Stop Faking It!

Finally Understanding Science So You Can Teach It

Air, Water, & Weather

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Preface

The book you have in your hands is the sixth in the *Stop Faking It!* series. The previous five books have been well received, mainly because they stick to the principles outlined below. All across the country, teachers, parents, and homeschoolers are faced with helping other people understand subjects—science and math—that they don't really understand themselves. When I speak of understanding, I'm not talking about what rules and formulas to apply when, but rather knowing the meaning behind all the rules, formulas, and procedures. I *know* that it is possible for science and math to make sense at a *deep level*—deep enough that you can teach it to others with confidence and comfort.

Why do science and math have such a bad reputation as being so difficult? What makes them so difficult to understand? Well, my contention is that science and math are *not* difficult to understand. It's just that from kindergarten through graduate school, we present the material *way* too fast and at too abstract a level. To truly understand science and math, you need *time* to wrap your mind around the concepts. However, very little science and math instruction allows that necessary time. Unless you have the knack for understanding abstract ideas in a quick presentation, you can quickly fall behind as the material flies over your head. Unfortunately, the solution many people use to keep from falling behind is to *memorize* the material. Memorizing your way through the material is a surefire way to feel uncomfortable when it comes time to teach the material to others. You have a difficult time answering questions that aren't stated explicitly in the textbook, you feel inadequate, and let's face it—it just isn't any fun!

So, how do you go about *understanding* science and math? You could pick up a high school or college science textbook and do your best to plow through the ideas, but that can get discouraging quickly. You could plunk down a few bucks and take an introductory college course, but you might be smack in the middle of a too-much-material-too-fast situation. Elementary and middle school textbooks generally include brief explanations of the concepts, but the emphasis is definitely on the word *brief*, and the number of errors in those explanations is higher than it should be. Finally, you can pick up one or fifty "resource" books that contain many cool classroom activities but also include too brief, sometimes incorrect, and vocabulary-laden explanations.

Given the above situation, I decided to write a series of books that would solve many of these problems. Each book covers a relatively small area of science, and the presentation is unrushed and hopefully funny in at least a few places. Typically, I spend a chapter or two covering material that might take up a paragraph or a page in a standard science book. My hope is that people will take it slow and digest, rather than memorize, the material.

This sixth book in the series is about air, water, and weather. It explores the physical science concepts associated with the behavior of air, water, and other fluids (yes, air can be considered a fluid!) and then uses weather as an interesting application of those concepts. As such, you will not find this to be a comprehensive book on weather. Of course, I do hope that the understanding you might gain from this book will help you immensely when you encounter other resources relating to weather concepts. After all, physical science concepts are at the heart of most weather concepts.

There is an established method for helping people learn concepts, and that method is known as the learning cycle. Basically, it consists of having someone do a hands-on activity or two, or even just think about various questions or situations, followed by explanations based on those activities. By connecting new concepts to existing ideas, activities, or experiences, people tend to develop understanding rather than rely on memorization. Each chapter in this book, then, is broken up into two kinds of sections. One section is titled, "Things to do before you read the science stuff," and the other is titled, "The science stuff." If you actually do the things I ask you to do prior to reading the science, I guarantee you'll have a more satisfying experience and a better chance of grasping the material.

It is important that you realize the book you have in your hands is *not* a textbook. It is, however, designed to help you "get" science at a level you never thought possible, and also to bring you to the point where tackling more traditional science resources won't be a terrifying, lump-in-your-throat, I-don't-think-I'll-survive experience.

Dedication

I dedicate this book to my mother, Arletta McIsaac, for her emotional, financial, and all other kinds of support that led me to this point. I also dedicate it to Donald McIsaac who, after the death of my father and in his infinite wisdom, became my stepfather and helped make two families even closer than they already were.

About the Author

As the author of NSTA Press's *Stop Faking It!* series, Bill Robertson believes science can be both accessible and fun—if it's presented so that people can readily understand it. Robertson is a science education writer, reviews and edits science materials, and frequently conducts inservice teacher workshops as well as seminars at NSTA conventions. He has also taught college physics and developed K–12 science curricula, teacher materials, and award-winning science kits. He earned a master's degree in physics from the University of Illinois and a PhD in science education from the University of Colorado. You can contact him at *wrobert9@ix.netcom.com.*

About the Illustrator

The soon-to-be-out-of-debt humorous illustrator Brian Diskin grew up outside of Chicago. He graduated from Northern Illinois University with a degree in commercial illustration, after which he taught himself cartooning. His art has appeared in many books, including *The Golfer's Personal Trainer* and *5 Lines: Limericks on Ice*. You can also find his art in newspapers, on greeting cards, on T-shirts, and on refrigerators. At any given time he can be found teaching watercolors and cartooning, or working on his ever-expanding series of *Stop Faking It!* books. You can view his work at *www.briandiskin.com.*

About the Cover

You probably recognize the character on the left as your basic loony weather forecaster, but you might be wondering who those other two guys are. The one blowing through the tent is supposed to be Daniel Bernoulli, a mathematician and physicist who studied, among many other things, air flow and air pressure. After you get through Chapter 2 in the book, you'll understand why he's blowing through a paper tent. The other dude is supposed to be Archimedes, who also studied math and physics, but did so much earlier than Bernoulli. He formulated a principle that explained buoyancy, which you'll read about in Chapter 3. Legend is he figured out buoyancy while trying to determine whether an object (a crown) was truly made of gold. He did so in his bathtub and then supposedly went around shouting, "Eureka!" Translation—"I have found it!" Not sure if that story is true. Anyway, the whole point of this cover drawing is to illustrate that a knowledge of the properties and behavior of air and water can serve as the basis for understanding a whole lot about weather.

