

# Stop Faking It!

Finally Understanding Science

So You Can Teach It

## ENERGY

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# Preface

When I was back in college, there was a course titled Physics for Poets. At a school where I taught physics, the same kind of course was referred to by the students as Football Physics. The theory behind having courses like these was that poets and/or football players, or basically anyone who wasn't a science geek, needed some kind of watered-down course because most of the people taking the course were—and this was generally true—SCARED TO DEATH OF SCIENCE.

In many years of working in education, I have found that the vast majority of elementary school teachers, parents who home school their kids, and parents who just want to help their kids with science homework fall into this category. Lots of “education experts” tell teachers they can solve this problem by just asking the right questions and having the kids investigate science ideas on their own. These experts say you don't need to understand the science concepts. In other words, they're telling you to fake it! Well, faking it doesn't work when it comes to teaching *anything*, so why should it work with science? Like it or not, you have to understand a subject before you can help kids with it. Ever tried teaching someone a foreign language without knowing the language?

The whole point of the *Stop Faking It!* series of books is to help you understand basic science concepts and to put to rest the myth that you can't understand science because it's too hard. If you haven't tried other ways of learning science concepts, such as looking through a college textbook, or subscribing to *Scientific American*, or reading the incorrect and oversimplified science in an elementary school text, please feel free to do so and then pick up this book. If you find those other methods more enjoyable, then you really are a science geek and you ought to give this book to one of us normal folks. Just a joke, okay?

Just because this book series is intended for the non-science geek doesn't mean it's watered-down material. Everything in here is accurate, and I'll use math when it's necessary. I will stick to the basics, though. My intent is to provide a clear picture of underlying concepts, without all the detail on units, calculations, and intimidating formulas. You can find that stuff just about anywhere.

## Preface

Also, I'll try to keep it lighthearted. Part of the problem with those textbooks (from elementary school through college) is that most of the authors and the teachers who use them take themselves way too seriously. I can't tell you the number of times I've written a science curriculum only to have colleagues tell me it's "too flip" or, "You know, Bill, I just don't think people will get this joke." Actually, I don't really care if you get the jokes either, as long as you manage to learn some science here.

Speaking of learning the science, I have one request as you go through this book. There are two sections titled *Things to do before you read the science stuff* and *The science stuff*. The request is that you actually DO all the "things to do" when I ask you to do them. Trust me, it'll make the science easier to understand, and it's not like I'll be asking you to go out and rent a superconducting particle accelerator. Things around the house should do the trick. If you are a classroom teacher, you might be tempted to do a number of the activities in this book with your students. If you do that, use a bit of common sense when it comes to safety. Ask yourself if you really want your students using open flames and the like!

By the way, the book isn't organized this way (activities followed by explanations followed by applications) just because it seemed a fun thing to do. This method for presenting science concepts is based on a considerable amount of research on how people learn best and is known as the *Learning Cycle*. There are actually a number of versions of the Learning Cycle but the main idea behind them all is that we understand concepts best when we can anchor them to our previous experiences.

One way to accomplish this is to provide the learner with a set of experiences and then explain relevant concepts in a way that ties the concepts to those experiences. Following that explanation with applications of the concepts helps to solidify the learner's understanding. The Learning Cycle is not the only way to teach and learn science, but it is effective in addition to being consistent with recommendations from *The National Science Education Standards* (National Research Council 1996) on how to use inquiry to teach science. (Check out Chapter 3 of the *Standards* for more on this.) In helping your children or students to understand science, or anything else for that matter, you would do well to use this same technique.

As you go through this book, you'll notice that just about everything is measured in *Système Internationale* (SI) units, such as meters, kilometers, and kilograms. You might be more familiar with the term *metric units*, which is basically the same thing. There's a good reason for this— this is a science book and scientists the world over use SI units for consistency. Of course, in everyday life in the United States, people use what are commonly known as English units (pounds, feet, inches, miles, and the like).

The book you have in your hands, *Energy*, covers not just the basics of energy (work, kinetic energy, potential energy, and the transformation of energy), but also energy as it relates to simple machines, temperature, and heat transfer. The final chapter draws on most of the concepts presented in the rest of the book to address how we generate electricity for various purposes. I do not address a number of energy topics that you might find in a physical science textbook, choosing instead to provide just enough of the basics so you will be able to figure out those other concepts when you encounter them. You might also notice that this book is not laid out the way these topics might be addressed in a traditional high school or college textbook. That's because this isn't a textbook. You can learn a great deal of science from this book, but it's not a traditional approach.

One more thing to keep in mind: You actually CAN understand science. It's not that hard when you take it slowly and don't try to jam too many abstract ideas down your throat. Jamming things down your throat, by the way, seemed to be the philosophy behind just about every science course I ever took. Here's hoping this series doesn't continue that tradition.

## Acknowledgments

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This book was reviewed by Lynn Cimino-Hurt (Flint Hill School, Virginia); Olaf Jacobsen (Mesa Public Schools, Arizona); and Daryl Taylor (Williamstown High School, New Jersey).

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## Recognizing Energy

**E**nergy is such a common idea that it might seem silly to have a chapter that's all about recognizing it. After all, we talk about energy all the time. Should you buy energy-efficient windows? The country needs an energy policy. That little kid at the store who's screaming at the top of her lungs sure has a lot of energy. Candy bars are good for an energy boost. Close the refrigerator; you're wasting energy!

