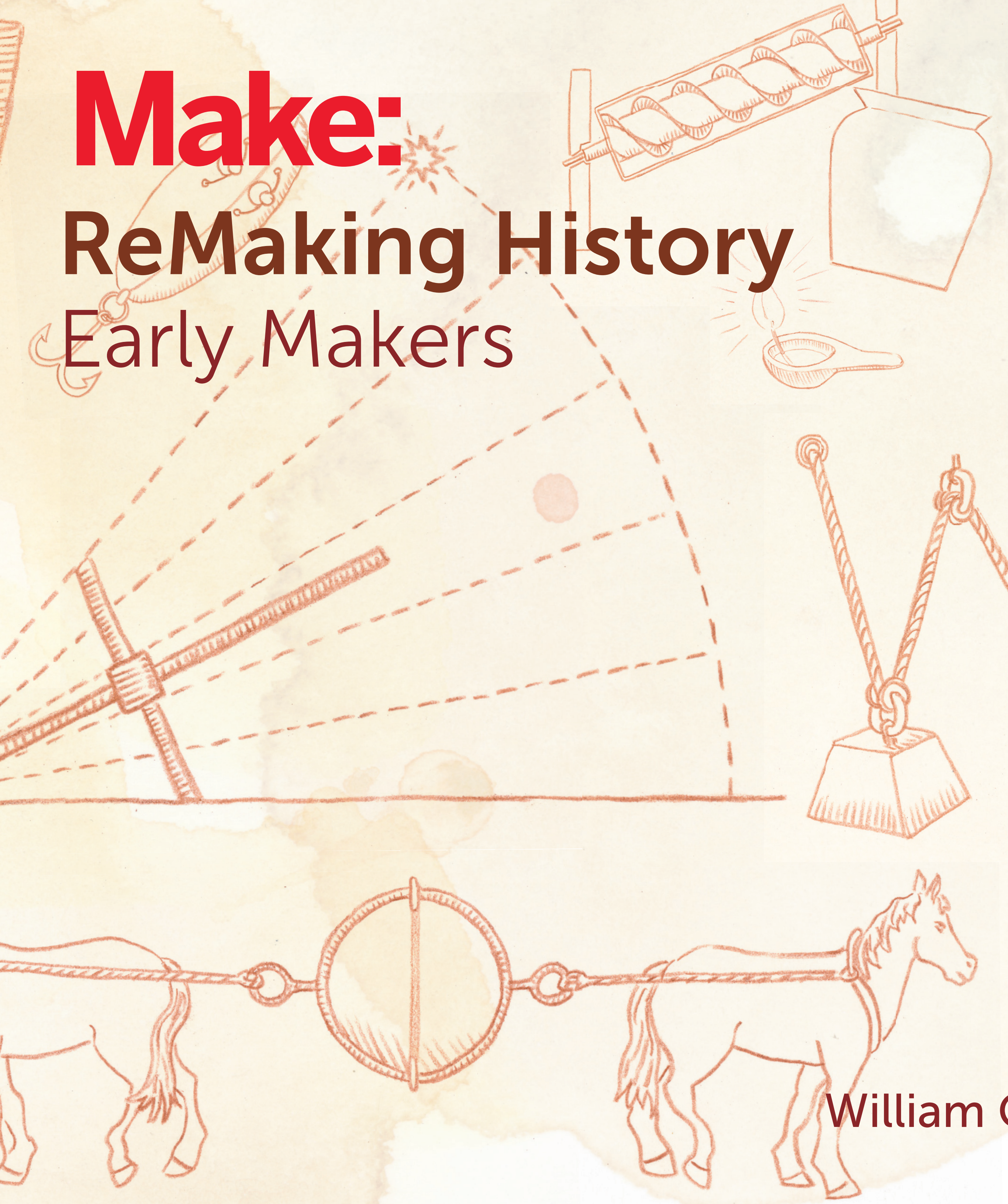
Make:

ReMaking History

Early Makers

Volume 1



William Gurstelle

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Early Makers
By William Gurstelle

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About the Author

William Gurstelle has been writing for *Make:* magazine pretty much since the beginning. Besides 40 or so "ReMaking History" columns, his work there has included do-it-yourself pieces on a gravity-powered catapult, a taffy-pulling machine, a Taser-powered potato cannon, and an ornithopter. He's also a bestselling author, a registered engineer, and a popular speaker on the world of science and technology.

Contents

Let's Remake History

I've found that history and science are two of my favorite topics. And maybe they are yours as well. If that's the case, you have come to the right place, because you'll learn plenty of both in this book. Not only will you read about both subjects, but you'll also have opportunities to step out and actually touch history by re-creating, at least after a fashion, some of the great inventions of the past. The way this happens is through something called *DIY science*. DIY stands for do-it-yourself, and that means you can actually do some of the same things that the great scientists you'll read about did.

There are many different ways to study these great inventions from the past. One way is to learn the history of how they were invented. That usually means learning about the people who invented them—where they lived, how they went about the inventing process, and if you're really a scholar, you will go on to find out how they came up with the idea in the first place.

Another way to study an invention is to learn the scientific principles behind it. For instance, if the invention is a construction crane, it would make sense to understand the physics of simple machines, and the materials science that explains why some materials are stronger and more suited for making such a contraption.

And a third way to study an invention is to re-create the invention yourself. This way gives you an intimate understanding of how and why something works. If you take the time to try a few of the projects in this book, you'll get a special type of understanding that can only come to you from doing things yourself.

This book is about using all three ways—history, science, and building the thing ourselves—to become knowledgeable about many great inventions from the distant past and why they are still relevant today.

The ReMaking History Timeline

First, let's take a look at the projects that this book covers. As you'll notice in Figure 1, the time period is a very long one! These inventions are some of the first technical creations ever devised, and they are the bedrock upon which much of future technology stands. The earliest invention described in this book is the oil lamp, and that goes back to the time before there were any written records.

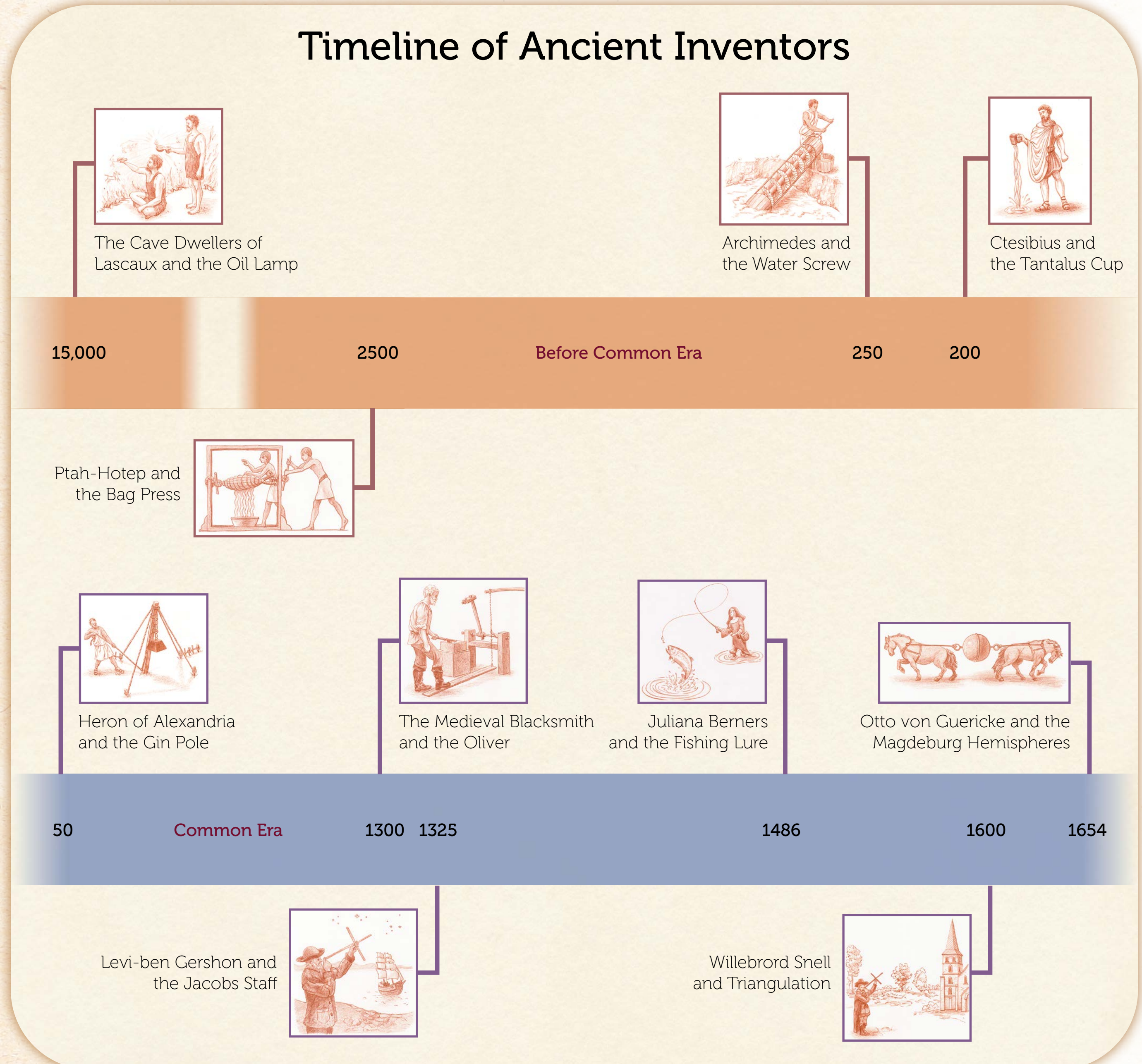


Figure 1: The timeline of ancient inventors

A long, long time elapses before we get to our next invention. But that doesn't mean nothing was happening during those 12,000 years or so. People were building cities, domesticating animals, figuring out how to farm, and taking many other steps forward on the march toward modern civilization. But if the truth be told, the pace of progress was pretty slow.

Eventually, however, things picked up. The Egyptians were incredible builders and makers. There are the pyramids, which you are familiar with, of course, but there's also the shadoof (a machine for irrigating farm fields), papyrus sheets for writing upon, the ox-drawn plow, and the project you'll find in one of the early chapters of this book called the bag press.

After the Egyptians came the Greeks and Romans, and they were no slouches at coming up with great new ideas. Metal casting, concrete, and steam power are just a few of their many contributions. There are three examples of history-making Greek and Roman inventions in this book—the water screw, the siphon, and the gin-pole crane.

But after this period of great advancement, another long stretch of time passes that sees a much slower rate of technological advancement. This period is often called the Dark Ages. It lasted a very long time, from roughly 500 CE to 1000 CE. But finally, the pace of progress began to pick up—an example of this is the Oliver hammer, which was thought up by an anonymous medieval blacksmith.

At long last, starting in the 1300s, the development of what we think of today as modern science and technology began in earnest—this period, which many historians refer to as the Early Modern Era, was the beginning of contemporary thinking. It was during this time that Greek and Roman science was rediscovered and people began to think in ways that helped them understand their world better.

There are quite a few projects in this book that date from the Early Modern Era. From the navigational devices of Levi ben Gershon to Otto von Guericke's vacuum pump, to Dame Juliana Berners's fishing equipment, the period between the end of the Dark Ages and Isaac Newton was the time during which a great many important scientific discoveries were made.

How This Book Is Organized

As you turn these pages, you may imagine yourself walking through the galleries and arcades of a science museum. As in a museum, each chapter spotlights a great thinker or inventor from the past and contains a description of what that person did to make it into the history books. This book focuses on a particular time—the years stretching from the dawn of civilization to the year 1700 CE or so. We'll meet and learn about the people who were scientists before the word "scientist" even existed.

First, we'll take a brief look at each person and what kind of man or woman they were. Next, we'll examine each one's claim to fame: that is, the wonderful or important thing they invented, the nature of the science behind that invention, and how it made the world a better place. Finally, and this is the best part, we'll build a simplified version of that invention so we can really understand it and see for ourselves how and why it works.

By the way, this book is part of a series. In addition to looking at the works of these early inventors in this book, the other books in this series examine the contribution of famous inventors like Benjamin Franklin, Charles Goodyear, and Humphry Davy, along with some less-well-known but still very important inventors such as Squire Whipple, Henry Bessemer, and August Möbius.

First Things First: Being Safe

The projects described in the following pages have been designed so you can make and use them as safely as possible. However, as you try them out, there is still a possibility that something unexpected may occur. Many of the projects involve the use of nails, saws, glue, and heavy weights, and you need to be careful when you work with these items. It is important that you understand that neither the author, the publisher, nor the bookseller can or will guarantee your safety. When you try the projects described here, you do so at your own risk.

These are your general safety rules. You will also find some specific safety instructions for particular projects or experiments in the chapters in which those projects are described.

- Read the entire project description carefully before you begin the experiment. Make sure you understand what the experiment is about, and what it is that you are trying to accomplish. If something is unclear, reread the directions until you fully comprehend them.
- Wear protective eyewear, gloves, and so on, when indicated in the directions.
- The instructions and information are provided here for your use without any guarantee of safety. Each project has been extensively tested in a variety of conditions. But variations, mistakes, and unforeseen circumstances can and do occur; therefore, all projects and experiments are performed at your own risk. If you don't agree with this, then put this book down; it is not for you.
- Finally, believe me when I tell you that it's no fun getting hurt. I want you to stay in one piece. And the very best way to do that is to use your own common sense. If something doesn't seem right, stop and review what's happening. (That doesn't just pertain to what's in this book; that's my advice to you in general.) You must take responsibility for your personal safety and the safety of others around you.

Part 1

Ancient Times

Humans have always created things that make their lives easier or safer. However, for the inventors and builders whose lives predate written language, the title of scientist or engineer doesn't seem to fit comfortably. Despite this, people who lived prior to the oldest known civilizations in Sumer and Mesopotamia did figure out a lot of important things. For example, they knew how to use fire, how to build a bow and arrow, and how to make a pot.

Once these ancient makers figured out a way to write things down, human history started to fill up with calculated numbers, written observations, and precise measurements. This period, starting around 3500 BCE (before the Common Era), is the dawn of technology and engineering. With the development of writing, civilization began to flourish. There is a great deal of historical and archeological evidence showing that Mesopotamians, Sumerians, and other ancient but literate people took a near-scientific look at their world and some of them became astronomers, geologists, and biologists—at least, of a sort.

Around 3000 BCE, the ancient Egyptians, who were builders of great structures and irrigators of large farms, had many citizens who qualified as real engineers; the proof of their abilities still stands in the great pyramids on the banks of the Nile.

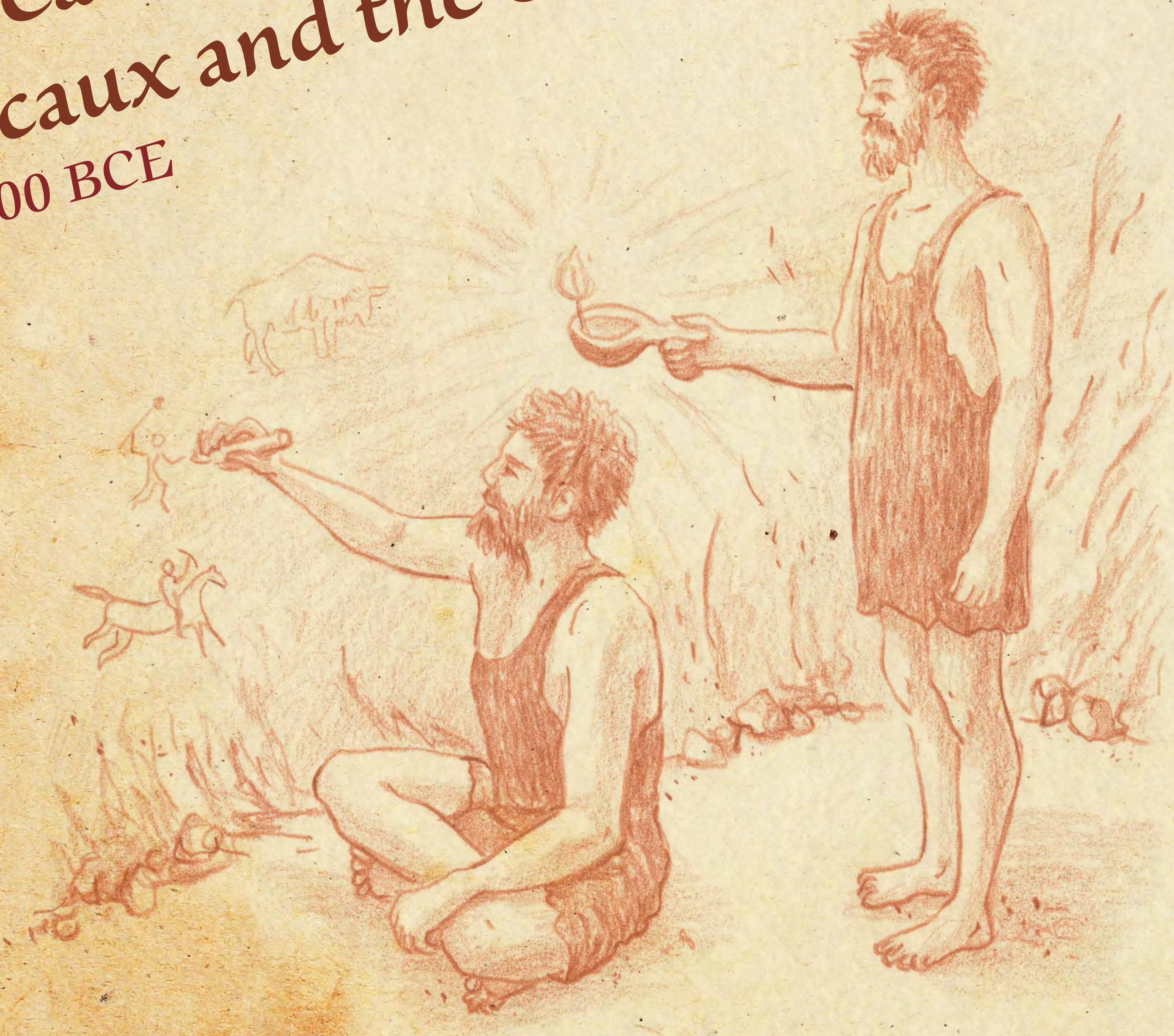
The people who lived near the shores of the Mediterranean Sea who came after the Egyptians also figured out a lot about the way the world worked. Thales, Archimedes, Aristotle, Heron (also known as Hero of Alexandria), and Pythagoras are just a few of the natural philosophers we unquestionably recognize as scientists today. And in addition to these famous Greeks, Romans and

Persians built cities made of brick and concrete with indoor plumbing, and the ancient Chinese, Indians, and other peoples invented paper, the compass, stirrups, musical notation, and windmills, among many other things. All of these cultures made important contributions to learning, and these ideas are still the bedrock on which a great deal of 21st century science stands.

Let's begin our exploration of the world of Ancient Makers with a trip to ancient France. The journey starts in a cave near the vineyards of present-day Bordeaux, in a beautiful, but secluded, spot not far from the Dordogne River.

The Cave Dwellers of Lascaux and the Oil Lamp

15,000 BCE



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Paleolithic nights were long and dark. It took our ancestors a while to figure things out, but eventually, they figured out a way to master fire, and banish darkness and cold forever.

Thagg and Grok Light Up the Night

In many parts of Africa and Europe, archeologists have uncovered the fossilized remains of caveman campfires. Near those buried rings of charred wood, they have unearthed the bones of people who lived so long ago that they predate modern human beings. So, it looks like our not-quite-human ancestors began taming fire as long as a million years ago! Although cavemen and women most likely did not have the brainpower to kindle fire, they did, it seems, have smarts enough to capture fire from, say, lightning strikes, tend it, and preserve it for long periods of time.

For Thagg and Grok, our cave-dwelling friends, campfires were important, not only for warmth and cooking, but also for light. Having a way to produce light was important for keeping away wild animals and other dangers at night, and it also allowed people to explore dark places where sunlight had never reached.

About 20,000 years ago, give or take a few thousand years, Stone Age humans painted images that were surprisingly beautiful. Even more surprising is where they were drawn—deep within long, winding caves in Western Europe. The best-known location of these rock paintings is the Lascaux caves in southwestern France (Figure 1.1). Narrow and deep, these caves are completely dark after the first few feet, so it must have been impossible for the artists who painted there to see anything without some source of artificial light.

So, how did Thagg and Grok paint their pictures? Many modern experts believe that these primitive Picassos placed a few lumps of animal fat on a stone that had a natural indentation, and then lit the fat with a burning straw from their campfire, which was kept under perpetual watch not far away.

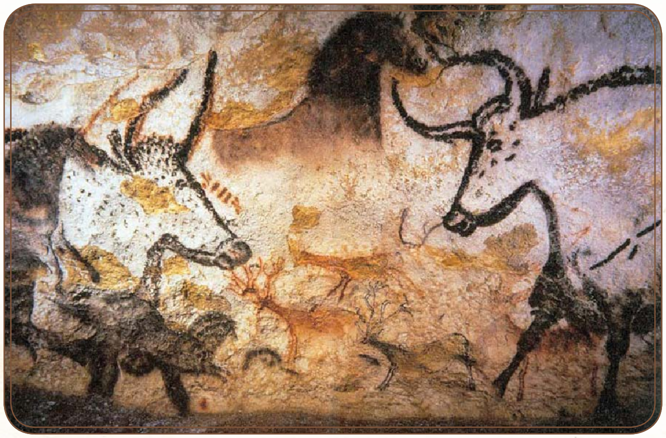


Figure 1.1: Lascaux Cave Painting

In other words, in order to produce the hundreds of pictures that are now considered some of the world's oldest artwork, these ancient makers made some of the world's first lamps.

The ability to build a lamp and find fuel for it was a huge advance, not just for the Lascaux cave dwellers but for their descendants as well. After this point, lamps were made from all sorts of materials, including shells, bone, stone, and chalk, and were fueled by whatever naturally burning, organic substance was locally available.

What sorts of fuels were used? In parts of the Middle East, especially in the area that stretched from what is northwestern Iran today north to Azerbaijan, many people were, no doubt, very pleased to find that burnable oil bubbled up naturally from the ground. The people who lived in this region filled their lamps with gooey petroleum such as liquid asphalt and naphtha, which they carefully collected from the tarry pools of dark ooze.

Evidently, there was a lot of it. The great 14th century explorer Marco Polo wrote about an extraordinary geyser that spewed up great jets of oil from the earth. He awed his readers when he described a place in the present-day Eurasian country of Georgia where a spring of oil released so much petroleum from the ground that local merchants used caravans of camels to cart it away. This oil, Polo wrote, "is not for the purpose of food, but as a medicine for men and cattle and it is also good for burning in lamps. People come from distant parts to procure it."

But what did people burn in places where there was no petroleum? In places where whales were common, such as Norway, Greenland, and Japan, the natives cut blubber into strips and then boiled them. This resulted in a large quantity of waxy oil that turned out to be an excellent fuel for home lamps. Catching and killing whales was hard and dangerous work, but the value of the meat and oil made it worth the bother.

Still, in most of the ancient world, whale oil and petroleum were rare commodities. Instead, most of the lamps used in those times burned animal fat or, where possible, olive oil. Olive trees have been cultivated for more than 4,000 years, and it's a fairly easy process to obtain oil from the olive fruits. Rome, Greece, Asia Minor, and Africa were just a few of the places where olives were an important crop. In each of these places, people designed lamps to bring together olive oil and a wick in order to provide a device that would light up their dark, long nights.

African and Middle Eastern lamps were open on top and often hung on chains from the ceiling. Later, great numbers of Roman lamps were manufactured using molds instead of hand-forming techniques. These were among the earliest examples of mass-produced housewares.

Unlike those from Africa and the Middle East, Roman lamps had covers, and sometimes they had multiple spouts and wicks that provided considerable light. The idea of a lamp with a cover was a big step forward in lamp technology because the cover prevented messy oil spills. In addition, the cover kept rats and mice from drinking the oil and prevented insects, attracted by the light, from falling into the oil.

It was in the orange-red glow of covered olive-oil burning lamps that people like Sophocles wrote, Socrates philosophized, and Archimedes invented.

Designing and fabricating a simple olive oil lamp is easy and fun, and, quite possibly, useful. But best of all, when you do it, you form a real, hands-on connection with the technology of the past. And not just the recent past, but much further back, to the earliest times of human civilization. What your smart phone is to you, the oil lamp may well have been to the cave dweller.

Making an Olive Oil Lamp

Basically, an oil lamp is just a container for oil with a support that holds the wick upright. That's the big deal that Thagg figured out—he built a device that can hold a wick upright so that one end soaks in oil and the other holds a flame.

Building a lamp is easy and you can make one from clay, plaster, or any other nonflammable material as long you can make a place for a wick and possibly have a separate hole into which you can add the oil. Making a lamp on a potter's wheel is a simple task because you need only throw a simple bowl and then pinch the wet clay to form a spout for the wick. But don't worry about finding a potter's wheel. You can make a decent lamp with just your hands.

Here are a couple ways to make a lamp.

Materials

A container of water putty or Plaster of Paris

Water

Two small, disposable, plastic cups or bowls

Scissors

Cotton cloth or 3″ piece of ⅛″-thick, wax-coated, 100% cotton yarn

Olive oil

Waterproof varnish or glaze

The Simple Saucer Lamp

To make the lamp, follow these steps:

1. In a disposable cup or bowl, mix 3 ounces or so of water putty or Plaster of Paris (the exact amount you need depends upon the size you want your lamp to be) with water according to the label directions.

> *Tip* When mixed with water, these compounds turn into a thick, yellowish putty that you can use to mold simple shapes. But be aware that it dries quickly, and once it dries, it becomes rock hard.

2. Use the second disposable cup or bowl as a form for the putty. Once you place the putty or Plaster of Paris into the second disposable cup or bowl, work quickly, using gloved fingers or a spoon to make a depression in the putty so that it too becomes bowl-shaped. Then, still working quickly, make an indentation in one side of the bowl to hold the wick upright.
3. Let your bowl lamp dry.
4. Remove the lamp from the disposable bowl.
5. Once your lamp is completely dry, paint on a couple coats of waterproof varnish on the interior to prevent the oil from soaking into the water putty or plaster.
6. Let the varnish dry.

   While the varnish is drying, it's time to make the wick. Choose one of the following options.

7. To make the simplest wick, cut a small piece of cotton cloth so it is roughly ¾ of an inch wide and about 4 inches long (the exact length depends on the size of your lamp). Then roll it up and insert it into the indentation you made in the reservoir of your lamp.

   Alternatively, you can make a slightly better wick from a 3-inch piece of ⅛-inch-thick, all-cotton twine or yarn that has been dipped in molten wax.

8. Now fill the bowl of your lamp with olive oil.

   After a few minutes, the oil will have been absorbed into the wick. Your lamp is ready to use!

Covered Lamp

Figure 1.2: Oil lamp materials and tools

Materials

(see Figure 1.2)

1 lb of air-dry clay

A 3″-piece of ⅛″-thick 100% cotton yarn

Olive oil

Waterproof varnish or glaze

Scissors

Spoon (optional)

Scribes or knives for adding decoration to lamp body (optional)

Note Not all air-dry clays become waterproof when they cure. If you are using a non-waterproof clay, coat the lamp interior with varnish or sealant to prevent the oil from soaking through the clay and leaking onto the surface below it.

Figure 1.3 shows an oil lamp assembly diagram, which will help you figure out how to make your own lamp. You can use almost any shape as long as it holds oil without leaking or spilling.

In the previous example, you made a simple saucer lamp with a single opening on top in which you inserted both the fuel and the wick. In this example, you'll make a more advanced covered lamp with separate holes for pouring in fuel and holding the wick.

This style of lamp is more sophisticated. Historically speaking, the saucer lamp was superseded by the covered lamp starting around 400 BCE. The covered lamp had several advantages. Covered lamps were less likely to spill and usually had molded handles that made them easier and safer to transport.