The Scope of This Book

Many people will probably look at the last word in the title and assume that this is primarily a book about weather. They might also assume that my discussion of the properties of air and water will serve only as a prelude to understanding weather. Well, not so. I will deal with a number of concepts related to air and water that have little or nothing to do with weather. The reason for that is that some of these concepts are part of most science curricula even though they don't relate to weather. If I exclude them, I'm letting you down a bit, I think.

On the other hand, my treatment of weather in this book is not comprehensive. I pretty much limit myself to weather concepts that are good applications of the physics of air and water, and ignore those that aren't. For example, I don't discuss lightning, damage due to hurricanes, the scale used for measuring winds, or cloud types. Fortunately for you, there are lots of books in existence that cover these topics adequately. No sense in me redoing what's done well elsewhere.

So, this is not a book that covers every single property of air and water, nor is it a comprehensive book on weather. It's a book that combines portions of each of those topics, and, hopefully, helps you gain a basic understanding of enough concepts that you can do a better job teaching in all three areas.

Everyday Items Used in Activities in This Book

- Fork
- Flat-head nail
- Coffee can
- Duct tape
- Two empty soda cans
- Plastic straws
- Shallow pan
- Kitchen tongs
- One meter of rubber tubing (Tygon or other)*
- One bucket or saucepan of water
- Plastic water bottle
- Round balloons
- Votive candle
- One pickle jar or jar of similar size
- Index card
- Funnel
- Ping-Pong ball
- Small resealable plastic bags, 3cm × 5cm*
- Paper clips
- Slotted craft sticks*
- Vegetable oil
- Rubbing alcohol
- Clear drinking glasses
- Food coloring
- One cork
- One small, one medium Styrofoam ball*
- Modeling clay*
- Small rock
- Metal washers (equal size and weight)
- Several empty 2-liter soda bottles
- Pepper
- Two Cheerios
- Incense or other harmless producer of smoke
- One tornado tube or short section of foam pipe insulation
- Eyedropper
- Wooden matches
- Flashlight
- Pencil
- Pliers
- One empty toilet paper tube
- Two pushpins
- One emery board
- One human hair
- One table lamp without lampshade
- One sharp pencil
- One clear baking pan
- One section of cardboard

*Available from your local hobby shop or craft store.

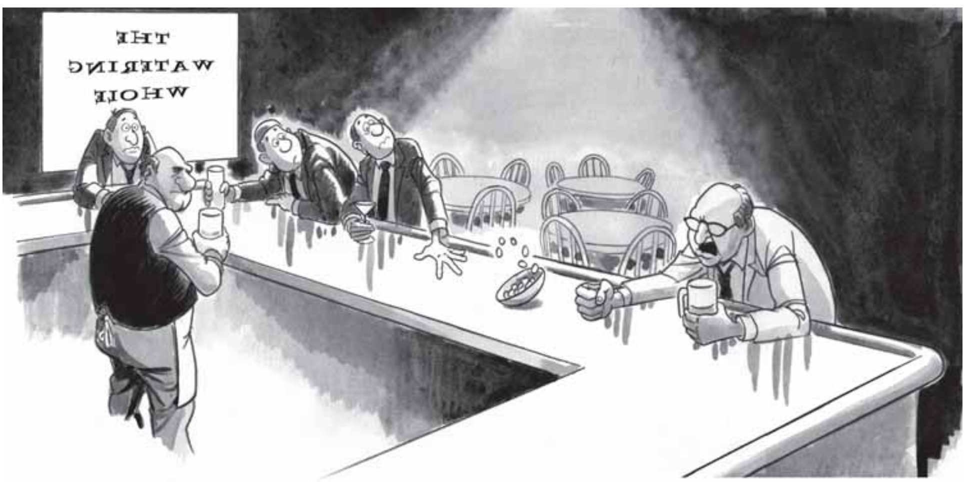
How can you avoid searching hundreds of science websites to locate the best sources of information on a given topic? SciLinks, created and maintained by the National Science Teachers Association (NSTA), has the answer.

In a SciLinked text, such as this one, you'll find a logo and keyword near a concept, a URL (*www.scilinks.org*), and a keyword code. Simply go to the SciLinks website, type in the code, and receive an annotated listing of as many as 15 web pages—all of which have gone through an extensive review process conducted by a team of science educators. SciLinks is your best source of pertinent, trustworthy internet links on subjects from astronomy to zoology.

Need more information? Take a tour—*www.scilinks.org/tour/*

Under Pressure[1]

The first thing I ought to address is why this book combines air, water, and weather. I addressed that in a preceding page, but it's worth another comment. In a regular physics textbook you'll find chapters on air and water and how they behave, and you can certainly find lots of books about weather. The reason I combine them here is that once you know a lot about air and other **gases**—and water and other **liquids**—you have many of the basics from which to understand weather patterns, what causes them, and how you can predict the weather. Of course, the air and water stuff is pretty interesting all by itself. If I didn't think that, I wouldn't waste your time and I'd spend my time more profitably, such as delivering pizzas.



"Pressure!! You want of know what pressure is?!! Air molecules trapped in a rigid container heated up to 212 degrees Fahrenheit. Unable to escape and moving faster than you can blink. That's pressure!!"

[1] I have no idea what your tastes in music might be, but if a David Bowie song comes to mind as you read this chapter heading, we're on the same wavelength.