We use the word energy a lot, but can you come up with a quick and easy definition that you didn't find in a textbook? Can you hold energy in your hands?

### Things to do before you read the science stuff

To help you with the little dilemma I just posed, I want you to do the following things. Some are actual activities and some are questions to answer. If you spend a bit of time on these, then the section that follows will make more sense.

- Roll a marble or ball across the floor. Does this marble have energy while it's rolling? How do you know?
- Does the wind have energy? How do you know?
- Clap your hands. Any energy present when you do that?



# 1 Chapter

- Hold an unstretched rubber band in your hand. Does it have any energy? Now stretch the rubber band. Any energy now?

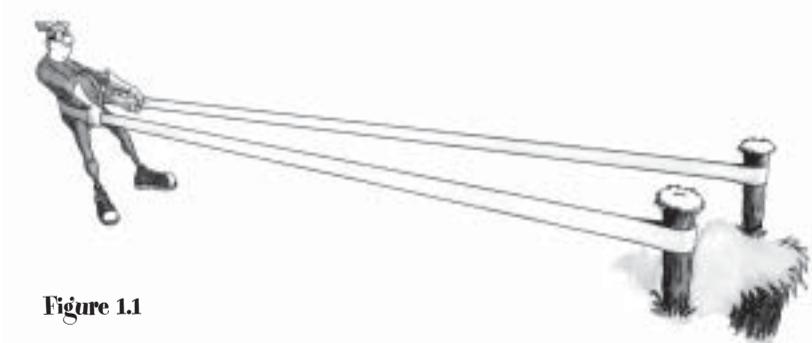


Figure 1.1

- Take your marble or ball and put it on the floor, at rest. Now pick it up and put it on a table. Push it off the table so it falls back to the floor. In which of these situations (on the floor, on the table, falling to the floor) did the ball have energy? Did it have more energy in one situation than in another?

Figure 1.2



- Grab a couple of small magnets. Refrigerator magnets will do if you don't have anything else lying around (tell the kids you'll put their artwork back when you're done). Place the magnets next to each other so they stick together. Now pull them apart just a tiny bit (about a centimeter). Let go—they should jump back together (Figure 1.2).

In which of the three situations (stuck together, pulled apart, jumping back together) did the magnets have energy? Any more energy in one situation than in another?

- Hold an unlit match in your hand. Does the match have energy? Strike the match. Any energy now? How do you know?
- Does a battery have energy? Does the Sun have energy? In both cases, how do you know?

## The science stuff

Now that you've done all those things, I can reveal that most of the questions in the previous section were trick questions. *Everything* I listed had energy. If that doesn't fit with your answers, be patient and I'll address all the situations by the end of this section. We'll start with the most obvious, though.

Anything that's moving has a special kind of energy known as "moving energy." To make that sound less silly and more sophisticated, physicists use a derivation of the Greek word *kinetikos* (which not surprisingly means "moving") and call this kind of energy **kinetic energy**. Later on, we'll figure out how to calculate the kinetic energy of something. For now, just know that a rolling ball, a falling ball, a running dog, two magnets heading towards each other, and anything else in motion, all have kinetic energy.

What about the wind? Does it have kinetic energy? Sure, as long as you believe in that invisible stuff called air. Wind is nothing but moving air.

On to the next kind of energy. Chances are you said a stretched rubber band has energy. How do you know? Because when you let go of it, it snaps back into place and perchance flies away and hits a bystander, who feels the result of that energy. By the same token, the two magnets, when pulled apart, have energy. You know this because they jump back together when you let go. The energy these things have is an energy of *relative position* (the position of one object compared to the position of another object) or shape. The rubber band has energy because it's stretched rather than relaxed. The magnets have energy because they're apart rather than together.

When something, or a group of things, has energy simply because of relative position or shape, it's known as **potential energy**. Showing remarkable consistency, physicists chose this name because, like kinetic energy, it's derived from a Greek word. Ummm—okay, no they didn't. The word *potential*



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Figure 1.3



In this relative position, the magnets have no potential energy



In this relative position, the magnets have potential energy

# 1 Chapter

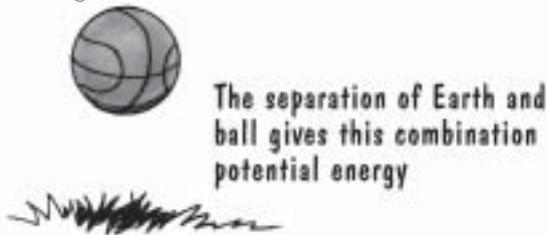
actually comes from a Latin word, but the meaning sort of fits. If someone has potential, they have the ability to do something, even if they never get around to doing it. A stretched rubber band has potential energy and thus the ability to do something—snap back into place if you let go. Two separated magnets have potential energy and the ability to jump back together when you let them go.

Of course, the “ability to do something” isn’t associated only with potential energy. A rock with kinetic energy has the ability to break a window, and a roller coaster with kinetic energy has the ability to turn your knuckles white. (Okay, strike that last one. Actual energy considerations with roller coasters coming up in Chapter 2.)