Making your coiled lamp is easy! Just follow these steps:

1. First, carefully examine Figure 1.3. Now that you've seen where you are heading, it's time to begin!
2. Make a base by flattening a piece of clay until it is about ¼-inch thick; then use a knife to cut it out into your desired shape.
3. Next, roll out several pencil-thick coils of moist clay, each one about the circumference of your lamp in length.
4. Press the first coil firmly onto the base.
5. Then, gradually build up the lamp walls by adding layers of coils to the first one in the shape you desire.
6. When your lamp shape looks right, smooth the coils inside and outside the lamp using a spoon or your finger.
7. With your finger or a spoon, form a spout on the rim of the lamp for the wick.

8. Roll out a piece of ¼-inch-thick clay and cut out the shape for your cover. Attach a clay knob in the middle so you can lift it off the lamp.
9. Let the clay pieces dry and harden.
10. Once your lamp is dry, you'll need to varnish the interior so the oil doesn't soak through the clay. Make sure to read and follow the manufacturer's directions that appear on the varnish container.

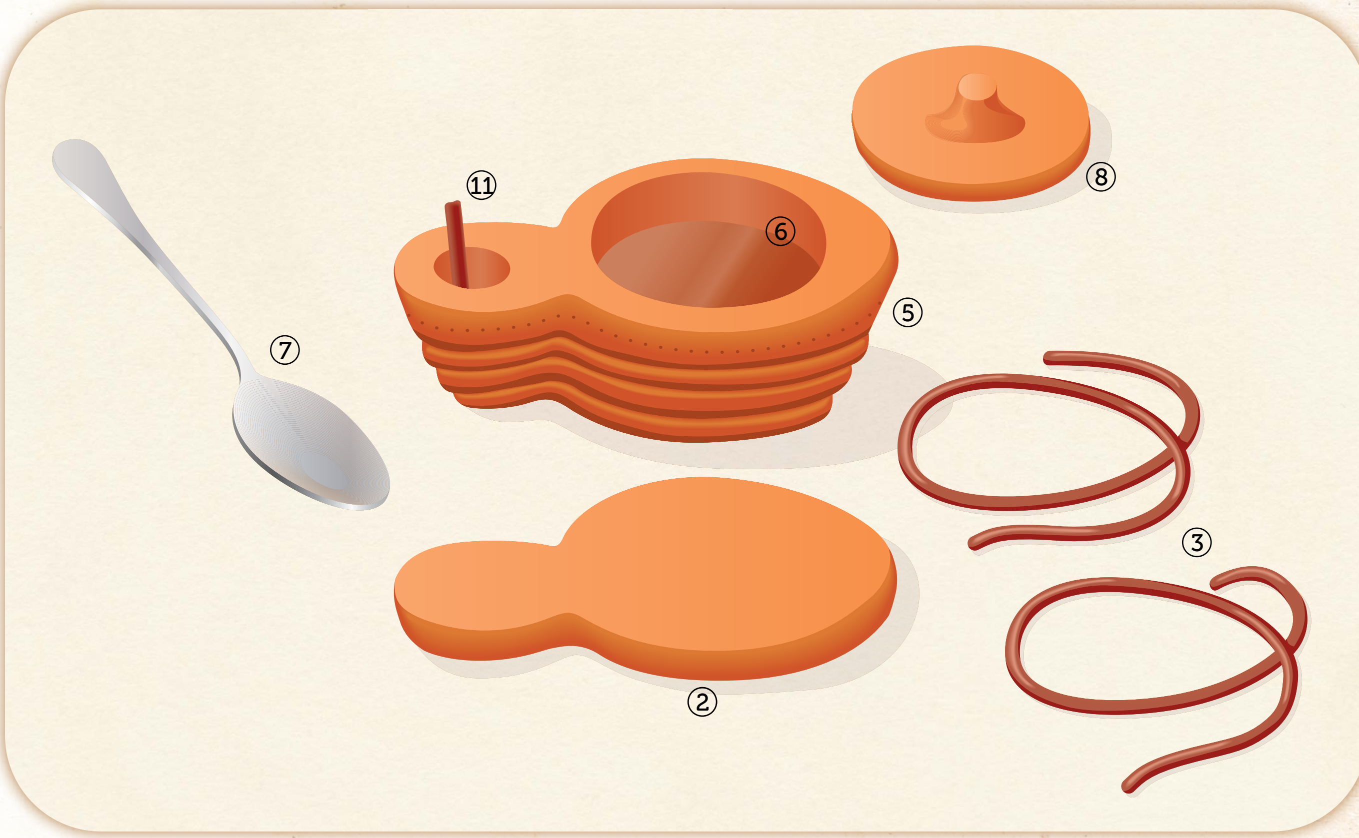


Figure 1.3: Assembly diagram, covered oil lamp

Figure 1.4: Lit oil lamp

11. Insert the wick into the wick hole.

12. Light the wick and enjoy the warm, soft light (Figure 1.4)!

13. (Optional) Add detail to your lamp with scribes or knives; you can also drill it or sand it if you want to. Historically, lamps were often decorated, and several themes were common. Motifs included mythology, animal and plant life, and repeating abstract designs.

    For a different look, add an interesting pattern to the lamp by poking small holes through the walls of the lamp, above the oil fill level, with your scribe. If you do this, you'll find that the flickering flame inside the lamp makes wonderful light-play through the holes.

Note Be certain to use your lamp under adult supervision only. As you've certainly noticed by now, olive oil is flammable, so use care to avoid spilling it and, if you do accidentally spill it, make sure to put out any nearby flame while you wipe it up. Also, olive oil produces a beautiful soft orange flame, but it generates a lot of soot and smoke. Carefully choose the location in which you use the oil lamp to avoid getting soot on walls and ceilings. Use the lamp with care. Oil lamps may set off smoke detectors.

Tip You may need to trim the wick at intervals with the scissors to make it burn faster or slower depending on the amount of light you want it to produce.

Note You can improve the finish of the lamp by lightly buffing it with cloth while it's warm.

The Wonder of Wicks

All simple oil lamps, whether they are ceramic, clay, or terra cotta, are pretty much the same. The lamp body is a container that holds the fuel. On the top of the lamp body are one or two holes: one for refilling the fuel, and another for containing the wick. (As already noted, in very simple lamps, there is only one opening for both purposes.) The wick is a fiber cord or string that holds the flame.

Although a wick looks simple (and indeed, it is merely a piece of twisted cotton), the chemical processes that are going on inside it at the molecular level are amazing (see Figure 1.5). At the microscopic level, the molecules in the oil are absorbed into the cotton wick and they move up to the flame via a phenomenon called *capillary action*. The upward drawing motion of capillary action is due to *surface tension*, or the attraction of one molecule to another molecule of a similar kind. Once this wicking process starts, it continues until the oil runs out; the oil molecules follow one another up the wick like ants marching up a log. At the top of the wick, the hydrocarbon molecules in the oil combine with the oxygen in the air, or, put a bit more scientifically, they

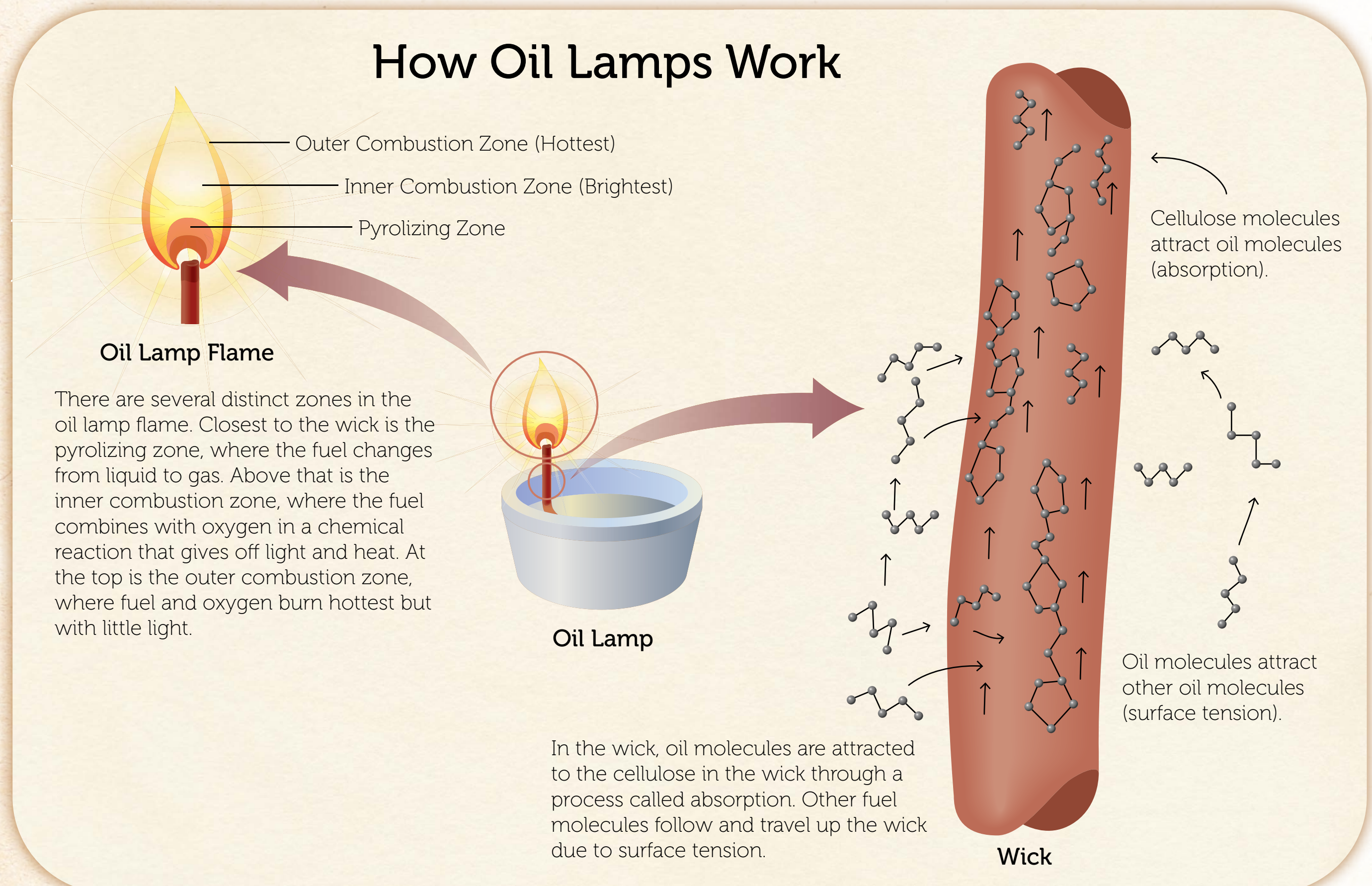


Figure 1.5: Explainer, oil lamp

oxidize, in a high-temperature, self-sustaining, and light-producing chemical reaction.

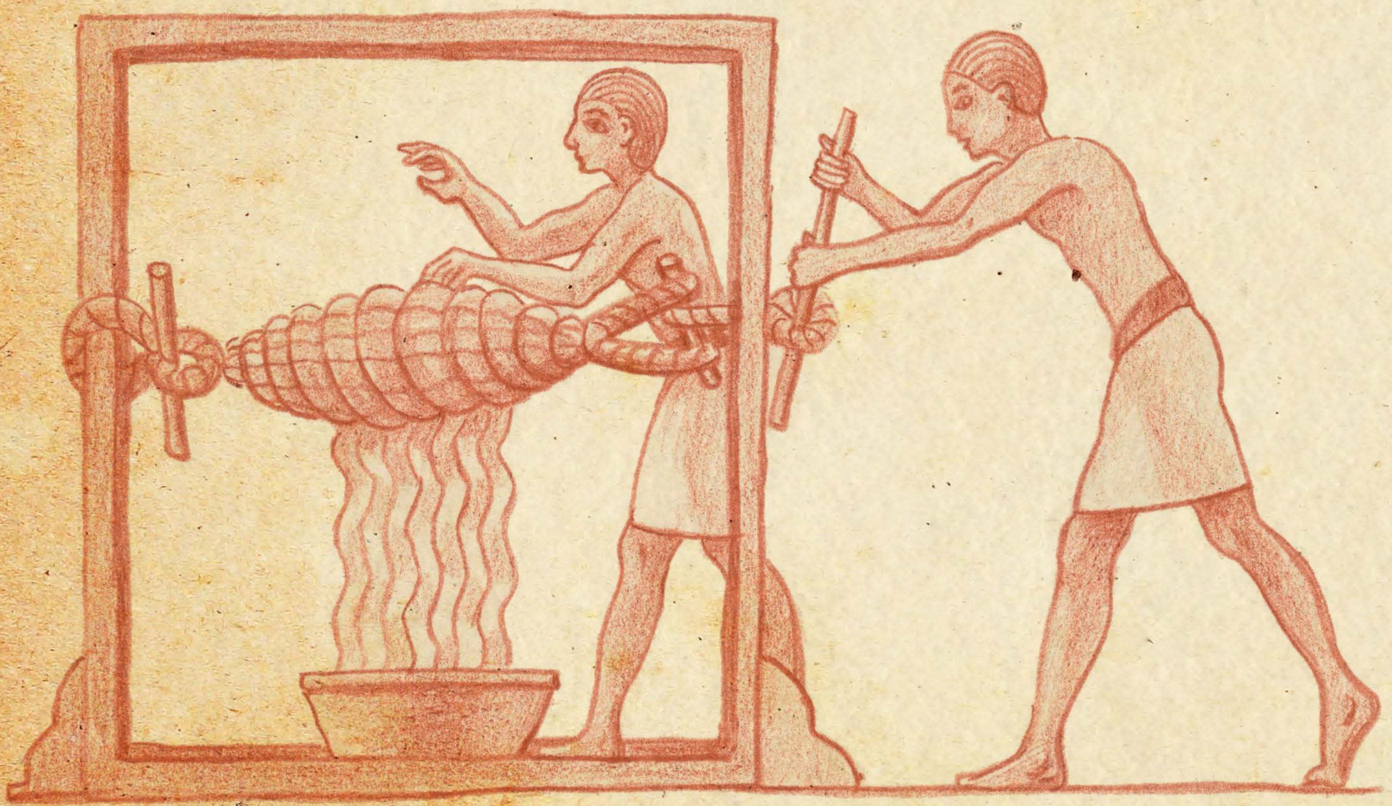
If you want to go even deeper into the science behind surface tension, here's what's happening: capillary action occurs because of sub-microscopic processes known as cohesion and adhesion.

Cohesion describes the attraction of molecules in liquids to molecules of similar kind. This is the atomic-level mechanism that causes oil molecules to follow one another, seemingly defying gravity, up the wick.

But cohesion isn't enough to keep your candle flame lit. There's a second process, called adhesion, at work as well. *Adhesion* is the molecular attraction between molecules of different types. Adhesion is the reason why oil is attracted to the fibers of the wick in the first place. Together, these two processes make up capillary action.

In an oil lamp wick, the burnable oil molecules are attracted to the fibers of the cotton, which are mostly made of cellulose. Cellulose naturally attracts oil. (A chemist would say that cellulose is a *lipophilic*, or oil-loving, material.) When the oil lamp is lighted, a few oil molecules more or less randomly begin to crawl up the surface of the cotton fibers of the wick string, and they drag even more oil molecules along with them as they go up the wick. As long as the flame burns, the chemical transport of oil molecules through the wick to the burning flame continues. It's hard to believe the complex chemical processes that are going on inside what looks like a simple piece of string!

Ptah-Hotep and the Bag Press
2500 BCE



2

The ancient Egyptians were excellent engineers, especially considering the paucity of tools and materials they had available. But with their human- and animal-powered machines, they invented a host of real and useful technologies.

Building a Replica of the First Food Processor

The ancient ruins of the Egyptian city of Memphis stretch for nearly 20 miles along the banks of the Nile River. The oldest artifacts date back five millennia to the "Old Kingdom," the period during which the earliest known pyramids were built. At the spot called Saqqara on the river's western shore is a particularly spectacular concentration of temples, tributes, and tombs—achievements credited to the laborers who worked more than 4,000 years ago for the pharaohs of the third, fourth, and fifth dynasties.

Among those pyramids and sphinxes lies a square, bench-like tomb called the mastaba of Ptah-Hotep. Ptah-Hotep was ancient Egypt's prime vizier and a close confident of Djedkara, the reigning pharaoh. The size and grandiosity of Ptah-Hotep's final resting place show that he was a BMON (Big Man on the Nile) and a person of great wealth and influence.

Many scholars believe that Ptah-Hotep's book, called *The Maxims of Ptah-Hotep*, is among the oldest texts in the world—it was written more than 4,000 years ago. It is a collection of maxims that he dictated to either his scribe or his grandson around the 25th century BCE. It seems to have been quite popular in its day, due, no doubt, to the sagacity of the advice it provides. The oldest known copy still exists in the collection of the National Library of France in Paris.

> *One who is serious all day will never have a good time, while one who is frivolous all day will never establish a household.*
>
> —Maxim 11 from *The Maxims of Ptah-Hotep*

It looks like Ptah-Hotep was able to establish a successful balance between seriousness and frivolity because he was interred in one of the largest and most impressive tombs in all of ancient Egypt. Not only that, but the carvings on the walls show the life of man who not only worked hard, but played hard as well.

The scenes on the walls of Ptah-Hotep's tomb that particularly interest archeologists include carvings that illustrate early boat building, cloth weaving, and fish drying. From those you can see he was serious about making Egypt prosper through industry, and from them, we modern folk can get some idea of how the people of those ancient times worked and lived.

But there are also scenes that show Ptah-Hotep's lighter side. Apparently the man enjoyed hanging out with friends and enjoying a nice glass of wine with his meals. How do we know this? By looking at the detailed illustrations on his tomb. There's one in particular (see Figure 2.1) that depicts people drinking wine, but it also shows perhaps the oldest piece of wine-making equipment ever made: the Egyptian bag press.

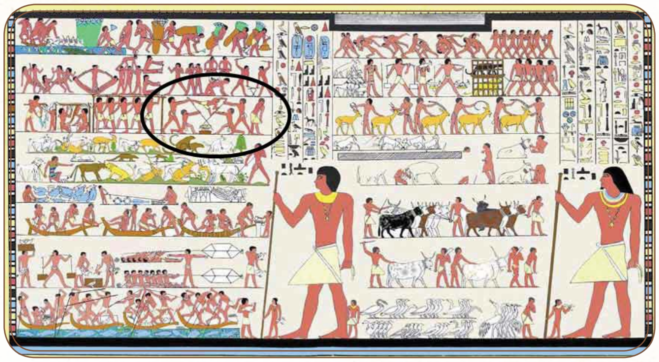


Figure 2.1: Making wine in Ptah-Hotep's time

The wall hieroglyphics show that some clever Egyptian thinker, perhaps even Ptah-Hotep himself, discovered how juice could be efficiently extracted from grapes by wrapping them in a linen bag and then twisting the ends of the bag. Like wringing water from a towel, exerting great torsional forces on both ends of the bag applies enormous pressure to whatever is inside. The press wrings out more juice than would be possible by other methods, including smashing grapes with mallets and feet and then collecting the liquid.

Modern archeologists refer to the operation of bag presses as "wringing the cloth." Images of the process appear frequently in hieroglyphs found throughout Egypt. In the detailed version of the hieroglyph shown in Figure 2.2, five men working together use a linen bag and poles to extract juice from grapes. Two men twist each stick in opposite directions while a fifth has the rather unenviable job of using his body to separate the two ends as the contracting motion of the twisting bag draws them together.

Three hundred years later, an improved version of the bag press appears in the hieroglyphic record. The ends of the bag are placed through holes in large wooden standoffs and the twist is applied at the points outside the frame, making the process easier and more efficient. You might

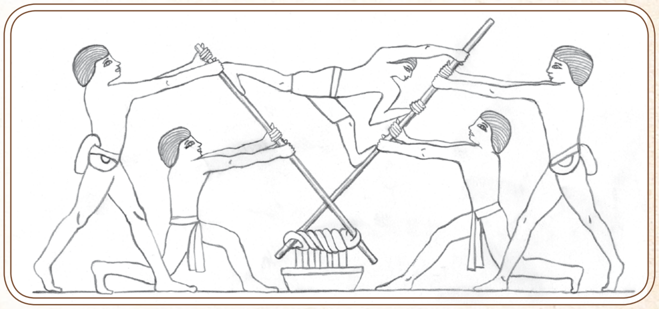


Figure 2.2: Using a bag press to make wine

wonder why it took the Egyptians so long to come up with the idea of a simple frame to hold the bag ends apart, but perhaps the pace of technology was slower back then.

Materials

- A 2″×6″ board, 12″ long
- Two 2″×6″ boards, 8″ long
- Two 8″×5½″ plywood triangles (see the diagram in Figure 2.6 for cutting information)
- Six 2½″-long deck screws
- Twenty-four 1¼″-long deck screws
- Two ¾″ NPT iron pipe flanges (NPT means National Pipe Thread taper. This is the type of pipe commonly found in hardware stores.)
- Eight #12 wood screws, 1″ long
- Linen cloth, approximately 12″×24″
- Two hardwood dowels, 5/8″ diameter by 8″ long
- A glass loaf pan, approximately 4½″×8½″×3″

Tools

- An electric drill and drill bits
- A 1″ spade bit
- Bits for the deck screws
- A sewing machine or needle and thread

Building an Ancient Egyptian Bag Press

Making the bag press is fun and, perhaps after a fashion, useful. But the main reason to build one is that when you do, you'll get a better understanding of the way modern science and history evolved from humble beginnings.

Note: To make the bag press as authentic as possible, you may choose to use cedar (a wood that was available to early Egyptians) for the 2″×6″ pieces and substitute thicker, solid cedar pieces for the plywood bracing triangles. Obviously, the early Egyptians did not have steel deck screws. They relied on mortise and tenon joints and pegs. If authenticity is important to you, you may use joinery techniques instead and omit the modern steel fasteners. But you should be aware that making wood joints takes a lot of skill and practice. If you go in this direction, you may want to check with a local woodworking expert for assistance.

Part 1: Preparing the Bag

Begin by laundering the linen cloth. Then, using a sewing machine or by hand using very fine stitching and strong thread, follow these steps:

1. Fold the linen in half along the long axis.
2. Next, fold one short end over twice and stitch a hem.
3. Stitch a seam along the long edge (see Figure 2.3).
4. Turn the bag inside out so the raw edges of the long seam are inside the bag.
5. Fold over the end you hemmed in step 2 and sew a pocket large enough to accommodate the diameter of the turning rods, leaving the top and bottom open for the rod. Leave the other end of the bag open (see Figure 2.4).

Figure 2.3: Stitching the bag

Figure 2.4: The finished bag

Part 2: Making the Press

Before you begin, examine the bag press assembly diagram shown in Figure 2.5. To assemble the press, follow these steps:

1. Locate and mark the holes in the uprights according the diagram. Drill a 1.5-inch-diameter hole in each 2″×6″ end plate.

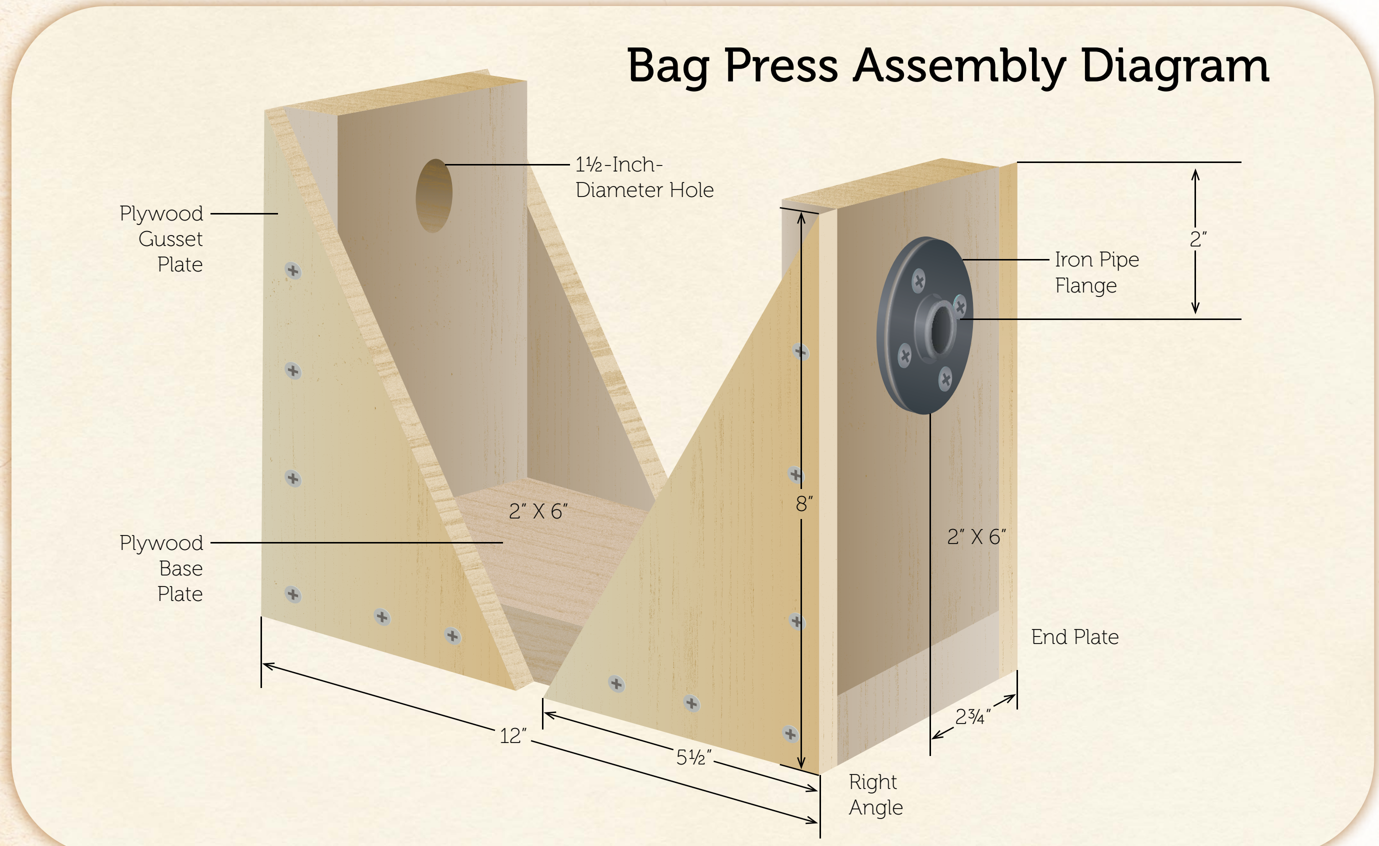


Figure 2.5: A sketch of all the parts of the bag press

2. Secure each 8-inch-long 2″×6″ piece with three long deck screws through the 12-inch 2″×6″ base piece.
3. Drive home the deck screws into the wood.
4. Attach the bracing triangles to the frame using the shorter deck screws (see Figure 2.6). Test the frame for rigidity.
5. Center the pipe flanges over the holes in the upright and attach, using the short #12 wood screws (see Figure 2.7).

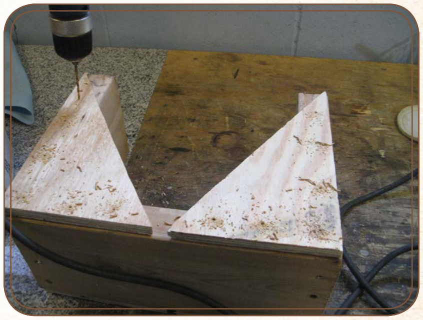


Figure 2.6: Attaching the bracing triangles

Figure 2.7: The frame with flanges attached

You've now built a sturdy bag-holding frame that is capable of withstanding the great stresses juice extraction creates. Next, you'll put the frame to the test by twisting the bag to squeeze out the precious liquid from your fruit.