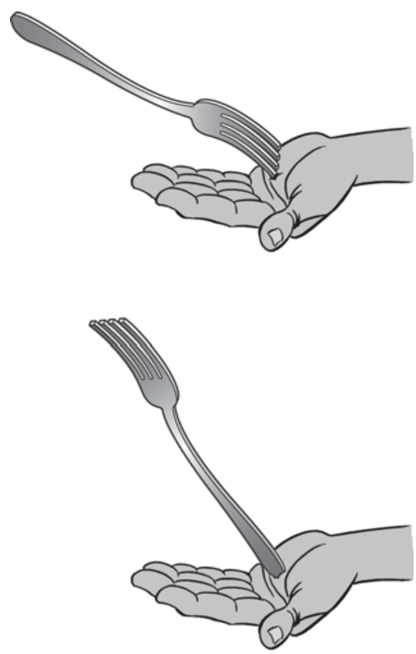
I'm sure you are well aware of the distinction between solids, liquids, and gases, which might make you think that I'd treat air and water as very different things. Turns out, though, that as far as scientists are concerned, liquids and gases behave so much alike that we treat them just about as the same kind of thing—**fluids**. So, much of what we cover here will apply to both air and water. Those two things aren't exactly alike though, so we'll take different approaches from time to time. Do expect, however, that I'll be jumping around between the behavior of air and other gases, and water and other liquids—all the while pointing out where the two are similar and where they're different.

On to the contents of this chapter: We're going to deal with **air pressure** and water pressure and what causes those things to increase and decrease. We'll also deal with the real-world results of those increases and decreases in air and water pressure.

Things to do before you read the science stuff

Get a metal fork. Push on the palm of one of your hands with one tine of the fork (Figure 1.1). Don't do this so hard that you draw blood, but it should hurt just a bit. Now turn the fork around and push on the palm of your hand with the non-business end of the fork. Try to push just as hard as you did with the single tine, and compare the level of pain you get with the single tine and the non-stabbing end of the fork.

Figure 1.1



Here's something potentially more painful but maybe easier to get the point across. Get a flat-head nail, one of those that's pointed on one end (wouldn't be much of a nail if one end weren't pointed) and a completely flat surface on the other end. Push on the palm of your hand first with the pointed end and then with the flat end. Try to use an equal push each time and please, please, don't draw blood with the pointed end. Best to avoid poking yourself with nails unless you enjoy getting tetanus boosters.[2] Compare the level of pain with the pointed end and with the flat end.

[2] This is probably a good time to emphasize that this is a book for adults, and not a collection of activities for use in the classroom. Yes, you can adapt most of these activities for classroom use, but take care when doing so. For example, you probably don't want to turn a bunch of kids loose after telling them to poke themselves with forks.

The science stuff

Assuming you did as I told you and didn't end up in the ER, you should have noticed something. Even though you pushed *equally hard* with flat ends and sharp ends of things, the sharp ends hurt more. If you pushed equally hard, then that meant you pushed with the same **force** each time.[3]

Okay, if you pushed with the same force each time, why didn't it hurt the same amount each time? The answer has to do with how widely distributed that force was each time. When you pushed with the pointed end of the nail, the force was distributed over a very tiny area, and when you pushed with the flat end of the nail, the force was distributed over a much larger area. To take this to the extreme, suppose someone smashed his or her elbow into you with a force of about 100 pounds.[4] That would definitely hurt and leave a mighty bruise, and to be clear, I'm not recommending you have it done. Now suppose someone smashes a steel spike into you with a force of 100 pounds (apologies for the violence in this chapter so far!). That wouldn't just hurt, but would rather do serious damage or even kill you.

Now that I've made my point, here's a concept that helps you take into consideration not just how big a force one might exert, but the amount of area over which that force is spread. That concept is called **pressure**, and pressure is defined by

$$pressure = \frac{force}{area}$$

In case your math is a wee bit rusty, that line on the right means "divided by." Because force is in the numerator of that fraction on the right, a larger force means a larger pressure, and a smaller force means a smaller pressure. The area, however, is in the denominator. So, a larger area means a smaller pressure (the force is more spread out so the pressure is smaller) and a smaller area means a larger pressure (the force is more localized, so the pressure is larger).

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[3] First shameless promotion for one of the other books in this series, *Force and Motion: Stop Faking It! Finally Understanding Science So You Can Teach It*. I'm not going to pretend that you can't find out what the term *force* means by looking somewhere else than the dictionary, but if you want the thorough treatment, well, ...

[4] Using English units (pounds) instead of *Système International* units (which would be newtons for force) is a big no-no in science books, but I figure it's okay just this once given that most people have a good idea of how big a force 100 pounds is and very little idea how big a force 100 newtons is. For the record, a force of 100 pounds is equal to a force of 445 newtons.

Before moving on, I should tell you why pressure is such an important concept in dealing with air and water. The reason is that we're dealing with large numbers of atoms or molecules, and we tend to be concerned about the collective effect of all those atoms or molecules pushing on something. Having to worry about the individual forces exerted by millions upon millions of tiny particles is a royal pain, so we use the concept of pressure that describes their cumulative effect without dealing with individual forces.

More things to do before you read more science stuff

What I want you to do in this section are things you've probably already done, so maybe all you need is a good memory. If you haven't done these things, you'll get to take a field trip, so be sure to have your parents sign that permission slip.

