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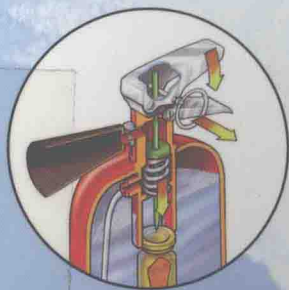
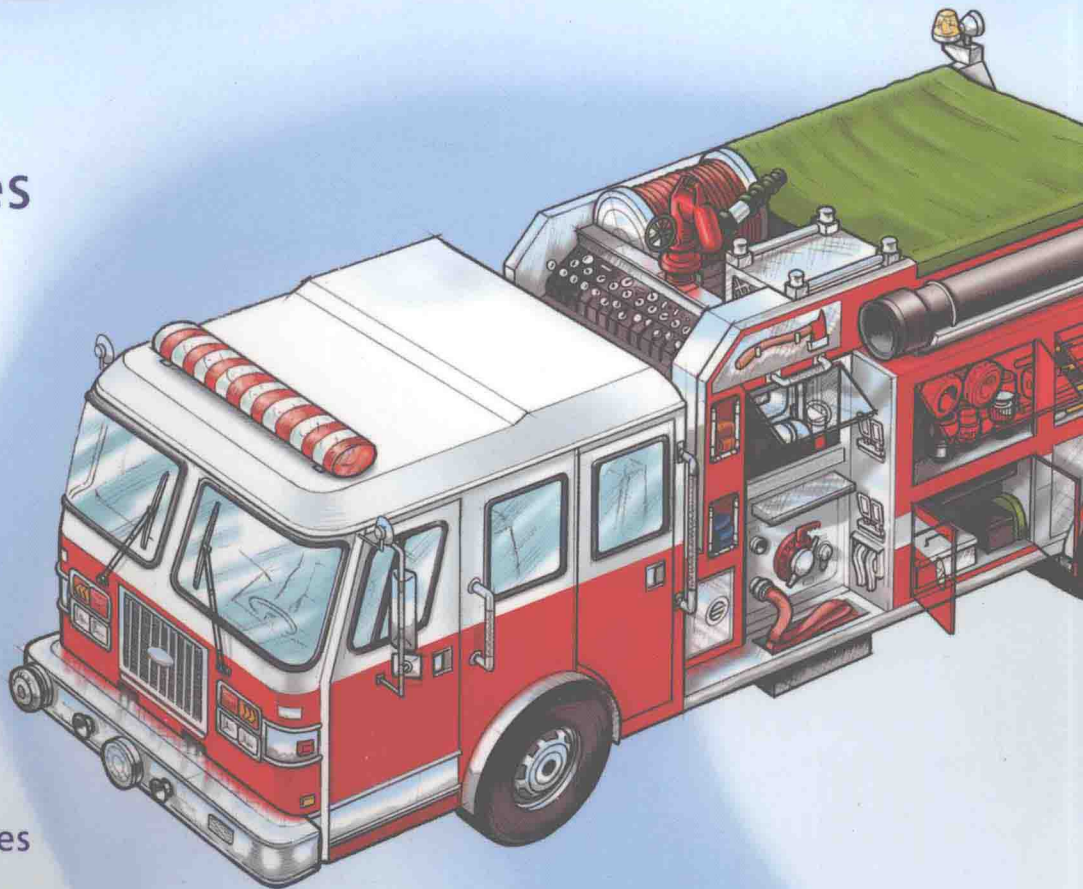
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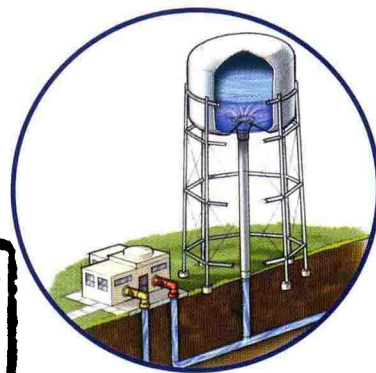
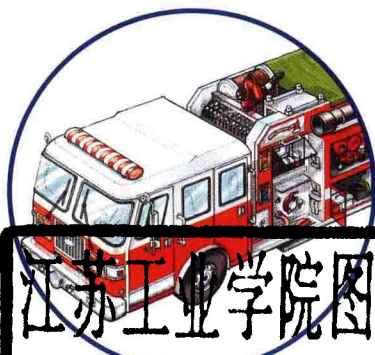
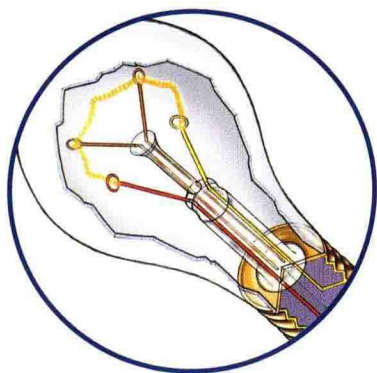
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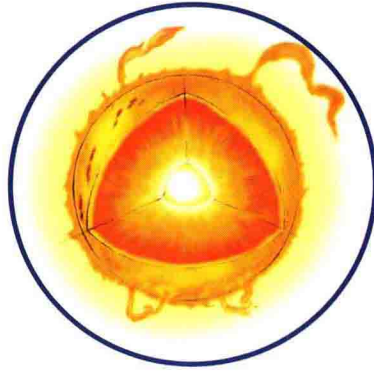
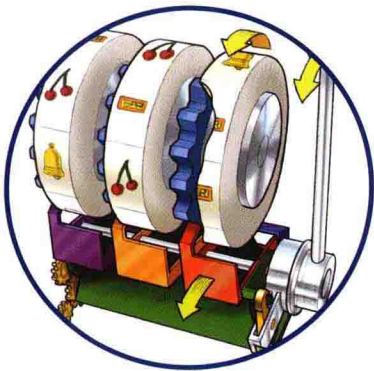
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Preface