How about when you lift a ball and place it on a table? Does the ball have potential energy once it’s on the table? Yes and no. You did create a situation where the ball had the ability to fall to the floor if knocked off the table, but that potential energy was created not just in the ball but in the ball and the Earth! You see, the reason the ball falls is because there’s a force of *gravity* between the Earth and the ball. If the Earth weren’t around, the ball wouldn’t fall from the table to the floor. So the potential energy resides in the pair—Earth

plus ball—just as the potential energy of separated magnets lies in the pair of magnets and not just in one of them.

**Figure 1.4**



A quick review before we move on. We’ve identified two kinds of energy. The first is kinetic energy, which is energy of motion. The second is potential energy, which is the energy two or more things have due to their relative position or shape. One caution regarding potential energy. Some books will refer to potential energy as “stored energy.” Makes sense, because things that have potential energy and no kinetic energy are not moving, so the energy must be “stored.” However, not all energy that is stored is potential energy. Imagine holding a bicycle just off the ground with its wheels spinning away (Figure 1.5).

**Figure 1.5**



What will happen if you drop this bike to the ground? Well, it will probably fall over but before it does that it should move forward a bit, exhibiting kinetic energy (Figure 1.6).

It wouldn't be too far-fetched to say that the bike had "stored energy" when it was off the ground with its wheels spinning. That kinetic energy (spinning wheels) isn't accomplishing anything—it's just there. You can think of it as stored energy. What

this means is that, although all potential energy can be thought of as stored energy, not all stored energy is potential energy.

All right, let's press on to all those other things I had you do. Start with clapping hands. Any energy? Well sure, your hands have kinetic energy while they're coming together, but there's also sound. Does sound have energy? It might not be obvious but yes, sound is a form of energy. If there wasn't any energy in sound, how could it cause your eardrum to move?

I'm betting you said the lit match had energy. After all, you can feel the heat from it. You could call that *heat energy*, but I'm going to suggest a different term—*thermal energy*. There's a reason for making that distinction and it has to do with a specific definition of what heat is. I'll cover that in a later chapter. If you think a lit match has energy, then you probably also think the Sun has energy (big match).<sup>1</sup> How about an unlit match? If an unlit match doesn't have energy, how do you get fire from it? Certainly all that energy of the fire doesn't come from just striking it. Otherwise any piece of wood would catch fire when you strike it. The key with an unlit match is that it has a specific arrangement of chemicals in the tip. We call that arrangement *chemical energy*. And while we're talking about chemical energy, that's what's in a battery (as long as it's not dead). A specific arrangement of chemicals inside the battery gives it its energy.

By now you might get the idea that we could go on naming different kinds of energy forever. Maybe we can't go on forever but we can name many different kinds of energy: elastic energy, thermal energy, radiant energy, electrical energy, chemical energy, nuclear energy. Seems complicated, yes? Not really, because it

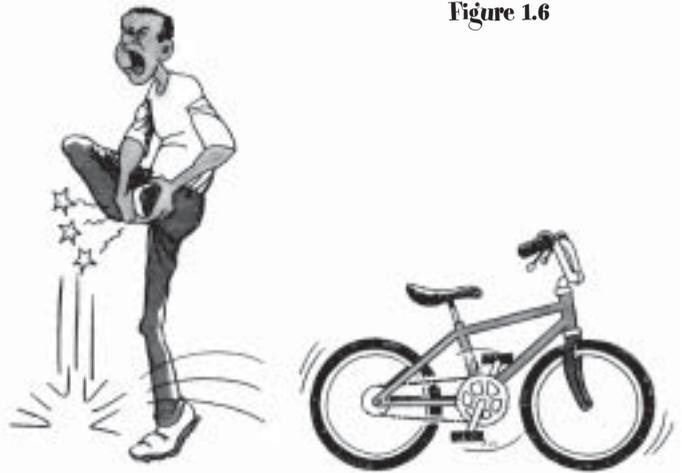


Figure 1.6

<sup>1</sup> Actually, the Sun has a wee bit more energy than a big match. There are nuclear reactions (yep, like hydrogen bombs) taking place inside the Sun, so you could say the Sun has nuclear energy.

# 1 Chapter

turns out that just about every single kind of energy boils down to two kinds—kinetic energy and potential energy. That’s fortunate, because physicists like things to be simple. The best theories of how the universe behaves tend to be the simplest ones, and it’s a sure bet that when your scientific explanation gets really, really complicated, you’re on the wrong track.

One big exception to kinds of energy being reduced to kinetic or potential energy is something called *mass energy*. You can think of mass as being the “amount of stuff” in an object—elephants have lots of mass and tsetse flies have very little mass. At any rate, it turns out that all things that have mass have energy just because of that mass. A really smart guy named Albert Einstein figured that out, and it’s represented by that very famous equation  $E = mc^2$ . (In this equation,  $E$  stands for energy,  $m$  stands for mass, and  $c$  stands for the speed of light.) We won’t be doing anything else with mass energy in this book, so now that I’ve introduced it, you can forget it if you want. But now at least you know why I told you at the beginning of this section that everything you looked at had energy.

A final thought before you hit the next section. I’ve shown you lots of ways to recognize energy, but you’d still have a tough time filling the blank in “energy is \_\_\_\_\_.” Sure, you could say something like “energy is cute,” but what I’m talking about is a definition. We don’t have a definition yet, nor a clear picture of what energy *is*. That’s because, common as it is, energy is a pretty abstract concept. Not so abstract, though, that you can’t get a grasp on it. If I thought otherwise, I’d end the book right here!