Your first task is to undergo a reasonably large change in altitude. You can do this by taking a ride in your car in the mountains so you change altitude at least 500 feet (easy if you live where I do in Colorado and a difficult task in other areas), taking off and landing in a plane (expensive field trip!), or finding a tall building and riding the elevator up and down at least 20 floors. If you choose the last option, try to find an express elevator that isn't likely to stop every few floors. You'll get the effect better if you travel all the floors without stopping. If the elevator is in a fancy hotel, and it's prom night, you can probably find several teenagers to join you on the ride.

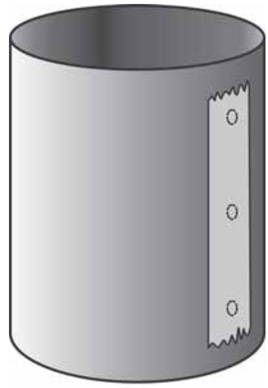
As you do any one of those tasks, or remember what it was like the last time you did, focus on the effect on your ears. Depending on whether you go up or down in altitude, and how far you have gone up or down, your ears will feel stopped up or they'll "pop" at some point. Some people can actually tell the difference in the feeling in their ears depending on whether they're going up or down in altitude, but to me it feels pretty much the same.

Okay, your next field trip is to a bathtub or a swimming pool. The swimming pool is a better option, but the bathtub (filled with water) will do. Basically, repeat your "change in altitude" procedure on a small scale. Move your submerged ears from one depth to another and notice changes in feeling in your ear. One caution, though. While there's no danger to your ears when you do this in a bathtub, it *is* possible to damage your eardrum doing this in a quick depth change in a pool (or a really large bathtub) of as little as four feet. So, just go for depth changes that are enough for you to feel a change in your ears. There's a safe way to change depths in water quickly. You plug your nose, close your mouth, and blow out gently as you submerge. This is called "clearing your ears," and it also works as you go *down* in altitude just in the air.[5]

One more fun thing to do: Take a large coffee can or something similar. Use a hammer and nail to poke three holes in the side of the can, one near the top, one at the middle, and one at the bottom (see Figure 1.2).

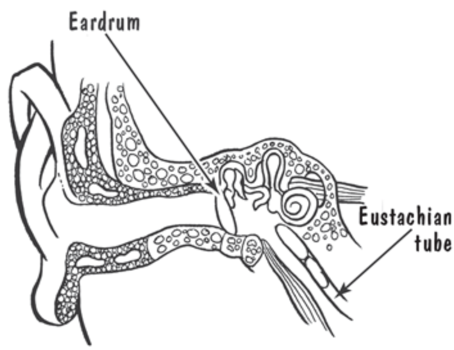
Use a strip of duct tape to cover all the holes, and then fill the can with water. Hold the can over a sink or outside, and quickly remove the tape. Notice how strong the water stream is that comes from each of the three holes in the can. There should be a difference between the results at each hole.

Figure 1.2



More science stuff

Figure 1.3



I'm guessing that it's no surprise to you that the reason you felt changes in your ears was due to changes in air pressure and water pressure. To really understand what's going on, it helps to have a basic idea of what the inside of your ear looks like, so take a look at Figure 1.3.

Notice that your **eardrum** separates your inner ear from your outer ear. One side of the eardrum is exposed to the outside of your ear and the outside air. On the other side of the eardrum is something called the **Eustachian tube**, which leads to your sinus cavities, your nose, and your mouth. In other words, this tube connects to the outside air through a different path that goes through your nose and mouth.

Your eardrum is sensitive to differences in pressure on either side of it. When the pressure on the inside of the eardrum is equal to the pressure on the outside of the eardrum, everything feels just fine. If the pressure on one side is greater than the pressure on the other side, the eardrum gets pushed out of its normal position and you get that "stopped up" feeling that can even get a little painful. If the difference in pressure gets too large, your eardrum can rupture, which can't be a good thing.

Before moving on, let's state something that might be relatively obvious:

Areas of high pressure tend to push things toward areas of low pressure.

[5] If this method doesn't work easily for you, don't push it. I'd really hate to get sued because someone broke an eardrum after reading this book!

Works with your eardrum and pretty much everything else.

Given that changes in altitude cause discomfort in your ears, we can assume that changes in altitude result in changes in pressure. Even if you don't want to assume that, just accept it because it's true! Here's what happens: As you go up in altitude (we're talking air, not water here), the outside air pressure gets lower. This makes the pressure inside your eardrum higher than the air pressure outside your eardrum, and your eardrum gets pushed outward. In order for your eardrum to get back to its normal position, the air pressure on the inside of your eardrum has to get lower. That happens once the air pressure inside your Eustachian tube gradually equals the outside air pressure, which you can help along by yawning or chewing gum. Once the air pressure on either side of your eardrum is equalized, you get that "popping" sensation in your ears.

If you're going down in altitude, the reverse happens. As you get to lower altitudes, the outside air pressure increases so it's larger than the air pressure on the inside of your eardrum, causing your eardrum to push inward. Once again, things get back to normal once you use the path through your Eustachian tube to equalize the pressure on the inside and outside of your eardrum. Again, yawning and chewing gum helps. Of course, there's that trick of holding your nose and blowing out gently. This trick (remember, it only works when going down in altitude) is the key to us knowing that increases in altitude decrease air pressure and decreases in altitude increase air pressure. When you hold your nose, close your mouth, and blow out gently, that increases the air pressure in your mouth, nose, and Eustachian tube, because it makes those air molecules inside push harder on your eardrum. Because that equalizes the pressure and makes your ears pop, that means that the air pressure inside the eardrum must have been lower than the outside air pressure before you performed the trick. And that means that as you went down in altitude, the outside air pressure increased. Yes, I realize that last paragraph might have gone by you just a bit too fast, so go ahead and review it slowly. Once you've done that, you should also realize why the "clearing ears" trick doesn't work when going up in altitude. When you go up in altitude, the air pressure inside your eardrum becomes greater than the air pressure outside your eardrum. Blowing gently with your nose plugged increases the air pressure inside your eardrum, and that doesn't help matters, but rather makes them worse.

