Make:

Brought to you by *Make:* magazine

make.co • makezine.com • makerfaire.com

MAKING FIREWORKS

YES IT'S LEGAL TO BUILD AND SHOOT YOUR OWN — WITH HELP FROM THE **DIY FIREWORKS COMMUNITY**

Written by Victor Chaney and Ellen Webb

Mike Garrett

Make fireworks? That sure sounds like fun! But isn't that illegal in a lot of places? No problem! Go to a fireworks convention, where you can take classes, build, and shoot amazing fireworks.

I got started at the Western Winter Blast, held annually by the Western Pyrotechnic Association. There, with about 800 other people, I learned how to make fireworks and shoot them in a safe, desert environment.

I also saw fireworks and fireworks shows that dwarfed anything I had ever seen before. I'd seen Fourth of July shows with 3-, 4-, and 5-inch shells, but here I found out about bigger shells (6- to 16-inch diameter and bigger), rockets, comets, and a whole lot of others.

This is where fireworks are made with loving care to create some amazing pyrotechnic works of art. You can spend hours making something that is gone in 20 seconds, but what a glorious 20 seconds it is! And thanks to photography, these moments can be preserved to enjoy again and again.

WHAT KIND OF FIREWORKS CAN YOU MAKE?

The foundation of many firework creations is the ***ball shell***. A spherical shell of papier-mâché holds the ***stars***, which are the bright points of light that make the colored trails. The shell is fired from a ***mortar***, or launch tube, where a ***lift charge*** of black powder sends it on its way in a predictable, pre-determined path.

Then to get more elaborate, stars can be placed in multiple layers, or ***petals***. ***Multi-break shells*** are cylindrical and can release groups of stars as they travel up, sometimes finishing with a ***bottom-shot*** or a very loud bang. ***Cylindrical shells***, sometimes known as ***Italian shells***, can be greater than 12" in diameter and 3–4 feet or longer. A ***shell of shells*** has several small shells inside a big shell.

Rockets are self-propelled and often explode at the top of flight into stars or ***salutes***, which are loud bangs. They go up with a *whoosh*, and while often smaller in payload than shells, the takeoff and burst make a dramatic display. They are less predictable in their path of travel, and so rocket areas are usually some distance from the shell shooting areas. Some shell enthusiasts refer to rocket making as "the dark side" of pyrotechnics.

There are so many other kinds of fireworks like ***mines***, ***comets***, ***gerbs***, ***Roman candles***, and ***fountains***. An interesting one is the ***girandola***, a wheel-shaped device rimmed with rockets that goes up in a spinning wheel of glittering, noisy spiral trails. Girandolas are challenging to make, and are spectacular when they work, and also when they don't!

BRINGING THE BOOM

At the heart of most fireworks is ***black powder***, a mixture of three ingredients. Potassium nitrate (KNO_3), is the oxidizer that provides oxygen for the reaction. Charcoal is the fuel, and sulfur is a fuel that serves to speed up the reaction.

Black powder is made by mixing these ingredients and milling them in a ***ball mill***, which is a jar full of lead balls. The mix is milled for hours with water, and since there is a small possibility of an accident, the mill is surrounded by sandbags. The milled powder can then be made into ***meal*** (very fine powder), and different grades of ***granules***. Without the milling process, the powder is very weak and may not explode. Making black powder is time consuming, possibly hazardous, and best not to try at home. The fireworks conventions have vendors, where it is pre-ordered and then picked

Italian shell with crossettes by AM Pyro of Buffalo, Missouri.

