village in Belize that lacked a clean water supply. In fact, the village children could not attend school because their time was devoted to collecting water from sources located miles away. After consulting with his colleagues on possible solutions, Dr. Amadei and a team of students from the University of Colorado Boulder returned to the village. The team built a new water supply system powered by energy from a nearby waterfall. Soon afterward Dr. Amadei founded Engineers Without Borders, an aid organization dedicated to providing engineered solutions to problems faced by people in need around the world.

Helping people in need can provide a great deal of personal satisfaction. Today you can get a college degree in humanitarian engineering. Engineers like the one shown at right, specialize in applying their knowledge and training to meeting the needs of people whose lives have been adversely affected by

war, poverty, or disaster. As a humanitarian engineer, you might work on a drinking water project like the one in Belize, or perhaps you'll find ways to use diminishing natural resources more efficiently and sustainably. One key to providing workable long-term solutions to such problems is to find answers that are affordable, self-sustaining, and designed to make good use of local resources—including the skills and labor of local people. If you enjoy physics, like to find answers to real-life problems, and have a heart to serve others, humanitarian engineering may be the right career path for you.