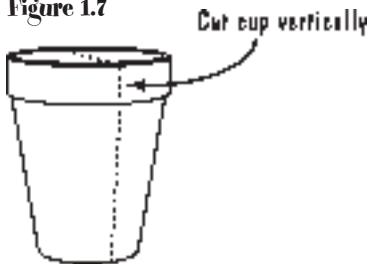
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## More things to do before you read more science stuff

Figure 1.7



Get a paper or disposable plastic cup and a couple of marbles or small balls. Cut the cup in half vertically, as shown in Figure 1.7.

Place one of the half-cups on its side on a smooth, level surface such as a linoleum floor or a countertop, as in Figure 1.8. It should look like a tunnel that’s closed off at one end.

Figure 1.8



Take a marble and roll it toward the open end of your neat little nonfunctional tunnel. When the marble hits the back, it should push the half-cup along the surface a short way. Do this a few times, rolling

the marble at differing speeds. The faster you roll the marble, the farther the cup should slide before coming to rest. Don't expect the cup to slide in one smooth motion; usually it goes a short distance when the marble first hits it and then slides again as the marble catches up and hits it again.

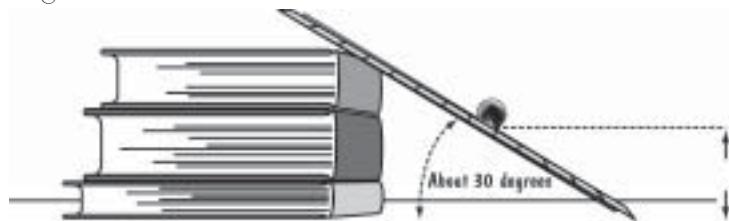
Now find something you can use as a ramp for the marbles to roll down. A clipboard or record album cover works well (you younger people ask your parents what that might be), as does one of those plastic rulers with a groove down the center on which the marble can roll. Prop your ramp against a box, a stack of books, or something similar, so the ramp is at about a 30° angle (this angle isn't critical, so don't measure it). And yes, you should do this on that smooth, level surface you've been using (Figure 1.9).

For what you're about to do, it's important that the ramp stay in the same position throughout. So even though the particular angle you use isn't important, that angle should stay constant. Sounds like a job for duct tape.

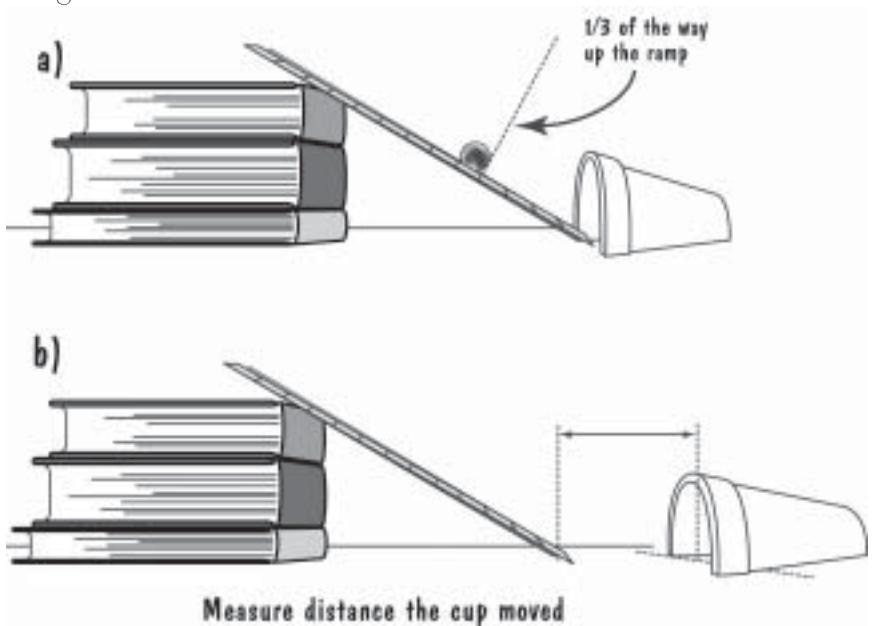
Place your half cup at the bottom of the ramp so that a marble rolling down the ramp will enter the cup and push it a ways. Set a marble about halfway up the ramp, let it go, and make sure it actually enters the cup.

**Experiment time.** With the cup positioned right at the bottom of the ramp, place the marble  $\frac{1}{3}$  of the way up the ramp. Let it go and then mark how far the cup goes before it stops (Figure 1.10).

**Figure 1.9**

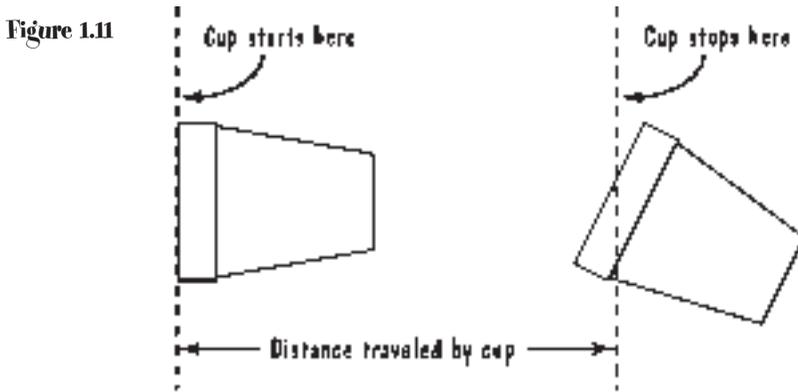


**Figure 1.10**



# 1 Chapter

Obviously you need to be careful about marking the distance the cup moves; use a small piece of paper or something similar rather than a permanent marker. Also, the cup usually twists a bit, so you should determine the distance as shown in Figure 1.11.