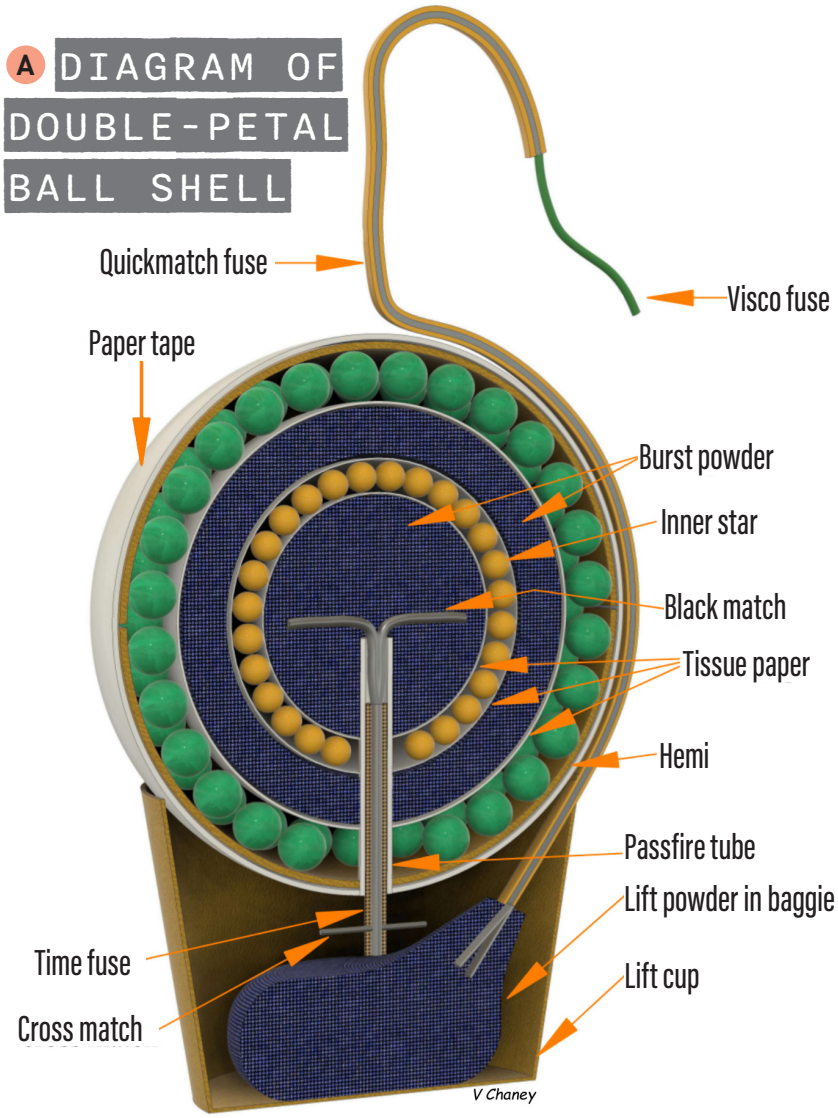
(Above) Double-petal ball shell and mines.
(Cover) Maltese *bebbuxu* ("snail") shell.

Mike Garrett, Wanda Garrett

Mike Garrett, Victor Chaney

Round shell "palm tree."

A DIAGRAM OF DOUBLE-PETAL BALL SHELL



up on site.

Technically, black powder does not explode, but burns *very* fast. When you want to explode a shell, it is wrapped in cardboard or papier-mâché, layers of paper tape, and sometimes string coated with glue. This allows the shell to build up a lot of pressure so that it bursts with great vigor. A dash of ***slow flash booster*** (KNO_3, sulfur, and aluminum) gives it some extra pop!

Fine black powder, coated onto rice hulls, is called ***burst powder*** and is used to fill up the inside of shells. Granular black powder, grade 2FA, is used for the lift charge to launch a shell. It is also at the heart of star compositions, rocket fuels, and fuses.

STAR POWER

Inside of most fireworks are the stars. These can be made in different sizes, and typically the bigger the firework, the bigger the stars. When stars are big, they may be known as comets, and these can act as stars in a shell or be fired individually. A large comet can leave a glittering trail over a long distance.

