Chapter 1

Getting Started with Physics

In This Chapter

- Laying down measurements
- Simplifying with scientific notation
- Practicing conversions
- Drawing on algebra and trigonometry

This chapter gets the ball rolling by discussing some fundamental physics measurements. At its root, physics is all about making measurements (and using those measurements as the basis of predictions), so it's the perfect place to start! I also walk you through the process of converting measurements from one unit to another, and I show you how to apply math skills to physics problems.

Measuring the Universe

A great deal of physics has to do with making measurements — that's the way all physics gets started. For that reason, physics uses a number of measurement systems, such as the CGS (centiment-gram-second) system and the MKS (meter-kilogram-second) system. You also use the standard English system of inches and feet and so on — that's the FPI (foot-pound-inch) system.

REMEMBER

In physics, all measurements (except for some angles) have units, such as meters or seconds. For example, when you measure how far a hockey puck slid, you need to measure both the distance in centimeters and the time in seconds.

For reference, Table 1-1 shows the primary units of measurement (and their abbreviations) in the CGS system. (Don't bother memorizing the ones you're not familiar with now; you can come back to them later as needed.)

Table 1-1 CGS Units of Measurement

Measurement	*Unit*	*Abbreviation*
Length	centimeter	cm
Mass	gram	g
Time	second	s
Force	dyne	dyne

(continued)

Table 1-1 *(continued)*

Measurement	***Unit***	***Abbreviation***
Energy	erg	erg
Pressure	barye	ba
Electric current	biot	Bi
Magnetism	gauss	G
Electric charge	franklin	Fr

These are the measuring sticks that will become familiar to you as you solve problems and triumph over the math in this workbook. Also for reference, Table 1-2 gives you the primary units of measurement in the MKS system.

Table 1-2 MKS Units of Measurement

Measurement	***Unit***	***Abbreviation***
Length	meter	m
Mass	kilogram	kg
Time	second	s
Force	Newton	N
Energy	Joule	J
Pressure	Pascal	P
Electric current	Ampere	A
Magnetism	Tesla	T
Electric charge	Coulomb	C

Q. You're told to measure the length of a race-car track using the MKS system. What unit(s) will your measurement be in?

A. The correct answer is meters. The unit of length in the MKS system is the meter.

1. You're told to measure the mass of a marble using the CGS system. What unit(s) will your measurement be in?

Solve It

2. You're asked to measure the time it takes the moon to circle the Earth using the MKS system. What will your measurement's units be?

Solve It

3. You need to measure the force a tire exerts on the road as it's moving using the MKS system. What are the units of your answer?

Solve It

4. You're asked to measure the amount of energy released by a firecracker when it explodes using the CGS system. What are the units of your answer?

Solve It

Putting Scientific Notation to Work

Physics deals with some very large and very small numbers. To work with such numbers, you use *scientific notation.* Scientific notation is expressed as a number multiplied by a power of 10.

For example, suppose you're measuring the mass of an electron in the MKS system. You put an electron on a scale (in practice, electrons are too small to measure on a scale — you have to see how they react to the pull of magnetic or electrostatic forces in order to measure their mass) and you measure the following:

0.00000000000000000000000000000091 kg

What the heck is that? That's a lot of zeros, and it makes this number very unwieldy to work with. Fortunately, you know all about scientific notation, so you can convert the number into the following:

9.1×10^{-31} kg

That is, 9.1 multiplied by a power of 10, 10^{-31}. Scientific notation works by extracting the power of 10 and putting it on the side, where it's handy. You convert a number to scientific notation by counting the number of places you have to move the decimal point to get the first digit in front of that decimal point. For example, 0.050 is 5.0×10^{-2} because you move the decimal point two places to the right to get 5.0. Similarly, 500 is 5.0×10^{2} because you move the decimal point two places to the left to get 5.0.

Check out this practice question about scientific notation:

Q. What is 0.000037 in scientific notation?

A. The correct answer is 3.7×10^{-5}. You have to move the decimal point five times to the right to get 3.7.

5. What is 0.0043 in scientific notation?

Solve It

6. What is 430000.0 in scientific notation?

Solve It

7. What is 0.00000056 in scientific notation?

Solve It

8. What is 6700.0 in scientific notation?

Solve It

Converting between Units

Physics problems frequently ask you to convert between different units of measurement. For example, you may measure the number of feet your toy car goes in three minutes and thus be able to calculate the speed of the car in feet per minute, but that's not a standard unit of measure, so you need to convert feet per minute to miles per hour, or meters per second, or whatever the physics problem asks for.

For another example, suppose you have 180 seconds — how much is that in minutes? You know that there are 60 seconds in a minute, so 180 seconds equals three minutes. Here are some common conversions between units:

- 1 m = 100 cm = 1000 mm (millimeters)
- 1 km (kilometer) = 1000 m
- 1 kg (kilogram) = 1000 g (grams)
- 1 N (Newton) = 10^5 dynes
- 1 J (Joule) = 10^7 ergs
- 1 P (Pascal) = 10 ba
- 1 A (Amp) = .1 Bi
- 1 T (Tesla) = 10^4 G (Gauss)
- 1 C (Coulomb) = 2.9979×10^9 Fr

The conversion between CGS and MKS is almost always just a factor of 10, so converting between the two is simple. But what about converting to and from the FPI system? Here are some handy conversions that you can come back to as needed:

- **Length:**
  - 1 m = 100 cm
  - 1 km = 1000 m
  - 1 in (inch) = 2.54 cm
  - 1 m = 39.37 in
  - 1 mile = 5280 ft = 1.609 km
  - 1 Å (angstrom) = 10^{-10} m
- **Mass:**
  - 1 kg = 1000 g
  - 1 slug = 14.59 kg
  - 1 u (atomic mass unit) = 1.6605×10^{-27} kg
- **Force:**
  - 1 lb (pound) = 4.448 N
  - 1 N = 10^5 dynes
  - 1 N = 0.2248 lb
- **Energy:**
  - 1 J = 10^7 ergs
  - 1 J = 0.7376 ft-lb