Hello,

Wow. Here we are again. It seems like yesterday that we were finishing the final edits for the first HowStuffWorks book and now, as you read this, you're holding a copy of its sequel. A lot has happened in the last 12 months. On one level, I've had some amazing changes in both my personal and professional life. And on another there have been certain events that have had an impact on people around the globe.

Personally, my wife and I were thrilled to welcome two more children to our happy family—our twin boys were born in April. Professionally, HowStuffWorks, Inc. has increased its presence across several media platforms. The Web site garnered a spot on TIME magazine's list "The 50 Best Web Sites." The completion of this book marks our fourth published work with Wiley Publishing, Inc. and the TBS Superstation plans to host the weekly program HowStuffWorks at the Movies.

One of the ways we come up with topics is from the emails we receive every day. Directly after the September 11th incident, we had an overwhelming number of emails from people around the world. Almost everyone wanted to know how biological and chemical warfare, gas masks, and body armor work. As airports stepped up security, thousands of people were reading our article about metal detectors every day. Almost daily, we received hundreds of emails thanking us for the incisive, practical descriptions we have regarding how certain military devices work. Because we received such an incredible response to these articles, we created a special chapter for this book titled Police, Military, and Defense.

The events surrounding September 11th have had a profound effect on a huge number of people. A common sentiment expressed by many of our readers was that they had a sense of confusion and helplessness. As I was responding to our readers by writing some of these articles, I found that having an understanding of this technology helped. Although some of the information I found could be alarming, it was actually very helpful to understand it all. Knowledge is empowering.

Other chapters of this book are filled with all kinds of technology that I find fascinating. From fire extinguishers to fax machines, water guns to weightlessness, and snow makers to skyscrapers—I hope you enjoy learning about how this stuff works as much as I do.

Sincerely,



A yellow sticky note with the handwritten signature 'Marshall' in black ink.



Marshall, Katherine, Tom, and Lee gaze at the gallery of Lee's handiwork.

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Creating a book like this is an incredible experience. This book contains more than 130 different articles and over a 100 hand-drawn illustrations. At any given time, there were dozens of people working on its content or look and feel. The entire team worked through a series of processes to produce what you now hold in your hands. To create a book like this, you need to:

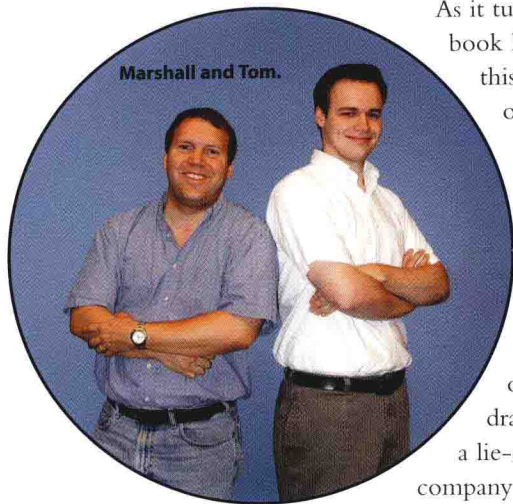
- Come up with the words.
- Come up with the art.
- Create the cover.
- Design the layout.
- Copyedit and proof everything.

In creating the first HowStuffWorks book last year, we came up with a basic layout design and cover that worked amazingly well with the content. So, this time we were able to work with and rely on those original concepts.

The process for creating the words was pretty similar to what we did last time, too. Of course we do have some really different content this time, including new categories like *Nature*, *Heavy Equipment*, and *Police, Military, and Defense*. A dozen or so people wrote the articles—including Karim, Kevin, Craig, Jeff, Tom, and myself. Tom, Katherine, and I then edited the articles for voice, reading level, and size.