As we move on to submerging yourself in water, the situation is pretty much the same. The only difference is that the thing causing the pressure on the outside of your eardrum is water rather than air. So we have pressure from the water on the outside of the eardrum and pressure from air (assuming you haven't drowned) on the inside of your eardrum. As before, the trick of "clearing your ears" works only when you submerge in water, not when you come up. That means that water pressure increases the deeper you go.

We have one more bit of evidence that the pressure in water increases as you get deeper. When you poked three holes in a can and filled it with water, you should have found that the stream of water from the bottom hole shot out farther than that from the middle hole, which shot out farther from that from the top hole. The higher the pressure (remember that pressure is force per unit area), the harder it pushes on the water as it leaves the hole. Makes sense, then, that the pressure gets higher and the water pushes harder as you get closer to the bottom of the can, or deeper in the water.

Maybe it's about time we came up with a reason that pressure decreases as you go up, in either water or air, and increases as you go down. The easiest way to think about this is with a swimming pool or other large body of water. What's the main difference between being one foot under a pool of water and being eight feet under a pool of water? Ding, ding, ding... time's up. In the first case you have just a little bit of water above you, and in the second case you have a lot of water above you. You see, the Earth's gravity pulls everything toward it, including water and air, and we call that pull of the Earth's gravity on something its **weight**. When you have a little bit of water above you, you have a little bit of the weight of water pushing on you and your ears. When you have a lot of water above you, you have a lot of the weight of water pushing on you and your ears. A greater push means greater pressure, so that explains what's going on. The pressure you feel when underneath a bunch of water is due to the weight of the water above you. The deeper you go, the more water you have on top of you, and the greater the pressure. In fact, there's a nifty little math relationship that tells you exactly what the pressure will be at a given depth of water. Here it is:

Pressure at a depth h = pressure at the surface + pressure due to the weight of the water above the depth h

Like all such relationships, we can express it with symbols, using P to represent the pressure at depth h, P_0 to represent the pressure at the surface of the water, and a combination of symbols, ρgh, to represent the weight per unit area of the water above the depth h. The symbol ρ is what is known as the **density** of the water, something I'm not going to explain for a couple of chapters, and g is a special number associated with the Earth's gravitational pull. Thus:

$$P = P_0 + \rho gh$$

Now, it's really bad form to just introduce a group of symbols multiplied together, such as ρgh, without making sure you have the experience to understand what they mean, but I'm going to go ahead and ask you to believe that these represent the weight per unit area of the water above a height h. When we get to Chapter 3, I'll explain the whole thing. For now, it will help if you realize that weight per unit area is a pressure, given that weight is the force due to gravity and pressure is force divided by area. Anyway, Figure 1.4 illustrates how the formula works.

All you really need to understand from this formula at this point is that, since *ρgh* always is a positive number, the pressure gets greater and greater the deeper you go in a body of water. You should also realize that because we have this nifty formula, we can calculate an exact number for the pressure at any depth of water, an important fact for SCUBA divers and dam builders (see the Applications section).

I told you that water and air, both being considered fluids, are a whole lot alike. Therefore, it shouldn't surprise you that there's a similar formula for determining the air pressure at a given altitude. Just as with water, the air pressure you feel at any height is due to the weight of the air that's above you (see Figure 1.5). For the record, when we talk about the air that's above you, we're referring to all the air that the Earth holds near its surface, otherwise known as the Earth's **atmosphere**.

Figure 1.4

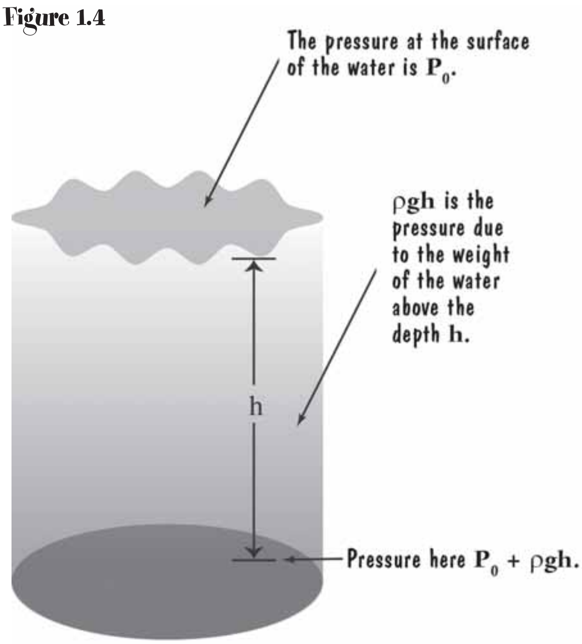
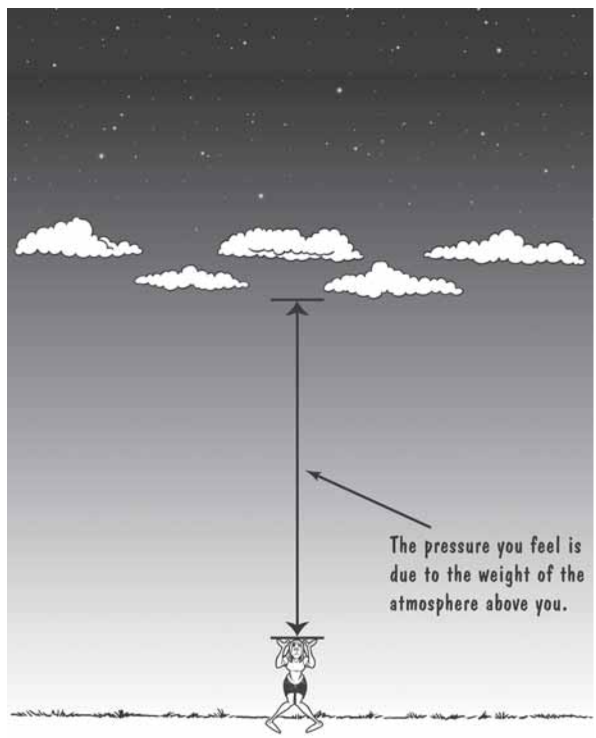