- 1 BTU (British Thermal Unit) = 1055 J
- 1 kWh (kilowatt hour)= 3.600×10^{6} J
- 1 eV (electron Volt) = 1.602×10^{-19} J

- **Power:**
  - 1 hp (horsepower) = 550 ft-lb/s
  - 1 W (Watt)= 0.7376 ft-lb/s

Because conversions are such an important part of physics problems, and because you have to keep track of them so carefully, there's a systematic way of handling conversions: You multiply by a conversion constant that equals one, and where the units you don't want cancel out.

EXAMPLE

Q. A ball drops 5 meters. How many centimeters did it drop?

A. The correct answer is 500 centimeters. To perform the conversion, you do the following calculation:

$$5.0\ \cancel{\text{meters}} \times \frac{100\ \text{centimeters}}{\cancel{\text{meters}}} = 500\ \text{centimeters}$$

Note that 100 centimeters divided by 1 meter equals 1 because there are 100 centimeters in a meter. In the calculation, the units you don't want — meters — cancel out.

9. How many centimeters are in 2.35 meters?

Solve It

10. How many seconds are in 1.25 minutes?

Solve It

11. How many inches are in 2.0 meters?

Solve It

12. How many grams are in 3.25 kg?

Solve It

Converting Distances

Sometimes you have to make multiple conversions to get what you want. That demands multiple conversion factors. For example, if you want to convert from inches to meters, you can use the conversion that 2.54 centimeters equals 1 inch — but then you have to convert from centimeters to meters, which means using another conversion factor.

Try your hand at this example question that involves multiple conversions:

Q. Convert 10 inches into meters.

A. The correct answer is 0.245 m.

1. You know that 1 inch = 2.54 centimeters, so start with that conversion factor and convert 10 inches into centimeters:

$$10\ \cancel{\text{in}} \times \frac{2.54 \times \text{cm}}{1\ \cancel{\text{in}}} = 25.4\ \text{cm}$$

2. Convert 25.4 cm into meters by using a second conversion factor:

$$10\ \cancel{\text{in}} \times \frac{2.54\ \text{cm}}{1\ \cancel{\text{in}}} \times \frac{1\ \text{m}}{100\ \text{cm}} = 0.254\ \text{m}$$

13. Given that there are 2.54 centimeters in 1 inch, how many centimeters are there in 1 yard?

Solve It

14. How many centimeters are in a kilometer?

Solve It

15. How many inches are in an angstrom, given that 1 angstrom (Å) = 10^{-8} cm?

Solve It

16. How many inches are in a meter, given that there are 2.54 cm in 1 inch?

Solve It

Converting Times

Physics problems frequently ask you to convert between different units of time: seconds, minutes, hours, and even years. These times involve all kinds of calculations because measurements in physics books are usually in seconds, but can frequently be in hours.

Q. An SUV is traveling 2.78×10^{-2} kilometers per second. What's that in kilometers per hour?

A. The correct answer is 100 km/hr.

1. You know that there are 60 minutes in an hour, so start by converting from kilometers per second to kilometers per minute:

$$2.78 \times 10^{-2}\ \frac{\text{km}}{\cancel{\text{sec}}} \times \frac{60\ \cancel{\text{sec}}}{1\ \text{minute}} = 1.66\ \text{km/minute}$$

2. Because there are 60 minutes in an hour, convert this to kilometers per hour using a second conversion factor:

$$2.78 \times 10^{-2}\ \frac{\text{km}}{\cancel{\text{sec}}} \times \frac{60\ \cancel{\text{sec}}}{1\ \cancel{\text{minute}}} \times \frac{60\ \cancel{\text{minutes}}}{1\ \text{hour}} = 100\ \text{km/hr}$$

17. How many hours are in 1 week?

Solve It

18. How many hours are in 1 year?

Solve It

Counting Significant Figures

You may plug numbers into your calculator and come up with an answer like 1.532984529045, but that number isn't likely to please your instructor. Why? Because in physics problems, you use significant digits to express your answers. *Significant digits* represent the accuracy with which you know your values.

For example, if you know only the values you're working with to two significant digits, your answer should be 1.5, which has two significant digits, not 1.532984529045, which has 13! Here's how it works: Suppose you're told that a skater traveled 10.0 meters in 7.0 seconds. Note the number of digits: The first value has three significant figures, the other only two. The rule is that when you multiply or divide numbers, the result has the number of significant digits that equals the smallest number of significant digits in any of the original numbers. So if you want to figure out how fast the skater was going, you divide 10.0 by 7.0, and the result should have only two significant digits — 1.4 meters per second.

Zeros used just to fill out values down to (or up to) the decimal point aren't considered significant. For example, the number 3600 has only two significant digits by default. That's not true if the value was actually measured to be 3600, of course, in which case it's usually expressed as 3600.; the final decimal indicates that all the digits are significant.

On the other hand, when you're adding or subtracting numbers, the rule is that the last significant digit in the result corresponds to the right-most column in the addition or subtraction. How does that work? Take a look at this addition example:

$$\begin{array}{r} 5.1 \\ +12 \\ +\ \ 7.73 \\ \hline 24.83 \end{array}$$

So is the result 24.83? No, it's not. The 12 has no significant digits to the right of the decimal point, so the answer shouldn't have any either. That means you should round the value of the result up to 25.