The copyediting and proofing was a multiphase process handled mostly by Suzanne, Ben, and Katherine.

This explains the words, cover, and layout, and the copyediting and proofing processes, but what about the art?



Marshall and Tom.

As it turns out, the process of creating art for a book like this is fascinating! The actual process this time was technically the same, but instead of simply seeing pieces of art at various stages like with the last book, this time I was able to witness the entire art process—from start to finish. Every day I couldn't wait to come to work to see what new illustration Lee had created. We even have our own gallery of Lee's illustrations throughout the HowStuffWorks office—just outside the conference room are drawings of a fire engine, bulletproof vest, and a lie-detector test set-up. On the way to the company breakroom, you see a yo-yo, a bug zapper, and a cut-away of an aerosol can. As I'm writing this, there

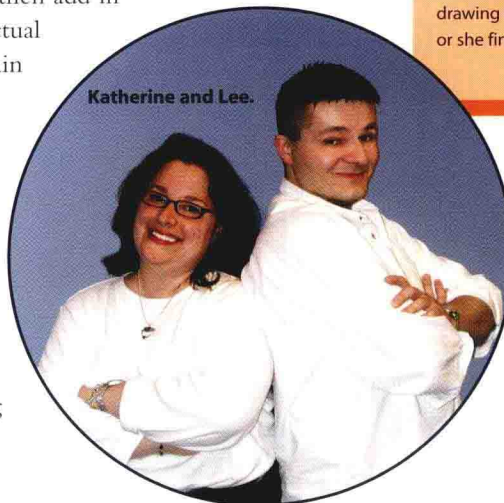
are sketches of a washing machine, a paintball gun, and a chain stitch for the sewing machine article plastered around Lee's desk.

An incredible amount of work goes into producing these illustrations and drawings. That's actually one of the coolest things about the first big HowStuffWorks book and it's the same for this book. The words and the art really must fit together to explain the inner workings of a subject. To make sure this happens, the first thing Lee does is read the article. After he's finished reading, Lee talks about the article with the author or editor. Together, they figure out what it is that Lee should illustrate.

Once the subject is decided upon, Lee has to do some more research—especially for drawings that show a 3-D view or a cut-away. He uses our Web site and other online resources, books, photos, and actual models to create his initial sketches. After he locates all of his reference material, he sketches out a diagram to establish a viewing angle and component locations.

Next, he uses that preliminary sketch to create what he calls a *working drawing*. At this stage, all of the components of an item are in their specific positions and the dimensions are finalized. Lee uses the photocopier (see "How Photocopiers Work" in *Around the Office*) to enlarge the working drawing so that he can then add in the *line weights* (the thickness of the line around the actual parts). He uses line weights to focus attention on certain areas or to make aspects of a drawing more clear.

This version of the illustration is then scanned (see "How Scanners Work" in *Around the Office*) to create a computer file. Using a graphics tablet, Lee colors everything in and voilà—the illustration is complete. When you look at the detail of something like the fire-engine illustration—just the sheer number of lines and curves Lee has put down on the sheet of paper—you realize how remarkable this process is and how rare his talent is. It is truly amazing to watch Lee work.

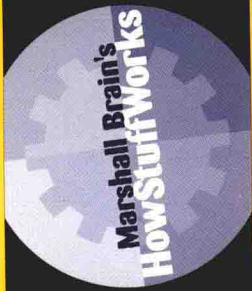


Katherine and Lee.

Scavenger Hunt

We write about thousands of topics for both the HowStuffWorks Web site and the HowStuffWorks books. In order to explain these things, we have to physically take them apart—to actually see inside them—so that we can figure out just how they work. Some objects, like a humidifier, are pretty easy to locate. For that, we simply went to a store around the corner. Other objects, however, aren't that easy to find—in fact, some objects are totally cost prohibitive or impossible to purchase at all! You can't just walk into someplace called "Firehouse Supplies R Us" for a fire engine!

So, how do we find all the stuff we need? It turns out it's a lot like being part of a scavenger hunt—the game where each player gets a huge list of all kinds of different objects and the players have to either locate the actual object, or at least a photo of it, for everything on the list. That's what we do. If it's too big or too expensive to buy, we send a lot of emails and make a lot of phone calls until we can locate something. Then a writer and a photographer go and check it out. The writer uses the information to create the article and then we either use the actual photos to illustrate the article or an artist will create an original drawing from the information he or she finds in the photos.



If you enjoyed this book, then you're going to love the cd!