Distance the cup travels is measured at the center of the lip of the cup

Repeat what you just did several times until you consistently get about the same distance moved (expect small differences each time—that's normal). Now repeat everything you've done, except with the marble  $\frac{2}{3}$  of the way up the ramp. Again, do this a number of times until you consistently get about the same distance moved by the cup. Compare the distance the cup moves when you release the marble  $\frac{1}{3}$  of the way up the ramp with the distance the cup moves when you release the marble  $\frac{2}{3}$  of the way up the ramp.

Repeat again with the marble all the way at the top of the ramp. After doing that, you have three distances to compare—the distances the cup moves when the marble is released  $\frac{1}{3}$  of the way up,  $\frac{2}{3}$  of the way up, and at the top of the ramp.

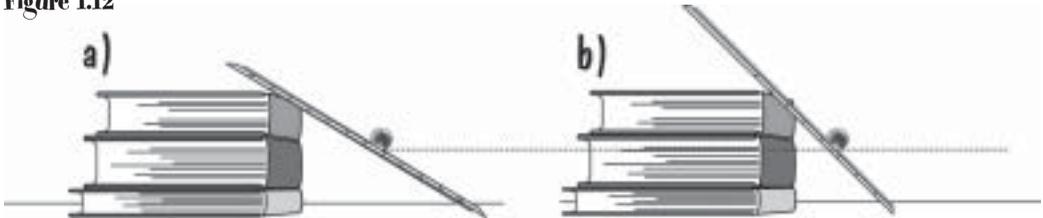
Because this little activity is so much fun, why not take one more measurement? Repeat your measurements for  $\frac{2}{3}$  of the way up the ramp, using two marbles instead of one. Make sure the marbles are about the same size and seem to weigh about the same. If you're using a ruler, you'll have to place the marbles one behind the other. If you're using some other ramp, you can place them side by side, making sure both of them enter the cup at the bottom. Compare the distance the cup moves using two marbles with the distance the cup moves using one marble. If you're feeling ambitious, you can repeat using three marbles, although it can be difficult to get all three to go into the cup.

Okay, I lied. One more thing to do. Compare the distances the cup moves using one marble in two different situations:

- (a) Ramp at the set angle, marble halfway up the ramp
- (b) Ramp set at a different angle, marble wherever it has to be on the ramp so its vertical height above the surface is the same as in Figure 1.12a

Seeing as how that probably totally confused you, take a look at Figure 1.12.

**Figure 1.12**



## More science stuff

We'll start with a big assumption, which is that the more energy the marble has, the farther it moves the cup. To take it a step further, I'm going to claim that if the marble moves the cup twice as far, the marble has twice the energy. If it moves the cup three times as far, it has three times the energy. For reasons I'll explain in the next chapter, this assumption turns out to be a pretty good one. It also just plain makes sense. Something with twice the energy should have about twice the effect on something else.

Unless something really strange happened, you should have gotten the following results in your experiment.

- One marble released  $\frac{2}{3}$  of the way up the ramp pushes the cup twice as far as one marble released  $\frac{1}{3}$  of the way up the ramp.
- One marble released from the top of the ramp pushes the cup three times as far as one marble released  $\frac{1}{3}$  of the way up the ramp.
- For a given distance up the ramp, two marbles push the cup about twice as far as one marble, and three marbles push the cup about three times as far as one marble.
- When you keep the *vertical* height of the marble the same, regardless of the angle of the ramp, the marble pushes the cup about the same distance.

If you got completely different results from these, you might want to check your procedure. Did you keep the ramp in the same position throughout? Did you measure the distance as shown in Figure 1.11? Was the surface really smooth and level, or were there bumps that might mess things up? Whatever your answers, you have the option of either redoing the steps or just taking my results.

# 1 Chapter

Of course, even if you did everything just right, you probably didn't get exactly my results. We're not looking to publish your experimental results but rather to give you a general idea of how marbles and ramps behave.

Okay, what in the world do all these results mean? First let's concentrate on the height. Releasing the marble from twice the height gives it twice the energy at the bottom (as evidenced by the cup moving twice as far). Releasing the marble from three times the height gives it three times the energy at the bottom. And remember that it's the *vertical* height that matters. You saw that when you changed the angle of the ramp and kept the vertical height the same.

Now comes a big leap of faith. I claim that this relationship between height and energy applies to *everything* and not just marbles that roll down ramps. In fact, what we're talking about is **gravitational potential energy**, the potential energy everything has because of its height above the Earth's surface. An object (actually the combination of the object and the Earth) has gravitational energy that depends on the separation (height of object) between the object and the Earth.

The height, however, isn't the only thing that affects gravitational potential energy. Recall that, for a given height, two marbles had twice the energy of one marble and three marbles had three times the energy of one marble. Because the marbles were all about the same size and weight, they all had approximately the same *mass*. That means that two marbles have twice the mass of one marble, and three marbles have three times the mass of one marble.