Rounding numbers in physics works as it usually does in math: When you want to round to three places, for example, and the number in the fourth place is a five or greater, you add one to the third place (and ignore or replace with zeros any following digits).

Q. You're multiplying 12.01 by 9.7. What should your answer be, keeping in mind that you should express it in significant digits?

A. The correct answer is **120.**

1. The calculator says that the product is 116.497.
2. Your result has to have the same number of significant digits as the least number of any two values you multiplied. That's two here (because of 9.7), so your answer rounds up to 120.

19. What is 19.3 multiplied by 26.12, taking into account significant digits?

Solve It

20. What is the sum of 7.9, 19, and 5.654, taking into account significant digits?

Solve It

Coming Prepared with Some Algebra

It's a fact of life: You need to be able to do algebra to handle physics problems. Take the following equation, for example, which relates the distance something has traveled (s) to its acceleration and the time it has been accelerated:

$$s = \frac{1}{2}at^2$$

Now suppose that the physics problem actually asks you for the acceleration, not the distance. You have to rearrange things a little here to solve for the acceleration. So when you multiply both sides by 2 and divide both sides by t^2, here's what you get:

$$\frac{2}{t^2} \cdot s = \frac{2}{t^2} \cdot \frac{1}{2} \cdot a \cdot t^2$$

Cancelling out and swapping sides, you solve for a like this:

$$a = \frac{2 \cdot s}{t^2}$$

So that's putting a little algebra to work. All you had to do was move variables around the equation to get what you want. The same approach works when solving physics problems (most of the time). On the other hand, what if you had to solve the same problem for the time, t? You would do that by rearranging the variables like so:

$$t = \sqrt{2s/a}$$

The lesson in this example is that you can extract all three variables — distance, acceleration, and time — from the original equation. Should you memorize all three versions of this equation? Of course not. You can just memorize the first version and use a little algebra to get the rest.

The following practice questions call on your algebra skills:

EXAMPLE

Q. The equation for final speed, v_f, where the initial speed was v_o, the acceleration was a, and the time was t is $v_f - v_o = at$. Solve for acceleration.

A. The correct answer is $a = \left(v_f - v_o\right)/t$

To solve for a, divide both sides of the equation by time, t.

21. The equation for potential energy, PE, of a mass m at height h, where the acceleration due to gravity is g, is $PE = m \cdot g \cdot h$. Solve for h.

Solve It

22. The equation relating final speed, v_f, to original speed, v_o, in terms of acceleration a and distance s is $v_f^2 - v_o^2 = 2as$. Solve for s.

Solve It

Physics problems require you to be able to work with sines, cosines, and tangents. Here's what they look like for Figure 1-1:

$\sin\theta = y/h$

$\cos\theta = x/h$

$\tan\theta = y/x$

You can find the length of one side of the triangle if you're given another side and an angle (not including the right angle). Here's how to relate the sides:

$x = h \cdot \cos\theta = y/\tan\theta$

$y = h \cdot \sin\theta = x \tan\theta$

$h = y/\sin\theta = h/\cos\theta$

And here's one more equation, the Pythagorean Theorem. It gives you the length of the hypotenuse when you plug in the other two sides:

$$h = \sqrt{x^2 + y^2}$$

25. Given the hypotenuse h and the angle θ, what is the length x equal to?

Solve It

26. If x = 3 and y = 4, what is the length of h?

Solve It

Answers to Problems about Getting Started with Physics

The following are the answers to the practice questions presented earlier in this chapter. You see how to work out each answer, step by step.

1 **grams**

The unit of mass in the CGS system is the gram.

2 **seconds**

The unit of time in the MKS system is the second.

3 **Newtons**

The unit of force in the MKS system is the Newton.

4 **ergs**

The unit of energy in the CGS system is the erg.

5 **4.3×10^{-3}**

You have to move the decimal point three places to the right.

6 **4.3×10^{5}**

You have to move the decimal point five places to the left.

7 **5.6×10^{-7}**

You have to move the decimal point seven places to the right.

8 **6.7×10^{3}**

You have to move the decimal point three places to the left.

9 **235 cm**

Convert 2.35 meters into centimeters:

$$2.35\ \cancel{m} \times \frac{100\ \text{cm}}{1\ \cancel{m}} = 235\ \text{cm}$$

10 **75 sec**

Convert 1.25 minutes into seconds:

$$1.25\ \cancel{\text{min}} \times \frac{60\ \text{sec}}{1\ \cancel{\text{min}}} = 75\ \text{sec}$$

11 **78.6 in**

Convert 2.0 meters into inches:

$$2.0\ \cancel{m} \times \frac{39.3\ \text{in}}{1\ \cancel{m}} = 78.6\ \text{in}$$

12 **3250 g**

Convert 3.25 kilograms into grams:

$$3.25\ \cancel{\text{kg}} \times \frac{1000\ \text{g}}{1\ \cancel{\text{kg}}} = 3250\ \text{g}$$

13 **91.4 cm**

1. 1 yard is 3 feet, so convert that to inches:

$$3\ \cancel{ft} \times \frac{12\ \text{in}}{1\ \cancel{ft}} = 36\ \text{in}$$

2. Use a second conversion factor to convert that into centimeters:

$$3\ \cancel{ft} \times \frac{12\ \cancel{in}}{1\ \cancel{ft}} \times \frac{2.54\ \text{cm}}{1\ \cancel{in}} = 91.4\ \text{cm}$$

14 **1.0 × 10^{-5} km**

1. Convert 1 centimeter to meters:

$$1\ \cancel{cm} \times \frac{1\ \text{m}}{100\ \cancel{cm}} = 1.0 \times 10^{-2}\ \text{m}$$