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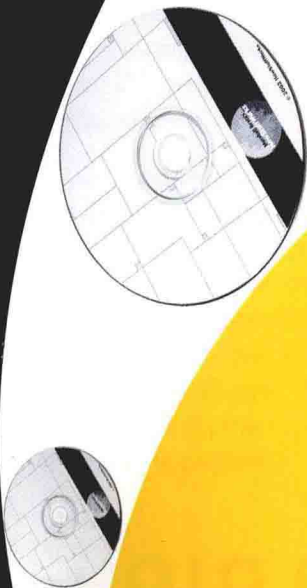
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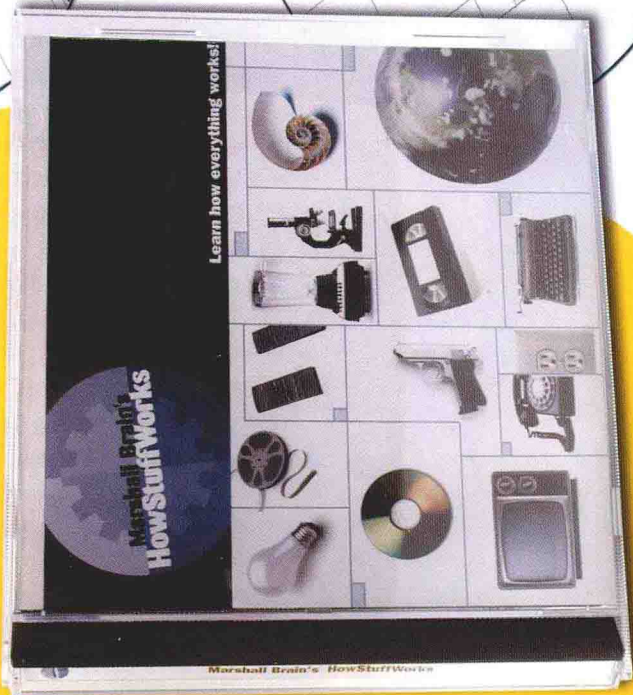
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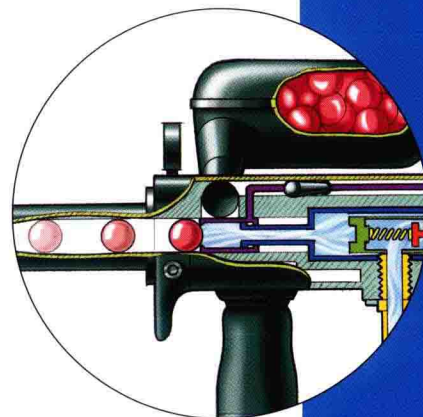
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How **WATER GUNS** Work

Soon after its introduction, the water gun took its place among the most popular summer toys of all time, and it's easy to see why: When you're a kid, or a kid at heart, what better way to cool off on a hot afternoon than waging an epic water battle against your friends and family?

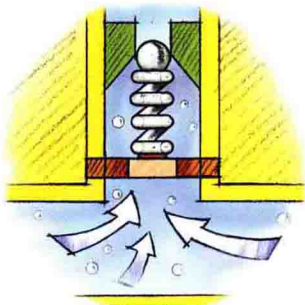
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Over the years, water guns have evolved considerably. Thirty years ago, a typical water warrior was armed only with a small squirt pistol that had a fairly short range and an even more limited ammunition reservoir. These days, you'll find an entire arsenal of water weapons at most toy stores, complete with water machine guns, water bazookas, and even water grenade launchers.

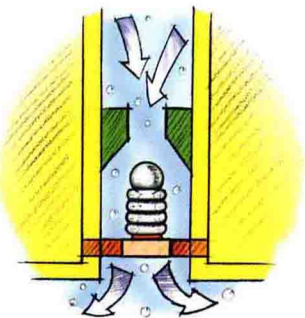
The Classic Water Gun

A classic squirt gun has just a few basic parts:

- A trigger lever, which activates a small pump.
- A pump that is attached to a plastic tube that draws water from the bottom of the reservoir. The pump forces this water down a narrow barrel and out a small hole at the gun's muzzle.
- A hole, or nozzle, which focuses the flowing water into a concentrated stream.



Valve Closed



Valve Open

The only complex part in this design is the water pump, and it's about as simple as they come. The main moving element is a piston, housed inside a cylinder. Inside the cylinder is a small spring. To operate the pump:

- 1) You pull the trigger back, pushing the piston into the cylinder.
- 2) The piston compresses the spring, causing the spring to push the piston back out of the cylinder when you release the trigger.

These two strokes of the piston, into the cylinder and out again, constitute the entire pump cycle.

The downstroke—the piston pushing in—shrinks the volume of the cylinder, forcing water or air out of the pump. The upstroke, the spring pushing the piston back out, expands the cylinder volume, sucking water or air into the pump. In a water gun, you need to suck water in from the reservoir below and

force it out through the barrel above. In order to get all the water moving through the barrel, the pump must only force water up—it cannot force water back into the reservoir. In other words, the water must move through the pump in only one direction.