To operate the bag press, follow these steps:

1. Place the loaf pan on the frame.
2. Insert a small quantity of soft, juicy fruit, such as grapes or peeled orange sections, into the bag.
3. Insert the ends of the bag through the holes in the uprights.
4. Insert one of the dowels through the pocket, centering the dowel on the flange hole.
5. Tie the open end of the bag around the middle of the remaining dowel, and your bag is finished (see Figure 2.8).
6. Now it's time to squeeze your fruit. As you rotate the dowels in opposite directions, the bag will tighten, squeezing juice into the loaf pan, and leaving the pulp in the bag.

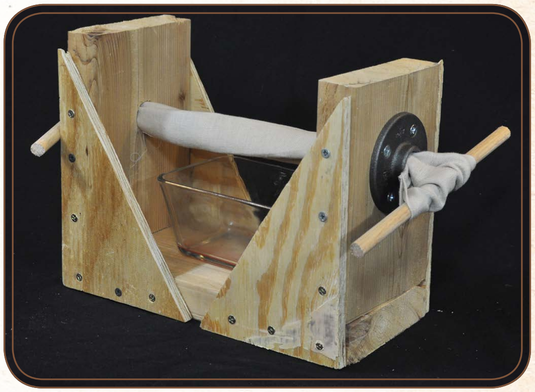


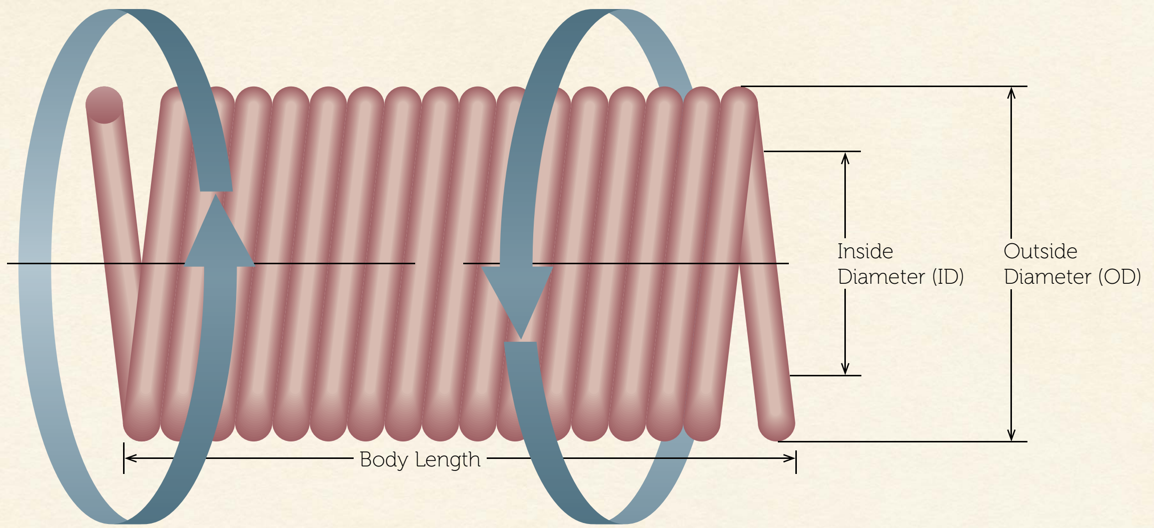
Figure 2.8: The assembled bag press

Pressing On

Why does twisting the ends of a cloth tube strung inside a rigid frame put a squeeze on the contents inside it? Well, that's a more complicated question to answer than you might think at first glance. Take a look at Figure 2.9.

Imagine that the cloth consists only of a great number of horizontal, nonstretchable

Wringing Out the Science



Unlike the oil lamp, the bag press qualifies as a machine. A machine, for our purposes, is a device that converts one type of force to another. There are many kinds of forces that engineers consider as they design machinery. The Egyptian bag press is a machine designed to convert one type of force (twisting or torsion) to another (squeezing or compression).

A torsional force is one that exerts a twisting force onto a shaft, or for the bag press, a cloth bag. What occurs in the bag is exactly what happens when you twist the ends of a wet towel to wring the water out of it. As you twist, the bag becomes narrow and stiff. This is because the forces you are exerting as you twist work perpendicularly to the surface, and all those forces are pointed toward the center of the bag. At the same time, these forces, called compressive forces, reduce the bag's diameter, crushing and squeezing anything inside the bag. If you operate the bag press, you'll find that twisting the bag becomes much harder as you continue to twist. That's because the ends of the bag pull inward against the bag press frame and the amount of friction working against you increases very quickly.

Figure 2.9: The bag press explained (Part 1)

threads in the shape of a hollow tube of length *x* (of course you probably realize that there are vertical threads as well, but we'll ignore these for now). When you twist those threads, the shape changes from a single hollow tube to two hollow cones that are touching, point to point. And since the horizontal threads don't stretch, and since the rigid frame maintains the distance from the ends as *x*, the diameter of the cones' bases shrinks. In other words, the volume of those two cones is much less than the volume of the original hollow tube. The squeeze is on!

If you add another twist, then the two hollow cones become four hollow cones, while the diameter of each cone continues to shrink, putting even more pressure on the contents inside the cloth (see Figure 2.10). This continues until either you stop twisting the ends or the threads rupture.

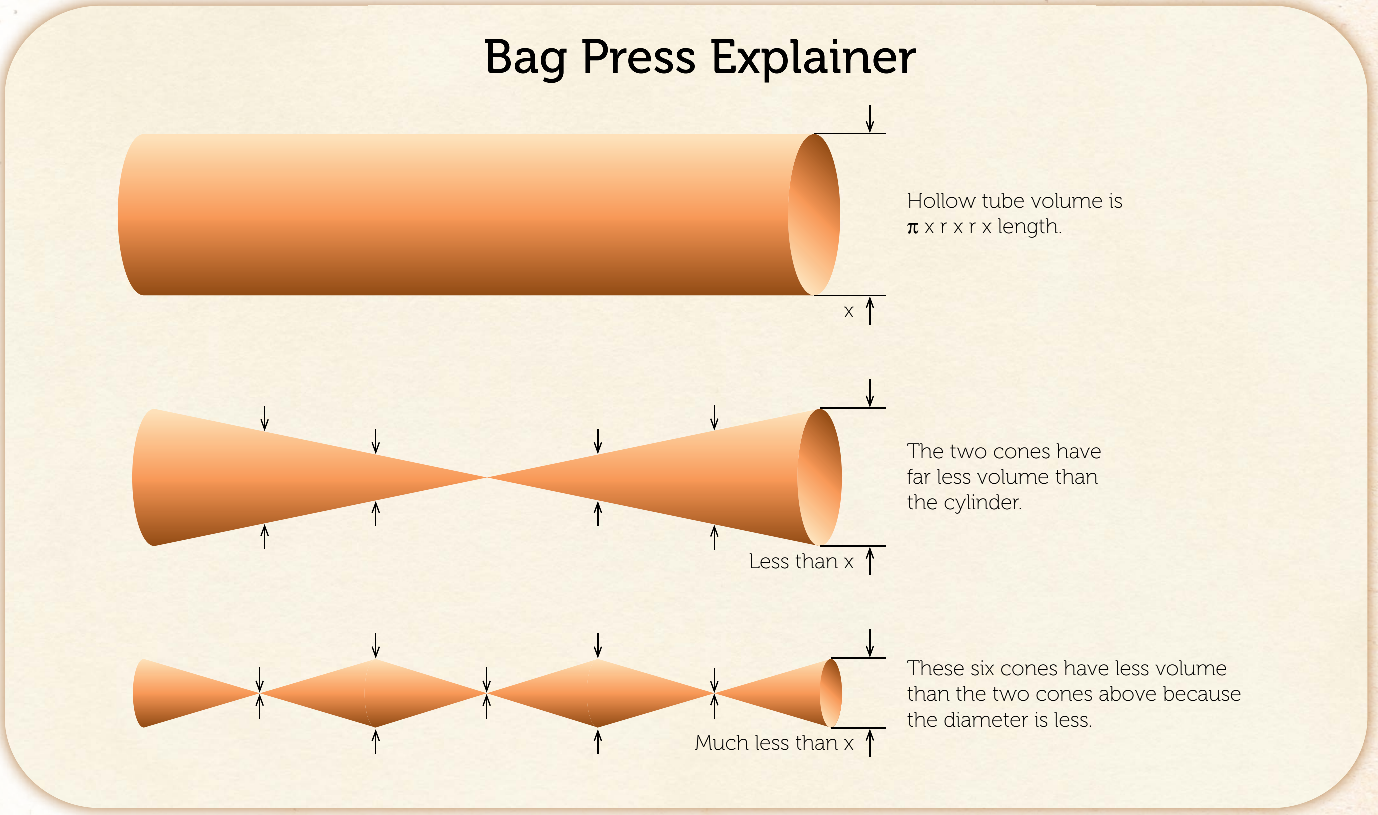


Figure 2.10: The bag press explained (Part 2)

Ctesibius and the Siphon

250 BCE

3

Starting around the 6th century BCE, Greek thinkers made the first great strides toward understanding the physical world. First came the astronomers, led by Thales of Miletus, who were followed by the mathematicians, such as Pythagoras and Euclid. Once the basic methods of scientific thinking were in place, the tap of knowledge was turned wide open, producing a stream of great thinkers in quick succession, including the famous scientists Archimedes, Aristotle, and a scientist who you may not know (yet), Ctesibius of Alexandria.

The Jokester of Alexandria

Although Ctesibius may not be as well-known as Greek scientists such as Archimedes, Aristotle, and Pythagoras, this Greek certainly deserves recognition as one of the world's first great engineers. He was, apparently, also a fellow who liked a good joke. He invented a moving statue that was carried on a cart in festival parades. The crowds lining the street were amazed to see the statue stand up and sit down, like a real person!

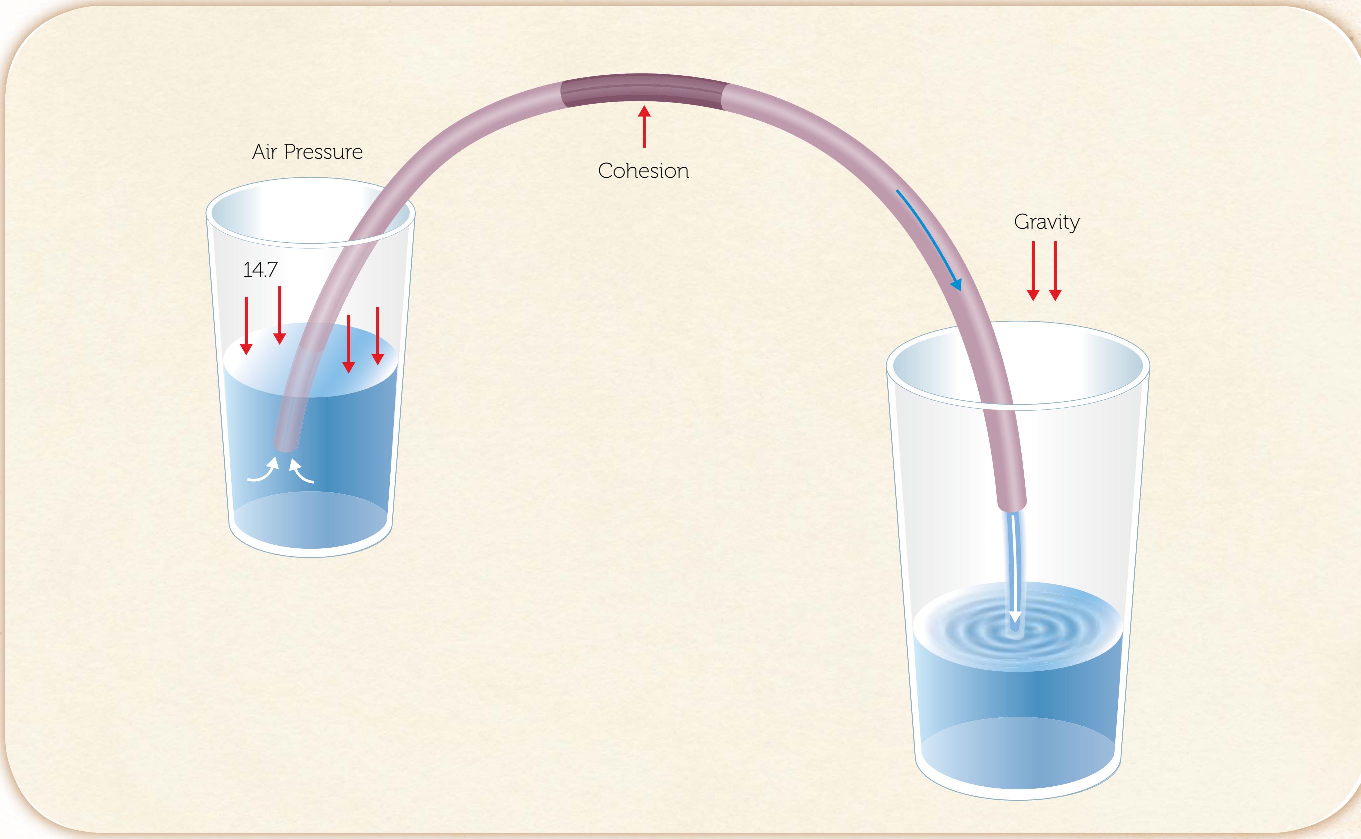
Ctesibius lived in the 3rd century BCE and is often referred to by modern scholars as "the father of pneumatics." *Pneumatics* is the engineering discipline that uses gases to make things move. One area in which Ctesibius's contributions were especially important was in machines that use siphons.

At one time, historians actually credited Ctesibius with inventing the siphon, but we know from more recent archeological studies that the siphon is much older. In 1500 BCE (during the reign of Pharaoh Amen-Hotep, and more than 1,000 years after Ptah-Hotep), Egyptian engravers etched several notable pictures on the walls of tombs at Thebes. These pictures show some of the earliest evidence that humans knew how siphons work.

One of these drawings shows a group of wine aficionados siphoning wine from several containers into a large punchbowl, presumably to produce a blend of superior flavor and bouquet. Beyond wine preparation, it appears that the ancient Egyptians used the siphon for many household purposes, including to purify drinking water.

Archeologists have also found that a few hundred years later, the Assyrians, under King Sennacherib, built a massive aqueduct to bring water to the then burgeoning city of Nineveh. A hill stood between the city and its water source, so a huge siphon was constructed to lift the water over it. This astounding piece of early engineering was conceived so masterfully that even modern hydraulic engineers could not improve on the technique until the 19th century.

Although siphons have been used for a very long time, it was the classical age Greeks, and Ctesibius in particular, who most carefully explored the scientific principles through which they work.



Even though siphons have been used since the time of ancient Egypt (and possibly well before), it seems that modern scientists still can't agree about the exact forces that make siphons work.

Many experts insist that siphons siphon because of the atmosphere. They contend that when a liquid within the siphon tube is "sucked" through the tube and over a higher point than at either end, the suction is due to a difference in atmospheric pressure between the high and low points in the tube. But when other scientists tested a siphon in a vacuum, they found it still worked. So some other explanation must be necessary.

Perhaps, say other scientists, they key ingredient is gravity, not air pressure. When liquid is sucked up the tube and over the hump, it's the force of gravity that continues to pull the liquid through the tube. Others say that small but numerous bonds between molecules pull other liquid molecules up and over. This theory, called the *chain model*, points to a phenomenon called *liquid cohesion* as the reason siphons work.

It may be that elements of all of these theories, or perhaps another not yet considered, may be at play. What we do know for sure is that siphons do work, and it's not easy to explain why.

Figure 3.1: How a siphon works

But despite Ctesibius's explorations and the generations of scientists who followed him, the exact mechanism through which siphons work, as Figure 3.1 shows, is still something of a mystery.

Like the siphon itself, we don't have all the details about Ctesibius's life. We do know he was probably either a barber at one time, or the son of a barber, and that his cleverness and ingenuity were such that he became quite famous. He rose from humble beginnings to become the head of the Library of Alexandria, which, at the time, was the greatest library on earth.

Ctesibius seemed to have a particular fondness for hydraulic and pneumatic things and siphons in particular. And, because he was a clever man with a wry sense of humor, he put the siphon to work in a number of different amusing inventions, including mechanical singing birds, a water-powered musical organ, and the *engibita*, which was apparently an automaton that could drink water and perform other lifelike acts.

The next project you'll build, called the Tantalus Cup, combines the science of siphons with a droll sense of humor. Did Ctesibius actually invent it? Well, no one can say for sure, but doubtlessly this is something that he would have found very amusing. And, his early research on how siphons work is the basis for how this cup works.

Designing and Building a Tantalus Cup

The Tantalus Cup is sometimes called a Pythagoras Cup despite the fact that Pythagoras did not invent it. The device itself is quite a clever joke: the cup works and acts like any other cup when it isn't filled with too much wine (or other liquid). But if the user fills the cup beyond a particular level, a hidden siphon empties the cup. So, if you get too greedy with your wine or juice, the cup teaches you a lesson in restraint and humility! Far cleverer than a run-of-the-mill dribble glass, it's a combination of a science lesson and a practical joke in one easy-to-make package.

Part 1: Preparing the Cup

To start the process of making your Tantalus Cup, follow these steps:

1. Begin by drilling a ¼-inch hole through the stem of the drinking cup as shown in Figure 3.2.
2. Next, file several openings in the bottom lip of the glass to make places for the water to exit (see Figure 3.3).

Now you're ready to make the siphon.

Materials

Plastic-stemmed drinking cup

Silicone glue/sealant

Option (A) 2½″-high pill bottle and a 2½″-long piece of ¼″ outside diameter (OD) copper or glass tubing

OR

Option (B) 6″ of ¼″ OD flexible plastic tubing and a 1″-long piece of 3/16″ OD aluminum tube and a small cable tie

OR

Option (C) 6″ of ¼-″ OD soft glass chemistry tubing

6″ of ¾″-diameter iron rod

Tools

Electric drill with 1/4″ bit

File

Hacksaw

Short length of 1½″-diameter iron pipe

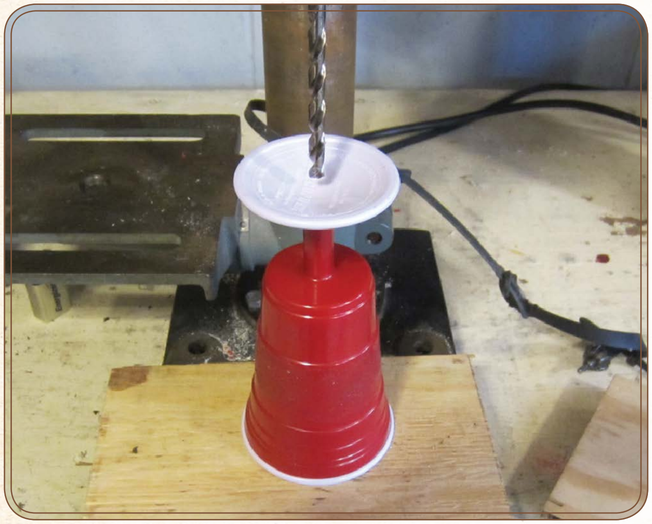


Figure 3.2: Drilling the hole

Figure 3.3: Filing the openings

Part 2: Making the Siphon

Before you begin, take a look at Figure 3.4 to get an idea of how this will work. As you'll see, you can make the siphon in three ways. Option A is slightly easier, but options B and C have nicer appearances.

Option (A): The Plastic Bottle Method

1. As shown in Diagram A in Figure 3.4, insert the 2½-inch tube into the hole you drilled into the stem of the drinking cup in Step 1.
2. The tube should extend about ½-inch into the hole. Fix it into place with the silicone sealant. Take care to spread the sealant so there is no leak where the tube enters the hole in the cup.

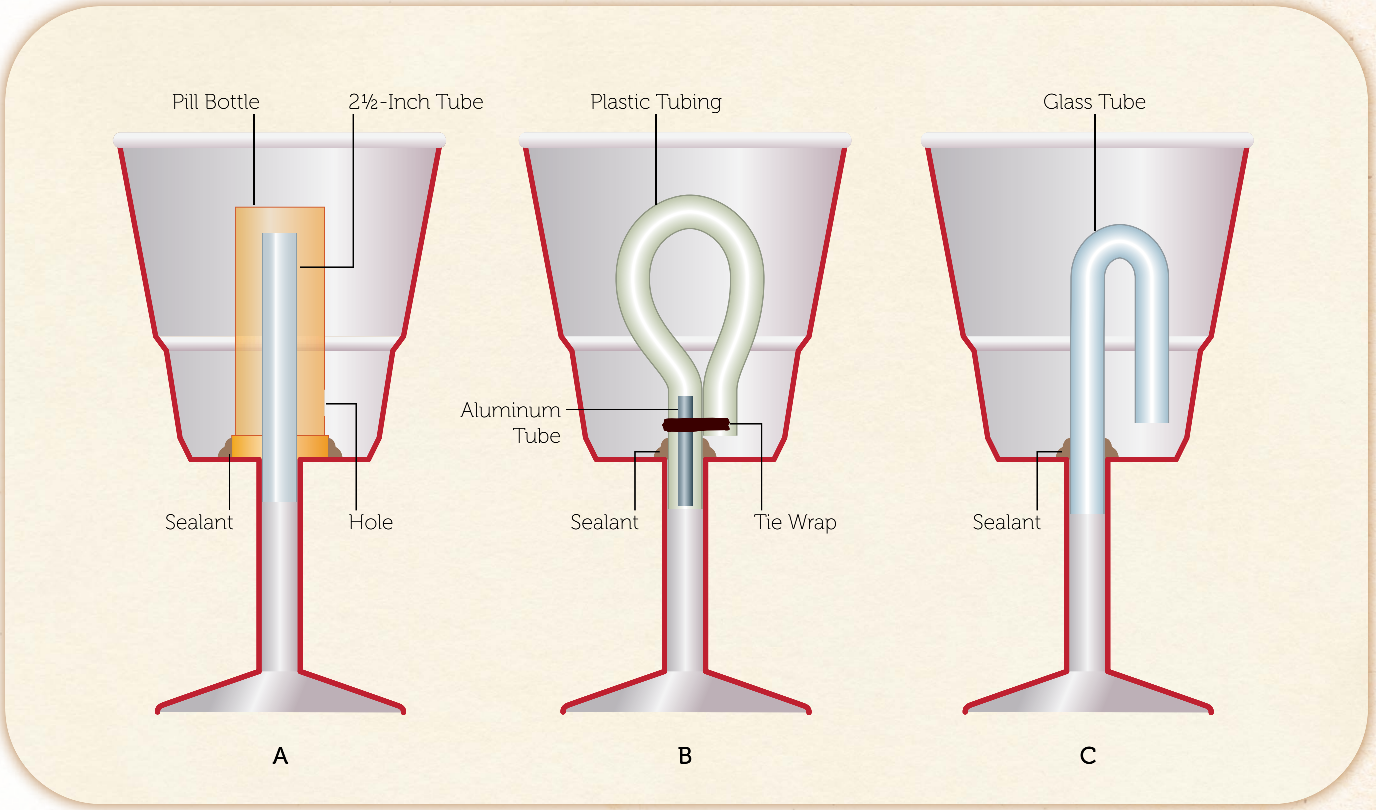


Figure 3.4: How to assemble the cup

3. While the silicone dries, use the file to make an opening in the lip of the pill bottle that is approximately ¼-inch by ¼-inch (see Figure 3.5).

4. Next, apply sealant to the lip of the pill bottle (taking care not to plug up the opening you just made with the file) and invert the pill bottle.

5. Press the pill bottle firmly onto the bottom of the cup and let it dry.

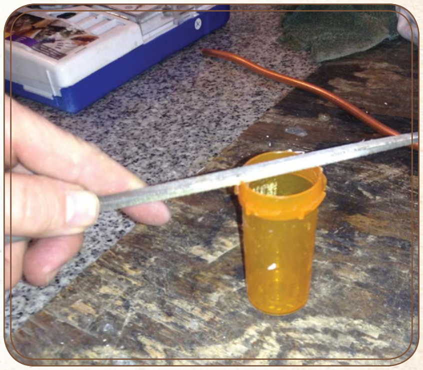


Figure 3.5: Filing an opening

Option (B): The Plastic Tube Method

Diagram B in Figure 3.4 shows how to assemble this project.

1. Insert the 1-inch-long aluminum tube halfway into the plastic tube and then insert the aluminum and plastic assembly into the hole that you drilled in the bottom of the drinking cup in Step 1.
2. Add silicone sealant to the joint.
3. Let it dry.
4. Bend the plastic into a loop so the open end is ¼-inch above the bottom of the cup. Fix it into place with a cable tie (see Figure 3.6).

Figure 3.6: The installed loop

Option (C): The Glass Tube Method

1. Light a propane or butane torch.
2. Don heat-proof gloves.
3. Refer to Diagram C in Figure 3.4 to see what you're aiming for and then rotate the section of the tubing to be bent as you hold it in the center of the flame.
4. When the glass becomes soft, remove the tube from the flame and quickly bend it around the metal rod so it forms a 180-degree turn (see Figure 3.7).
5. Once the tube is cool, insert the long leg of the glass tube in the hole as shown in Diagram C. Add silicone adhesive to the joint and let it dry.

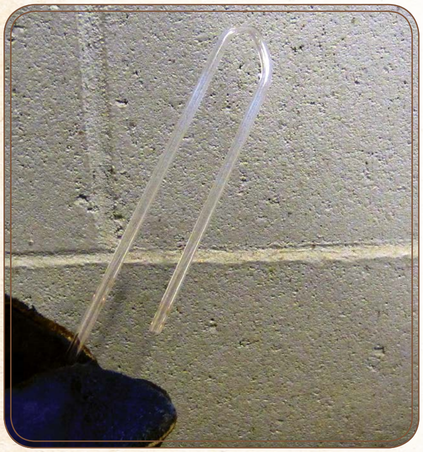


Figure 3.7: The finished tube

Note: Propane torches must be used according to the manufacturer's instructions. They should be used only by adults or under close adult supervision.

Exploring Siphons with the Tantalus Cup

The legend of the Tantalus Cup is that it was designed to teach moderation. The cup appears normal, except for the copper coil or plastic column inside. If you pour a small to moderate amount of water or wine into the cup, you can then drink out of it in a normal fashion. But if you fill the cup to the brim (actually, to any level over the height of the siphon assembly) the cup will empty itself! Every last drop will drain out from a hole in the stem, and you won't get a drink at all.

The trick is that there is a hidden siphon in the cup. When the water level is below the level required for the siphon to actuate, nothing happens—the cup is just a cup. But if the cup's owner adds so much liquid that the level rises above the activation point, the siphon kicks in and the glass empties out completely, dribbling its contents out the bottom of the cup via secret holes.

Let that be a lesson to live in moderation!

Archimedes and the Water Screw

200 BCE

4

Thousands of years ago, mechanical irrigation first made it possible to grow food in times of low rainfall. Without irrigation, the great civilizations of ancient Egypt, China, and Mesopotamia could not have risen. There were many types of ancient irrigation technologies, including dams, canals, and human- or animal-powered pumps. One of the first really useful pumps was called the water screw.

Re-creating the Invention That Made the Desert Bloom

Archimedes, the great mathematician of ancient Syracuse, was said to be something of an oddball. Apparently, he would become so involved with whatever project he was working on that he simply would forgo everything else, including eating and drinking. Even worse, at least for his assistants, was that he would forget to bathe and clean himself. On occasion, his coworkers would get so fed up with Archimedes that they would lift him up and bodily drag him to the public bath and wash away some of the stink.

Despite his lack of hygiene, so great was his genius, and so prodigious was his intellect, that the rich and powerful of the city would come to him, beseeching him to solve their most pressing technological problems.

A prime example of an important Archimedean invention was the *water screw*, a simple but effective device that provided ancient farmers with a better way to grow crops. By dipping one end of the machine into a river or stream and rotating its auger-like conveyor, farmers could irrigate large tracts of otherwise arid farmland (see Figure 4.1).

Archimedes' water screw was a technological breakthrough. The device was later adapted throughout the ancient world and also put to use removing water from the bilges of ships and pumping water and muck out of mines.