Figure 1.5



SCILINKS THE WORLD'S A CLICK AWAY

Topic: atmosphere

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When dealing with the atmosphere, the pressure gets smaller as you go up in altitude, so the formula is just a bit different. It's

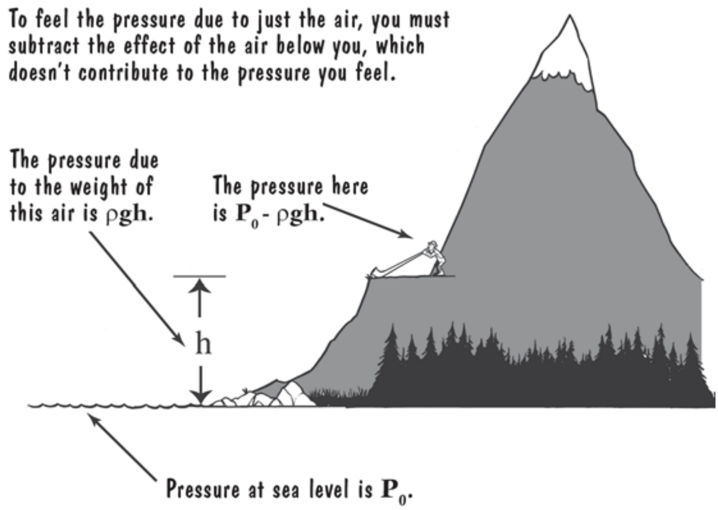
Pressure at a height h = Pressure at the Earth's surface – pressure due to the weight of the air below the height h

In symbol form, we can write this as

$$P = P_0 - \rho g h$$

The only differences between this and our formula for water are that P is the pressure at the *height h,* ρ is the density of *air,* and there's a minus sign because the pressure gets *lower* as you go to greater heights. You *subtract* the pressure due to the weight of the air below you because although that contributes to the air pressure at the surface of the Earth, it doesn't contribute to the air pressure at the height h. Only the air *above* you contributes to that pressure.

Figure 1.6

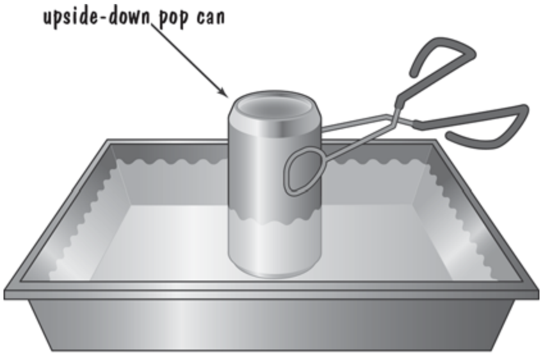


Even more things to do before you read even more science stuff

We've talked about the pressure at the surface of the Earth due to the weight of the Earth's atmosphere that surrounds the Earth. Time to find out just how large a pressure that is. To do that, you need an empty aluminum pop can, a pan or pie tin of cold water, a pair of tongs large enough to hold the can, and a stove. Keep the pan of cold water (you need just a few centimeters depth of water in the pan—enough to cover the top of the can if you put it in the pan upside down) near the stove.

Put a couple of teaspoons of water in the aluminum pop can, hold it over the flame (or electric heating element) of the stove, and wait until the water inside the

Figure 1.7



can starts to boil, leading to steam coming out of the top of the can.[6] Once that happens, remove the can from the heat and immediately turn it upside down in the pan of cold water (Figure 1.7) and hold it there. The can should do just a bit of collapsing.

The activity you just did is a lot more dramatic if you use an empty paint thinner can. If you happen to have one of those lying around, great. Put about a half a cup of water in the can and heat it over the stove with the *lid off*. Once the water inside is boiling furiously, remove the can from the stove (use hot pads), quickly put the lid on, and then just set the can in a safe place and watch a great show as the can collapses.

Before I move on to the next section where I explain all of this, I should let you know that there are lots and lots of cool activities to do that relate to air pressure. I'll tell you about them in the next chapter, after we have a really nice scientific model to explain what's going on.