The device that makes this possible is called a *one-way valve*. The one-way valve in a basic squirt pistol consists of a tiny rubber ball that rests neatly inside a small seal. There are actually two of these simple one-way valves: one between the reservoir and the pump, and another between the pump and the nozzle.

This pump design is beautiful in its simplicity, but it has two big limitations:

- The amount of water in each blast is limited.
- The duration of the blast is also limited.

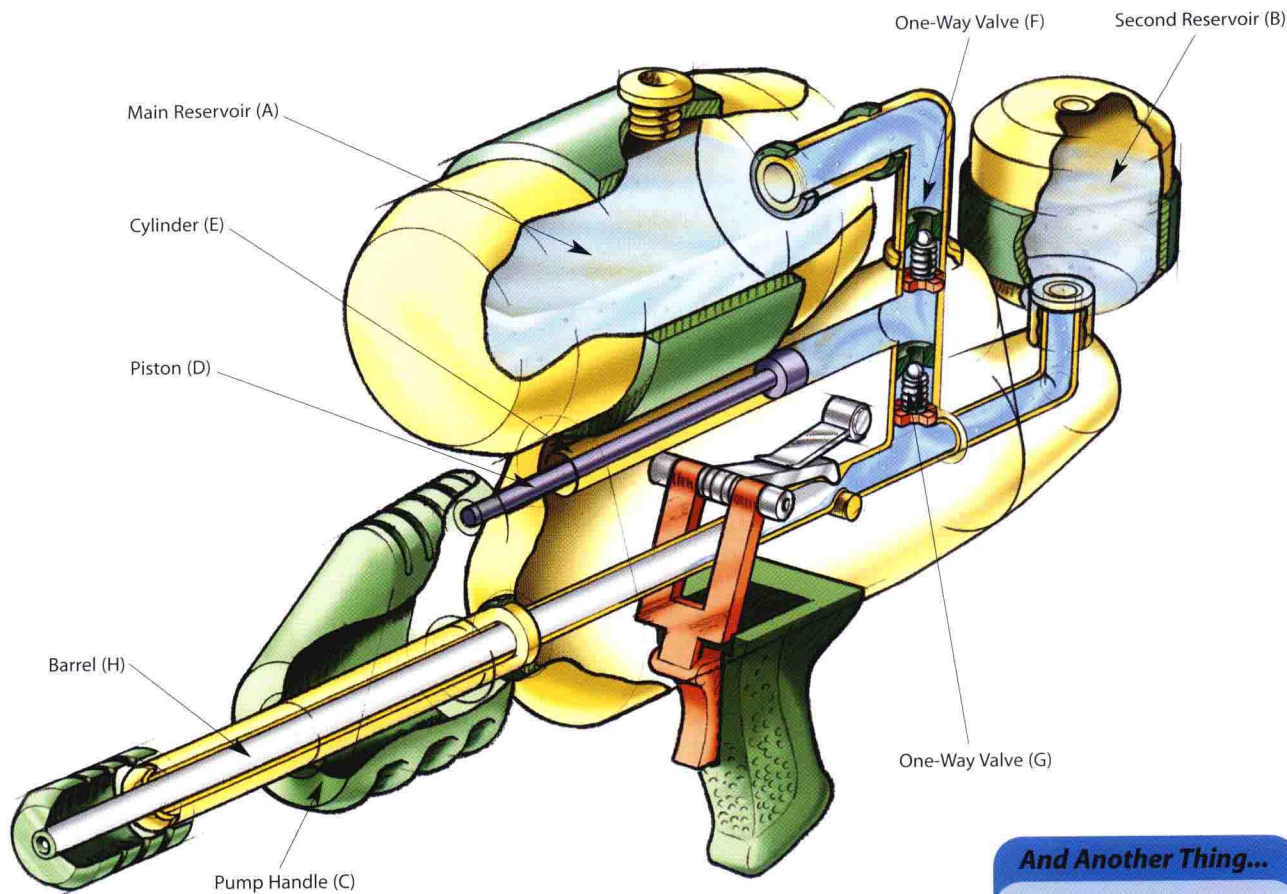
Throughout the history of water guns, designers have been wrestling with these two problems to create a better pumping system.

Under Pressure

In 1982, a nuclear scientist named Lonnie Johnson came up with an ingenious solution to these problems. In his spare time, he was working on a new heat-pump system that would use moving water to regulate temperature. Late one night, he attached a model of the pumping mechanism to the bathroom sink and was startled by the powerful water blast that shot across the room. In that instant, he was struck by the idea for a water gun that would use compressed air to provide pressure for a water blast.

To make his idea a reality, Johnson enlisted the help of an accomplished inventor named Bruce D'Andrade. Together, D'Andrade and Johnson came up with the basic design that would become the Super Soaker.