The bottom line here is that gravitational potential energy depends not only on the height, but also on the mass of the object. The formula looks like this:

$$\text{Gravitational potential energy} = mgh$$

where  $m$  is the mass of the object,  $h$  is the height of the object above some surface, and  $g$  is a special number that equals 9.8 meters per second squared.<sup>2</sup>

Note to those of you who cringe when you see a formula like this: The letters are called *variables* and they're placeholders for actual numbers.

Also, when two or more letters are put side by side, that means you're supposed to multiply them together. For example, the expression  $vt$ , where  $v$  equals 3 and  $t$  equals 7, is equal to 3 times 7, or 21.

So, to figure out an actual number for gravitational potential energy, you put numbers in for  $m$ ,  $g$ , and  $h$ , and multiply all three together.

If you use SI units for  $m$  (kilograms),  $g$  (meters per second squared) and  $h$  (meters), the unit that results for energy is known as the *joule*, named after Sir

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<sup>2</sup>  $g$  is actually the acceleration due to gravity of objects that are falling freely near the Earth's surface. For a more thorough understanding of what  $g$  represents, check out the *Force and Motion* book in this series.

James Joule, an amateur physicist and son of an English brewer (Gotta like a guy like that!). The surname is pronounced *jowl*, but for some reason, physicists pronounce the unit *jool*. To see that this formula fits with our experiment, put in any old numbers for  $m$  and  $h$  (use 9.8 meters per second squared for  $g$ ), say 4 kilograms and 6 meters. That gives us an energy of:

$$\begin{aligned} \text{Gravitational potential energy} &= mgh \\ &= (4 \text{ kg})(9.8 \text{ m/s}^2)(6 \text{ m}) \\ &= 235 \text{ joules (approximately)} \end{aligned}$$

If you double or triple the 4 kg to 8 kg or 12 kg, you get twice or three times the energy. If you double or triple the 6 m to 12 m or 18 m, you get twice or three times the energy. Those results agree with what we found in our experiment. In Figure 1.13, George has twice the gravitational potential energy of Wally, Martha has six times the gravitational potential energy of Wally, and Petunia has three times the gravitational potential energy of Wally. Hope that makes sense.

Before moving on, there's one thing that might be bothering you. If not, it should bother you after I mention it. Maybe you did your experiment on the second floor of a house, or some other place that wasn't level with the surface of the Earth. Yet the values for  $h$  were measured from the surface the cup was sliding on, rather than from the surface of the Earth. Shouldn't something sitting on the second floor of a building automatically have more gravitational potential energy than something sitting on the first floor of a building?

Well, yes. In fact, to get an accurate number for the gravitational potential energy between a marble and the Earth, we would have to use a much more complicated formula and we would have to use the distance between the marble and the center of the Earth! It turns out, however, that we can get a good picture of what's going on by considering only *changes* in potential energy. The *change* in potential energy in going from the bottom of a ramp to halfway up is the same on the first floor as it is on the second floor as it is on the tenth floor.

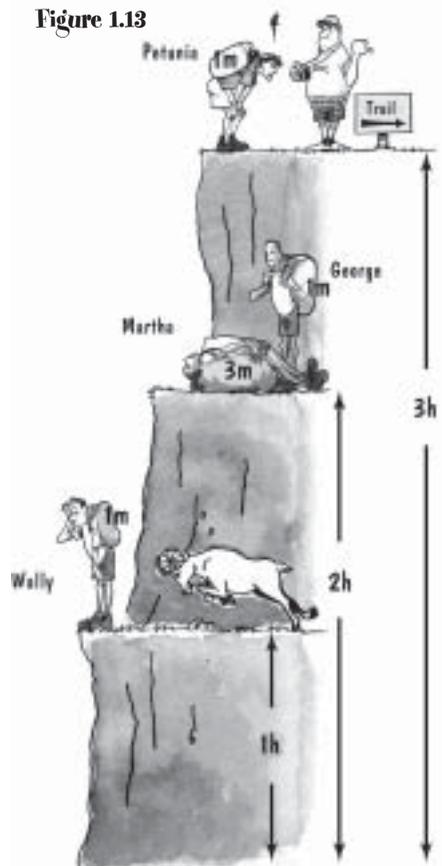


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Figure 1.13



# 1 Chapter

So, I've been lying just a wee bit. The formula  $mgh$  doesn't give you *the* potential energy between an object and the Earth, but if you calculate it at one height and then at another height, it *does* give you the right answer for the change in potential energy that took place in going from one height to the next. You can arbitrarily choose a point from which to measure all the heights (known as the *reference level*), and everything works out just fine. If that's still a bit fuzzy, don't worry. I'll hit on it again in the next chapter.

## Even more things to do before you read even more science stuff

Back to the ramp and marbles (no need for the cup this time). Set up the ramp as you did at the start of these experiments and mark off a distance of about 1 meter (the exact distance isn't important) from the base of the ramp. (See Figure 1.14.) You're going to time how long it takes for the marble to go from the base of the ramp to the point you mark off, so a stopwatch will be a big help. No big deal if you don't have a stopwatch, though. Just use the old "one one thousand, two one thousand . . ." method to get a rough idea of the time in seconds.