Even more science stuff

When you heat the small amount of water inside a pop can, you heat all of the air inside the can as well. As these air molecules get hotter and hotter, they move faster.[7] As they move faster, a bunch of them escape from the can. The bottom line is that lots of air leaves the can (certainly not all of it), leading to very little air inside the can compared to what's outside the can. Once the air inside the can cools as a result of putting the can in cold water, you end up with regular old atmospheric air pressure (due to the weight of the air above you and the can) on the outside, and not a lot of air pressure on the inside. The dramatic collapse of the soda can (or the paint thinner can if you were able to do that) is an indication that the air pressure around us is pretty darned large. In fact, the atmospheric air pressure at sea level is around 100,000 newtons[8] per square meter (14.7 pounds per square inch).

[6] The heating shouldn't take so long that the tongs start to get hot, but if they do, start over using an oven mitt or hot pad to hold the tongs.

[7] Lots more detail on what air molecules are doing when you heat them up in the next chapter.

[8] A newton is the unit of force in the *Système International* of units. A pound is the unit of force in the English system of units. Scientists generally use the *Système International* of units.

Think about that number for awhile, and you'll realize that we're talking about a *really big* pressure—14.7 pounds of weight hitting every square inch of your body! That might make you wonder about a couple of things. One is how in the world our bodies can withstand that kind of **atmospheric pressure**. The other is how in the world something as light as air can exert such a large pressure. I'll address both of those "how in the world" questions in the Applications section.

By the way, when considering the pressure at a certain depth of water, the value of P_0, which is the pressure at the surface of the water, is often just the atmospheric pressure at the surface of the water.

Chapter Summary

- For many purposes, both air and water can be considered fluids.
- Pressure is force divided by the area over which that force is exerted. We use the concept of pressure extensively in studying air and water because it is an efficient way to deal with the large number of atoms and molecules involved.
- Areas of high pressure push things toward areas of low pressure.
- Atmospheric pressure decreases with altitude and water pressure increases with depth. In both cases, one considers the pressure due to the weight of either air or water above a given position.
- Atmospheric pressure at sea level is about 100,000 newtons per square meter, or 14.7 pounds per square inch.

Applications

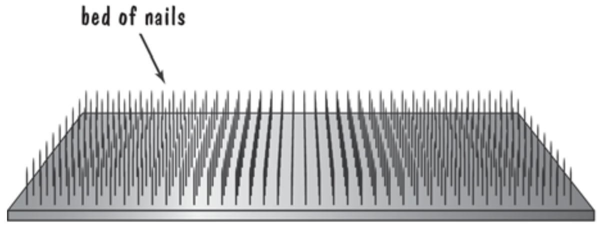
1. There are a couple of magic tricks that seem rather amazing, but aren't so amazing once you understand the concept of pressure. One trick is lying on a bed of nails, and the other is walking across a layer of broken glass. In neither case does the magician get hurt. Let's start with the bed of nails. If that bed of nails were instead a single nail, you'd be in trouble. Your entire weight (a force) would be spread out over a very small area. Because pressure is equal to

$$\frac{force}{area}$$

a small area leads to a large pressure. That large pressure would put the single nail right into your body. Now let's turn that single nail into an entire bed of nails. Even though the point of each individual nail has a small area, all of the nails considered together have a rather large surface area. That means the weight of your body is spread out over a large area rather than a small area. With the area being large and being in the denominator of the formula for pressure, the pressure is relatively small. With a small pressure, no nails will be penetrating your gentle skin (Figure 1.8).

A layer of glass is basically the same situation. As long as you have lots and lots of relatively small pieces of glass, the surface area exposed to your foot, and to the weight of your body, is pretty large. Once again, a large surface area leads to a small pressure, and not a lot of blood coming out of your foot.

Figure 1.8



Although the point of each nail has a very small surface area, together many nails have a large surface area leading to a relatively small pressure.

2. People who build dams—the ones you build across rivers—know all about water pressure, and that's a good thing. They build dams so they get thicker and thicker as you get toward the bottom of the dam. Why? Because the deeper you go in a body of water, the greater the water pressure. You want the dam thickest where the pressure is the greatest.

3. Maybe you've heard of something called "the **bends**" in association with SCUBA divers.[9] It all has to do with changes in pressure. As you already should know, as you go deeper underwater, the pressure increases. This pressure causes **nitrogen** in your bloodstream and in all other liquids in your body to dissolve. It's the same process one uses to make carbonated beverages, except the gas involved there is carbon dioxide rather than nitrogen. When you shake up a carbonated beverage and open it quickly, you know what happens—the gas escapes all at once and makes a big commotion. If you are SCUBA diving at a great depth and then rise to the surface quickly, the quick change in pressure causes the nitrogen dissolved in your body fluids to escape quickly. That's the bends, and it can be fatal. To counteract this effect, there are guidelines for how quickly a diver can surface safely.

4. One of our "how in the world" questions is the mystery that, with atmospheric pressure at the surface of the Earth being around 100,000 newtons per square meter (about 15 pounds per square inch), our bodies don't collapse under that pressure. The answer is that inside our bodies is an equal pressure pushing outward. Our bodies are about 65% water, and it's the inside pressure of that water plus various gases and even solids such as bones pushing outward that keep us from becoming a mush of over-pressurized gunk.

[9] Some say that SCUBA stands for Self Contained Underwater Breathing Apparatus. Others say it stands for Some Come Up Barely Alive.