2. Use a second conversion factor to convert that into kilometers:

$$1\ \cancel{cm} \times \frac{1\ \cancel{m}}{100\ \cancel{cm}} \times \frac{1\ \text{km}}{1000\ \cancel{m}} = 1.0 \times 10^{-5}\ \text{km}$$

15 **4.0 × 10^{-9} in**

1. Convert 1 angstrom to centimeters:

$$1\ \cancel{\text{Å}} \times \frac{10^{-8}\ \text{cm}}{1\ \cancel{\text{Å}}} = 10^{-8}\ \text{cm}$$

2. Use a second conversion factor to convert that into inches:

$$1\ \cancel{\text{Å}} \times \frac{10^{-8}\ \cancel{cm}}{1\ \cancel{\text{Å}}} \times \frac{1.0\ \text{in}}{2.54\ \cancel{cm}} = 4.0 \times 10^{-9}\ \text{in}$$

16 **39.3 in**

1. Convert 1 meter into centimeters:

$$1\ \cancel{m} \times \frac{100\ \text{cm}}{1\ \cancel{m}} = 100\ \text{cm}$$

2. Use a second conversion factor to convert that into inches:

$$1\ \cancel{m} \times \frac{100\ \cancel{cm}}{1\ \cancel{m}} \times \frac{1\ \text{in}}{2.54\ \cancel{cm}} = 39.3\ \text{in}$$

17 **168 hours**

1. Convert 1 week into days:

$$1\ \cancel{\text{week}} \times \frac{7\ \text{days}}{1\ \cancel{\text{week}}} = 7\ \text{days}$$

2. Use a second conversion factor to convert that into hours:

$$1\ \cancel{\text{week}} \times \frac{7\ \cancel{\text{days}}}{1\ \cancel{\text{week}}} \times \frac{24\ \text{hours}}{1\ \cancel{\text{day}}} = 168\ \text{hours}$$

18 **8760 hours**

1. Convert 1 year into days:

$$1\ \cancel{\text{year}} \times \frac{365\ \text{days}}{1\ \cancel{\text{year}}} = 365\ \text{days}$$

2. Use a second conversion factor to convert that into hours:

$$1\ \cancel{\text{year}} \times \frac{365\ \cancel{\text{days}}}{1\ \cancel{\text{year}}} \times \frac{24\ \text{hours}}{1\ \cancel{\text{day}}} = 8760\ \text{hours}$$

19 **504**

1. The calculator says the product is 504.116.
2. 19.3 has three significant digits, and 26.12 has four, so you use three significant digits in your answer. That makes the answer 504.

20 **33**

1. Here's how you do the sum:

$$\begin{array}{r} 7.9 \\ +19 \\ +\ 5.654 \\ \hline 32.554 \end{array}$$

2. The value 19 has no significant digits after the decimal place, so the answer shouldn't either, making it 33 (32.554 rounded up).

21 **h = PE/mg**

Divide both sides by mg to get your answer.

22 $\mathbf{\frac{v_f^2 - v_o^2}{2a} = s}$

Divide both sides by 2a to get your answer.

23 $\mathbf{\frac{s}{t} - \frac{1}{2}at = v}$

1. Subtract $at^2/2$ from both sides:

$$s - \frac{1}{2}at^2 = vt$$

2. Divide both sides by t to get your answer.

24 $\mathbf{v = \sqrt{\frac{2KE}{m}}}$

1. Multiply both sides by 2/m:

$$\frac{2}{m}KE = v^2$$

2. Take the square root to get your answer.

25 **x = h cos θ**

Your answer comes from the definition of cosine.

26 **5**

1. Start with the Pythagorean theorem:

$$h = \sqrt{x^2 + y^2}$$

2. Plug in the numbers, and work out the answer:

$$h = \sqrt{3^2 + 4^2} = 5$$

Chapter 2

The Big Three: Acceleration, Distance, and Time

In This Chapter

- Thinking about displacement
- Checking out speed
- Remembering acceleration

Being able to connect displacement, speed, and acceleration is fundamental to working with physics. These things concern people every day, and physics has made an organized study of them.

Problems that connect displacement, speed, and acceleration are all about understanding movement, and that's the topic of this chapter — putting numbers into the discussion. You'll often find physics problems about cars starting and stopping, horses racing, and rocket ships zooming back and forth. And after you finish this chapter, you'll be a real pro at solving them.

From Point A to B: Displacement

Displacement occurs when something moves from here to there. For example, suppose that you have a ball at the zero position, as in Figure 2-1A.

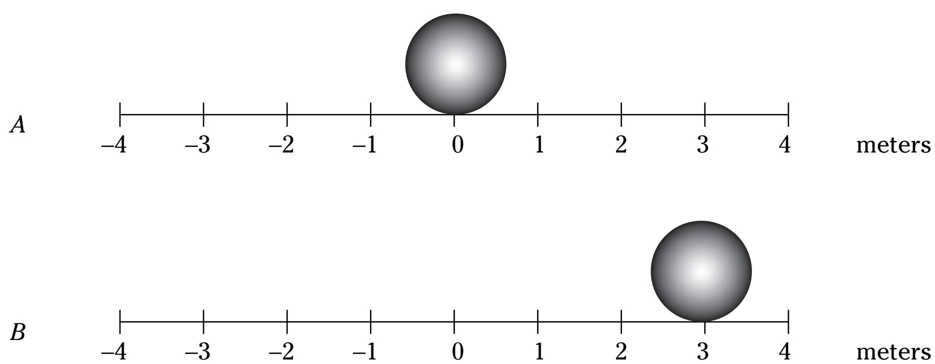

Figure 2-1: A moving ball.

Now suppose that the ball rolls over to a new point, 3 meters to the right, as you see in Figure 2-1B. The ball is at a new location, so there's been displacement. In this case, the displacement is just 3 meters to the right. In physics terms, you'll often see displacement referred to as the variable s. In this case, s = +3 meters.