Parts of fireworks are sometimes named after parts of flowers, since exploding fireworks often resemble flowers. A ***peony star*** will be a glowing star without much trail behind it. A ***chrysanthemum star*** leaves a glittery trail behind it. A ***golden willow star*** leaves a long, glittering trail of gold sparkles that droop down like branches of a willow tree. ***Firefly stars*** leave trails of sparkles that flash on and off, twinkling like fireflies. ***Crackling stars*** make lots of little explosions. ***Color changing stars*** change from one color to another as they travel across the sky. ***Go-getters*** change to random paths from their initial straight trajectory.

Stars are made of a composition of chemicals, or ***star comp***, often an oxidizer, a fuel, a binder, and something to make it shine. Copper compounds give a blue color, strontium gives red, and barium gives green. Metal powders make sparkles— typically aluminum, titanium, magnesium, and iron.

After stars are made, they are ***primed***. This means adding a layer of more energetic material to the outside of each star to help them catch fire when the shell bursts. For this, sometimes a layer of black powder is used, and sometimes including an even more energetic oxidizer such as potassium perchlorate ($KClO_4$).

HOW A SHELL IS MADE

Shells are made by hand from cardboard, paper, tape, and glue, along with some very energetic chemicals. I will describe a double-petal ball shell (Figure A), but your imagination can take you many different directions from this.

For a double-petal ball shell, you start with two ***hemis***, or halves of a shell made of papier-mâché or plastic. One of the hemis has

YOU CAN SPEND HOURS MAKING SOMETHING THAT IS GONE IN 20 SECONDS, **BUT WHAT A GLORIOUS 20 SECONDS IT IS!**

Placing stars in a hemi for a large shell.

Half of a 10" shell of shells.

A 3D-printed jig allows compaction of burst powder over the outer petal of stars, saving space for the inner petal.

Layers of stars, burst, stars, burst, with black match in the passfire tube.

a ***passfire tube*** glued into it, which will allow the fire to get into the finished shell. The hemis are then lined with a layer of stars, as in Figure B. (To make a shell of shells, you'd line each hemi with little shells instead, as in Figure C.)

Next, a layer of tissue paper holds the stars in place, and a layer of burst powder is placed. Another layer of tissue paper is placed, and then a layer of smaller stars forms the inner petal. Different methods can be used to create this layer of tissue paper to put the inner petal of stars against. Figure D shows a 3D-printed jig to hold space for the inner petal while packing burst powder against the outer petal.

Add another layer of tissue paper, and the center of the shell has a final sphere of burst powder inside (Figure E). Sometimes some additional stars in the center can form a third petal, or just a few can make a "pistil" for the flower.

After the two hemis are put together, the shell is wrapped with multiple layers of gummed paper tape to give a dense outer layer that allows plenty of pressure to build up inside before the shell bursts!

Mike Garrett, Wanda Garrett

The shell of shells in Figure C, made by Mike and Wanda Garrett.

The preferred method of wrapping shells is the ***WASP machine*** from Connecticut Pyrotechnic Manufacturing (ctpyro.com), aka Widmann's Automated Shell Paster (Figure F). This CNC machine automatically wets the gummed tape and wraps it around the shell in a perfect pattern, and saves considerable time that might have been spent pasting the tape by hand. One benefit of a fireworking club is the availability of the club's machine to do this. A nail in the hole of the passfire tube allows a magnet to find the opening after the shell is pasted, then the wrapping is cut to remove the nail and expose the hole to the passfire tube.

This forms the shell, but now we need a way to ignite it. A ***time fuse*** is inserted into the passfire tube, and its length is chosen to time the fire reaching the center of the shell so that the shell bursts at the top of its flight. Short pieces of ***black match*** (black powder-coated string) get the flame from the inside end of the time fuse to the burst powder of the shell, and more black match is put in a slot or hole through the outside end of the time fuse to get the flame into the time fuse.