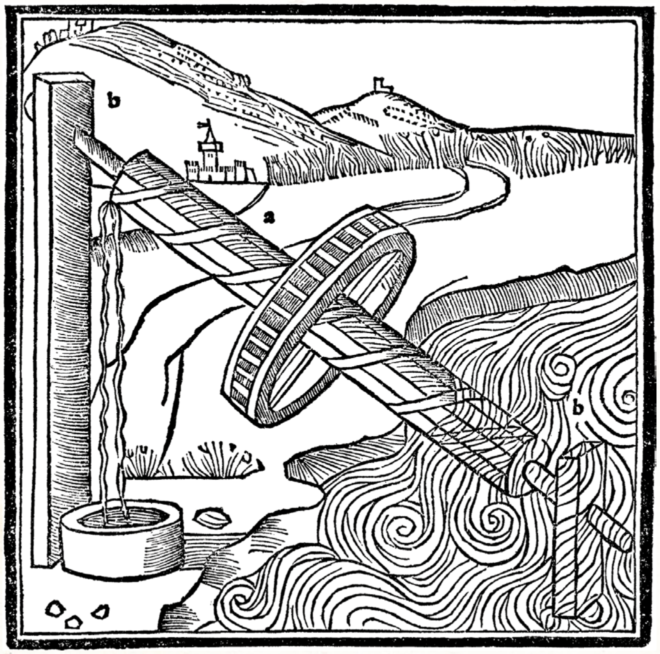


Figure 4.1: Water screw woodcut

The Genius of Archimedes' Water Screw

Water screws are still quite common. They transport liquids in sewage treatment plants, fish hatcheries, and farmlands; they move solids in coal mines, grain elevators, snowblowers, and a host of other devices.

At first glance, the manner in which Archimedes' water screw works is something of a mystery. Just how does turning a crank cause water to rise and move?

A mechanical engineer would classify Archimedes' water screw as a simple type of progressive cavity pump. In this sort of pump, a water-holding cavity progresses up a twisting path from the water inlet at the bottom to the discharge spout at the top of the pump (see Figure 4.2).

If you're still having trouble imagining exactly how Archimedes' water screw works, try to picture what happens to a small ball if you place it in the screw-auger mouth at the bottom of the device. The ball rests in the depression defined by the curve of the screw. As the crank is turned, the instantaneous location of the ball-holding cavity moves up the centerline of the screw, and so, too, does the ball.

Old Greek-style water screws like this have been examined by scientists, who have found them to be about 30 efficient. This means that about a third of the energy you put into cranking the spiral around and around actually goes into lifting the water.

Replacing the ball with water makes visualizing what's going on with the screw a bit harder. And, if you want to get mathematical about it, you'll need a lot of pencil lead and time, because in order to calculate the volume of water you will move with one turn of the screw, you need to manipulate many different parameters, including the radius and angle of the screw, the ratio of the screw's outer and inner cylinders, and the pitch of the blades.

But that's likely more detail than you are interested in. Suffice it to say that if you understand that a screw pump works because it simply creates a cavity that is formed by the screw blade and the side of the tube, and that the cavity moves upward with each turn of the screw, you have a rough idea of how a water screw pump works.

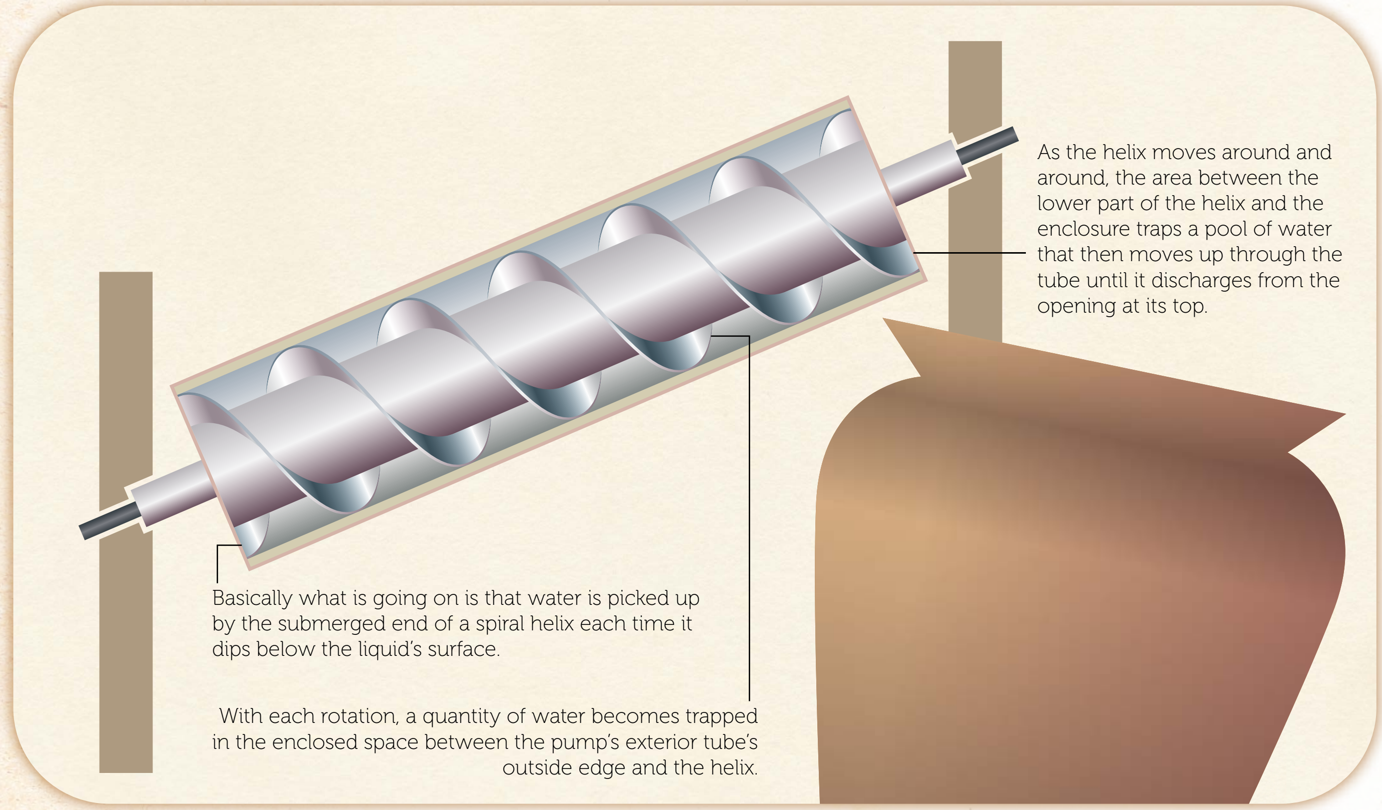


Figure 4.2: How a water screw works

Making a Water Screw Pump

Building a traditional screw pump takes a lot of woodworking skill. But luckily for us, we can greatly simplify re-creating Archimedes' water screw by using a great invention of the 20th century—inexpensive plastic tubing. Building a model screw pump this way is quick and simple, and such a pump has the advantage of being easy to reconfigure, so many experiments are possible.

Here's what you'll need and how to build a water pump that works on the same principle as Archimedes' original screw.

Assembling the Water Screw

To make the water screw pump, follow these steps:

1. Fasten the bottom end of the first hose piece, as shown in Figure 4.3, to the area near the bottom of the incline tube using a deck screw.
2. Screw through the hose's inner wall only (the wall that's touching the PVC pipe) because you want its mouth to remain open and unobstructed.
3. Wrap the tube around the incline tube using a 4-to-1 pitch (see Figure 4.3) and fasten the upper end to the incline tube with another deck screw in the same fashion.
4. Cut off any excess tubing with a pair of scissors.
5. If you desire, add a second, third, or even fourth hose to the incline tube next to the first. Again, fasten each to the incline tube using deck screws.

   Now you should build a base for the screw pump.
6. Assemble the 45-degree elbow, a 1-inch-long pipe, the pipe union (not screwed too tight), another

Materials

Plastic or rubber hose, ½″ in diameter, cut into 32″ lengths (You'll need between 1 and 4 of these.)

PVC pipe, 1″ diameter, 38½″ total length, cut into the following lengths: 22″ (1), 6″ (2), and 1½″ (3)

The following PVC pipe fittings, all 1″ diameter: 90° elbows (2), cap (1), union (1), 45° elbow (1), flange (1)

A flat, heavy weight, such as a barbell plate

A shim, 15°

Deck screws, 1⅝″ (1 box)

Screwdriver to match your deck screws

1-inch-long pipe, the flange, and the weight, as shown in Figure 4.3. (You may have to improvise a bit to attach the flange to the weight.)

7. Cement the pipe fittings and place the 15-degree shim under the flange so the screw is held at an angle of about 30 degrees from horizontal.

8. Build a crank for the upper end of the screw from the two 6-inch lengths of pipe, the two elbow fittings, and the cap.

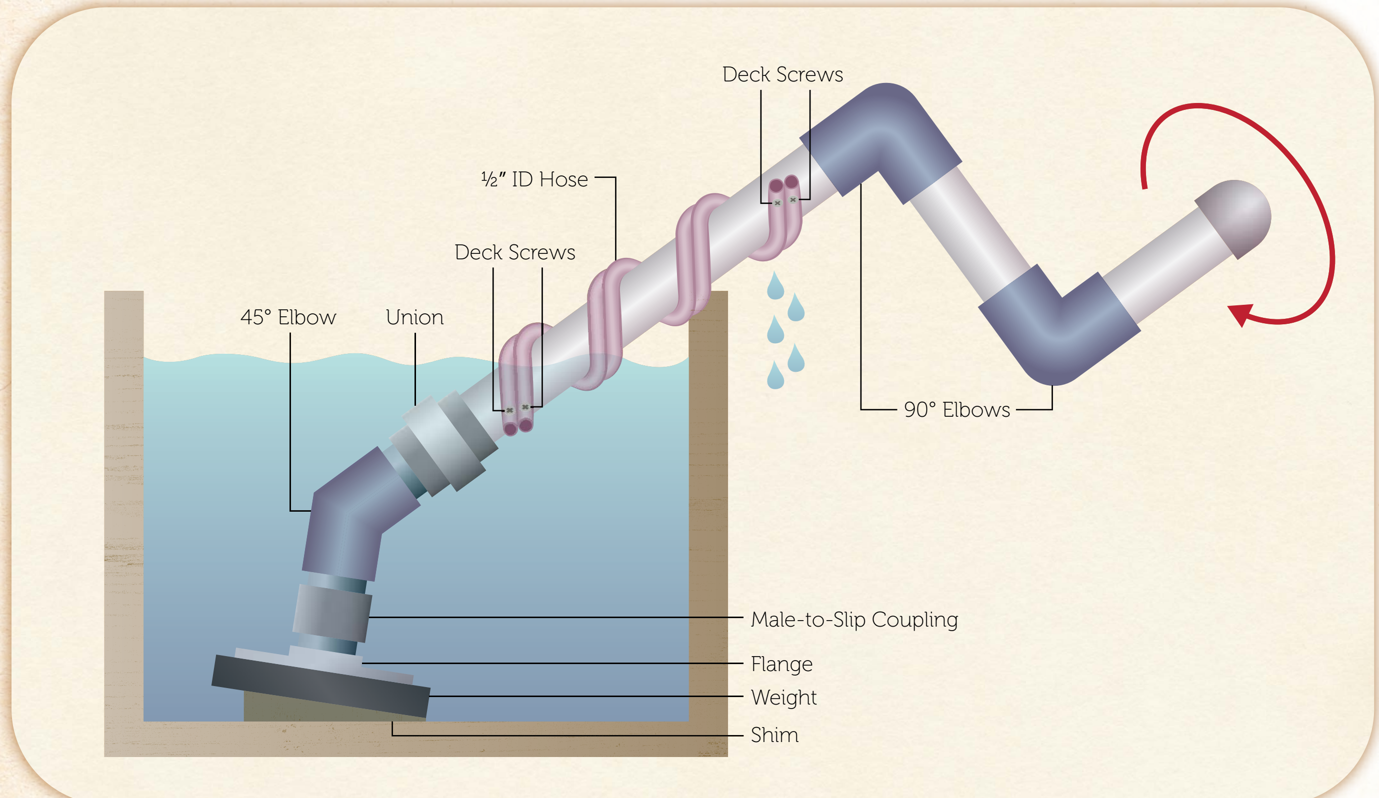


Figure 4.3: Assembling the water screw pump

9. To operate the screw pump, place its bottom end in the water.

10. Turn the crank so that as the screw rotates, the open end of the tubing scoops up water. With each subsequent turn, the scoop of water will rise one pitch-length up the screw shaft, finally emptying the water out at the top.

Explorimenting with Your Water Screw

In the first century CE, the Roman architect Marcus Vitruvius studied the work of Archimedes and figured out ways to make the original water screw work a bit better.

You can do the same. Although the water screw is simple, it lends itself to a host of science experiments. For example, you can easily experiment with a number of parameters, including these:

- Finding the best angle between the PVC shaft bearing the spiral tube and the vertical
- Determining the number of turns of tubing around the shaft and documenting the volume of water moved and the effort it takes to move it
- Discovering the effect that the diameter of tubing has on the volume of water moved and the time it takes to move it

Heron of Alexandria and the Gin Pole

50 CE

5

Ancient Alexandria was hotbed of scientific discovery. Euclid, the father of geometry, lived there, as did Eratosthenes, the mathematician who first measured the circumference of the earth. In Chapter 3, we met Ctesibius when we explored his siphons, and now we'll explore the work of Heron, perhaps Alexandria's earliest, if not its greatest, mechanical engineer.

You Can Lift Heavy Things

Prior to the 5th or 6th century BCE, the only ways to raise a heavy object were to either climb up on a ladder, put a rope over the object to be lifted, and pull, or, if you had enough time, build a ramp. The ancient Egyptians, who had a lot of people and a lot of time, much favored the ramp technique, and the great pyramids show that very durable things could be built this way.

But the Egyptians eventually did come up with better ways to hoist stuff. Around 1500 BCE, Nile farmers invented a counterbalanced lifting device called a *swape* that they used to irrigate their crops. With a swape, sometimes also called a *shadouf* (see Figure 5.1), they could lift buckets of water or baskets of rocks to a height of nearly 15 feet.

Figure 5.1: A shadouf in action

Fifteen feet was more or less the limit for machine-assisted lifting for 1,000 years—until the Greeks mounted a pulley on the end of a pole and thus invented the construction crane in the 6th century BCE. They soon realized that with such a device, the sky was the limit.

Who engineered those first cranes? Their names are lost; only their marks remain on the stones of the classical Greek temples. It is through the books of Heron (Hero) of Alexandria (c. CE 10–70), written by Heron, a Greek engineer who lived in Roman Egypt, that we first become well acquainted with the ancient construction cranes. The cranes Heron describes were simple affairs to look at, but they were world changers. Dependable and efficient lifters, they made it possible to build buildings taller than two stories without ramps.

Sadly, there just aren't enough records to provide an understanding of what kind of person Heron was. But we can glean a bit of insight by reading between the lines of his writings on mathematics and mechanics. Certainly, he was well educated and he appeared to have been strongly influenced by Ctesibius of Alexandria, who we met in Chapter 3. Heron may even have been Ctesibius's student.

Like Ctesibius before him, Heron appears to have been a clever sort of fellow, often using ingenious means to attain his goals. For example, Heron is often credited with designing the first coin-operated vending machine. He built a machine that dispensed holy water to be used in the Greek temple in Alexandria. When a temple visitor put a coin in a slot, the water valve would open for a predetermined amount of time and dispense a measured quantity of holy water from the spigot (see Figure 5.2).

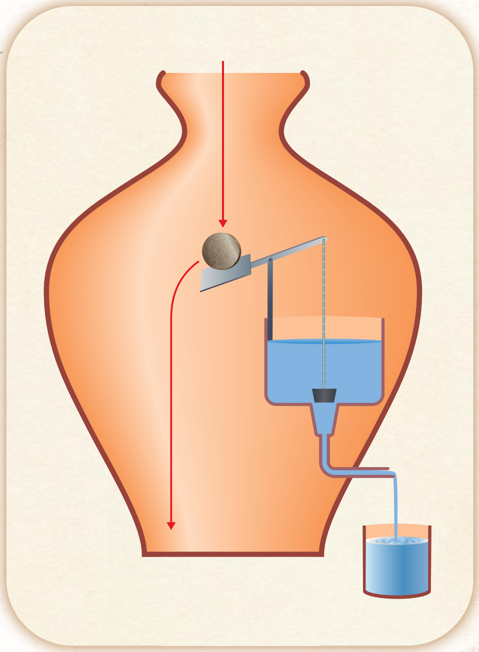


Figure 5.2: The first coin-operated vending machine

Heron's Ancient Crane

Heron's ancient crane is basically a long, strong pole, held in place with anchored ropes, with a strong ring attached at the top. Ancient crane makers looped a rope through the ring and tied one end of the rope to the thing they wanted to lift. To the other end of the rope, they connected a big wheel called a *windlass*. This became the standard tool in building construction for the next millennium and a half. That ancient, one-masted crane lives on today in an incarnation known as the *gin pole*.

The gin pole is the simplest crane possible; it consists of a single upright spar with hoisting tackle at the top and a system of loops to direct the ropework. In this setup, there's no heavy base or counterweight to deal with. Instead, a system of guy lines stabilizes the spar and its bottom is constrained by simply being placed in a shallow hole. The gin pole

Materials

100′ Manila hemp rope, 3/8″ in diameter

(1) 3″×3″×8′ long landscape timber, round—your gin pole

(8) Wooden dowels, 1″ to 1½″ in diameter, 24″ long—your stakes

Triple-pulley block and tackle with at least 60′ of rope—your hoist (These are available inexpensively at places such as Harbor Freight, Tractor Supply, and Amazon.)

(4) Pine blocks, 2″×2″×1″—your cleats

(1) Large screw eye

(12) 8d nails

(4) ½″ dowels, all 12″ long—your Spanish windlass

Tools

Saw

Mallet or sledgehammer

Shovel

Hammer

can handle a lot of weight. For example, a 6-inch diameter, 20-foot-long wood pole rig can heft more than two tons.

But, and this is a big but, such enormous lifting capacity comes with inherent risks. Having spent time using a gin pole and other lifting equipment, I can tell you that lifting heavy objects can be a dangerous business if it is done improperly. Inadequate staking, poorly tied knots, undersized masts, or old, weak ropes can result in a broken rig and a bad situation. Rigging is an art, so start small, and increase your loads slowly as you become more proficient. And remember, *never* get under the load or mast during a lift!

Building a Gin Pole Crane

The gin pole is the aspirin of construction equipment—it's a simple type of crane that's been around a long time and it still works great. Used mostly for vertical lifts, the gin pole can hoist a load up to 50 feet.

Before you begin making your gin pole, please take a look at Figure 5.3 so you have a visual of what you are going to build. You'll need to tie a simple type of knot called a clove hitch to attach ropes to the wooden pole. A Boy Scout manual or other knot handbook will show you how, if you don't already know.

Follow these steps to build your gin pole:

1. Dig a hole 8 to 10 inches deep a short distance from the load you want to lift. The distance from the gin pole to the load should be no more than one third the length of the pole.

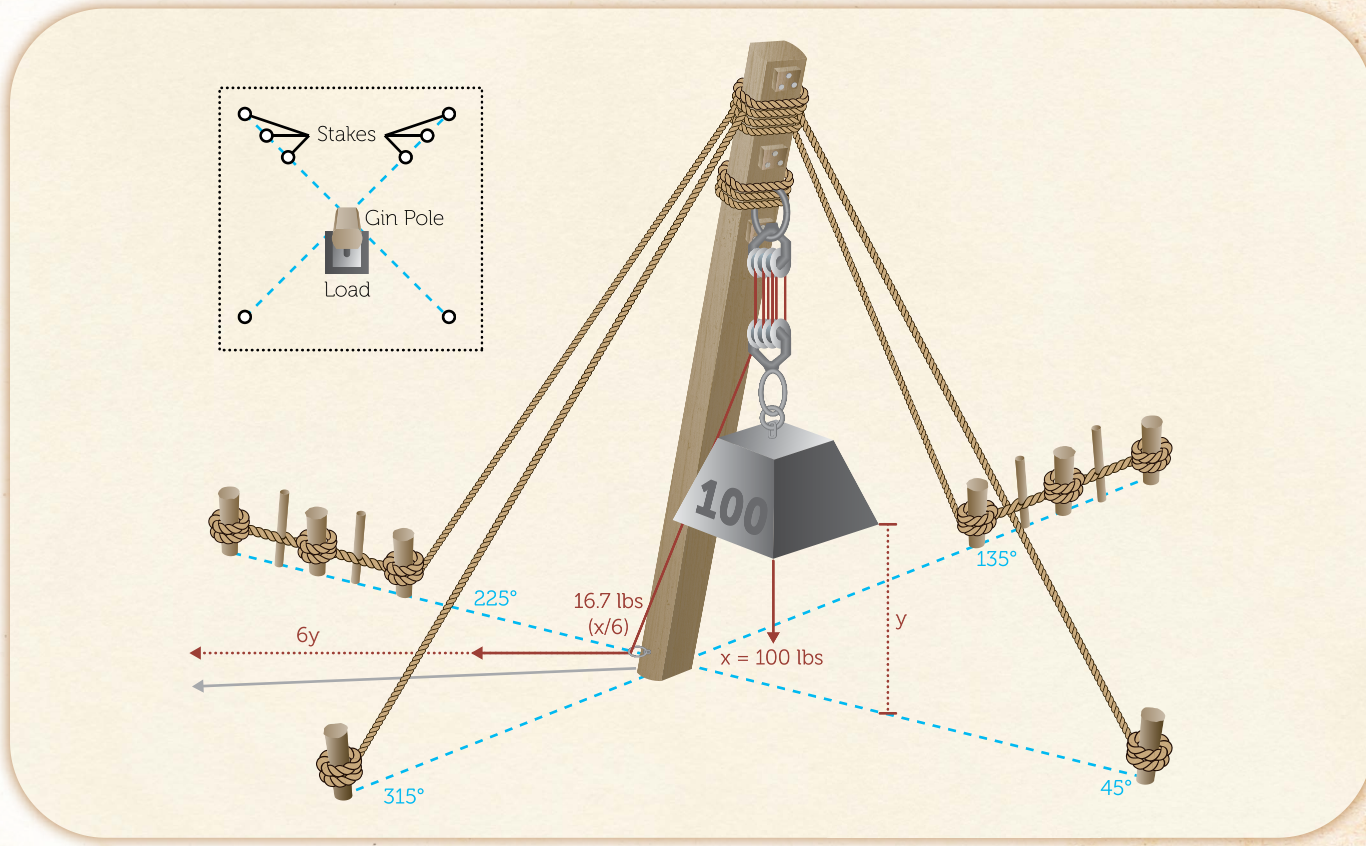


Figure 5.3: The gin pole diagram

2. Attach cleats to the gin pole with three nails per cleat, as shown in Figure 5.4. The cleats will keep the ropes from sliding down the pole.

3. Attach the screw eye to the pole about 1 foot from the lower end.

4. Next, connect the hoist by lashing the upper block and tackle hook to the top of the gin pole just above the lower cleat.

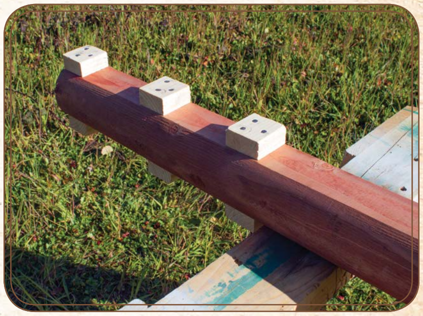


Figure 5.4: Attaching the cleats

5. Loop the rope around the hook three times and then use a secure knot such as a clove hitch to tie off (see Figure 5.5). This is known as the fixed block.

6. Now cut four guy lines, each about 20 feet long.

7. Place the gin pole on its side and tie four clove hitch knots just above the upper cleat (see Figure 5.6). Tie the knots so that when each guy line extends straight out, the rope is not bent or doubled back.

8. Position the stakes so they are all 9 feet from the hole you dug at these compass points—45 degrees, 135 degrees, 225 degrees, and 315 degrees—all measured from the imaginary line that extends between the load and the hole.

9. Pound in the stakes until about 8 inches of the stakes remain exposed, at an angle of about 25 degrees from vertical, extending away from the pole.

   Staking things is a skill in and of itself. Depending on the weight of the load you are trying to lift, *a lot* of force

Figure 5.5: The hoist attached to the gin pole

Figure 5.6: Adding guy lines to the gin pole

will be pulling on those stakes. Make sure you use the 1-1-1 staking technique (shown in Figure 5.7) to increase the holding power of the rear guy lines at 135 and 225 degrees (the front guy lines don't hold much, if any, load).

To complete the 1-1-1 staking process, follow these steps:

a. Place three stakes in a line, spaced about 1 foot apart, and connect each to the others.

b. Insert a twisting pole, called a *Spanish windlass*, in the middle of each rope loop and twist the loop until the connecting rope is nice and taut. Securely anchor one end of the Spanish windlass against the ground (see Figure 5.7).

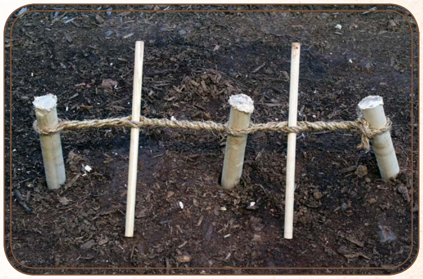


Figure 5.7: Staking the gin pole

10. Now that you have your stakes positioned, place the lower end (the end closer to the screw eye) of the gin pole into the hole you dug. Angle your crane so that the hoist is directly over the load.

    To do so, have a helper hold the pole while you extend the rear guy lines (the lines at 135 degrees and 225 degrees) to the stakes and tie them each off with a secure knot like a clove hitch.

11. Now extend the guy lines to the stakes at 45 degrees and 315 degrees. When you actually start to lift, these lines will go slack, because all of the weight will be borne by the gin pole and two rear guys, but you need to tie them off securely anyway.

12. Now rig your triple block and tackle and thread the load rope through the screw eye.

13. After your block and tackle is attached, you need to attach the load to the bottom pulley block; this is the moving block.

14. Now to put your gin pole to use, all you need to do is pull steadily on the load rope. The weight will slowly rise (see Figure 5.8).

    Your ancient crane is now giving you a 6:1 mechanical advantage. The amount of weight that your gin pole can handle depends on the length and thickness of the gin pole, the capacity of the rope, the quality of your knots, and the holding power of the stakes. Take it easy to begin with as you learn the capability of your rig.

Once you get the hang of it, there's almost no limit to what you can lift!

Figure 5.8: The gin pole being put to nefarious use

The Science of Lifting of Heavy Things

Heron's original manuscript on how to lift stuff, a tome called *Mechanics or the Elevator*, was lost. Luckily, Arabic translations survived with the no-nonsense title *Book about the Lifting of Heavy Things*. One of the really big ideas in Heron's book is that of using a force-amplifying block and tackle rig (a system of ropes and pulleys) attached to the top of the crane that allows a person to lift heavy objects by trading displacement for force. As the diagram in Figure 5.9 shows, with a single block and tackle (where one pulley is fixed and the other moves), you can lift a weight of x pounds to a height of y feet by applying a force of only $\frac{1}{2}x$ if you are willing to pull on the rope for $2y$ feet. That's a 2:1 mechanical advantage! This bit of knowledge may be well-known now, but in ancient Greece, this was an incredible insight.

Figure 5.9 shows how the 2:1 mechanical advantage actually occurs. Instead of a single rope bearing the entire weight, the addition of a second pulley means that the weight is now suspended by ropes from two pulleys rather than one. So, the weight is split between the two pulleys, and each rope supports only half of the total weight.

So, to hold the weight of say, 100 pounds, suspended in the air, you only need to apply 50 pounds of force to the rope holding the 100-pound weight.

There is, of course, that trade-off we discussed a few paragraphs earlier. If you want to lift the weight 10 feet higher (y feet), then you have to pull in 20 feet ($2y$ feet) of rope. There's no free lunch in the world of physics. That's the bargain that Heron made—with his crane, the force you need to pull the weight has been cut in half, but the distance you have to pull the rope is twice as long.