Like any other measurement in physics, displacement is always expressed in units, usually centimeters or meters, as in this example. Of course, you also can use kilometers, inches, feet, miles, or even *light years* (the distance light travels in one year — 5,865,696,000,000 miles).

The following example question focuses on displacement.

EXAMPLE

Q. You've taken the pioneers' advice to "Go West." You started in New York City and went west 10 miles the first day, 14 miles the next day, and then back east 9 miles on the third day. What is your displacement from New York City after three days?

A. s = 15 miles west of New York City

1. You first went west 10 miles, so at the end of the first day, your displacement was 10 miles west.
2. Next, you went west 14 days, putting your displacement at $10 + 14$ miles = 24 miles west of New York City.
3. Finally, you traveled 9 miles east, leaving you at $24 - 9 = 15$ miles west of New York City. So s = 15 miles west of New York City.

1. Suppose that the ball in Figure 2-1 now moves 1 meter to the right. What is its new displacement from the origin, 0?

Solve It

2. Suppose that the ball in Figure 2-1, which started 4 meters to the right of the origin, moves 6 meters to the left. What is its new displacement from the origin — in inches?

Solve It

Reading That Speedometer

In physics terms, what is speed? It's the same as the conventional idea of speed: *Speed* is displacement divided by time.

For example, if you went a displacement *s* in a time *t*, then your speed, *v*, is determined as follows:

$$v = \frac{s}{t}$$

Technically speaking, speed is the change in position divided by the change in time, so you also can represent it like this if, for example, you're moving along the x axis:

$$v = \frac{\Delta x}{\Delta t} = \frac{x_f - x_o}{t_f - t_o}$$

Q. Suppose that you want to drive from New York City to Los Angeles to visit your uncle's family, a distance of about 2781 miles. The trip takes you four days. What was your speed in miles per hour?

A. $v = \frac{\Delta x}{\Delta t} = \frac{x_f - x_o}{t_f - t_o} = 28.97$ miles per hour

1. Start by figuring out your speed (the distance traveled divided by the time taken to travel that distance):

$$\frac{2781\text{ miles}}{4\text{ days}} = 695.25$$

2. Okay, the speed is 695.25, but 695.25 *what?* This solution divides miles by days, so it's 695.25 miles per day — not exactly a standard unit of measurement. So what is that in miles per hour? To determine that, you cancel "days" out of this equation and put in "hours." Because 24 hours are in a day, you can multiply as follows (note that "days" cancel out, leaving miles over hours, or miles per hour):

$$\frac{2781\text{ miles}}{4\ \cancel{\text{days}}} \times \frac{1\ \cancel{\text{day}}}{24\text{ hours}} = 28.97\text{ miles per hour}$$

So your speed was 28.97 miles per hour. That's your average speed, averaged over both day and night.

3. Suppose that you used your new SpeedPass to get you through the tollbooths at both ends of your trip, which was 90 miles on the turnpike and took you 1 hour and 15 minutes. On your return home, you're surprised to find a traffic ticket for speeding in the mail. How fast did you go, on average, between the tollbooths? Was the turnpike authority justified in sending you a ticket, given that the speed limit was 65 mph?

Solve It

4. Suppose that you and a friend are determined to find out whose car is faster. You both start your trips in Chicago. Driving nonstop, you reach Los Angeles — a distance of 2018 miles — in 1.29 days, and your friend, also driving nonstop, reaches Miami — a distance of 1380 miles — in 0.89 days. Whose car was faster?

Solve It

Putting Pedal to Metal: Acceleration

In physics terms, *acceleration* is the amount by which your speed changes in a given amount of time. In terms of equations, it works like this:

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

Given initial and final velocities, v_o and v_f, and initial and final times over which your speed changed, t_o and t_f, you can also write the equation like this:

$$a = \frac{\Delta v}{\Delta t} = \frac{v_f - v_o}{t_f - t_o}$$

To get the units of acceleration, you divide speed by time as follows:

$$a = \frac{v_f - v_o}{t_f - t_o} = \frac{\text{distance/time}}{\text{time}} = \frac{\text{distance}}{\text{time}^2}$$

Distance over time squared? Don't let that throw you. You end up with time squared in the denominator just because it's velocity divided by time — that's something you get used to when solving physics problems. In other words, acceleration is the *rate* at which your speed changes because rates have time in the denominator.

So for acceleration, you can expect to see units of meters per second^2, or centimeters per second^2, or miles per second^2, or feet per second^2, or even kilometers per hour^2.

Q. Suppose that you're driving at 75 miles an hour and suddenly see red flashing lights in the rearview mirror. "Great," you think, and you pull over, taking 20 seconds to come to a stop. You could calculate how quickly you decelerated as you were pulled over (information about your law-abiding tendencies that, no doubt, would impress the officer). So just how fast did you decelerate, in cm/sec^2?