Super Soakers are built around a pump mechanism, but moving the pump doesn't actually drive water out of the gun; it serves to build up water pressure before the blast. In the



first wave of Super Soakers, you build up this pressure by pumping air directly into a single water reservoir. As you pump in more air, it becomes more and more compressed and applies greater pressure to the water inside.

In later models, you build pressure by pumping water instead of air. This sort of gun has two water reservoirs (labeled A and B), which are connected together via a network of tubes. To load the gun, you fill the larger reservoir (A) with water. To prime the gun for a blast, you pull the pump handle (C) in and out several times. The pump handle is connected to a long, narrow piston (D), which moves back and forth inside a cylinder (E). This pump is similar to the one in a squirt-gun pistol, and it relies on the same one way–valve system to control the direction of water flow. The first valve (F) is positioned between the large water reservoir and the pump mechanism, and the second valve (G) is positioned between the pump and the smaller water reservoir, which feeds into the barrel of the gun (H).

On the upstroke of the pump cycle, when you pull the pump handle out, the

receding piston pulls in water from the large reservoir above. The second one-way valve (G) keeps water from flowing up from the smaller reservoir (B). On the downstroke of the pump cycle, when you push the pump handle in, the plunging piston drives the water out of the cylinder, through the second one-way valve (G) and into the small reservoir (B). The first one-way valve (F) keeps the pressurized water from flowing back up into the large reservoir (A).

All Wet

The only thing keeping the water inside the gun is the trigger mechanism. The trigger is simply a lever secured to the gun housing. A stiff length of metal attached to the housing holds the top part of this lever against the flexible plastic tube leading to the gun's barrel, pinching it so no water can get through. When you pull the trigger back, the metal piece bends, and the lever releases the plastic tube. With this passageway open, the pressurized air can push all of the water out of the gun. If you build up enough pressure, the water is expelled at a very high velocity.

And Another Thing...

In the late 1990s, a new wave of Super Soaker guns came out that boasted higher pressure levels. These guns, developed by Bruce D'Andrade, feature the Constant Pressure System. The main component in this system is a simple water bladder. This bladder is like a balloon, but it is made of much more rigid material. These guns have the same sort of pump as other Super Soakers, but the water and air are driven into the water bladder rather than into a plastic reservoir. As you pump more water in, the bladder expands, in the same way a balloon expands as you blow more air into it. When it is stretched, the bladder wants to return to its natural shape, so it applies a good deal of inward pressure on the water. When you pull the trigger and open up the passageway to the gun barrel, this pressure drives all of the water out of the gun. This allows for much more powerful water blasts than can be achieved with compressed air alone.

How PAINTBALL Works

Since its introduction in the 1980s, paintball has become a worldwide phenomenon. Enthusiasts have formed teams, set up leagues, and organized tournaments. Paintball is still a long way from the popularity of older sports like basketball or football, but new paintball playing fields and organizations are popping up all the time. The main thing that sets paintball apart from other sports is the equipment involved. To play paintball, you need a gun (called a marker), a supply of paintballs, and a safety mask.

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Cool Facts

Originally, paintball markers weren't intended for sport. The first markers were developed in the 1970s for use in forestry and agriculture. Foresters used the markers to tag certain trees (for research or for planning trails, for example). Farmers also used markers to tag cattle. At some point, it occurred to a few foresters or farmers to shoot the markers at each other, and the game of paintball was born. But things didn't really get going until 1981, when a group of 12 weekend warriors used some forester markers to play a grown-up version of capture the flag.

Paintballs have the same basic design as gel-cap pills or bath-oil beads. They consist of a glob of colored liquid encased in a gelatin capsule and measure about half an inch in diameter. The "paint," which comes in many colors, is non-toxic, biodegradable, and water soluble (so it washes off skin and clothing). The capsule is durable enough to hold up to normal handling, but if you throw it against something, it will burst.

The Way of the Marker

A paintball marker shoots a paintball out of the barrel at about 300 feet per second (about 90 meters per second). Most paintball markers do this using a compressed gas source, such as a tank of liquid carbon dioxide or compressed air.

At the beginning of the firing cycle, a sear piece holds the bolt back in the cocked position. With the bolt in this position, a single paintball can fall out of the ammunition hopper and land in the *breech* (the area behind the barrel). A small catch holds the paintball in place.

When you pull the trigger, it pushes the sear. As the sear moves back, it unlocks the bolt. The bolt spring throws the bolt forward, toward the gas valve.

When the marker is cocked, a spring-loaded plunger blocks the passageway between the valve and the rest of the marker. When the bolt slides forward, it hits a pin connected to this plunger. This impact pushes the plunger against the spring, opening up the gas passageway to the rest of the marker. At the same time, the front section of the bolt pushes the paintball forward and blocks the hopper port.