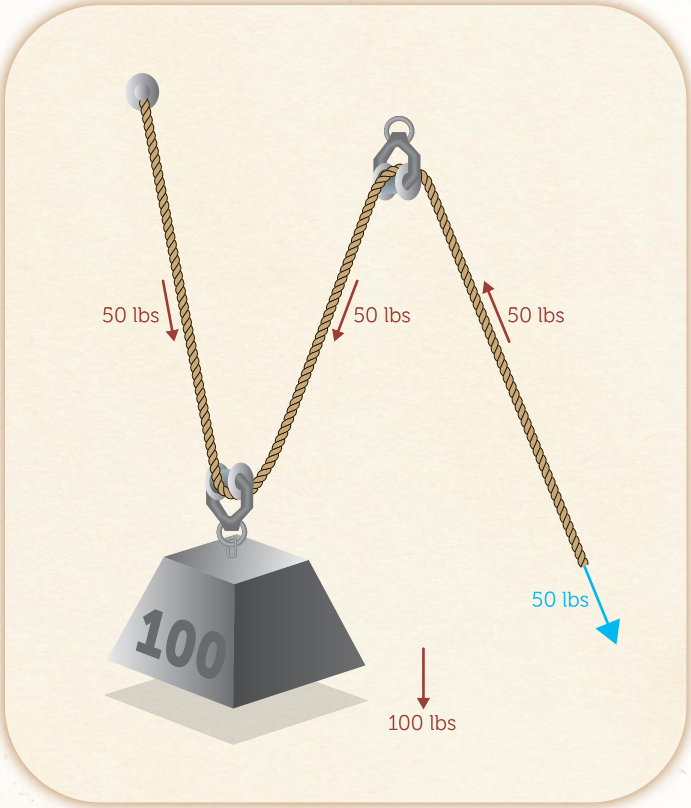


Figure 5.9: How a block and tackle works

Part 2

The Hall of Medieval Makers

The pace of invention during the Middle Ages is often considered to have been pretty sluggish. But that doesn't mean that the inventions that were conceived were not important.

In fact, lots of valuable things were invented, or at least improved upon, and some of those things are still around today.

For example, the medieval period was the golden age of castle building. Some of the medieval architects were incredibly talented, and the builders of that time really knew their way around Heron's gin pole crane!

Another important advance by medieval makers was the heavy steel plow. Early plows, like those of the Egyptians, were simply sharp sticks dragged behind an ox or horse that scraped a furrow in the ground. But that sort of plow wouldn't work in heavy soil or fields with lots of rocks. Around 600 CE, big, heavy, and strong iron plow blades became popular, and, as a result, farmers were able to grow a lot more food.

In addition to the plow, perhaps the greatest example of Middle Ages technology was the water mill. Although the classical Greeks invented it, its popularity really exploded during the Middle Ages. With all the additional grain that was made available by the use of the heavy steel plow, millers and their water mills were put to work. With water-powered grindstones, they could process the grain efficiently, which led population growth all over the world.

But who made the tools, fasteners, and other items required to build the castles, the plows, and the mills? In the next chapter, we meet the master makers of the Middle Ages—the blacksmiths.

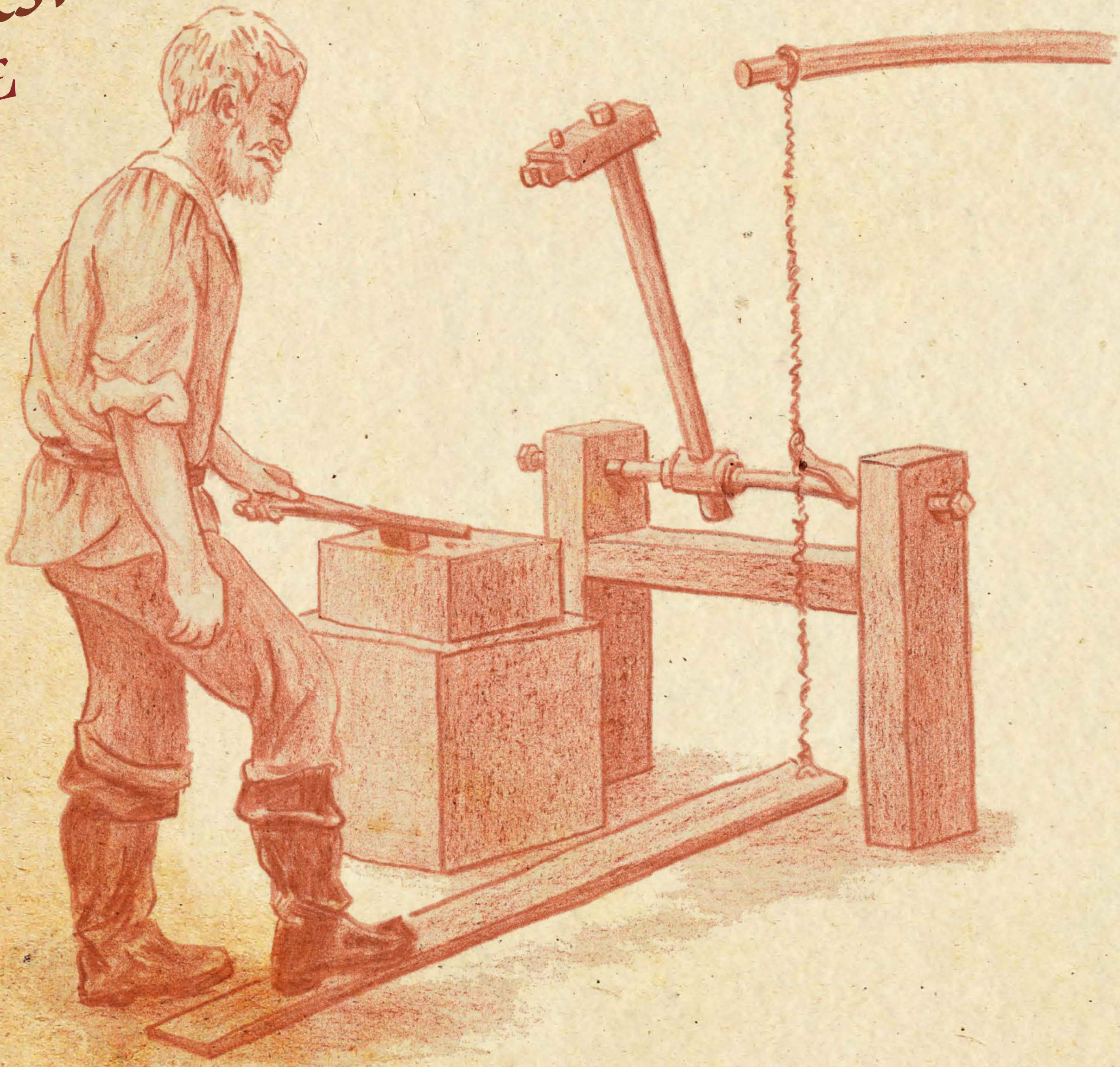
The word *smith* means metal worker and comes from the word *smite*, which, in Olde England, meant "to hit." There were two general types of smiths. Blacksmiths worked with black metals, which meant iron, and whitesmiths worked on copper, tin, and just about everything else. It took a long time for a blacksmith to become proficient at his trade, but once he did, he was one of the most important tradesmen in any village.

Besides know-how, it takes tools to become a smith. This list describes a few of the most important.

- **Anvils**—Large, specially-shaped iron blocks upon which the smith would smite heated metal pieces to their desired shape.
- **Bellows**—A squeezable bag with a nozzle, used to stoke the coal and wood fires of the blacksmith's forge.
- **Forge**—The hearth used for heating metals. The blacksmith's forge was one hot place, because iron has to be heated to a very high temperature in order for it to be shaped.
- **Hammers**—Every smith had a variety of these all-important smiting tools.
- **Swages**—Iron molds were used for forming metal into various shapes. Using hammers, the smith would pound the hot metal work piece against the swage to shape it.
- **Tongs**—Long, jointed tools used to grip and lift hot metal objects.

The Medieval Blacksmith and the Oliver

1300 CE



6

Before the Industrial Revolution, most smaller cities and towns depended on local blacksmiths to make the iron tools and fasteners needed for daily life. Without a doubt, blacksmithing was hot, hard work. But the invention of the foot-operated hammer, or Oliver, made it possible for the smith to produce more items faster and with a bit less effort.

Constructing the Big Hammer of the Middle Ages

If you examine the nails that hold medieval European buildings together, you'll find they are very different from the nails available at today's hardware stores. Believe it or not, in many ways, medieval nails were better than the modern ones we use now. Modern nails are sliced from a strand of hardened wire by machines; the end of each nail is then cut mechanically so it becomes round and pointed. When you pound a modern wire nail into wood, the hammer blows force it between the individual fibers of the wood. Such nails work adequately in softwoods, like pine and fir, but they often split hardwoods, like maple or walnut.

The medieval iron nail is an entirely different animal. Each nail was wrought individually by a blacksmith; that is, it was beaten into shape by hammer blows. The wrought iron nail is rectangular in cross section with a hand-filed chisel point. The chisel point doesn't simply push wood fibers aside; it actually cuts through the wood fibers. Wrought nails can even be driven into oak without splitting it, and once they're in, they are nearly impossible to remove.

Of course, wrought nails, like just about everything else a smith made, required a lot of effort. To make a nail, the muscular smith heated a bar of iron to red hot in his forge. Then, he hammered the bar into a thin, square rod and squashed one end into a flattened point. Next, he reheated the nail and, using a special form, he banged the other end with an even bigger hammer to form the nail head.

Large-scale nail making was invented by the Romans and continued on without much change until a nameless, but clever, 14th-century blacksmith in the north of England came up with a better idea—one that allowed him to leverage gravity and substitute the far larger muscles in his legs for the relatively puny muscles in his arms. This invention, which came to be called the Oliver, revolutionized ironworking.

An *Oliver* is a type of machine also known as a *lift hammer*. The Oliver uses a sapling (the wood of the holly tree was preferred by English smiths) as a tension spring to pull up a hammer attached to an axle that is operated by a foot-operated treadle (see Figure 6.1). To pound the metal, the smith

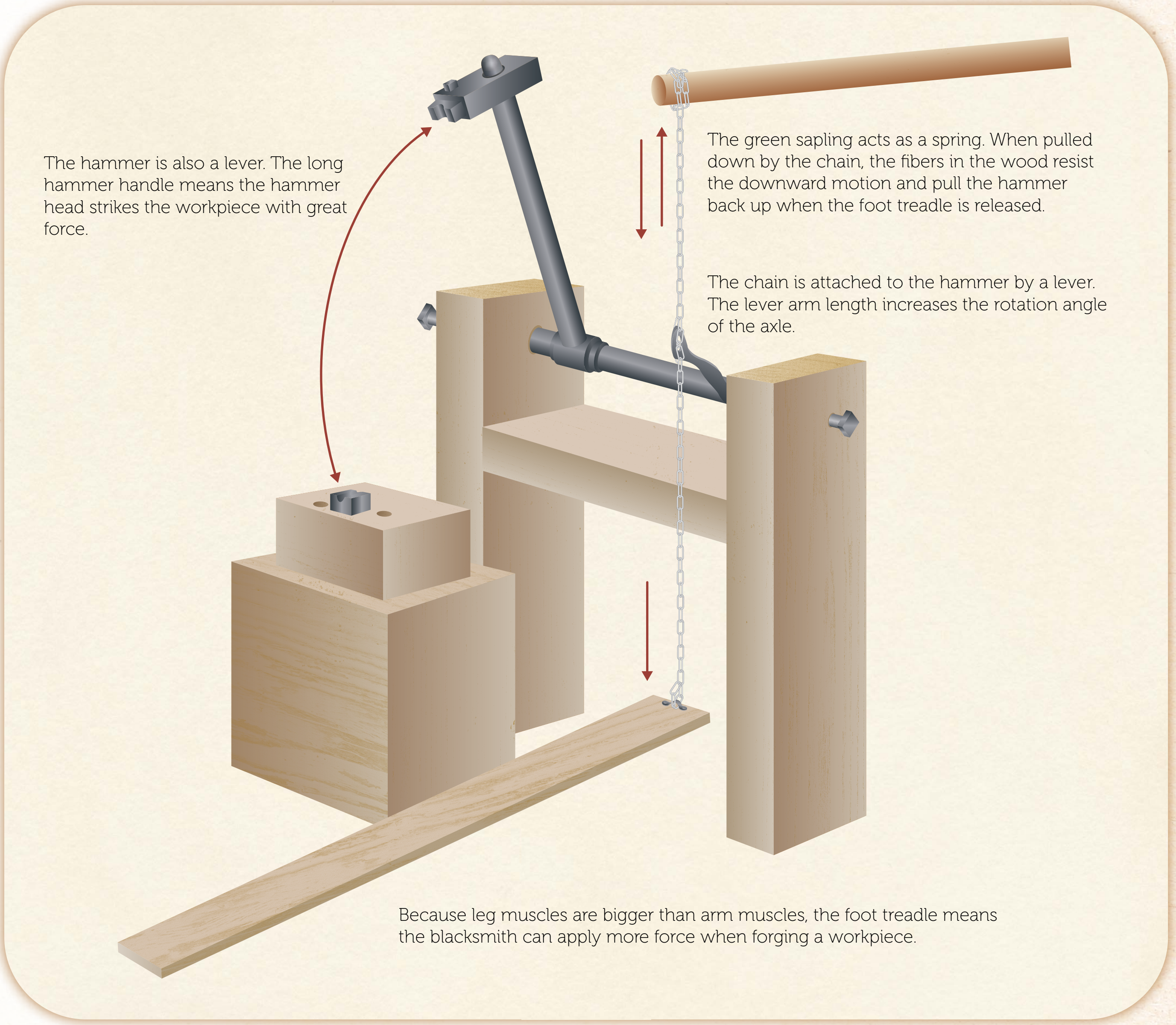


Figure 6.1: How an Oliver works

stomps hard on the treadle, bringing the hammer down on the work. When he releases the pedal, the springy pole brings the hammer back up.

The earliest records we have of Olivers come from the north of England in the early 1300s. They continued to be used into the 18th century, when water- and steam-powered hammers made the springy pole method of raising the hammerhead obsolete. For about 500 years the Oliver was one of the most important machines in the world. With it, nails and other valuable pieces of ironwork could be made more quickly and less expensively.

Making a Model Oliver

A real Oliver is a massive machine, often weighing over a ton. Though our project is only a working model of the medieval lift hammer, the machine works using the same principles as the large Olivers used by 14th century blacksmiths.

> **Note** The following pipes and pipe fittings are made from ½-inch diameter black iron. This sort of pipe is available in nearly every hardware store.

Building the Oliver

To build your Oliver, first take a look at how to assemble it, as shown in Figure 6.2. Then use the following steps:

1. Assemble the treadle and hammer frame according to the assembly diagram in Figure 6.2. Note that some connections are to be screwed together tightly and others left loose.

   a. Start assembling the frame at the bottom, beginning with the flanges, and work your way up.

Materials

2′×4′ sheet of ¾″ plywood

For the side supports:

(2) flanges

(2) 1½″-long nipples

(2) Tees

(2) 6″-long nipples

(2) Elbows

(8) #10 wood screws, ⅝″ long

For the hammer axle:

(2) 3″-long nipples

(1) 1½″-long nipple

(2) Tees

For the treadle axle:

(1) 3″-long nipple

(1) 6″-long nipple

(1) Tee

For the hammer and treadle:

(2) 8″-long nipples

(1) 6″-long nipple

(1) Tee

(2) Plugs

(1) Cap

For the yokes:

(2) 18″ long nipples

(2) Flanges

(2) Tees

(8) #10 wood screws, ⅝″ long

For the spring:

A ½″ diameter (or slightly smaller) tree branch or wooden dowel 3′ in length

Tools

Two medium pipe wrenches

Screwdriver

b. Because all the pipe threads are right handed, you may find it difficult to screw the last pipe nipple into the last elbow. To work around this problem, temporarily over-tighten the nipple into the upper tee fitting, moving the nipple into place between the tee and elbow.

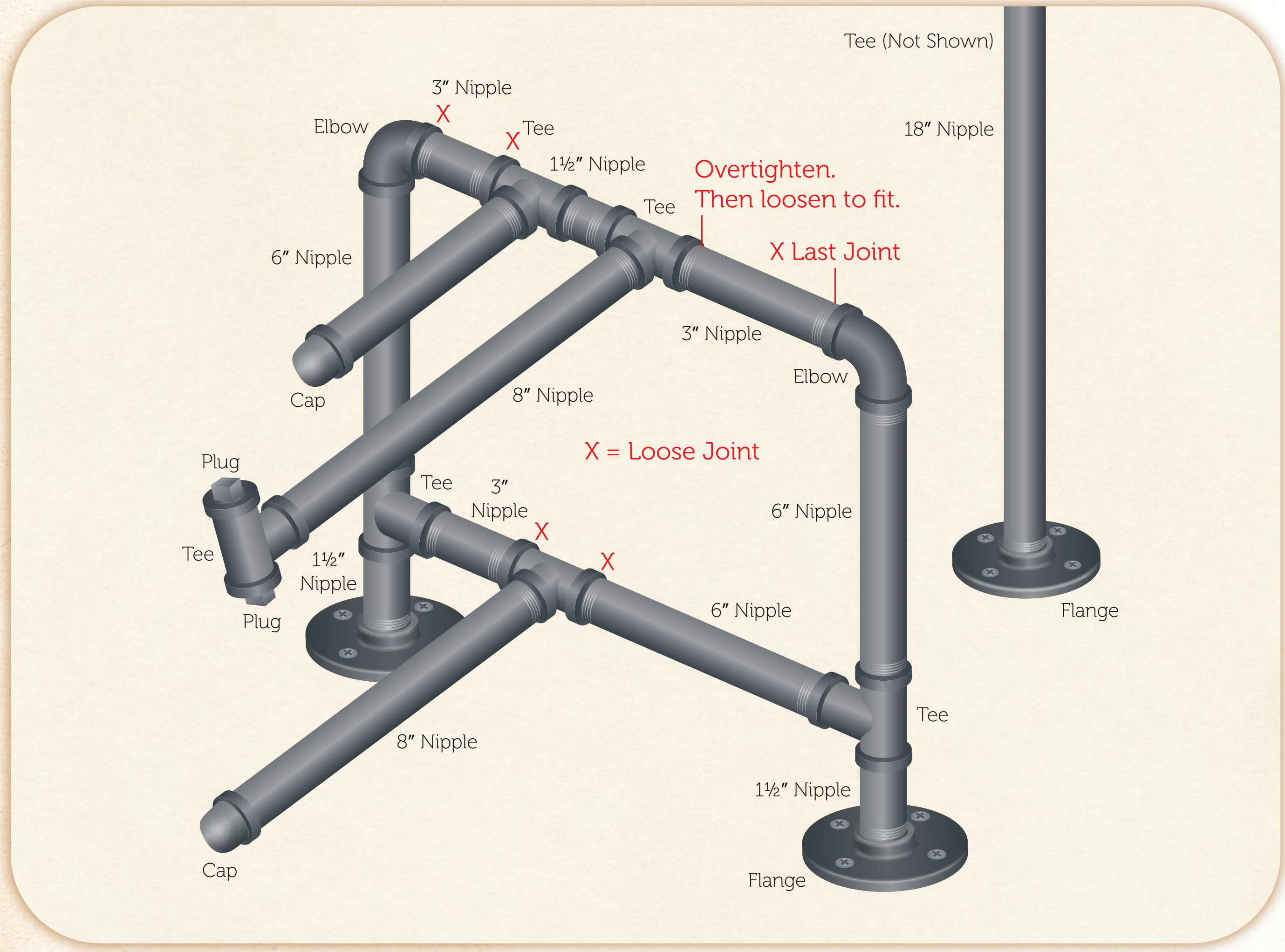


Figure 6.2: The assembled Oliver

Note The ½-inch-diameter black iron pipe used to build this project can be greasy, so begin by removing the grease with a household cleaner. After the pieces are clean, if necessary, you can lightly reapply pipe grease to the pipe threads to make them turn smoothly.

c. Then rotate the nipple into the elbow while you simultaneously loosen the connection into the tee. If you're careful, this will allow the horizontal shafts to pivot smoothly and easily.

Figure 6.2 shows which joints to twist tight and which to leave loose. Note also the location of the last joint.

d. When you've completed the assembly, attach the flanges to the plywood base with wood screws.

2. Assemble the hammer and attach it to the open end of the upper tee fitting.

Note The pieces of this replica are made from cast iron, which is not hard enough to tolerate the blows of a real hammer.

3. Assemble the two yokes from the flanges, the 18-inch pipe nipples, and the tees.

4. Fasten the treadle and hammer frame and the two yokes to the plywood base with #10 wood screws as they are in Figure 6.3.

5. Insert the dowel or branch through the tees at the top of the yokes so that one end is just above the middle of the hammer.

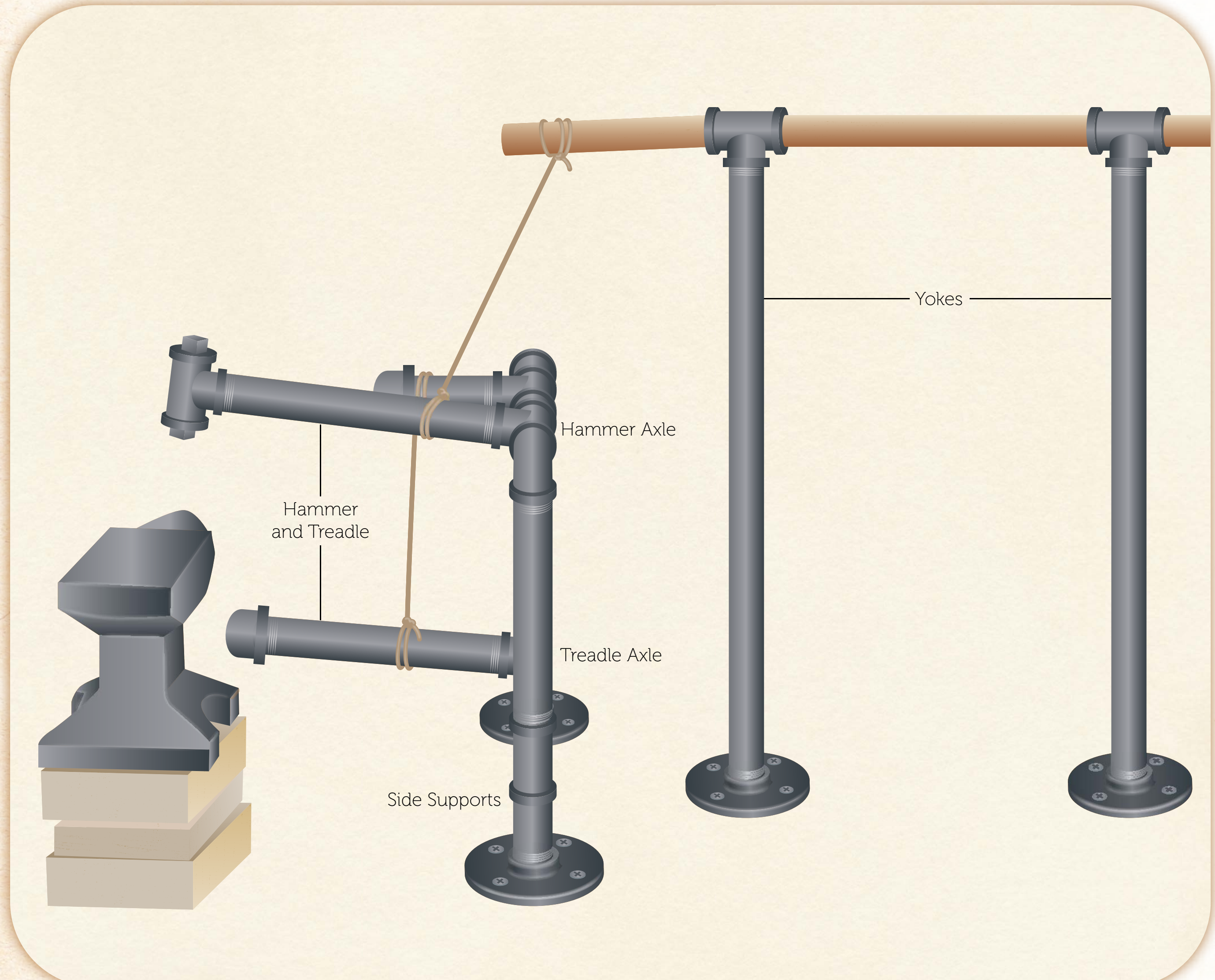


Figure 6.3: The assembled Oliver

6. Move an anvil or other suitable hammering surface into place below the hammer.
7. Adjust the hammer and treadle tees so the treadle and hammer levers are roughly parallel.
8. Connect the hammer to the tip of the green branch with string as shown in Figure 6.3.

When you depress the treadle, the hammer will strike the anvil. When you release the treadle, the green branch will pull the hammer back up (see Figure 6.4).

Figure 6.4: The Oliver replica from the front

The Smithy

The brick- or stone-lined fireplace in which the blacksmith heated metal is called a hearth and the building that contained the hearth is called the forge or smithy. (Never call a blacksmith a "smithy"—that's a bit like referring to a chef as a kitchen.)

For centuries, the smithy was one the most important buildings in any city or town. Medieval craftsmen and farmers depended upon the smith for the iron tools they needed to do their jobs; knights depended on iron weapons and armor to maintain their fiefdoms. And since nearly everyone relied on horses for transportation, those animals had to have iron horseshoes to protect their hooves. So, the improvements made possible when Oliver hammers appeared in the smithy was an important advance, not simply in metalworking, but in the entire Western economy.

Pound away, mighty smith!

Levi ben Gershon and the Jacob's Staff

1325 CE

7

There are two different methods for finding one's way at sea. One way is to hug coastlines, watching for familiar landmarks like mountains or islands or towns and then steering the ship toward them. This method works pretty well as long as you have familiar landmarks and a map that shows them.

But what do you do when you are far out on the open ocean with only stars and the sun for guides? That's the time when you employ celestial navigation, the technique of using the positions of stars, the moon, and the sun in the sky to find your current position. One of the earliest instruments for celestial navigation was the Jacob's staff.

The Rabbi Finds His Way

In the days before global positioning systems, satellites, and computers, how did sailors like Christopher Columbus navigate from one port to another? Well, there were several methods.

Dead reckoning was a popular one. The captain would trail a floating line of a known length from the back of his ship and record the time it took to pay out completely. He then knew roughly how fast the ship was traveling, and using this information combined with a compass, he could estimate his ship's change in position from one day to another.

In theory, this was a pretty straightforward process. Say it took a sailor 6 minutes (or 1⁄10th of an hour) to unreel a line that was 1,056 feet (1⁄5th of a mile) long. That meant the ship was sailing .2 mile/.1 hour, or 2 miles an hour.

But in practice this method wasn't a very accurate way of knowing where you were. Small errors really added up over long distances, and changing wind and weather added a lot of inaccuracy. So instead, Medieval- and Renaissance-era navigators used a somewhat more accurate technique called "running down a latitude." This meant the captain would take the ship to whatever latitude the desired port was on and then he would steer due east or west until he more or less ran into it (see Figure 7.1).

This simple method required an instrument that would allow the navigator to accurately determine and track a ship's current latitude. The first really scientific navigational instrument that could do this was invented by a now little-known, but immensely gifted, 14th century French mathematician and rabbi named Levi ben Gershon. In addition to the invention of the Jacob's staff, Rabbi Gershon was responsible for a number of important mathematical advances in the fields of geometry, trigonometry, logic, and mathematical education.

Gershon wrote many books, all of them in Hebrew. He was highly respected, not only within the Jewish community, but among all the learned men of his day. In fact, while he was alive, Christian scholars translated several of his books and published them in Latin. This is noteworthy, given the significant amount of work involved in pre-Gutenberg book publishing.