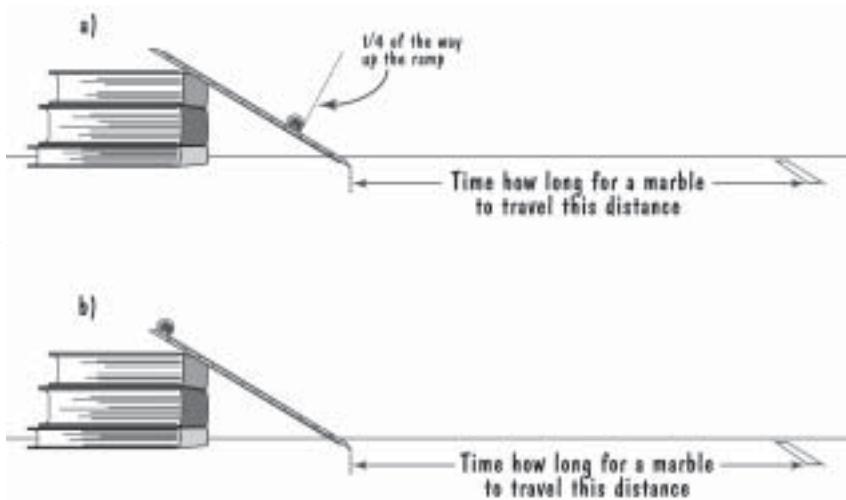
Figure 1.14



Compare how long it takes the ball to travel the marked distance for two situations:

- (a) Marble released at rest from  $\frac{1}{4}$  of the way up the ramp
- (b) Marble released from rest at the top of the ramp

Figure 1.15



Do this a bunch of times until you get more or less consistent results. Remember, this ain't rocket science.

## Even more science stuff

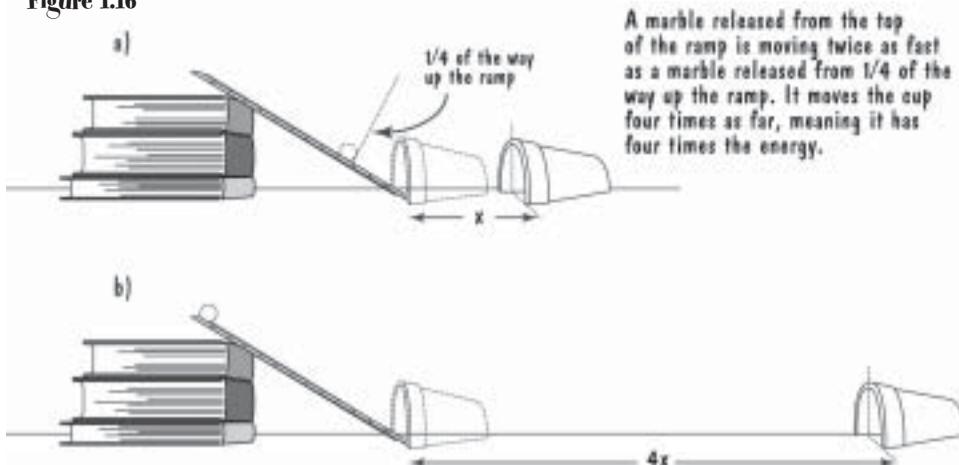
So you know where I'm headed in this section, I'm going to do something similar to what I did in the last explanation section. I'm going to use the results of the activity you just did to try and convince you of the plausibility of a formula for the kinetic energy of an object.

When I did the previous experiment, I got to just a bit more than “three one thousand” with the marble  $\frac{1}{4}$  of the way up the ramp and I got to “two one th . . .” with the marble at the top of the ramp. This tells me it took the marble just about twice as long in the first situation as in the second situation. Hopefully you got similar results. With a good stopwatch, I'm betting you got almost exactly double the time.

What this result means is that the marble is moving twice as fast in the second situation (released from the top of the ramp) as in the first situation (released from  $\frac{1}{4}$  of the way up the ramp). Stands to reason. If you take half the time to go a distance, you must be moving twice as fast. If you don't believe that, try it in a car sometime, where you can check your speed the whole way. What's one little speeding ticket in the name of science?

Now think back to moving the cup with the marble. There we found out that a ball released from the top of the ramp would have *four times* as much energy as one released from  $\frac{1}{4}$  of the way up the ramp. That tells us that when a marble is moving twice as fast, it has four times as much energy.

Figure 1.16



# 1 Chapter

This suggests that maybe the kinetic energy of an object depends on the *square* of the speed, because  $2^2 = 4$ . Of course to check that out, we'd have to repeat the experiment with the marble released, say,  $1/9$  of the way up the ramp and then from the top of the ramp. Then the marble would have nine times the energy at the top as it would  $1/9$  the way up the ramp. If our "squared" relationship is true, then we would get speeds at the bottom that differed by a factor of 3, because  $3^2 = 9$ . In fact, if you do that carefully, that's the result you get. Feel free to try that in your spare time!

We also know that kinetic energy depends on the mass of an object, because if we double the mass (two marbles) and keep the speed the same, the cup will move twice as far (you actually did that earlier in the chapter). All right, enough beating around the bush. Here's the formula for kinetic energy:

$$\text{Kinetic energy} = \frac{1}{2} mv^2$$

where  $m$  is the mass of the object and  $v$  stands for velocity.