Surrounding the bottom of the shell is a paper ***lift cup***, containing a plastic baggie of ***lift powder***, which is black powder in a more granular form. This is weighed to give the correct amount of lift to launch the shell to the correct height. Shells are typically sent to 100 feet of height for each inch of shell diameter. The burst diameter of the shell is about ¾ of the height of the burst.

A length of ***quickmatch fuse*** brings the flame into the burst powder. Quickmatch burns at about 60 feet per second, so we need something much slower to ignite it, to give us time to move a distance away before the shell is fired. A length of ***visco fuse*** is attached to the end of the quickmatch. Visco burns at about 2 seconds per inch (or ½" per second), so 5–6 inches gives enough time to light the fuse, calmly walk away with our back to the mortar, and finally turn around at about 20–30 feet away to observe our shell being launched into the sky.

ROCKETS

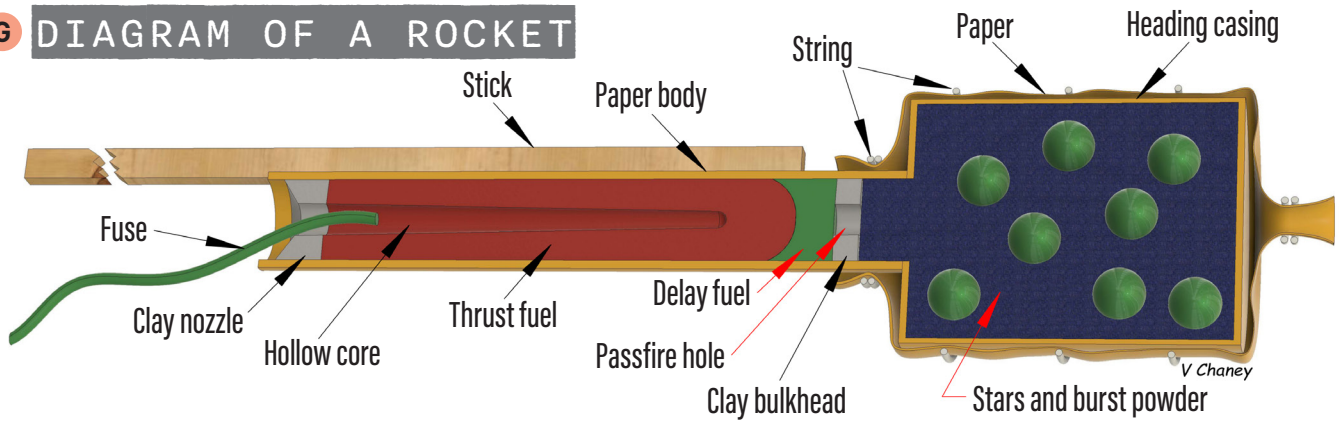
Rockets have a tube of paper for a body. The tube is packed with fuel, which is usually a variation of black powder (Figure G). There is a ***nozzle*** formed of clay, and there is a hollow channel through the nozzle and the fuel. ***Thrust fuel*** propels the rocket upward. Then it burns to the ***delay fuel***, which burns slower and allows the rocket to slow down. When this burns up to the ***heading*** — *boom!* — the stars are released. Sometimes the thrust fuel and the delay fuel are the same thing.

ROCKETS ARE LESS PREDICTABLE IN THEIR PATH OF TRAVEL. SOME SHELL ENTHUSIASTS REFER TO ROCKET MAKING AS **"THE DARK SIDE" OF PYROTECHNICS.**

Wanda Garrett, VictorChaney

Mike Garrett pasting his big shell in the WASP machine.

G DIAGRAM OF A ROCKET



Mike Garrett

A flight of rockets is ready to launch.

Wanda Garrett compressing fuel into a rocket with a large press.

BLACK POWDER IS LESS POWERFUL THAN OTHER KINDS OF EXPLOSIVES, AND HAS A **GREATER SAFETY MARGIN.** AFTER ALL, THE OBJECT IS TO DISPERSE STARS INTO THE SKY, NOT COMPLETELY OBLITERATE THINGS.