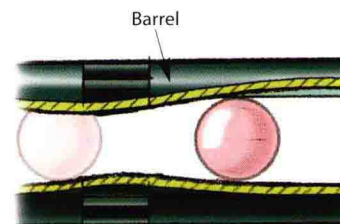
As soon as the bolt hits the plunger pin, the compressed gas rushes out and flows around the valve box to the area behind the paintball. The substantial air pressure forces the paintball down the barrel, out of the marker.

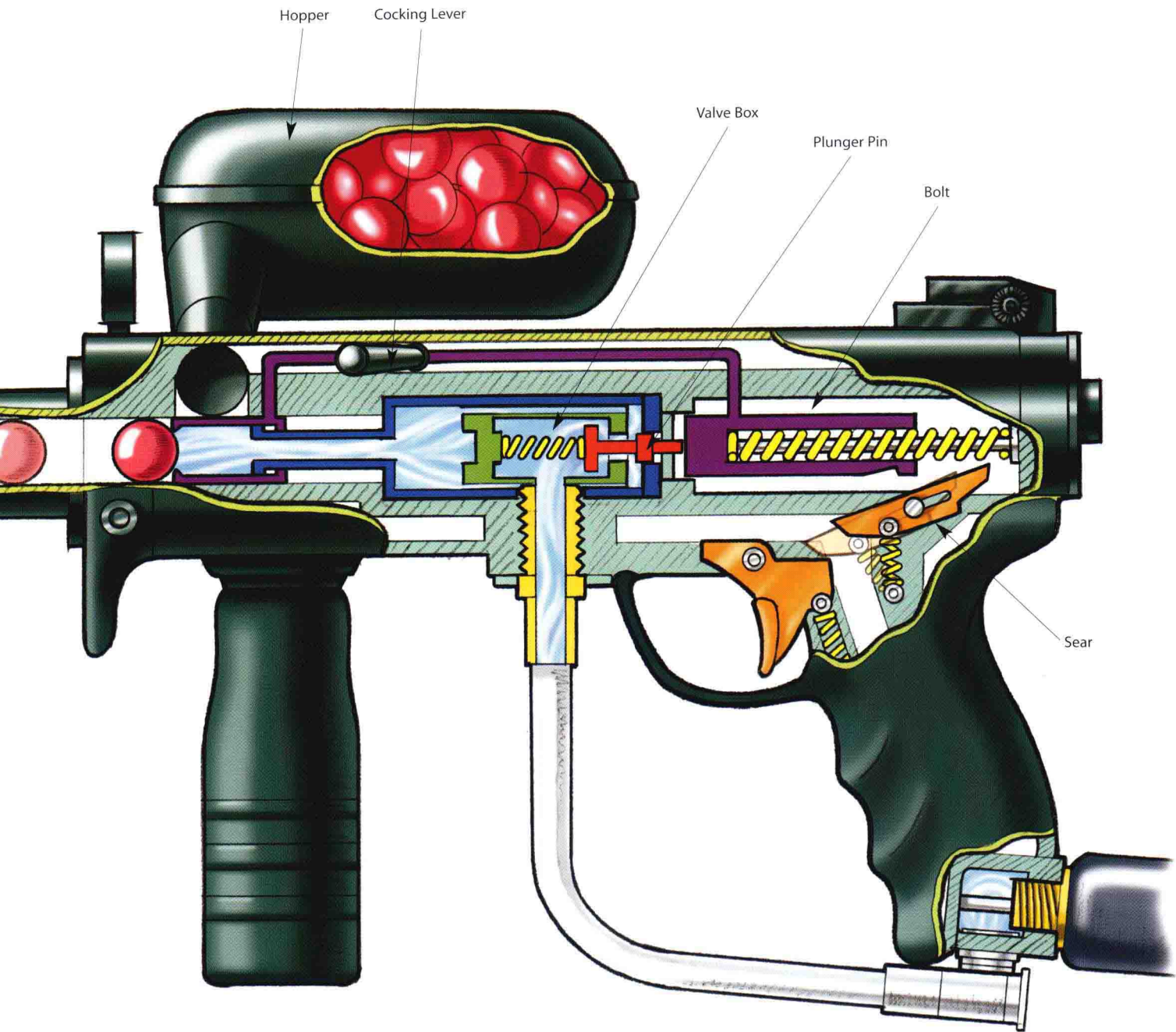
A raised portion on the plunger pin initially blocks the gas passageway to the rear of the marker. But as the pin keeps moving forward, the raised portion clears the passageway, and the gas flows backward. This pressure pushes the bolt all the way back, and the sear locks it into position again. As the front of the bolt slides backward, it opens up the hopper port, and another paintball falls into position. The marker is ready for another shot.

Changing Firing Speeds

Many markers have a simple tool for varying firing speed: A screw in the breech. Tightening the screw constricts the gas passageway, reducing gas flow. This means less gas pressure, and therefore less force acting on the paintball. Loosening the screw allows greater gas flow, increasing the force on the paintball. Some markers use more sophisticated pressure regulators.