But Rabbi Gershon was more than a theoretician. He applied his mathematical discoveries to real-world problems. The most notable example of this is the Jacob's staff.

Also called a cross-staff, Gershon's invention was a navigational instrument that had a pair of sliding sights and a horizontal bar that bore a carefully incised geometric scale. By measuring the arc between the measured object and the horizon with the cross-staff, the navigator could accurately determine angles and, therefore, latitude. This allowed ships to run down a latitude and safely reach their intended port (see Figure 7.1).

For 200 years, ship captains used Jacob's staffs to find their way at sea. There was nothing better and more reliable until the more sophisticated backstaff was invented in 1590 by English sea captain John Davis.

Running Down a Latitude

This map shows how easy it is to sail from Los Angeles to Maui, Hawaii (as long as you know the latitude of Maui and can use a Jacob's staff).

Because (at least in the Northern Hemisphere) Polaris would always be at a constant angle to the horizon for any island or city, sailors could use a Jacob's staff to find their destination. As long as the last stage of the journey was a simple trip due east or due west, all the captain had to do was steer his ship until Polaris was at the same latitude as the destination and then head east of west.

Figure 7.1: Running down a latitude

Materials

1″×1″ square wooden dowel, 36″ long

(2) 1″×1″ square wooden dowels, 4½″ long (Note: If you live south of 30°N latitude, cut the dowels so they are 3″ long.)

(2) 1″×5″ thin brass strips

(4) 1½″ #8 round head machine screws, each with (2) washers and a nut

Piece of paper, 40″×10″ (Note: If you are south of 30°N latitude, make the paper 40″×7″.)

Tools

Saw

Electric drill with 3⁄16″ bit

Screwdriver

Fine-lined marking pen

Protractor

Straightedge

Laying Out a Jacob's Staff

Making your own Jacob's staff is easy if you are precise about cutting wood to length and are careful about layout lines. Make sure both your saw and pencil points are sharp!

Assembling the Jacob's Staff

Before you begin, take a look at the assembly diagram in Figure 7.2.

After you've seen what you're shooting for, follow these steps:

1. Saw a 45-degree angle onto one end of each 4½-inch dowel.
2. Position the short dowels on either side of the long dowel.
3. Place and center the brass strip over the short dowels and then attach it by drilling a 3⁄16-inch hole and fastening it to the dowels with the machine screws, washers, and nuts. (Refer to the assembly drawing in Figure 7.2.) The short-dowel/brass-strip assembly should slide easily along the length of the 36-inch dowel.

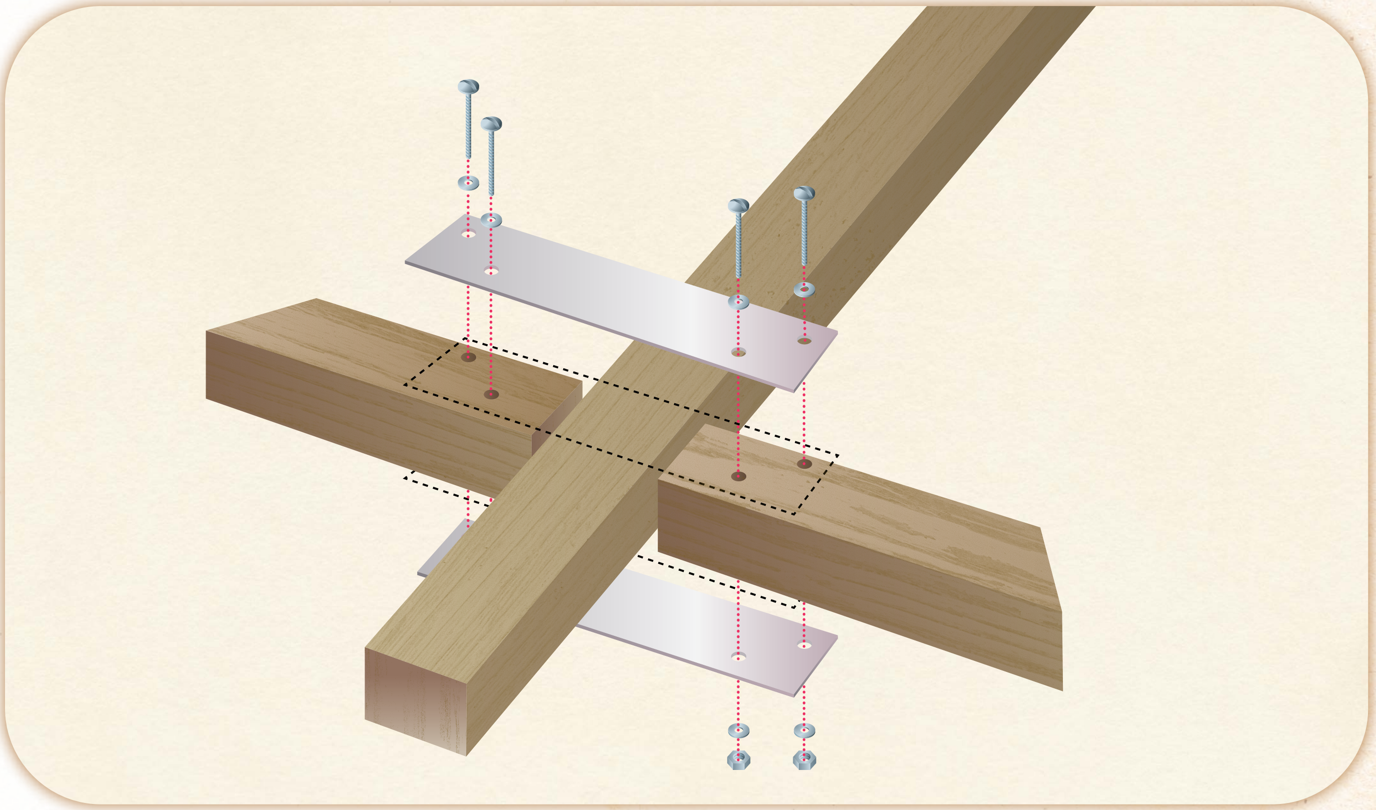


Figure 7.2: Assembling the Jacob's staff

Now that you've constructed the staff, it's time to add the scale that allows you to read latitude. Refer to Figure 7.3 for the remaining steps.

4. Now draw a vertical line 2 inches from one of the shorter edges of your piece of paper.

5. Next, draw a horizontal line down the center of the long dimension of the paper.

6. Align your protractor's bottom edge with the vertical line and place the protractor's center point at the intersection of the two lines. Note that the paper is exactly the same width as the length of the short-dowel/brass-strip assembly.

7. With a pencil, draw 100°, 80°, 60°, 45°, 40°, 30°, 20°, and 10° lines, radiating from the protractor's center

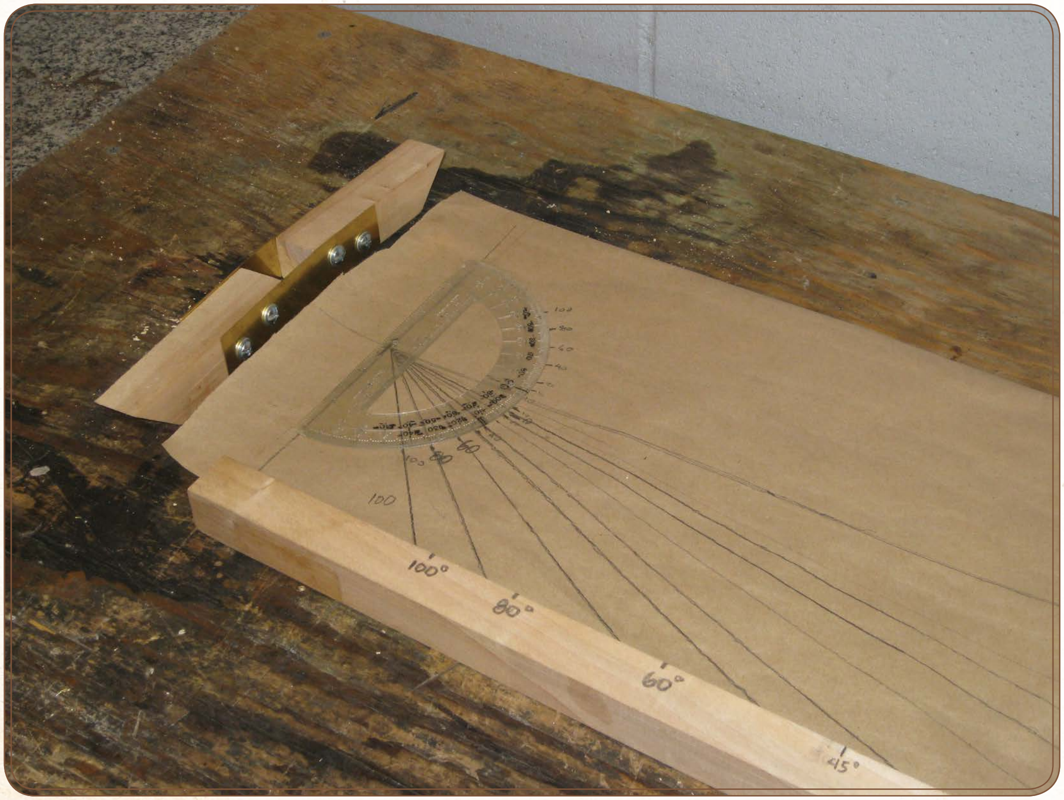


Figure 7.3: Marking the latitude scale

point to the paper's bottom edge as shown in Figure 7.3.

8. Place the 36-inch dowel next to the paper and align one edge of the dowel with the vertical line.
9. Mark the dowel with the corresponding degrees where the lines intersect the paper's edge.

Congratulations! Your Jacob's staff is complete (see Figure 7.4) and you are ready to navigate!

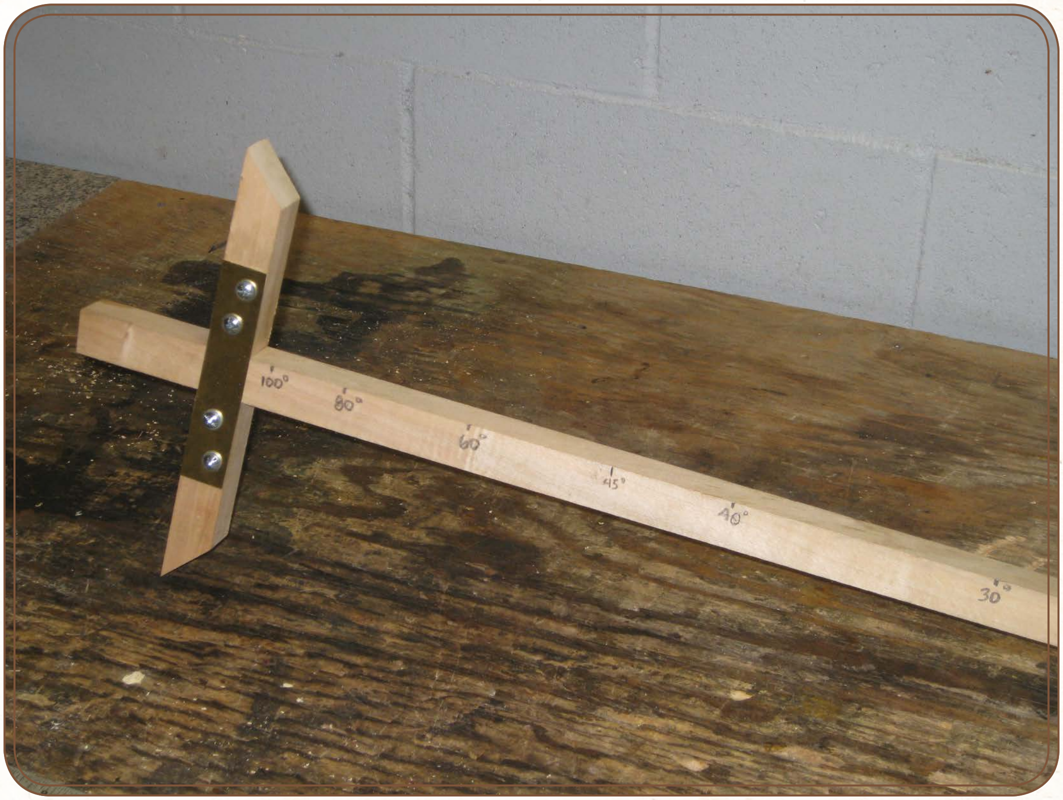


Figure 7.4: The assembled Jacob's staff

Go West (or East) Young Man

Now that you've assembled your staff, it's time to try it out. After dark, go outside with your staff and slide the short-dowel/brass-strip assembly until the edge of top dowel aligns with Polaris (the North Star) and the edge of the bottom dowel aligns with the horizon. Once you've positioned your dowels, you can read your current latitude from the scale you marked on the long dowel. If you have done a careful job of drawing the scale, you can figure out your latitude with reasonably good accuracy. Take a look at Figure 7.5 for a more detailed explanation of what's going on.

If you can maintain a constant reading on the Jacob's staff as you travel, you are staying on the same line of latitude. But if you veer south, Polaris appears to sink in the sky as you sight it through your device. If you travel north, Polaris seems to rise.

Note If you live south of the equator, you're out of luck using Polaris because it is below the horizon.

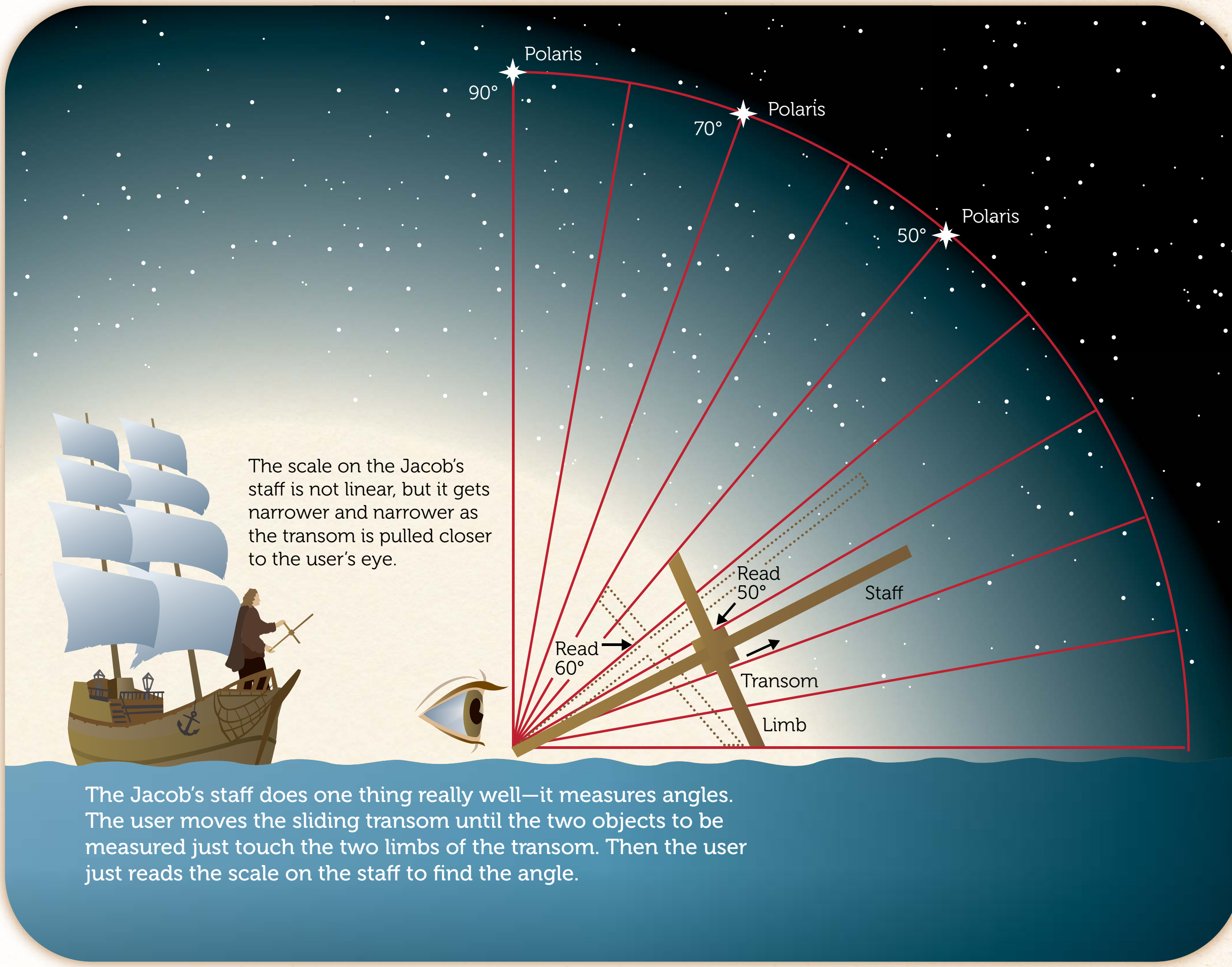


Figure 7.5: Using the Jacob's staff

Experienced navigators can also use the Jacob's staff with the noon sun to determine their latitude during the day (assuming it's a clear day). This requires a darkened lens that allows the navigator to safely stare at the sun, as well as a special astronomical table called an *ephemeris* that provides data on where the sun is in the sky at noon on any given day.

Part 3

The Inventions of the Early Modern Scientists

After the slow intellectual growth of the Middle Ages, things picked up. By the dawn of the 15th century, technology was on a roll. The next couple of centuries produced some extremely important inventions. Books, as we know them today, were born when moveable type was invented in what is now Germany. The feudal system died when gunpowder made its way to Europe from China and made armored knights obsolete. Many things still in common use today—oil paint, telescopes, screwdrivers, and pencils, to name a few—made their first appearances.

What name do we give to the 15th and 16th centuries and this time of great invention? It's the Age of Early Modern Science, when science as we think of it today began.

The Age of Early Modern Science started slowly. Religious leaders of the time persecuted scientists who spread ideas that contradicted their strict interpretation of the holy books. For example, Catholic church leaders forbade people (those few who could read, anyway) from reading any book that was placed on the dreaded *Index Librorum Prohibitorum* (the Index of Prohibited Books). Nicholas Copernicus, Galileo Galilei, and Johannes Keppler (who wrote that the earth revolved around the sun instead of the other way around) were just a few of the great scientists whose books were placed on the Index.

Eventually, the tide of exploration and the new knowledge that it brought could not be stemmed and scientific thinkers were freer (although not until much later would scientists be altogether free) to express their ideas without the fear of being deemed heretics.

These thinkers, led by Galileo Galilei, Nicholas Copernicus, and Isaac Newton, accumulated scientific knowledge far more rapidly than the scientific community ever had previously. Advances in physics, chemistry, and mathematics ushered in a whole new way for people of the time (at least educated people) to separate science from superstition and understand the world as it really is.

This section introduces three makers that you may not have ever heard of—two men and one woman. The things they invented—the tools of modern fishing, a way to make accurate maps, and a method for creating a vacuum—didn't make them particularly rich or famous. But those inventions were still very important and we use them in many ways in our modern daily lives.

Dame Juliana Berners and the Fishing Lure

1486 CE

8

Recreational fishing has been around for a long, long time. Ancient writers like Plutarch, Plato, and Aristotle, to name a few, make references to this pastime. But the first real fishing guide, with instructions on how to make rods, lines, and lures, was an interesting little manual called *Treatyse of Fysshynge with an Angle*, published at the beginning of the age of Early Modern Science—around 1486 CE. Perhaps a bit surprisingly, its author was an English nun.

The Lure of Making Lures

Dame Juliana Berners, prioress of the Priory of St. Mary of Sopwell, was the Ernest Hemmingway of her day. Like Hemingway, she wrote books about outdoorsy, adventurous subjects, such as hunting, hawking, and shooting. She is best known for her do-it-yourself (DIY) book on how to catch fish, *The Boke of Saint Albans*, in which "Fysshynge" appears.

"Ye can not brynge a hoke into a fyssh mouth without a bayte," she begins, and then goes on, in a hundred pages or so, to concisely explain how to use hand tools (hamour, knyfe, and fyle, for example) to make rods, line, and fishing lures.

Getting to know Dame Juliana is difficult because there is very little reliable information regarding her life. Indeed, details about her are so hard to come by that a few modern fishing historians are skeptical she actually wrote the book. But plenty of others are convinced that she did, and so to her belongs the title of "Mother of Recreational Fishing" because her work influenced every major fishing writer from Izaak Walton to Gadabout Gaddis.

Goin' Fishin'

How easy it is in our modern world to go fishing! You merely visit a sporting goods store, buy a rod, some fishing line, and a lure or two, and head off to the lake. But preparing for a day of fishing was a complicated task in Dame Juliana's day. Two weeks was barely enough time to make everything you needed.

First, you had to make a rod. As the *Treatyse* points out, you don't simply cut a stick off the local elm tree. That would be the work of a lazy fisher indeed. To do it correctly, Dame Juliana recommends that you hike into the local woods, preferably between the holidays of Michelmas and Candelmas, and cut a length of hazel, willow, or ash; you then heat the cutting over a charcoal fire, shape it carefully (presumably with the hamour, knyfe, and fyle), and then allow it to cool in smoke for two days.

Making fishing line was even harder. This required yanking hair from your horse's tail, weaving it into a thin cord, and then coloring it with dyes made from walnuts, soot, and ale.

Thankfully, the section on how to make bobbers is quite simple and requires only a cork and a pin.

Lure making—mostly tying flies—concludes Dame Juliana's treatise. Her advice on this subject is excellent and still relevant, even after 600 years. In her description of 12 different artificial flies—yellow flies, stone flies, wasps, and drake flies to name a few—she provided centuries of fisherfolk with sound advice on making lures that actually catch fish.

Given that modern fishing rods and fishing lines are relatively inexpensive and work extremely well, few modern Makers would likely invest the time and effort they'd need to wind their own fishing line out of linen or horse hair, or even carve their rod from wood. But making their own lures is an altogether different story. Lure-making is straightforward, and just imagine the satisfaction you'd feel if you caught a trophy fish on a lure you made yourself! Such a scenario would provide you with bragging rights that are simply not available to those who purchase all their equipment.

Lures can be made out of many materials, including wood, metal, and plastic. The key to making a successful lure is to construct a device that mimics the motion of bait animals, causing the predatory sport fish to bite onto an attached hook. There are many different types of lures. A *jig* is a weighted hook that is made to bounce or "jig" at the end of a fisherman's line. A *plug* is an irregularly moving lure in the shape of a small fish. And a *fly* is a tied and feathered hook that alights on the water's surface to mimic a bug landing on the water; it was this type of lure that was much beloved and discussed in Dame Juliana's treatise.

Among the most popular modern lures are those known as *spoons*. A spoon is a concave metal oval with a hook at the back. Spoons dart and wobble as they are pulled through the water, exciting game fish and

Materials

(1) Medium-sized metal table spoon (Selecting the right spoon weight is important. If it is too light, the spoon won't sink and will skip along the surface; if it's too heavy, the lure won't look lifelike to the fish.)

(2) 3/8″ diameter glass beads (Buy these at a bead or craft store.)

2′ of 24-gauge steel bead wire

(2) #4 split rings (Buy these and the next two items at a sporting goods store.)

(1) #10 barrel swivel

(1) #4 treble fish hook

Tools

Marker pen

Safety glasses

Hack saw or rotary tool with an abrasive cutoff wheel

Steel punch

Sandpaper, grinder, or rotary tool with a grinding head

enticing them to bite. Spoons were not known to Juliana, because they were not invented until the 19th century. But had she known about them, it's quite likely she would have found them extremely useful.

Many fishing historians credit J. T. Buel of Castelton, Vermont, as the person who designed and crafted the first spoon lure in about 1820. An apocryphal account of how Mr. Buel came up with the idea is that he saw a large fish swallow a spoon he accidentally dropped into a lake.

Whether that story is true or not, there is certainly widespread agreement that spoons are very effective fishing lures. They can be made in various sizes (small ones for pan fish, large ones for pike), and by slightly changing the concavity and edge shape of the spoon, you can get a vast array of motions.

Making Your Own Fishing Lure

When you start thinking about making your own lure, remember that you have a great deal of latitude in choosing spoon size, hook size, the shape of the spoon, and so on. Some choices will work better than others depending on the type and size of fish you are trying to catch.

Making Your Lure

Before you begin, take a look at Figure 8.1, which shows the assembled lure, so you know what you're working toward.

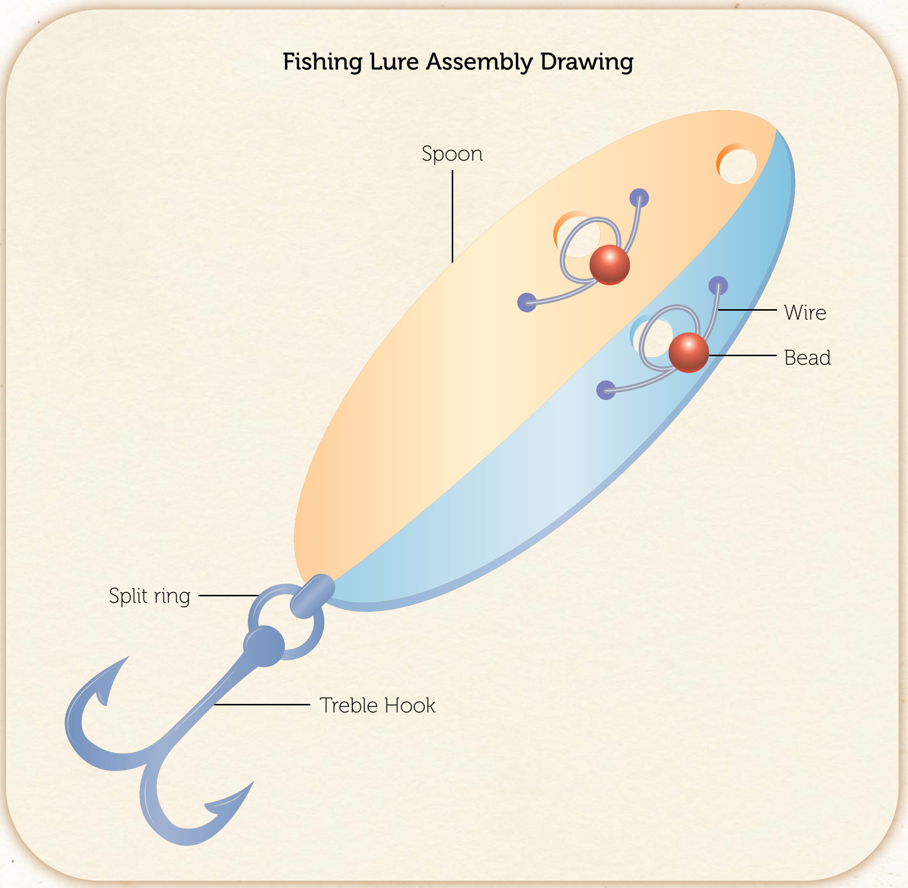


Figure 8.1: The assembled lure

Figure 8.2: Removing the spoon's handle

Figure 8.3: Sanding the burr smooth

Figure 8.4: Drilling pilot holes

To prepare the spoon for use, follow these steps:

1. Don safety glasses.
2. Use the hack saw or cutoff wheel to remove the handle from the spoon as shown in Figure 8.2.
3. Remove the burr from the cut with the grinder or rotary tool as shown in Figure 8.3 (easier) or with sandpaper (harder). Make sure you sand the edge smooth.
4. Use a marker to mark the location for the eye beads on the lure.
5. Use the steel punch to make an indent on the spoon surface for each eye.
6. Drill a 1/16-inch pilot hole for each wire attachment and starter hole for each eye bead (see Figure 8.4).

   It can be difficult to drill through the spoon with a hand drill because the bit tends to wobble. Take your time and apply minimal pressure while starting the hole.
7. Change bits in your drill and enlarge the holes to 3/8-inch diameter.
8. Drill 1/16-inch-diameter holes in the spoon for the attachment wire above and below the eye bead holes as shown in Figure 8.5.
9. Drill 1/8-inch-diameter holes for the hook and leader attachment as shown in Figures 8.1 and 8.5.