A. $a = \frac{\Delta v}{\Delta t} = \frac{3350\ \text{cm/sec}}{20\ \text{seconds}} = 168\ \text{cm/sec}^2$

1. First convert to miles per second:

$$\frac{75\ \text{miles}}{\cancel{\text{hour}}} \times \frac{1\ \cancel{\text{hour}}}{60\ \cancel{\text{minutes}}} \times \frac{1\ \cancel{\text{minute}}}{60\ \text{seconds}} = .0208 = 2.08 \times 10^{-2}\ \text{miles per second}$$

2. Convert from miles per second to inches per second:

$$\frac{2.08 \times 10^{-2}\ \cancel{\text{miles}}}{\text{second}} \times \frac{5280\ \cancel{\text{feet}}}{1\ \cancel{\text{mile}}} \times \frac{12\ \text{inches}}{1\ \cancel{\text{foot}}} = \frac{1318\ \text{in}}{\text{second}}$$

3. Your speed was 1318 inches per second. What's that in centimeters per second?

$$\frac{2.08 \times 10^{-2}\ \cancel{\text{miles}}}{\text{second}} \times \frac{5280\ \cancel{\text{feet}}}{1\ \cancel{\text{mile}}} \times \frac{12\ \cancel{\text{inches}}}{1\ \cancel{\text{foot}}} \times \frac{2.54\ \text{centimeters}}{\cancel{\text{inch}}} = \frac{3350\ \text{cm}}{\text{second}}$$

4. What was your acceleration? That calculation looks like this:

$$a = \frac{\Delta v}{\Delta t} = \frac{v_f - v_o}{t_f - t_o} = \frac{0 - 3350\ \text{cm/second}}{20\ \text{seconds}} = -168\ \text{cm/sec}^2$$

In other words, –168 cm/sec^2, *not* +168 cm/sec^2. There's a big difference between positive and negative in terms of solving physics problems — and in terms of law enforcement. If you accelerated at +168 cm/sec^2 instead of accelerating at –168 cm/sec^2, you'd end up going 150 miles per hour at the end of 20 seconds, not 0 miles per hour.

In other words, the *sign* of the acceleration tells you *how* the speed is changing. A positive acceleration means that the speed is increasing in the positive direction, and a negative acceleration (also known as *deceleration*) tells you that the speed is increasing in the negative direction.

5. A rocket ship is going to land on the moon in exactly 2 hours. There's only one problem: It's going 17,000 miles an hour. What does its deceleration need to be, in miles per second^2, in order to land on the moon safely at 0 miles per hour?

Solve It

6. You're stopped at a red light when you see a monster SUV careening toward you. In a lightning calculation, you determine you have 0.8 seconds before it hits you and that you must be going at least 1.0 miles an hour forward at that time to avoid the SUV. What must your acceleration be, in miles per hour^2? Can you avoid the SUV?

Solve It

7. A bullet comes to rest in a block of wood in 1.0×10^{-2} seconds, with an acceleration of -8.0×10^4 meters per second^2. What was its original speed, in meters per second?

Solve It

8. The light turns red, and you come to a screeching halt. Checking your stopwatch, you see that you stopped in 4.5 seconds. Your deceleration was 1.23×10^{-3} miles per second^2. What was your original speed in miles per hour?

Solve It

Connecting Acceleration, Time, and Displacement

You know that you can relate speed with displacement and time. And you know that you can relate speed and time to get acceleration. You also can relate displacement with acceleration and time:

$$s = \frac{1}{2}a\left(t_f - t_o\right)^2$$

If you don't start off at zero speed, you use this equation:

$$s = v_o\left(t_f - t_o\right) + \frac{1}{2}a\left(t_f - t_o\right)^2$$

Q. You climb into your drag racer, waving nonchalantly at the cheering crowd. You look down the quarter-mile track, and suddenly the flag goes down. You're off, getting a tremendous kick from behind as the car accelerates quickly. A brief 5.5 seconds later, you pass the end of the course and pop the chute.

You know the distance you went: 0.25 miles, or about 402 meters. And you know the time it took: 5.5 seconds. So just how hard was the kick you got — the acceleration — when you blasted down the track?

A. 26.6 meters/second^2

1. You know that

$$s = \frac{1}{2}a\ t^2$$

You can rearrange this equation with a little algebra (just divide both sides by t^2 and multiply by 2) to get

$$a = \frac{2s}{t^2}$$

2. Plugging in the numbers, you get

$$a = \frac{2s}{t^2} = \frac{2\ (402\ \text{meters})}{(5.5\ \text{seconds})^2} = 26.6\ \text{meters/second}^2$$

What's 26.6 meters/second^2 in more understandable terms? The acceleration due to gravity, *g,* is 9.8 meters/second^2, so this is about 2.7 g. And that's quite a kick.

9. The light turns green, and you accelerate at 10 meters per second^2. After 5 seconds, how far have you traveled?

Solve It

10. A stone drops under the influence of gravity, 9.8 meters per second^2. How far does it drop in 12 seconds?

Solve It

11. A car is going 60 miles per hour and accelerating at 10 miles per hour^2. How far does it go in 1 hour?

Solve It

12. A motorcycle is going 60 miles per hour, and decelerating at 60 miles per hour^2. How far does it go in 1 hour?

Solve It

13. An eagle starts at a speed of 50 meters per second and, decelerating at 10 meters per second^2, comes to rest on a peak 5 seconds later. How far is the peak from the eagle's original position?

Solve It

14. A trailer breaks loose from its truck on a steep incline. If the truck was moving uphill at 20 meters per second when the trailer broke loose, and the trailer accelerates down the hill at 10.0 meters per second^2, how far downhill does the trailer go after 10 seconds?

Solve It

15. A block of wood is shooting down a track at 10 meters per second and is slowing down because of friction. If it comes to rest in 20 seconds and 100 meters, what is its deceleration, in meters per second^2?

Solve It

16. A minivan puts on the brakes and comes to a stop in 12 seconds. If it took 200 meters to stop, and decelerates at 10 meters per second^2, how fast was it originally going, in meters per second?

Solve It

Connecting Speed, Acceleration, and Displacement

Suppose you have a drag racer whose acceleration is 26.6 meters/second^2, and its final speed was 146.3 meters per second. What is the total distance traveled?

This scenario sets you up to use one of the important equations of motion:

$$v_f^2 - v_o^2 = 2as = 2a\,(x_f - x_o)$$

This is the equation you use to relate speed, acceleration, and distance.