A rocket is not stable by itself and requires something for stabilization. Often a stick is used (Figure H), but fins can also be used. Sometimes the rocket is stabilized by spinning it very fast and it doesn't need fins or stick. These are called *stinger missiles*.

The fuels are compacted into the rocket tube in layers using a form to maintain the hollow core. Sometimes they are packed in with a mallet and tamper (using no steel), and sometimes they are compressed with a mechanical or hydraulic press (Figure I). Some rocket fuels are sensitive to percussion and can't be compacted with a mallet. Many hydraulic presses used in rocket making have a 1½-inch-thick acrylic shield between the business end of the press and the operator, which indicates there are safety concerns about this procedure.

SAFETY

There are certain dangers involved in making fireworks, and with proper safety procedures these dangers can be minimized. This article is intended only as an introduction to pyrotechnics; we recommend that you study further, and take classes at a convention, before starting into firework making.

There are many kinds of explosives, and black powder is much less powerful than most of the other kinds, and has a greater safety margin. After all, the object is to disperse stars into the sky, not completely obliterate things. Still, it is obviously hazardous and requires stringent precautions, including the following:

- Obviously, **no smoking or open flame** around fireworks production is extremely important.
- When making or shooting fireworks, **wear only non-synthetic clothing**, with long sleeves, long pants, and closed-toe shoes. If a burning star lands on you, synthetic clothing will melt, and the melted plastic will leave a much worse burn than if it lands on cotton, wool, or leather.
- **Wear a hard hat and safety glasses.**
- **Only have out the material you are using.** Leave the rest safely stored. If you're placing one kind of stars in a shell, all the other stars and energetic materials should be in a box on the other side of your car from where you are working.
- **Your car is a great blast shield** between you and your neighboring builders, and should be parked facing the exit with the windows up and the keys in the ignition. Accidents are not common with safe fireworking and we would like to keep it that way.
- **Don't do any fireworking in your garage** — always outside and away from any dwelling.
- Many fireworking chemicals and mixtures are **sensitive to static electricity**. Anti-static spray should be sprayed on clothing.

  For mixing slow flash booster, pound a metal stake in the ground, attach a wire, and connect the wire to an anti-static pad and a grounding wrist-strap, and pour water on the ground around the stake for better conduction. Anti-static pads and wrist-straps are often used in wiring electronic parts and are available through electronics suppliers. Not everyone does the grounding steps, but I am very cautious and like to be as safe as I can be.
- **Flash powder using potassium perchlorate** is especially sensitive to static, friction, dropping, and percussion, and should only be used by experienced people with the utmost care.
- **Explosive materials should be stored in plastic.** Metal or glass containers pose a danger of shrapnel. Paper containers like those for storing ice cream are sometimes used.

Rocket with Italian shell heading.

Shell with color changing stars and rising effect.

Mike Garrett

- **No steel tools.** Ordinary steel tools can create a spark, so only brass, aluminum and stainless steel are acceptable metals around fireworking chemicals. Some alloys of stainless steel may have enough iron to create a spark, so caution is advised with stainless steel. And some feel that a shiny stainless steel mixing bowl has the potential of focusing the sun and creating enough heat to ignite some materials.
- **No scissors.** Scissors create friction that can set off some chemicals, so they should not be used in the vicinity of chemicals. For cutting fuses like quickmatch, time fuse, and visco, ***anvil cutters*** should be used. These are used normally for trimming plants, and the blade compresses the object to be cut against a flat piece of metal, without blades sliding against each other.
- **Wear ear plugs** to protect your hearing. An evening of fireworks exploding is enough to damage your hearing.
- **Latex gloves** are not essential, but when handling a lot of black powder and stars they will keep your hands much cleaner. Otherwise, your fingernails will not look clean for days after it is all over.
- When loading a shell into a mortar, **do not place any body parts over the top of the mortar.** If there is a glowing ember remaining at the bottom from a previous shell, your shell could go off before you expect it. The exit velocity of a shell is about the same as the velocity of a 45-caliber bullet from a gun. I cannot verify the exact truth of this, but the lesson is plain: Don't put *anything* over the top of the mortar that you want to take home with you.