Now that your spoon is prepared, it's time to assemble the lure:

1. Place eye beads in the ⅜-inch holes and fix them into place using the bead wire.
2. Insert the wire through the ¹⁄₁₆-inch-diameter holes, and then the hole in the center of each bead, and then pull it taut and tie it off as shown in Figure 8.6.
3. Attach the #4 split rings to the hook hole and the leader hole.
4. Attach a #4 treble hook to the split ring in the hook hole.
5. Attach a #10 barrel swivel to the split ring in the barrel swivel hole (see Figure 8.7).

Remember, the idea behind any successful lure is to make the fish think the lure is something good to eat. You can change the lure's movement through the water by using a hammer to make it more or less concave, or by slightly bending the leading or trailing edge of the spoon. You also can add feathers or colors if you think it will make the lure more attractive. You're ready to catch some fish!

Figure 8.5: The eye bead holes and wire holes

Figure 8.6: Securing the beads

Figure 8.7: The completed lures

The Science of Hooking Fish

By the time Dame Juliana was writing her treatise, quite a lot of thought had gone into designing fishhooks. Although you may not have considered it up to this point, a fishhook is actually far more involved than simply being a sharpened piece of curved metal.

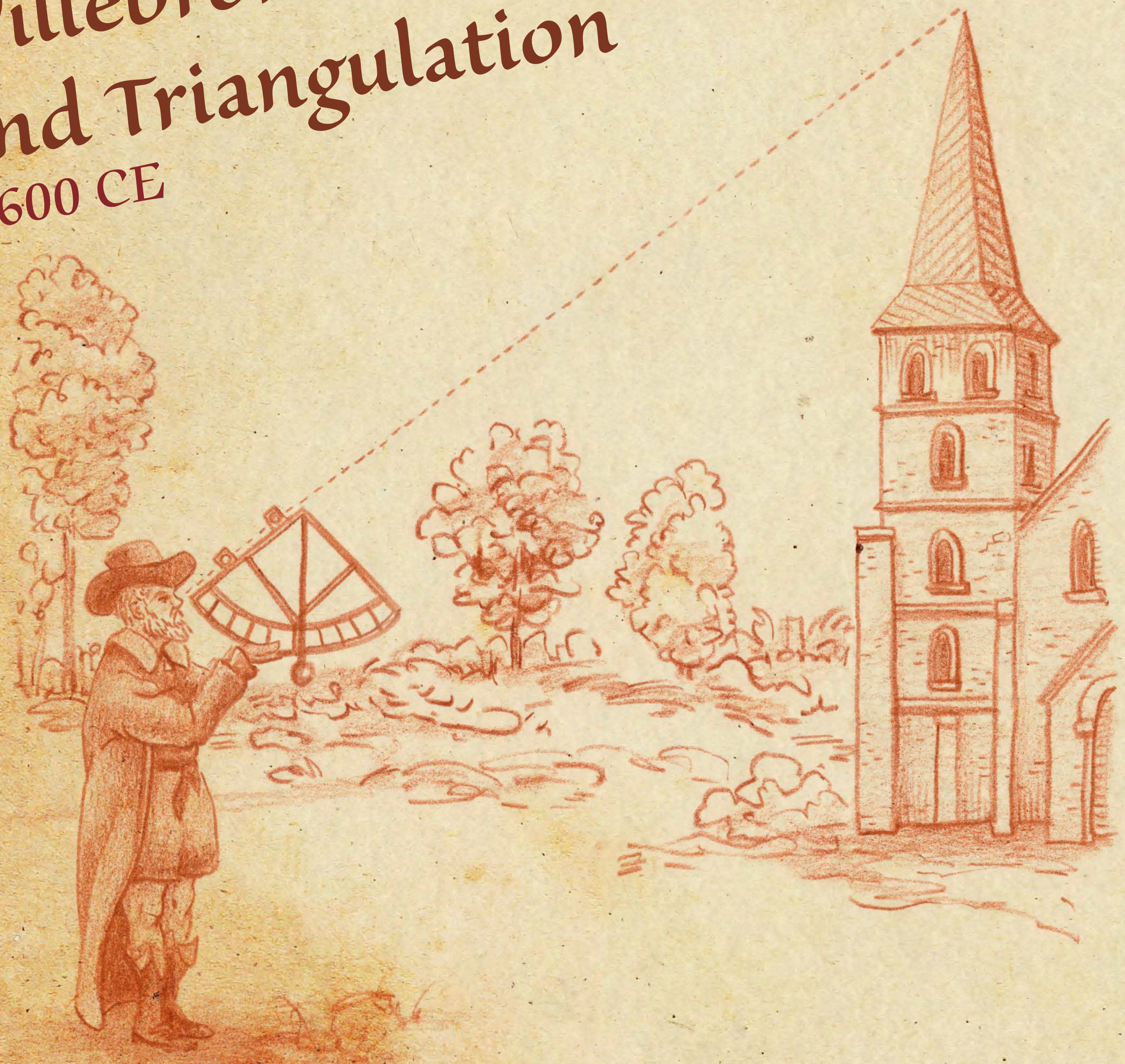
First of all, there's that barbed point. The barbed hook is a clever, one-way device that was first used by our friends the ancient Egyptians in roughly the time of Ptah-Hotep. When the fish bites it, the barb goes in easily, but because of the distance between the hook point and the barb end, once hooked, it is very difficult for the fish to remove the hook.

Second, there's the bend pattern that is forged into the hook. There are many different types of bends that have been figured out over time. When the fish bites down on the hook, the hook rotates on the line like a lever. The lever length determines where the hook winds up. Some shapes and levers work especially well for wide, flat-mouthed fish like catfish, whereas other shapes are better suited for narrow, elongated-snout fish like pike.

Finally, consider the material properties of fish hooks. Almost all modern hooks are made from alloy steel. In freshwater fishing, corrosion isn't much of a problem, and any high-quality steel does well. In saltwater, though, stainless steel and other rust-resistant alloys last longer and are less likely to break when a big one is on the line. Some hooks are made by bending wire on a die while others are made via a metal-forming process called forging. Forged hooks are shaped by pounding, and that changes the structure of the metal to make the hook very, very strong.

Willebrord Snell and Triangulation

1600 CE



9

Modern mapmakers use specialized equipment to take measurements and mathematics to figure out what those measurements mean. We have maps that cover nearly every part of the world, including under the oceans, across mountains, and over the polar ice caps. Perhaps the most important foundation upon which surveying and mapmaking stands is the mathematical discipline of trigonometry.

Measuring Long Distances by Using Triangles

The burghers of Leiden, Holland, must have wondered what that odd professor from the university was up to. Throughout the years 1614 and 1615, they saw Willebrord Snell, a young professor of mathematics, repeatedly climbing up and down the town's church steeples and bell towers, lugging a huge quarter circle of iron. Then they saw him carefully rolling out and then rolling up a long metal chain, all the while carefully writing down notes in a notebook. What could this fellow have been up to?

It turns out he was busy making scientific history. Professor Snell was inventing the science of geodesy and laying the baselines for the future practice of surveying.

Specifically, Snell was attempting to figure out the exact size of the earth. The first attempt to do so was made almost two millennia earlier by the Greek scientist Eratosthenes of Cyrene, who used the different lengths of the sun's shadows at noon as the basis of his calculations. The figure Eratosthenes came up with was pretty accurate, but Snell thought he could do better using a new technique. His idea was a mathematical process called triangulation that he had invented for the purpose of measuring long distances. Snell's method was a game changer, and soon, people of science all over Europe saw what an incredibly valuable tool triangulation was.

Prior to Snell's work, the only way to measure the distance between two towns or landmarks was to measure it directly. A common method was to make a couple of extremely long rulers and leapfrog them along the flattest and most direct path possible between the two points. That got old fast, so somebody came up with the slightly better idea of measuring the number of turns of a wagon wheel and then applying basic algebra to figure out how many feet or yards the wagon had traveled. Neither of these methods was very accurate, and if there was something in the way of the end points, say a mountain or a river, these methods didn't work at all.

As a mathematics professor, Snell was well versed in the trigonometric principles formulated by early Greek and Arab mathematicians. From their work, he understood that every triangle is composed of three sides and three angles. Further, Snell was aware that if you know the values of two angles and one side, or two sides and one angle, you can accurately calculate all of the other sides and angles.

Specifically, there are two trigonometry formulas—the law of cosines and the law of sines—that Snell used to calculate distances. Using these meant that he and the thousands of land surveyors who followed him could make much more accurate and usable maps than the cartographers who relied solely on direct measurement methods.

Snell invented the practice of *triangulation*: the calculation of the distance between points by first making an accurately measured baseline and then measuring the angles made between distant points and the two ends of the baseline. With this technique and his trusty quadrant (the large iron quarter circle that mystified the burghers), he charted Holland. Soon after, surveyors and mapmakers the world over were redrawing the world, making maps far more exact and boundaries much more precise than they had ever been before.

Triangles: The Mapmaker's Best Friend

The word *trigonometry* means "measurement of triangles" in Greek. It is an ancient mathematical discipline first explored by the Egyptians and Babylonians and then refined by the ancient Greeks.

Triangulation is just the use of trigonometry to measure distances. It isn't a terribly difficult technique to understand. In this chapter, we'll make a simple piece of measuring equipment that allows anyone to calculate the distances necessary for making good maps.

Suppose you need to determine the distance from point A to point C as shown in Figure 9.1. Because of the mountains, you can't measure the distance directly, although you can see point C from both point A and point B.

The first thing you need to do is to make an accurately measured baseline, in this case from point A to point B since there are no obstructions (see Figure 9.2). The longer your baseline is, the more accurate your subsequent distance

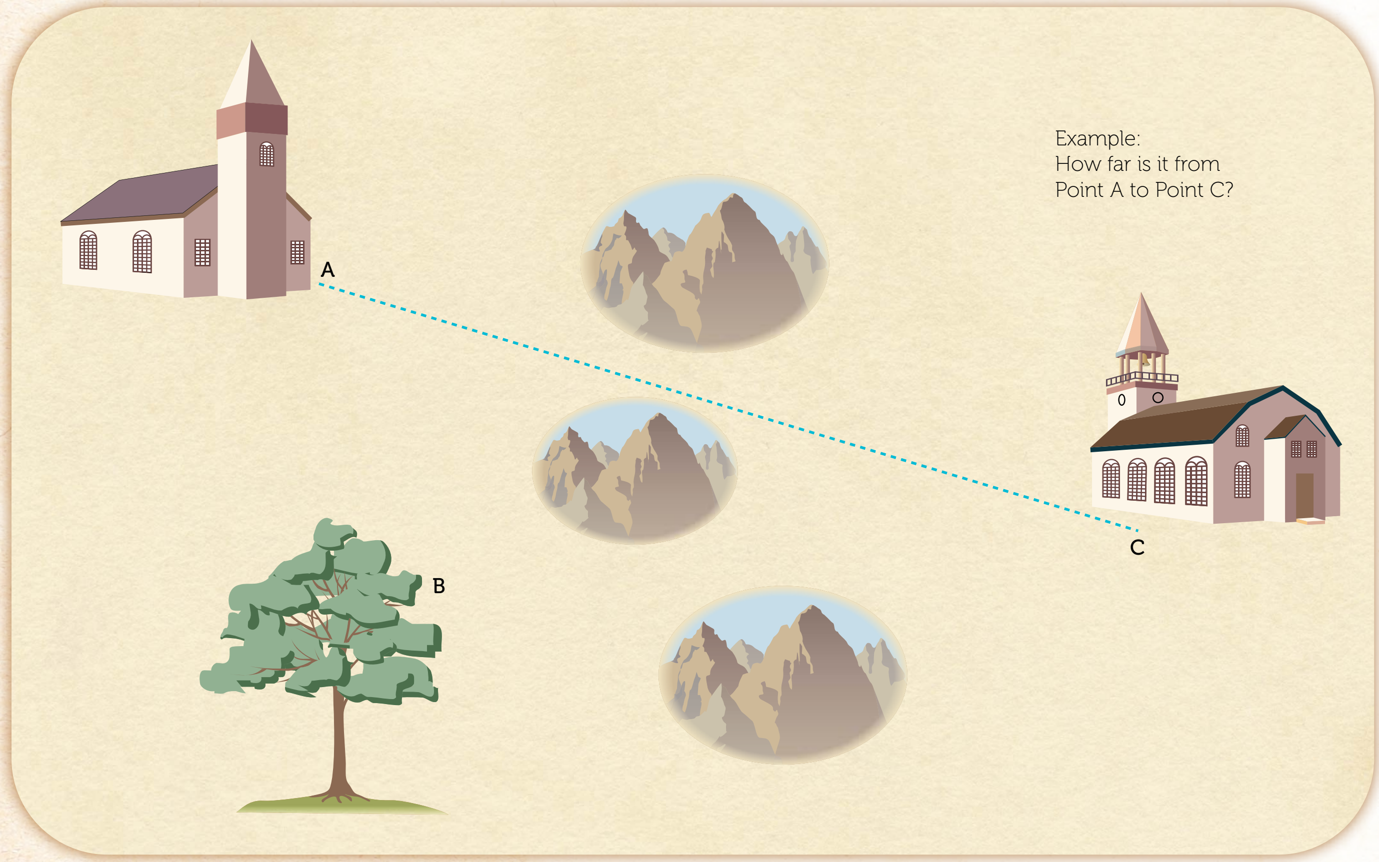


Figure 9.1: Measuring distance with an obstacle

calculations will be. Use a reel-type tape measure or other direct measuring device for this.

Then you need to go to point A and measure the angle between point B and point C using an accurate angle-measuring device. You can use a sextant, a quadrant, or a circumferentor. Making your own circumferentor, which is described later in this chapter, is easy and provides reasonably accurate results. Next, go to point B and measure the angle

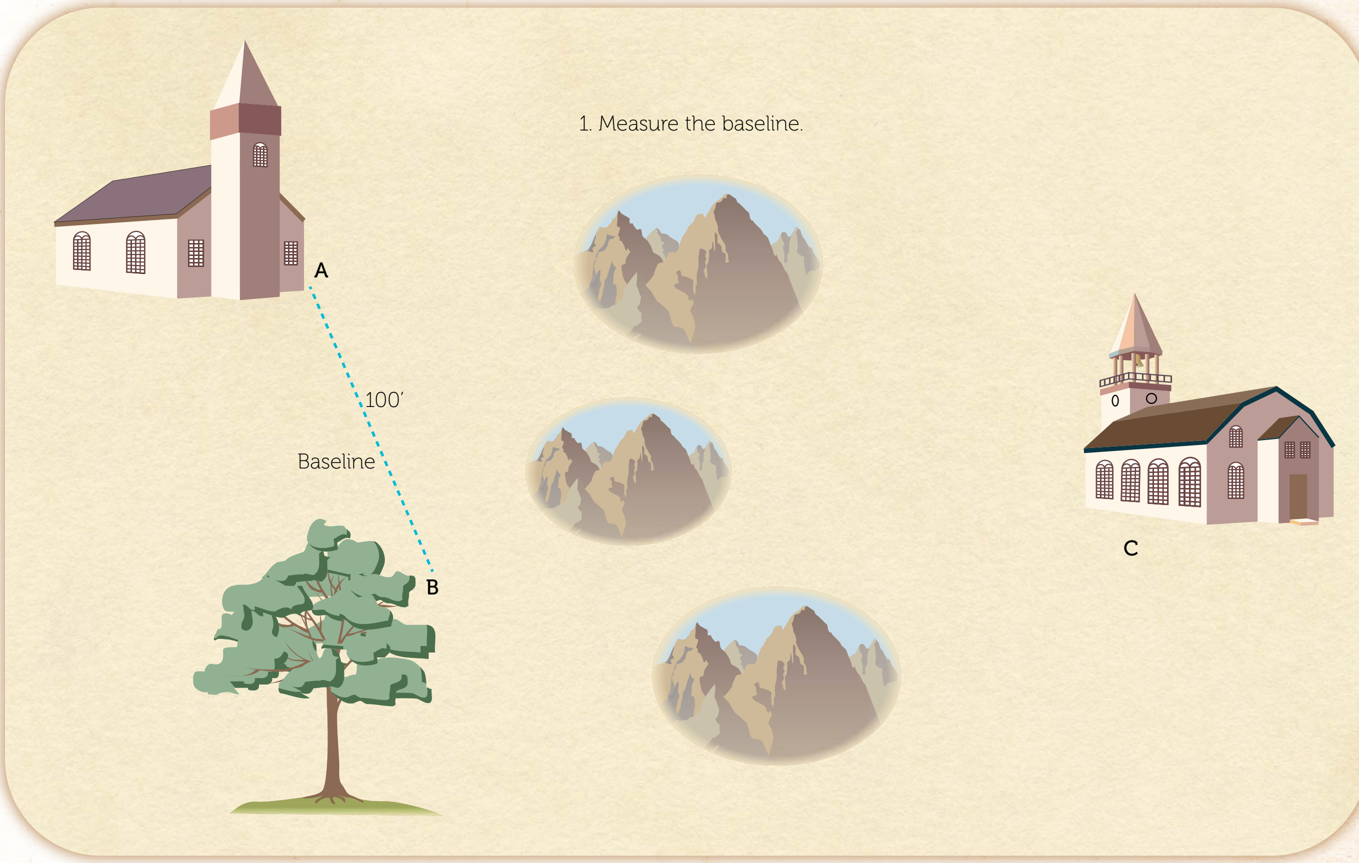


Figure 9.2: Measuring the baseline

between point A and point C (surveyors call this *shooting an angle* [see Figure 9.3]). You now know two angles. Use the fact that the three angles in a triangle must add up to 180 degrees to calculate the third angle.

$$\frac{\text{sin CAB}}{\text{(segment BC)}} = \frac{\text{sin ABC}}{\text{(segment AC)}} = \frac{\text{sin ACB}}{\text{(segment AB)}}$$

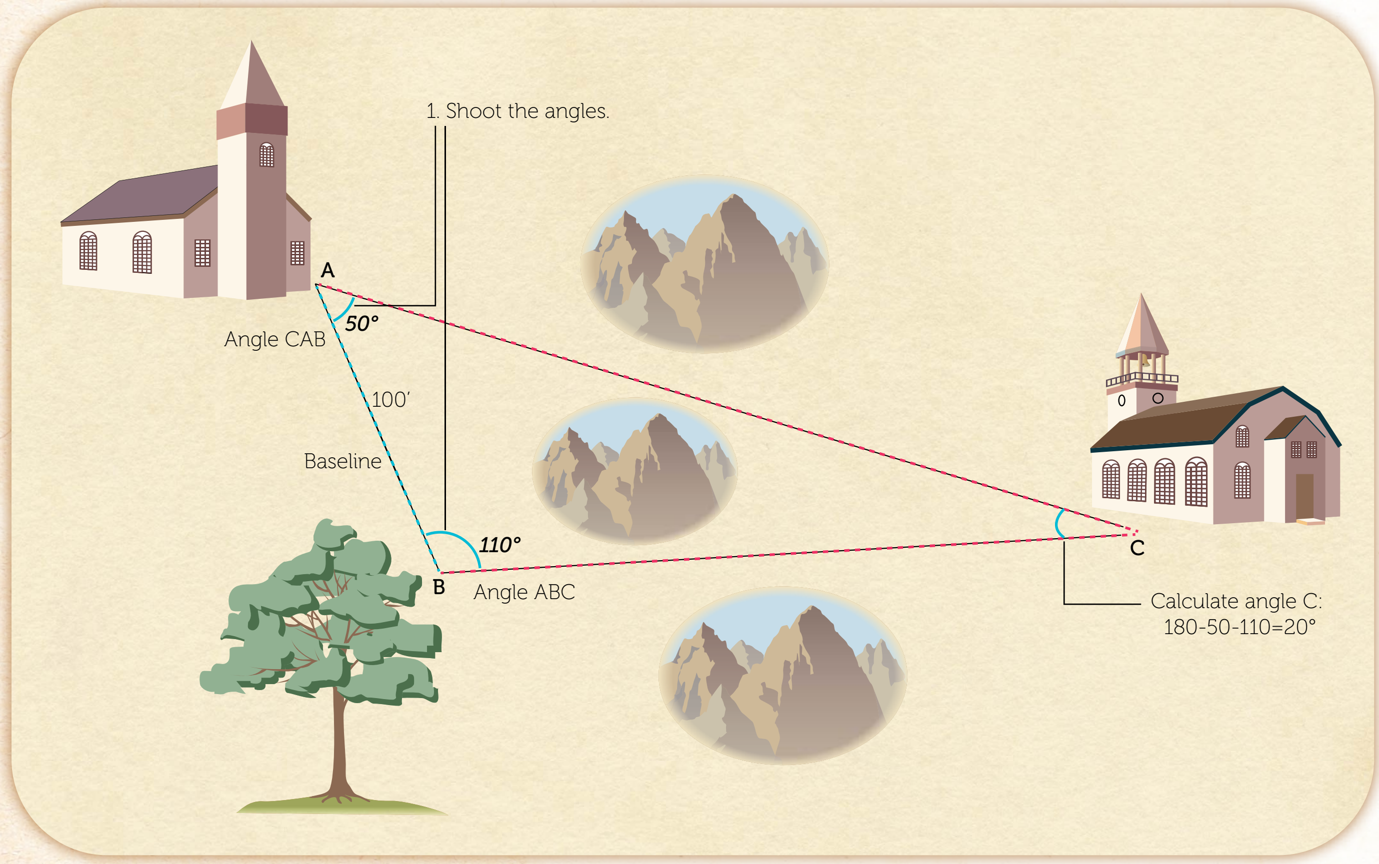


Figure 9.3: Measuring the angles

It's an easy job to calculate the length of segment AC, the distance between the church spire and the city hall in this diagram. You know the length of segment AB, and the angle values for angle ACB and angle ABC. Just look up the sine values (in degrees, not radians), set up the equivalent ratios using the Law of Sines, and solve for the length of segment AC (see Figure 9.4).

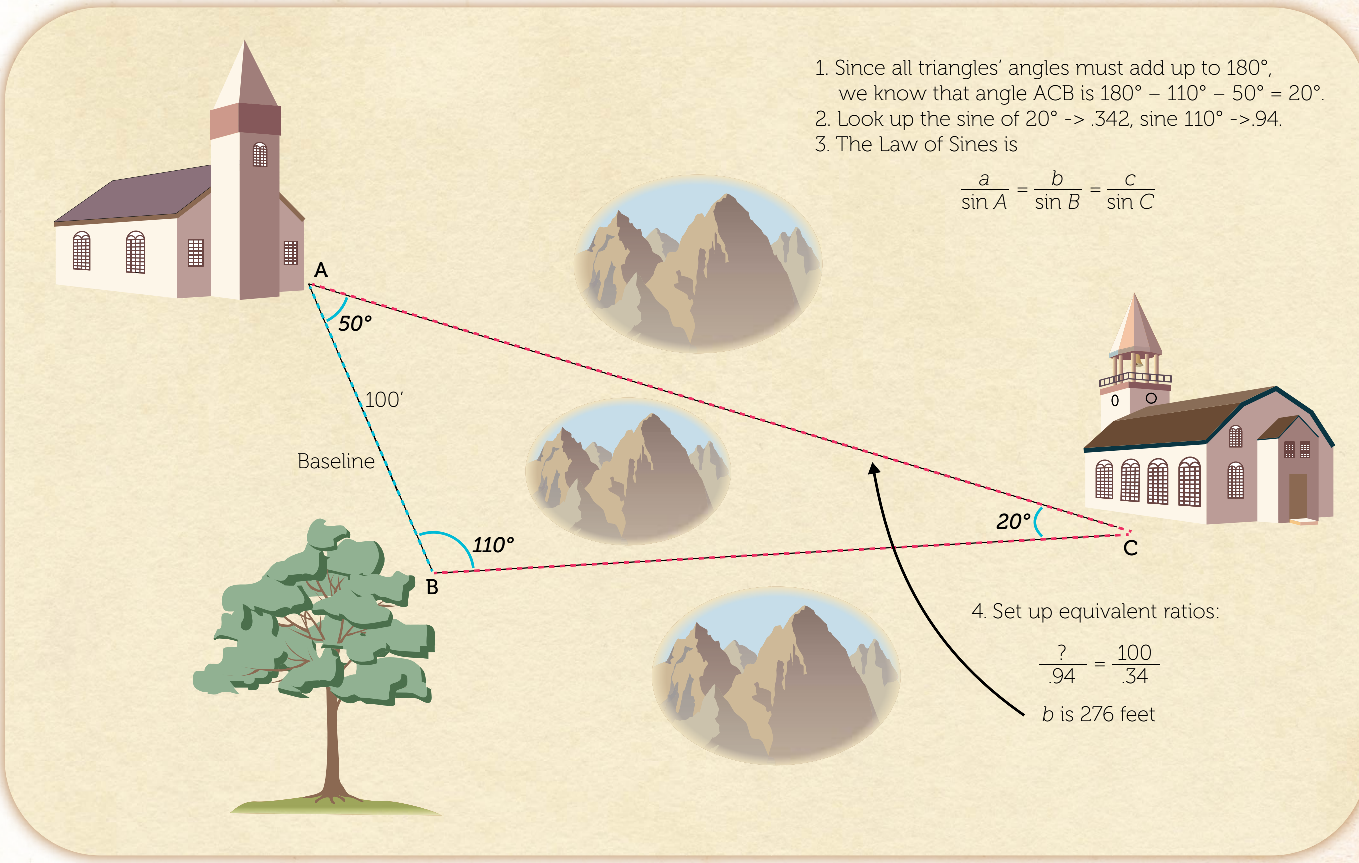


Figure 9.4: Using the Law of Sines

Building a Circumferentor

The key to accurate triangulation is measuring angles precisely. To make it possible for you to do that, we'll make an instrument for measuring angles called a *circumferentor*.

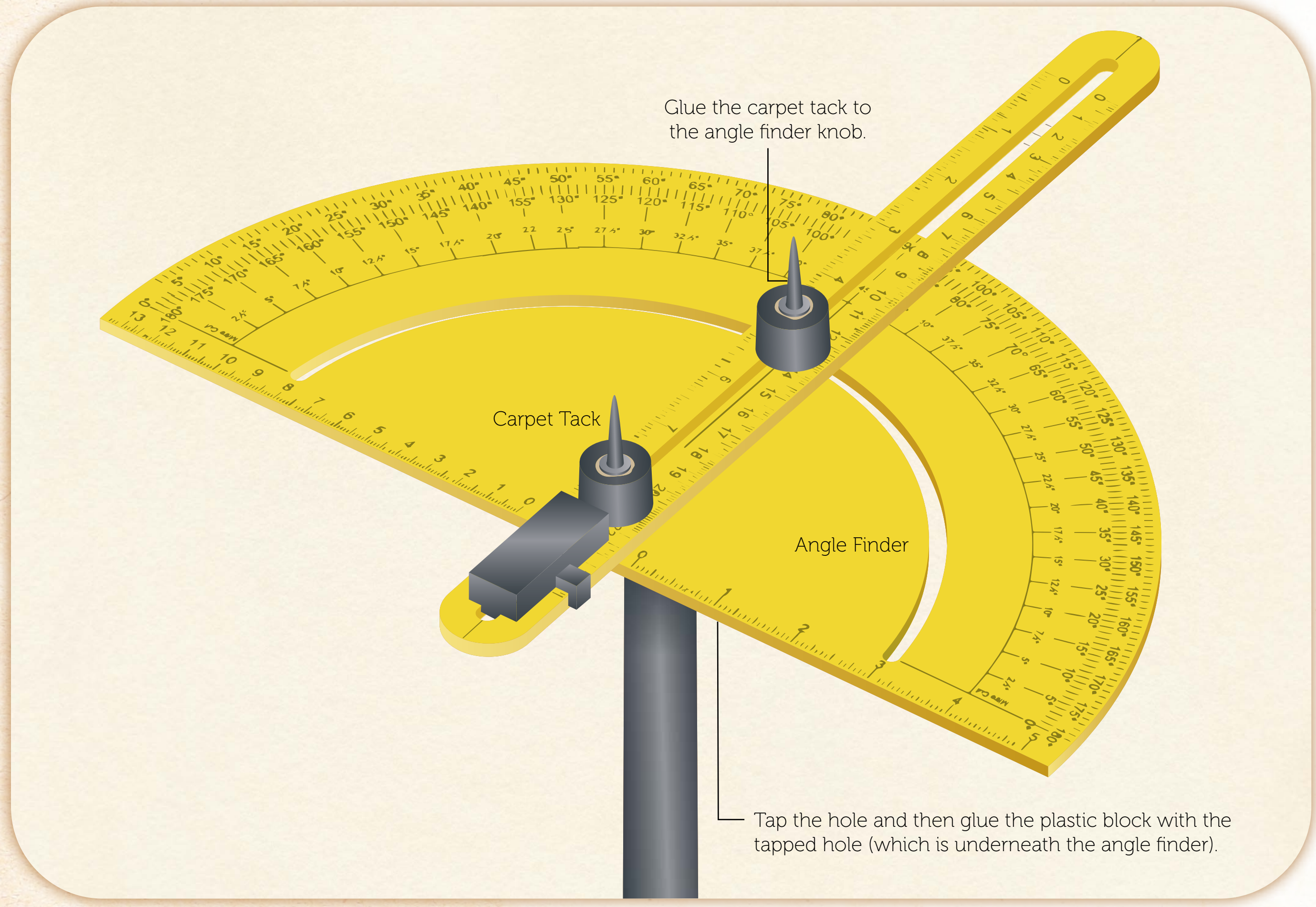


Figure 9.5: How to build your circumferentor

How to Build Your Circumferentor

Before you begin, take a look at Figure 9.5 to see what you're aiming for.