Q. A drag racer's acceleration is 26.6 meters/second^2, and at the end of the race, its final speed is 146.3 meters per second. What is the total distance the drag racer traveled?

A. $s = \frac{1}{2a} v_f^2 = \frac{1}{2(26.6)} \quad (146.3)^2 = 409$ meters

1. To solve this problem, you need to relate speed, acceleration, and distance, so you start with this equation:

$$v_f^2 - v_o^2 = 2as = 2a\,(x_f - x_o)$$

2. In this scenario, v_o is 0, which makes this equation simpler:

$$v_f^2 = 2as$$

3. Solve for s:

$$s = \frac{1}{2a} v_f^2$$

4. Plug in the numbers:

$$s = \frac{1}{2a} v_f^2 = \frac{1}{2(26.6)} \quad (146.3)^2 = 409 \text{ meters}$$

So the answer is 409 meters, about a quarter of a mile — standard for a drag racing track.

17. A bullet is accelerated over a meter-long rifle barrel at an acceleration of 400,000 meters per second^2. What is its final speed?

Solve It

18. A car starts from rest and is accelerated at 5.0 meters per second^2. What is its speed 500 meters later?

Solve It

19. A rocket is launched at an acceleration of 100 meters per second^2. After 100 kilometers, what is its speed in meters per second?

Solve It

20. A motorcycle is going 40 meters per second and is accelerated at 6 meters per second^2. What is its speed after 200 meters?

Solve It

Answers to Problems about Acceleration, Distance, and Time

The following are the answers to the practice questions presented earlier in this chapter. You see how to work out each answer, step by step.

1 **s = 4 meters**

The ball was originally at +3 meters and moved 1 meter to the right. +3 + 1 = 4 meters.

2 **s = –78.6 inches**

1. The ball started at 4 meters and moved 6 meters to the left, putting it at +4.0 – 6.0 = –2.0 meters with respect to the origin.
2. Convert –2.0 meters into inches:

$$-2.0\ \cancel{\text{meters}} \times \frac{39.3\text{ inches}}{1\ \cancel{\text{meter}}} = -78.6\text{ inches}$$

3 **v = 72 miles an hour. The ticket was justified.**

1. It took you one hour and fifteen minutes, or 1.25 hours, to travel 90 miles.
2. Divide 90 miles by 1.25 hours:

$$\frac{90\text{ miles}}{1.25\text{ hours}} = 72\text{ miles/hour}$$

4 **Your speed = 1564 miles per day; your friend's speed = 1550 miles per day. You're faster.**

1. Note that to simply compare speeds, there's no need to convert to miles per hour — miles per day will do fine. First, calculate your speed:

$$\frac{2018\text{ miles}}{1.29\text{ days}} = 1564\text{ miles/day}$$

2. Next, calculate your friend's speed:

$$\frac{1380\text{ miles}}{0.89\text{ days}} = 1550\text{ miles/day}$$

So you were faster than your friend and probably more tired at the end of your trip.

5 **6.6 x 10^{-4} miles per second^2**

1. Start by converting 17,000 miles per hour into miles per second:

$$\frac{17{,}000\text{ miles}}{\cancel{\text{hour}}} \times \frac{1\ \cancel{\text{hour}}}{60\text{ minutes}} \times \frac{1\ \cancel{\text{minute}}}{60\text{ seconds}} = \mathbf{4.72\text{ miles per second}}$$

2. To land on the moon, v_f must be 0 miles per second, and $t_f - t_o$ = 2 hours, or 2 × 3600 seconds = 7200 seconds, so:

$$a = \frac{\Delta v}{\Delta t} = \frac{v_f - v_o}{t_f - t_o} = \frac{4.72 - 0}{7200 - 0}$$

3. Calculating this yields

$$a = \frac{\Delta v}{\Delta t} = \frac{v_f - v_o}{t_f - t_o} = \frac{4.72 - 0}{7200 - 0} = 0.00066 = 6.6 \times 10^{-4}\text{ miles per second}^2$$

So the rocket needs a constant deceleration of 6.6×10^{-4} miles per second^2 in order to land on the moon at a speed of 0 miles per second, touching down lightly.

6 **4.5×10^3 miles per hour^2**

You will avoid the collision.

1. Start by converting 0.8 seconds into hours in order to get all the quantities in units you want, miles and hours:

$$0.8\ \cancel{\text{seconds}} \times \frac{1\ \cancel{\text{minute}}}{60\ \cancel{\text{seconds}}} \times \frac{1\ \cancel{\text{hour}}}{60\ \cancel{\text{minutes}}} = 2.22 \times 10^{-4}\ \text{hours}$$

2. Calculate the acceleration needed to get you to 1.0 miles per hour:

$$a = \frac{\Delta v}{\Delta t} = \frac{v_f - v_o}{t_f - t_o} = \frac{1.0 - 0}{2.22 \times 10^{-4}} = 4.5 \times 10^3\ \text{miles per hour}^2$$

That's about 0.05g, which is possible for any car. You'll avoid the SUV.

7 **$\Delta v = a\ (\Delta t) = 800$ meters per second**

1. You can calculate the change in speed, because it is acceleration multiplied by time:

$$\Delta v = a\ (\Delta t) = -8.0 \times 10^4 \times 1.0 \times 10^{-2} = -800 \text{ meters per second}$$

2. So if the bullet lost 800 meters per second of speed to come to a rest ($v = 0$), it must have been going 800 meters per second originally.