FIREWORKS CONVENTIONS

The fireworks convention, such as the **Western Pyrotechnics Association's Western Winter Blast** in Lake Havasu City, Arizona, is one of the best places to learn fireworking. You get a vacation of building, learning, shooting, and meeting other enthusiasts. You can camp there or take advantage of special hotel rates. There are many classes to give you information and hands-on experience. A class on safely lighting shells is offered, and you must take this training class to be eligible to shoot. There are also classes on photography and on putting together fireworks shows.

Vendors are there to sell fireworking equipment and memorabilia. Class C fireworks (less than one pound per item) are available to purchase and shoot. Class B (more than one pound) fireworks are available to pre-order and shoot, and black powder and stars also can be pre-ordered. If your state has outlawed fireworks, you can still get what you need there (but don't take it home with you). Many kinds of fireworks are legal in Arizona, but some which aren't legal are still allowed at this convention, under supervision of the club.

The weekend evenings have professional shows that dwarf anything I have ever seen. Professionals show off for other professionals, and the displays are amazing. Members can show off their masterpiece creations. The people living in town turn out by the thousands to see the fun. Everyone attending loves fireworks.

For those that are making fireworks, a manufacturing area is set aside, where groups are separated by a safe distance. Pop-up

Two double-petal ball shells with purple and glitter mines, made by AM Pyro.

Wanda Garrett

canopies and folding tables give a nice site for making them, and the very friendly folks doing it are usually glad to offer help and advice.

Three large areas are dedicated to shooting fireworks. There is a Class C area for the small stuff. A big area for Class B has all the mortars you need for shooting, with shells 8 inches and larger in a special area where they are fired electrically. A third area for rockets is set farther away.

There's even a group for kids called the PIT Crew, Pyrotechnicians In Training, where the kids learn to put together an impressive fireworks show.

The **Pyrotechnics Guild International (PGI)** annual convention in Oshkosh, Wisconsin, is where it all started. It's like going to the World's Fair when you have only been to county fairs. The convention is always in the late summer and runs for one week, a Saturday to the next Friday, and people plan for it the whole year. The reason? World class fireworks! Some of the most skilled pyrotechnic show designers and fireworks builders convened in one location makes for enough excitement to draw spectators from around the world. Last year there were attendees hailing from Germany, Malaysia, Lithuania, and other countries, and just about all 50 states were represented by people there to see some of the most unique and spectacular fireworks available.

If you're able to attend a PGI convention there are many things to keep you interested and entertained.

for outdoor entertaining, and the large campgrounds full of tents, banners, golf carts, and bicycles can spark in you that lovely feeling of being a part of something exciting.

For added entertainment and education, there are classes offered covering a multitude of subjects. You can take classes to learn ball shell or Italian shell building, rocket making, different insert components, or even Fire Dancing and flamethrower operation.

After those activities you can cruise through the vendors display, chemical supply displays, take in the Art Show or the Collectors Display where you can see and purchase various types of vintage fireworks memorabilia.

When you're ready to go see experienced fireworks builders actually working, go check out the Manufacturing Building. After checking in and getting a brief safety talk from the Manufacturing Safety Chair you can walk around to the various stations to see a huge variety of devices in different stages of production. You will see rockets, various rocket headers, a variety of shells, girandolas, and many other things. You may see some silly novelties such as a Donkey Piñata stuffed full of salutesm or a rocket with a huge roll of toilet paper as the header. People are very much there to have fun and are happy to tell you the planned launch times of their devices,

THE **PGI CONVENTION** IS LIKE GOING TO THE WORLD'S FAIR WHEN YOU'VE ONLY BEEN TO COUNTY FAIRS. PEOPLE PLAN FOR IT THE WHOLE YEAR. THE REASON? **WORLD CLASS FIREWORKS!**

Italian cylinder shells ready to load into the guns.