Follow these steps:

1. Drill a 13⁄16-inch hole in the center face of the 1″×1″×½″ plastic block.
2. Cut screw threads in the hole using the ¼-inch UNC tap.

   The tool you use to cut a male threaded piece is called a *die*. When you make a female threaded piece, you use a *tap*. In this case, you are making threads in a hole, and that means you're making a female threaded piece.

   a. Start the threading process by carefully positioning the main axis of the tap parallel to the hole.

   b. Turn the tap a half turn and then back out the tap a quarter turn to remove shavings so the tap doesn't get clogged.

   c. Keep doing this until the hole is fully threaded.

Materials

(1) Angle finder—Harbor Freight #94963

(2) Small box nails or carpet tacks

(1) 1″×1″×½″ block of plastic (You can glue (2) ¼″-thick pieces together if you need to.)

(1) Camera tripod

Tools

(Electric drill and a 13⁄16″ drill bit

¼″ UNC hole tap and handle

Glue

Figure 9.6: Gluing the block

3. Glue the block with the tapped hole to the angle finder (see Figure 9.6).
4. Glue the sighting nails to the knobs on the angle finder (see Figure 9.7).
5. Screw the tripod mounting screw into the tapped hole.

To find angles between distant objects, use the nails as sights, lining up the object with both the front and back nails. Note the angle separating the objects on the dial.

Now, all you need is to do the trigonometry and you can measure the distance to just about anything you can see!

Figure 9.7: Gluing the aiming sights

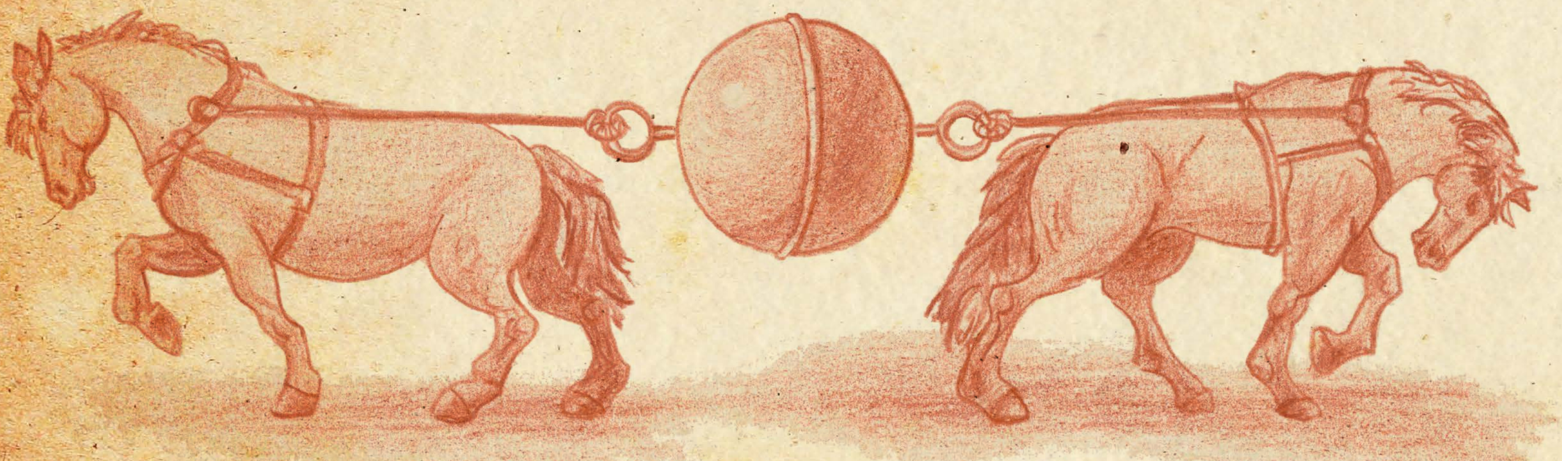
Surveying the Modern World

Willebrord Snell's quadrant was a state-of-the-art piece of surveying gear for his time, but not long after, it was replaced by smaller, lighter, and more accurate equipment. By the 18th century, the *theodolite*, a device that could measure both vertical and horizontal angles, came into widespread use. With theodolites, surveyors and cartographers could use Snell's triangulation techniques to make maps and draw boundaries quickly and with great accuracy.

With the introduction of electronic instrumentation and satellites in the 20th century, there are few spots, if any, for which accurate maps do not exist.

Otto von Guericke and the Vacuum Pump

1654 CE



10

There's an old saying that goes "nature abhors a vacuum." It's commonly attributed to the Greek philosopher Aristotle.

Although Artistole's views played a profound role on the development of science and learning, a lot of what he wrote turned out to be wrong. Nature, it now appears, loves vacuums. There are vacuums in outer space, glass barometers, toilet plungers, and radio tubes. It was a 17th century German scientist who figured out a way to produce them whenever and wherever we need them.

Even Wild Horses Couldn't Drag Them Apart

In the spring of 1654, Otto von Guericke, a city official and part-time scientist, put out notices all over Magdeburg, a city in what is now Germany. The notices stated that all the townspeople of Magdeburg were invited to come out to the public square for an important demonstration.

What did Otto have in mind? It turns out the townspeople were in store for a spectacular demonstration of science!

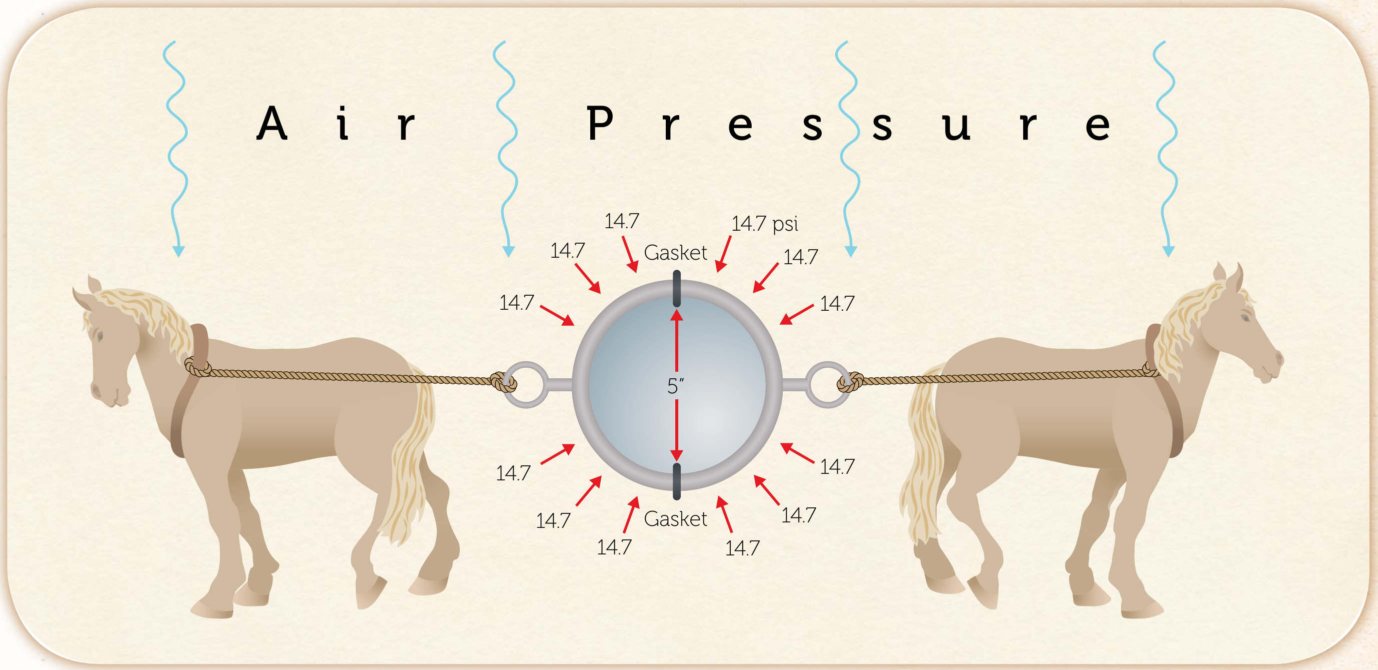
Von Guericke came from a leading family in the city of Magdeburg. His father was the mayor of the city, as was his grandfather. Under their leadership, the city had grown large and prosperous. In 1626, Otto also began working for the city when he returned to his hometown after studying a dizzying number of subjects at the University of Leyden.

He was an able administrator, and over time, he earned a reputation as an exceptional city administrator and civil servant. But his true love was putting natural philosophy to work—in modern times we call this engineering.

Von Guericke wanted to stage a dramatic demonstration of his new mechanical invention, the vacuum pump. Otto was so excited by the possibilities of his pump that he wanted to show it off in a very big way. He arranged for a public demonstration of his machine to be held in the town square. But exactly how would someone really show off something as prosaic as a vacuum pump?

Because he was something of a showman as well as a scientist, he assembled two teams of draft horses that he said would try to pull apart a 20-inch-diameter metal sphere, which had been cut in half earlier.

The two halves of the sphere had not been bolted, welded, glued, or otherwise mechanically reconnected to one another. Instead, von Guericke had used his new vacuum pump to evacuate the air inside the sphere. Strain and pull as they might, the dray teams could not part the spheres—the force of the vacuum inside the metal halves was stronger than the horses (see Figure 10.1).



We live at the bottom of a sea of air. The air above us pushes down with a force of 14.7 pounds for every square inch (psi). If we removed all of the air from a strong hollow globe made from two hemispheres gasketed together, then there would be no air pressure inside. So, the globes would be pushed together by a force equal to atmospheric pressure multiplied by the cross-sectional area of the globe.

If the globe were 5" in diameter, then the force holding the hemispheres together is

$\pi \times$ Radius^2 (in inches) $\times$ air pressure
or
$\pi \times (5)^2 \times 14.7 = 1232$ pounds of force!

Figure 10.1: Horses trying to pull apart a vacuum

Exactly how hard would those horses have to pull to separate the hemispheres? To figure this out, you first need to calculate the area of a 20-inch-diameter circle. The radius of a 20-inch circle is simply half the diameter, or 10 inches.

$$\text{Area} = \pi \times r^2$$

where *r* is the radius, so, the area of the separation space in the sphere is $\pi \times 100$, or 314 square inches.

If von Guericke's pump was capable of pulling a pretty good vacuum of about 1 pound per square inch (psi), then the force required to pull the halves apart is this:

$$314\ \text{in}^2 \times (14.7 - 1)\ \text{psi} = 4300\ \text{lbf}$$

It would take over two tons of force to separate those spheres!

Materials

- (2) 8″-diameter cake pans
- (2) Cabinet knobs with attaching screws
- (8) Sheets of newspaper
- Water
- Silicone cement
- Cotton balls
- Aluminized tape
- Denatured or rubbing alcohol

Tools

- Electric drill with a ⅛″ drill bit
- Scissors
- Marking pen
- 6d nail
- Match or lighter

Re-creating the Magdeburg Hemispheres

It's easy and fun to build your own Magdeburg hemispheres, although in this case, we'll use aluminum cake pans instead of copper hemispheres. Hooking up horses to pull the pans apart is definitely optional!

Before you get started, take a look at Figure 10.2, which shows how your hemispheres will be assembled.

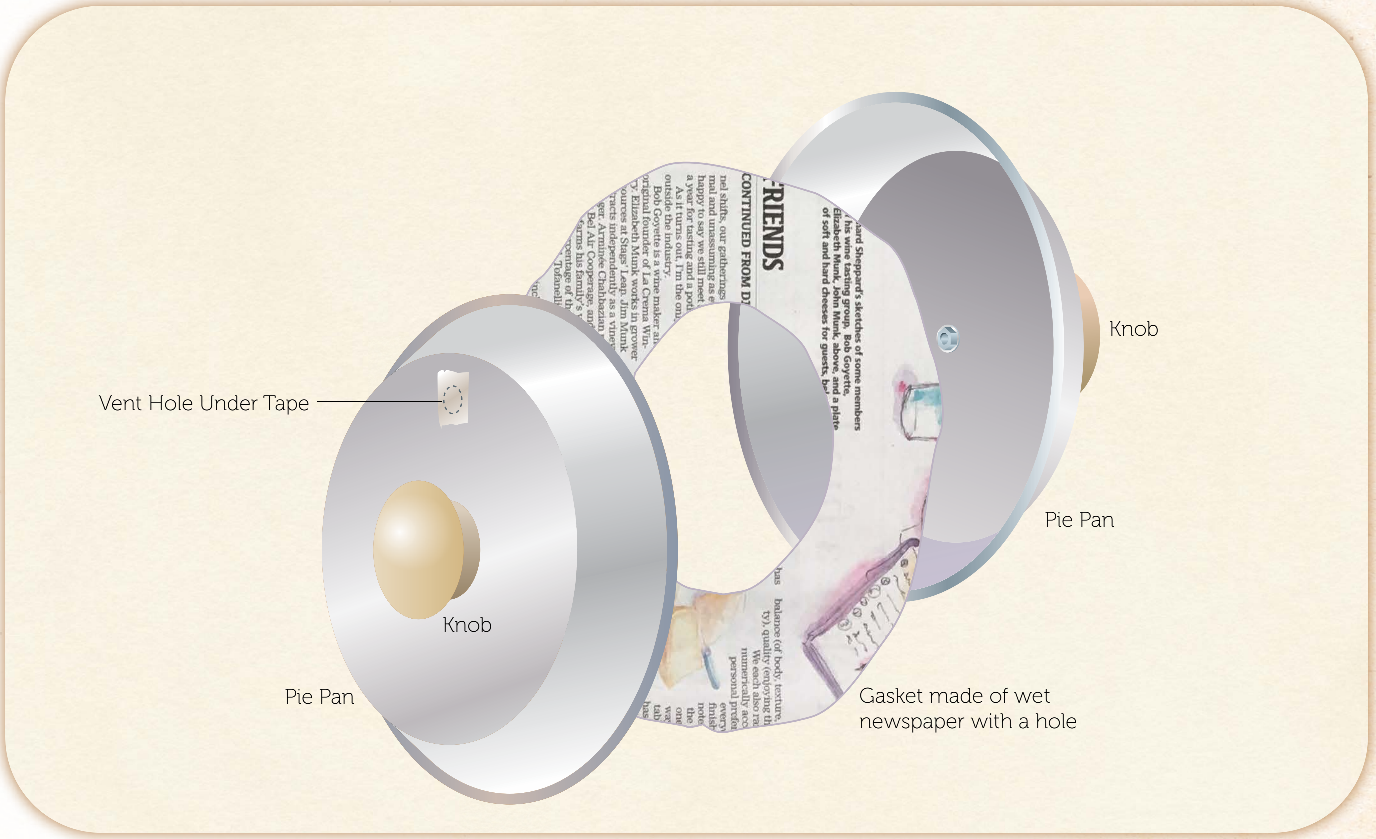


Figure 10.2: Assembly diagram for Magdeburg hemispheres

Part 1: Attaching Knobs to Cake Pans

Follow these steps to attach the knobs:

1. Drill a hole in the center of the cake pan that is the same diameter as the screws that came with the cabinet knobs (probably 1/8-inch, but check prior to drilling the hole).
2. Place a dollop of silicone cement on the hole (see Figure 10.3).

Figure 10.3: Sealing the knob hole

3. Insert the knob screw through the hole and into the receiving hole on the knob and tighten it. The silicone will seal around the screw, making the connection airtight.

Part 2: Making the Vacuum Release Port

Figure 10.4: Making and covering the release port

To make the release port, follow these steps:

1. Place one of the cake pans on a wooden block.
2. Mark a point about 2 inches from the center knob with the marking pen and drill a 1/8-inch hole.
3. Cover the hole with a piece of aluminized tape (see Figure 10.4).

Part 3: Making a Paper Sealing Gasket

Figure 10.5: Cutting out the paper circles

To make the gasket, follow these steps:

1. Lay seven or eight sheets of newspaper on top of one another.
2. Mark a circle that is slightly larger than the cake pan with a marking pen and then cut out the paper circles (see Figure 10.5).
3. Cut a 4-inch diameter doughnut hole in the middle of the paper circles.
4. Arrange the paper circles neatly on top of one another and soak them briefly in water. Remove them from the water as soon as the inside paper circles are wet.

Part 4: Pulling a Vacuum

Now it's time to create your vacuum. Follow these steps:

1. Arrange the one cake pan and the wet newspaper as shown in Figure 10.6.
2. Pour a small amount of fuel (about 3 drops) onto a small cotton ball and then place the cotton ball in the approximate center of the cake pan, but away from the vacuum release port.
3. Carefully light the cotton ball with a long match or fireplace lighter (Figure 10.7).
4. Quickly place the other cake pan atop the paper gasket, taking care to align the rims of the cake pans, one on top of the other.

   Caution: The burning cotton ball will locally heat the cake pans; avoid this area with your bare hands.

   The burning cotton ball produces water vapor. The vapor quickly condenses into a liquid, and it is this that produces a partial vacuum inside the container.

Figure 10.6: Arranging newspaper on cake pan

Figure 10.7: The lit cottonball

Part 5: Attaching a Draft Horse Team to Attempt to Separate the Halves

Now let's see if your vacuum worked!

1. Attach one team of horses to each knob. (If you have no horses available, have a friend pull one knob while you pull the other.)

Figure 10.8: Attempting to pull apart the cake pans

2. Start the horses moving in opposite directions and see if they can separate the two cake pans.

   If you've worked carefully, the halves will not separate, even if you apply a great deal of force (see Figure 10.8)!

Part 6: Releasing the Vacuum

Now that you've seen the vacuum in action, you might want to take it apart. To do so, use the 6d nail to poke a hole in the aluminum tape that covers the vacuum release port. Once the seal is broken, the two halves will release.

> *Tip* If you have trouble making a good vacuum seal, check the edges of the pans to make sure they are smooth and free of nicks. If necessary, use additional pieces of newspaper or try different pans.

Vacuums Everywhere

The ability to draw a vacuum is a very important part of many industrial processes. Certainly, scientists use a lot of vacuum pumps. For example, electron microscopes require high vacuums to work, as do the dryers that make freeze-dried foods, and the centrifuges that make fuel for nuclear reactors.

Although you probably don't handle many vacuum pumps directly on a daily basis, they are hiding just behind the scenes in a hundred different places. For instance, farmers use them to milk dairy cows, as do mechanics who service automotive brake and fueling systems and the technicians who keep air conditioners and refrigerators working properly.

The Inventor's Workshop

If you enjoy making things, eventually you'll need a space to work and tools to work with. In the days of the early inventors, a tool was simply a handheld implement, such as a hammer, saw, or file, and it was used for performing or facilitating mechanical operations, like cutting, pounding, or filing. But in modern times, tools do so much more. They measure quantities and qualities precisely, they join electrical components into circuits, and they perform a hundred other useful operations.

The Workbench

First and foremost, you'll need some sort of flat, solid surface on which to work. Any sturdy table will do, but a workbench is a great help, because it provides the foundation you need in order to work skillfully.

You can make or buy a workbench. Many lumberyards sell prebuilt workbenches or kits containing all the materials you'll need. You can also find a design for one or draw one yourself. Designs for homebuilt workbenches run from complex Scandinavian designs with beechwood frames that are mounted on self-leveling hydraulic cylinders down to a simple plywood door nailed to two sawhorses. No matter what sort of bench you have, the addition of a wood vise and pullout shelf make it more versatile.

Necessary Tools

Ask an expert what sort of tools to buy and the typical advice is to buy the best-quality tools you can afford. In most cases, that's good advice. Cheap screwdrivers, for example, can be a big mistake; the soft metal edges of inferior blades can bend or even break under stress, and the plastic handles chip when you drop them. For any tool you use frequently, it makes sense to go with quality.

On the other hand, when you've got a one-off job, and you're not sure if you'll ever have another use for piston ring pliers or a gantry crane, buying an inexpensive tool may make sense.

Here are some ideas for outfitting your workspace.

Basic Tools

These handheld tools are useful in a wide variety of situations. They are as important for adjusting or repairing existing items as they are for making new ones.

Screwdrivers. Choose an assortment of good-quality Phillips-head and flat-head (and, possibly, Torx) screwdrivers in a variety of sizes.

Handsaw. Most often, you'll be cutting dimensional lumber (2′× 4′s, 2′× 6′s, etc.) to size, so choose a saw with crosscut instead of ripping teeth.

Hacksaw. You need this type of saw for those occasions when you have to cut through something harder than wood.

Hammers. Start with a claw hammer for nailing and a rubber mallet for knocking things apart.

Socket and wrench set. If you work on things mechanical, you'll appreciate the quality of a good socket set. Spend the money and get English and metric sockets as well as Allen wrenches.

Pliers. Pliers come in a variety of shapes. At a minimum, your shop should have standard, needle-nose, and vise grips.

Cutters and mat. You'll want diagonal cutters, a utility knife, tin snips, a wire cutter/crimper/stripper, and a good pair of scissors. You'll also find a self-healing cutting mat to be a great help. Buy one at any fabric store.

Clamps. Clamps securely hold workpieces, allowing you to work safely and accurately. Clamps come in various sizes and are selected based on the size of the workpiece.

Linear measuring tools. Make sure you have a tape measure, a protractor, and a combination square.

Files and brushes. You'll need flat and round bastard files and a wire brush. (A bastard file refers to a file that has an intermediate tooth size.)

Mixing and volume measuring equipment. Stock your work area with plastic bowls in different sizes, disposable spoons, measuring cups, and measuring spoons.

Safety equipment. Safety glasses, hearing protection, a fire extinguisher, goggles, a dust mask, and gloves are all very important. All safety glasses, even inexpensive ones, must conform to government regulations, so they all provide adequate protection. However, more expensive ones are more comfortable and look better, making you more inclined to always use them.

Cordless and/or corded electrical drill. A drill with a variety of screwdriver tips and drill bits may well be your most frequently used power tool. Corded drills are lighter and more powerful, but many people appreciate the flexibility of a cordless model. The larger the top-end voltage (e.g., 14.4 or 18 volts) of a cordless drill, the greater its torque and the more it weighs.

Specialty Tools

Inventors often need specialized tools to perform certain tasks. They are typically not expensive, at least for entry-level tools.

Soldering iron. Choose a variable-temperature model with changeable tips.

Magnifying lens. You'll find a swing-arm magnifier with a light to be a very helpful addition to your shop. It mounts directly to your workbench and swings out of the way when not in use. It's great for everything from threading needles to examining surface finishes.

Scale. A triple-beam balance or an electronic scale is a necessity for chemistry projects and mixing stuff.

Digital multimeter. If you do any electronics work, a volt-ohm meter with several types of probes and clips is indispensable.

Power Tools

These are great, if you can justify their cost:

Drill press. A sturdy drill press provides far more accuracy and drilling power than a hand drill.

Belt sander. Belt sanders utilize a rotating abrasive belt to quickly remove material from workpieces.

Grinder. Grinders have rapidly spinning abrasive wheels and are used for shaping metal and sharpening tools.

Table saw/Band saw/scroll saw. Electrically powered saws cut wood much faster than handsaws. However, they must be used with great care.

Beyond these basics, there are hundreds, if not thousands, of tools available—all of which may be useful, depending on the project. In regard to stationary power tools, it's a tough call. Because they are expensive and require a lot of shop real estate, it really depends on what you're going to do *most*. I use my table saw all the time, but I know people who consider a band saw to be an absolute necessity, and others who say a scroll saw is their number one power saw priority.

Supplies

Besides raw materials and tools, stock your shop with key general supplies. Here's my suggested checklist:

- Duct tape
- Electrical tape
- Transparent adhesive tape
- Powdered graphite lubricant
- Rope or cord
- String or twine
- Light all-purpose oil
- White glue
- Superglue (cyanocrylate)
- Quick-set epoxy
- Extended-set epoxy
- Sandpaper: fine, medium, and coarse
- Heat-shrink tubing
- Zip ties
- Pencils
- Ink markers
- Rags, wipes, and towels

It takes time and money to accumulate a good supply of tools. But a well-stocked workshop or tool box and the ability to use the tools properly are valuable assets for any inventor.

Further Reading

Do you want to read more about early scientists and technology, or find more do-it-yourself (DIY) projects that are based on ancient to medieval history? These books are excellent places to start:

The Ancient Engineers, by L. Sprague de Camp (Doubleday, 1963)
Although his name might not be so well known now, L. Sprague de Camp was one of the best-known science fiction writers of the 1930s and 1940s. But it's this 1963 work of science fact that I highly recommend. As Isaac Asimov said of it, "it's the history (of science) as it should be told."

A Splintered History of Wood, by Spike Carlsen (Harper, 2008)
So, so many DIY projects use wood as the primary building material. There are a lot of books out there about how to cut it, nail it, glue it, and so on. But this book explores the science and history of the stuff in a very entertaining manner. Maybe it's because it's so common and familiar that we don't really think much about it, but wood, in and of itself, is incredibly interesting.

The Knowledge: How to Rebuild Our World from Scratch, by Lewis Dartnell (Penguin, 2014)
This strange and interesting thought experiment is, in a sense, the ultimate DIY book. The premise: if most of the modern industrial

world were to suddenly disappear due to, say, an asteroid hit, an ultra-virulent disease, or nuclear war, then society would need a reboot manual to get things going again. In a nutshell, that manual is *The Knowledge*, at least sort of.

Made by Dad: 67 Blueprints for Making Cool Stuff, by Scott Bedford (Workman, 2013)

Actually, this book is good for any dad or mom with little kids. Most of the projects here are clever and fun and are a great introduction to the world of DIY. Really, why buy toys when it's so much more fun to make them?

Defending Your Castle: Build Catapults, Crossbows, Moats, Bulletproof Shields, and More Defensive Devices to Fend Off the Invading Hordes, by William Gurstelle (Chicago Review Press, 2014)

What better way to combine science, history, and DIY than to fortify your home against attacks by Huns, Mongols, or Vikings? This book covers everything from the art and science of moat building to the construction of watchtowers and catapults. It also explores the long and colorful history of how ancient peoples defended themselves from the (really, really) bad guys.

Ancient Inventions, by Peter James and Nick Thorpe (Ballantine, 1995)

As we've seen in this *ReMaking History* book, our modern era has no monopoly on clever and important inventions. Cranes, compasses, and clocks were invented long ago, and although most of the names of the inventors of these items are lost in the mists of history, their importance continues. This book sheds light on a great many more.

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