8 **$\Delta v = a\ (\Delta t) = 20$ miles per hour**

1. The change in speed is acceleration multiplied by time, so:

$$\Delta v = a\ (\Delta t) = 1.23 \times 10^{-3} \times 4.5 = 5.55\ 10^{-3} \text{ miles per second}$$

2. Convert this result to miles per hour:

$$\frac{5.55 \times 10^{-3}\ \text{miles}}{\cancel{\text{second}}} \times \frac{60\ \cancel{\text{seconds}}}{1\ \cancel{\text{minute}}} \times \frac{60\ \cancel{\text{minutes}}}{1\ \text{hour}} = 20\ \text{miles/hour}$$

9 **125 meters**

1. You want to relate distance to acceleration and time, so use this equation:

$$s = \frac{1}{2} a\ t^2$$

2. Plug in the numbers:

$$s = \frac{1}{2} a\ t^2 = \frac{1}{2} 10.0\ 5^2 = 125 \text{ meters}$$

10 **–705 meters (that's 705 meters downward)**

1. To relate distance to acceleration and time, you use this equation:

$$s = \frac{1}{2} a\ t^2$$

2. Substitute the numbers:

$$s = \frac{1}{2} a\ t^2 = \frac{1}{2}(-9.8)\ 12^2 = -705 \text{ meters}$$

11 **65 miles**

1. To relate distance to speed, acceleration, and time, you use this equation:

$$s = v_o(t_f - t_o) + \frac{1}{2} a \left(t_f - t_o\right)^2$$

2. Plug in the numbers:

$$s = v_0(t_f - t_o) + \frac{1}{2} a \left(t_f - t_o\right)^2 = 60\,(1.0) + \frac{1}{2} 10\ 1.0^2 = 65 \text{ miles}$$

12 **30 miles**

1. You want to relate distance to speed, acceleration, and time, so you use this equation:

$$s = v_o(t_f - t_o) + \frac{1}{2}a(t_f - t_o)^2$$

2. Plug in the numbers:

$$s = v_0(t_f - t_o) + \frac{1}{2}a(t_f - t_o)^2 = 60(1.0) - \frac{1}{2}60\ 1.0^2 = 30 \text{ miles}$$

13 **125 meters**

1. To connect distance with speed, acceleration, and time, you use this equation:

$$s = v_o(t_f - t_o) + \frac{1}{2}a(t_f - t_o)^2$$

2. Plug in the numbers:

$$s = v_0(t_f - t_o) + \frac{1}{2}a(t_f - t_o)^2 = 50(5.0) - \frac{1}{2}10\ 5^2 = 125 \text{ meters}$$

14 **–300 meters**

1. To relate acceleration to speed and time, use this equation:

$$s = v_o(t_f - t_o) + \frac{1}{2}a(t_f - t_o)^2$$

2. Plug in the numbers:

$$s = v_0(t_f - t_o) + \frac{1}{2}a(t_f - t_o)^2 = 20\ 10 - \frac{1}{2}10.0\ 10^2 = -300 \text{ meters}$$

15 **–0.5 meters per second^2**

1. To relate acceleration to speed and time, use this equation:

$$s = \frac{1}{2}a\ t^2 + v_o t$$

2. Solve for a:

$$a = \frac{2(s - v_o t)}{t^2}$$

3. Plug in the numbers:

$$a = \frac{2(s - v_o t)}{t^2} = \frac{2(100 - 10 \times 20)}{20^2} = -0.5 \text{ meters per second}$$

16 **76.6 meters per second**

1. Start with this equation:

$$s = v_o(t_f - t_o) + \frac{1}{2}a(t_f - t_o)^2$$

2. Solve for v_0:

$$v_0 = \left[s - \frac{1}{2}a(t_f - t_o)^2\right]\ \frac{1}{t_f - t_o}$$

3. Plug in the numbers:

$$v_0 = \left[s - \frac{1}{2}a(t_f - t_o)^2\right]\ \frac{1}{t_f - t_o} = 76.6 \text{ meters per second}$$

17 **v_f = 894 meters per second**

1. Start with this equation:

$$v_f^2 - v_o^2 = 2as = 2a\,(x_f - x_o)$$

2. v_o is 0, so that makes things easier. Plug in the numbers:

$$v_f^2 = 2as = 2\ 400{,}000\ 1.0 = 800{,}000\ (\text{meters per second})^2$$

3. Take the square root:

$$v_f = 894 \text{ meters per second}$$

18 **v_f = 70.7 meters per second**

1. You want to find speed in terms of distance and acceleration, so use this equation:

$$v_f^2 - v_o^2 = 2as = 2a\,(x_f - x_o)$$

2. Plug in the numbers:

$$v_f^2 = 2as = 2\ 5\ 500 = 5{,}000\ (\text{meters per second})^2$$

3. Take the square root:

$$v_f = 70.7 \text{ meters per second}$$

19 **v_f = 4470 meters per second**

1. You want to find the speed of the rocket ship, having been given distance and acceleration, so use this equation:

$$v_f^2 - v_o^2 = 2as = 2a\,(x_f - x_o)$$

2. 100 kilometers is 100,000 meters, so plug in the numbers:

$$v_f^2 = 2as = 2\ 100\ 100{,}000 = 2.0 \text{ x } 10^7\ (\text{meters per second})^2$$

3. Take the square root to get the rocket's speed:

$$v_f = 4470 \text{ meters per second}$$

20 **v_f = 63.2 meters per second**

1. To determine the motorcycle's final speed, use this equation:

$$v_f^2 - v_o^2 = 2as$$

2. v_0 = 40 meters per second, so plug in the numbers:

$$v_f^2 - 40^2 = 2as = 2\ 6\ 200 = 2400\ (\text{meters per second})^2$$

3. That means that v_f^2 is

$$v_f^2 = 4000\ (\text{meters per second})^2$$

4. Take the square root to get v_f:

$$v_f = 63.2 \text{ meters per second}$$