Mike Garrett

as crowd appreciation is always part of the good time. Most all manufactures are happy to show you what they are doing and talk about their device and techniques used … unless they're preparing items for competitions.

Competitions for a large variety of devices are held most nights of the convention, where beginners and experts compete for the trophy in their category or level of choice. The competitor that has accumulated the most points across a variety of devices is awarded the honor of Grand Master for the year.

After you have filled your day with the different things to view, you will be alerted to the beginning of the evening's festivities with the traditional 5 p.m. ***musculeta*** boom. The musculeta is a large salute that will give a loud *BOOM* that can be heard throughout the convention grounds and has a tendency to get louder each evening. After 5 p.m. the Class C shooting area opens, where members can shoot Class C devices purchased from vendors on site. This area is usually quite festive as people are waiting for the show to begin.

The evening shows are spectacular and were described to me thus: "These shows are like going to a major Broadway production after only seeing community theatre productions." They do not disappoint and keep the crowd enthralled with an hour plus of some of the best fireworks on earth.

But after that is over, you still are not done with the day. There are competitions where you will see fireworks you can't see anywhere else, as they have been made during the convention and will reflect the individual builders' skill and artistry. Some of the shells and devices are breathtaking, leaving you wondering how anyone could build such a device.

After you have almost completely been overwhelmed by the show and competition, you can wander to the open shooting areas to watch builders shoot individual shells, or stroll on over to the dark side and watch the happenings on the rocket line. Regardless of how you spend your day, if you enjoy fireworks, attending a PGI Convention is a unique and exciting week that may just end up being more fun for you than Disneyland.

At fireworks events there is a palpable level of enthusiasm and excitement. The sounds of explosions all around, and the "ooohs" and "aaahs" add to the fun of it all. When you make a shell, and the fill the sky with stars and a big *boom*, that is a beautiful sight and a fine feeling.

Photography and diagrams by Victor Chaney, Wanda Garrett, and Mike Garrett

FURTHER INFORMATION:

- **Skylighter** (skylighter.com) has enough free articles and information on firework making to keep you busy for days. It also is a good place to buy fireworking materials and tools.
- **Fireworking.com** is the most complete source of information on fireworks, with well-illustrated articles, videos, and discussion forums. Most of is pay-to-access, but well worth it for the dedicated pyrotechnician.
- The **Western Pyrotechnic Association** (westernpyro.org) has two big fireworks events a year in the desert. The Western Winter Blast is a great place to learn, make fireworks, and immerse yourself in fireworks. It has 500–800 attendees, some from all over the world.
- The **Pyrotechnics Guild International** (pgi.org) has a gigantic event once a year, with about 2,400 attendees. It is the biggest of its kind, and includes classes, building, competitions, and amazing shows.
- **Jig for making double-petal ball shells** is on Vic's website at www.chaneyproductions.com/fireworking.

VICTOR CHANEY is a dentist and lifelong maker who has been making fireworks for 4 years. He has written for *Nuts and Volts Magazine* and Instructables.

ELLEN WEBB and her innovative fireworks designs have won in competition at the Pyrotechnics Guild International convention. She has furthered firework making as an instructor at firework events, and she is the expert on the PGI convention for this article.

WANDA GARRETT has been making and photographing shells with her husband, Mike, for several years. She encourages all newbies to expand their capabilities in workshops at sanctioned fireworks events such as Western Winter Blast, where she is part of the instructional staff.

MIKE GARRETT has been making fireworks since 2009. Mike uses his background in physics and engineering as a foundation to make traditional and not-so-traditional fireworks. He thinks fireworks is the perfect blend of science, technology, engineering, art, and math to express his creative visions.