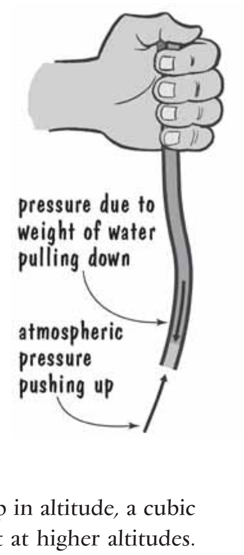
5. The other "how in the world" question has to do with how something as light as air can produce an atmospheric pressure at the surface of the Earth of 100,000 newtons per square meter. The answer here has to do with just how gosh darned high the atmosphere rises above the surface of the Earth. Although it's impossible to define exactly where the atmosphere ends (there're always *some* air molecules farther away no matter where you decide the cutoff point is), the generally accepted height of the atmosphere is about 600 kilometers, or 372 miles, above the Earth's surface. So, even though a cubic meter of air (one meter on each side of a cube) only weighs around 2–3 pounds (the exact weight depends on temperature and altitude), 600 kilometers of air can weigh quite a bit.[10]

6. For a final application, how about something that people think has a lot to do with air pressure but in fact has almost nothing to do with it? Let's figure out how a **siphon** works so you can steal gasoline from your neighbor's car.[11] Get about a meter's length of tygon tubing (clear plastic tubing—ask at the hardware store) or any other kind of hose-type material. Fill a large pan with water and place it next to a sink so the pan is above the sink. You can also just take the pan of water outside. Next fill your length of tubing with water by submerging it in the pan of water. Make sure there aren't any air bubbles in the tubing. Next seal off one end of the tubing with your finger or thumb and pick the tubing out of the pan of water, as shown in Figure 1.9.

Figure 1.9

None of the water should come out of the tubing. The reason is that the atmospheric pressure at the bottom of the tubing is enough to offset the pressure of the weight of water trying to pull the water out of the tubing. See Figure 1.10.

Figure 1.10



Now submerge that end you're holding in the pan of water and make sure the open end of the tub-

[10] This is the weight of a cubic meter of air at the Earth's surface. As you go up in altitude, a cubic meter of air weighs less and less, because the air molecules are farther apart at higher altitudes. Because of this, calculating the weight of the air above you can get a bit complicated, but we're not going to do that calculation, so no need to worry.

[11] I probably should state that this is supposed to be a joke, and I am not advocating a life of crime.

Figure 1.11

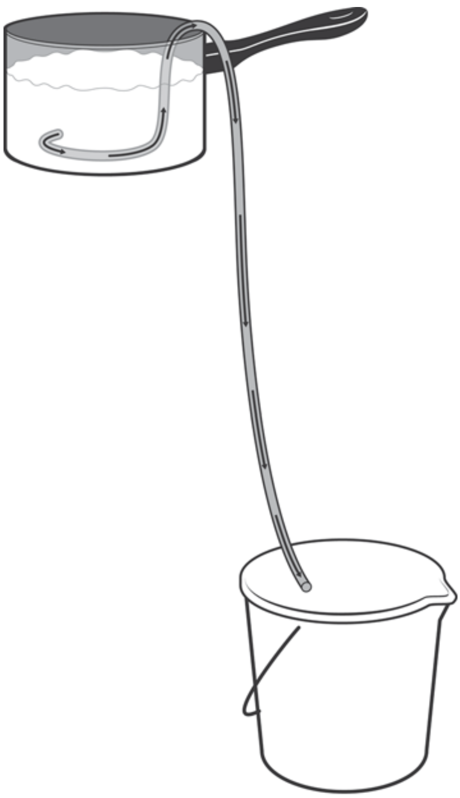
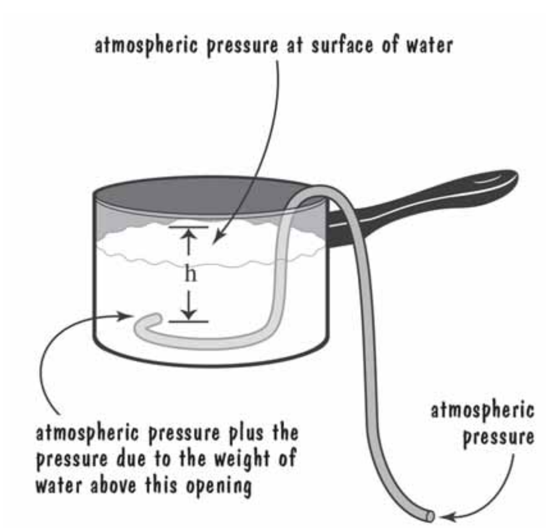


Figure 1.12



ing is lower than the pan of water. Remove your thumb or finger. As long as you keep the end in the pan submerged and the other end lower than the pan, water will flow through the tubing and out of the pan, as in Figure 1.11.

Now let's analyze this. Once you let go of the end of the tubing that's in the pan of water, you have a pressure exerted on that end. The pressure is due to atmospheric pressure plus any added pressure due to the weight of water that might be above the opening. Because the lower end of the tubing (the one not in the pan) is open to the air, there is also atmospheric pressure at that end. Figure 1.12 illustrates the situation.

Because there isn't a whole lot of height difference between the ends of the tubing, the air pressure at each end is essentially the same. That means there's a *slightly* greater pressure at the end in the pan because of the weight of water above it. That does tend to push water from the pan on out the tubing, but something else is also at work. Because the end of the tubing in the pan is no longer covered, the pressure due to the weight of the water in the tubing is no longer counteracted by atmospheric pressure pushing up (that pressure is now canceled by the atmospheric pressure on the top of the tubing). So, the water simply falls out of the tube. As it falls, it creates low pressure behind it, ensuring that the water in the pan will be pushed into the tube. Note, however, that a siphon will not work if the open end of the tubing is not lower than the end submerged in the pan. Figure 1.13 should explain why.

Figure 1.13