A number of modern marker designs have built-in electric motors, solenoids, and electronic controls. In an electric semiautomatic marker, the electronics primarily control the gas valves and the pressure regulators. In automatic models, the electronics might also control motors to continually cock and fire the marker. As long as the player keeps the trigger depressed, the marker will keep launching paintballs.





Safety First, Not Last

One of the most important developments in the history of paintball has been safety equipment. When a paintball hits you on the body, you only feel a brief sting. But a speeding paintball could actually “knock your eye out,” as moms everywhere might say. In the early days, many players wore

no eye protection at all, and others wore only basic safety goggles. These days, paintball players wear full face masks and helmets. This protects them from damage to the eyes, ears, nose, and mouth. Just as in football and hockey, safety equipment is a necessity in paintball.

How YO-YOS Work

On the surface, the yo-yo is an incredibly simple toy—it's really nothing but a spool attached to a length of string. But in the right hands, it can be something extraordinary: An accomplished yo-yoist can send the toy flying out in all directions, make it hover in mid air, then snap it back. Ordinary string and plastic are brought to life!

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Name Dropping

The word *yo-yo* and the modern yo-yo design come from the Philippines. Unlike the original Chinese and Greek yo-yos, Philippine yo-yos (the word means *come come* or *come back* in the native Tagalog language) had the ability to sleep. This unique toy may have been an adaptation of the Chinese yo-yo, or it may have developed out of a Philippine hunting weapon. In any case, it apparently dates back a few hundred years in the region.

In the 1920s, a Philippine immigrant named Pedro Flores decided to bring this yo-yo design to the United States. He achieved some success right away, and in 1929, he sold his company to a businessman named Donald Duncan. Duncan trademarked *yo-yo* and, over the next few decades, built his company up into the premier yo-yo manufacturer. In 1965, the Federal Court of Appeals ruled that the term *yo-yo* had become generic, and so could be used by anyone.

A yo-yo may seem like magic, but it's actually just physics at work. Both the classic yo-yo and the sophisticated automatic yo-yos that have popped up in the past few years are remarkable demonstrations of fundamental scientific principles.

One Good Turn

The yo-yo is one of the most popular and enduring toys of all time. The ancient Greeks were playing with terra cotta versions more than 2,500 years ago, and there's some evidence that the Chinese had developed similar toys before that. In any case, the yo-yo has demonstrated phenomenal longevity—it's older than any other toy except the doll.

In early yo-yos, the string was tied securely to the axle. In the modern yo-yo, brought to the United States from the Philippines in the 1920s, the string is looped around the axle, not tied to it. This change gives the yo-yo the ability to “sleep”—to spin on the end of its string so that it doesn't immediately return.

The physical principles at work are very simple. Sitting in the yo-yoist's palm, the yo-yo has a certain amount of potential energy (energy of position). This potential energy takes two different forms:

- The yo-yo is held up in the air, giving it the potential to fall to the ground.
- The yo-yo has string wound around its axle, giving it the potential to spin as it unwinds.

Releasing the yo-yo converts both forms of potential energy to kinetic energy. The yo-yo spool falls straight to the ground (and the yo-yoist may help it along with a flick of the wrist as well). As it falls, it builds a certain amount of *linear momentum* (momentum in a straight line). At the same time, the string unwinds, and the spool spins, which builds

up *angular momentum* (momentum of rotation). When the yo-yo reaches the end of the string, it can't fall any farther. But, because it has a good deal of angular momentum, it will keep spinning.

The spinning motion gives the yo-yo gyroscopic stability. A spinning object resists changes to its axis of rotation. This phenomenon keeps a yo-yo's axis perpendicular to the string, as long as the yo-yo is spinning fast enough.

Since the spool isn't tied securely to the string, the yo-yo can spin freely once it unwinds. The yo-yoist jerks the string a little bit to make the yo-yo return. This tug briefly increases the friction between the string and the axle so that the axle starts rewinding the string. Once it starts rewinding, the string around the spool provides friction to reel in more string.

Asleep at the Wheel

The ability to make the yo-yo spool spin on the end of its string—to sleep, as yo-yoists put it—makes yo-yoing a much more interesting challenge. Yo-yoists try to keep the spool sleeping while making shapes with the string and swinging the yo-yo around the shapes. Another trick is to “walk the dog”—to let the spinning spool roll along the ground before pulling it back in.

Over the years, manufacturers have come up with a number of mechanisms to make doing these sorts of tricks easier. One of the simplest improvements was to redistribute the weight in the yo-yo to alter its moment of inertia. An object's *moment of inertia* is a measure of how resistant it is to changes in rotation. This is determined by two factors: how much mass the object has and how far that mass is from the object's axis of rotation. Increased mass makes an object harder to rotate and harder to stop rotating, as does