There is a definite difference between speed and velocity, but for now you can think of them as being the same thing. As for the  $1/2$ , well, it's just there. I'll try to justify that number in the next chapter. I know you must be getting pretty excited about the next chapter given all the things I'm putting off until then! Notice that kinetic energy depends on mass and on the *square* of the velocity, as we knew it had to.

Now we have expressions for two important kinds of energy—gravitational potential energy or  $mgh$  and kinetic energy or  $\frac{1}{2} mv^2$ . If an object is a given distance above a reference point, you can put that distance in for  $h$ ; plug in the object's mass,  $m$ ; plug in 9.8 for  $g$ ; and get a number that represents the object's gravitational potential energy. If an object is moving at a given velocity, you can square that velocity, multiply by the object's mass, multiply by  $1/2$ , and get a number that represents the kinetic energy of the object.

That bit of knowledge might not have you dancing around the room, but we can use those numbers to solve quite a few real-life problems, as you'll see in the next chapter. There I go again. Maybe it's time to get to the next chapter.

## Chapter Summary

- Energy can take on many different forms, such as thermal energy, sound energy, electrical energy, and chemical energy.
- With the exception of mass energy, all forms of energy are some kind of kinetic or potential energy.
- Kinetic energy is the energy something has by virtue of its motion. It equals  $\frac{1}{2} mv^2$ , where  $m$  equals the mass of the object and  $v$  is its velocity.

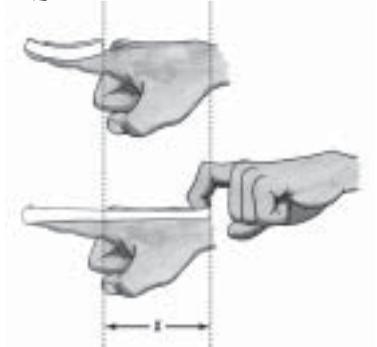
- Potential energy is the energy an object or group of objects has due to the position or shape of the object(s). Potential energy often can be thought of as “stored energy,” but it is incorrect to say that all stored energy is potential energy.
- Gravitational potential energy is the potential energy contained in the system consisting of an object and the Earth. For objects near the surface of the Earth, we often speak of the *object* having the gravitational potential energy, even though that energy resides in both the object and the Earth. For objects near the surface of the Earth, gravitational potential energy is equal to  $mgh$ , where  $m$  is the mass of the object,  $g$  is equal to 9.8 meters/sec<sup>2</sup>, and  $h$  is the height of the object above some arbitrarily chosen reference level.

## Applications

1. Let's see how well you understand the process we went through in this chapter. Get a rubber band and stretch it. It now has potential energy, right? Yep, because it's an energy that results from the new shape of the rubber band, not because it's moving. Now here's the challenge. Use the half-cup and a smooth, level surface to figure out how the potential energy in a stretched rubber band depends on the distance it's stretched. Cue the Jeopardy theme song while you think about it . . . .

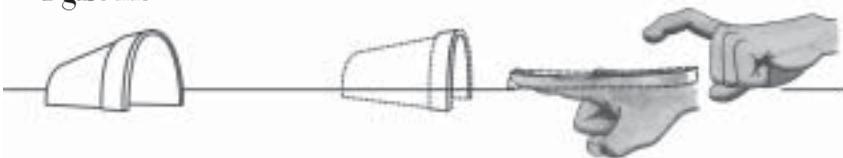
Did you figure out how to do it? If not, here's the answer. Stretch the rubber band as if you're going to fire it at someone. Note the position of the end of the rubber band before it's stretched and then after it's stretched (Figure 1.17).

Figure 1.17



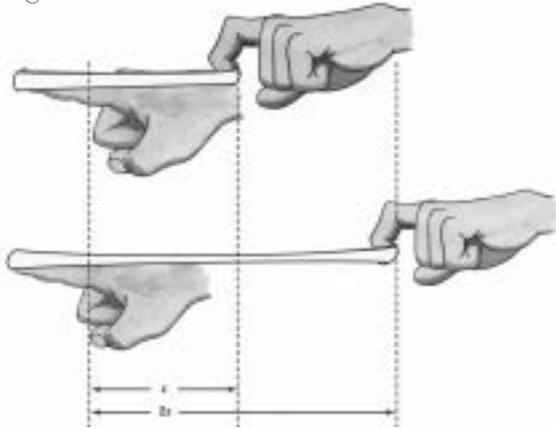
Fire the rubber band at the half-cup so you hit the back side of the cup and move it. Notice how far the cup goes (Figure 1.18).

Figure 1.18



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Figure 1.19



Now stretch the rubber band twice as far and repeat (Figure 1.19).

Here's the result I get: Stretching the rubber band twice as far moves the cup about four times as far, meaning the potential energy of the rubber band depends on the *square* of the stretched distance.

2. Using some special relationships known as *kinematic equations*,<sup>3</sup> you can calculate how fast something will be moving when it falls from rest through a certain distance.

Let's say a rock with a mass of 2 kilograms falls off a cliff 20 meters high. Using those kinematic equations, I can calculate that the rock's velocity just before it hits is 19.8 meters per second. Your task: Calculate the gravitational potential energy of the rock (use  $h = 20$  meters) at the top of the cliff. Then calculate the kinetic energy of the rock, just before it hits bottom. You should get the same number for each kind of energy. I'll explain this result in the next chapter. Hmmmm—foreshadowing for the science geek!

<sup>3</sup> See the *Force and Motion* book for a brief discussion of these.