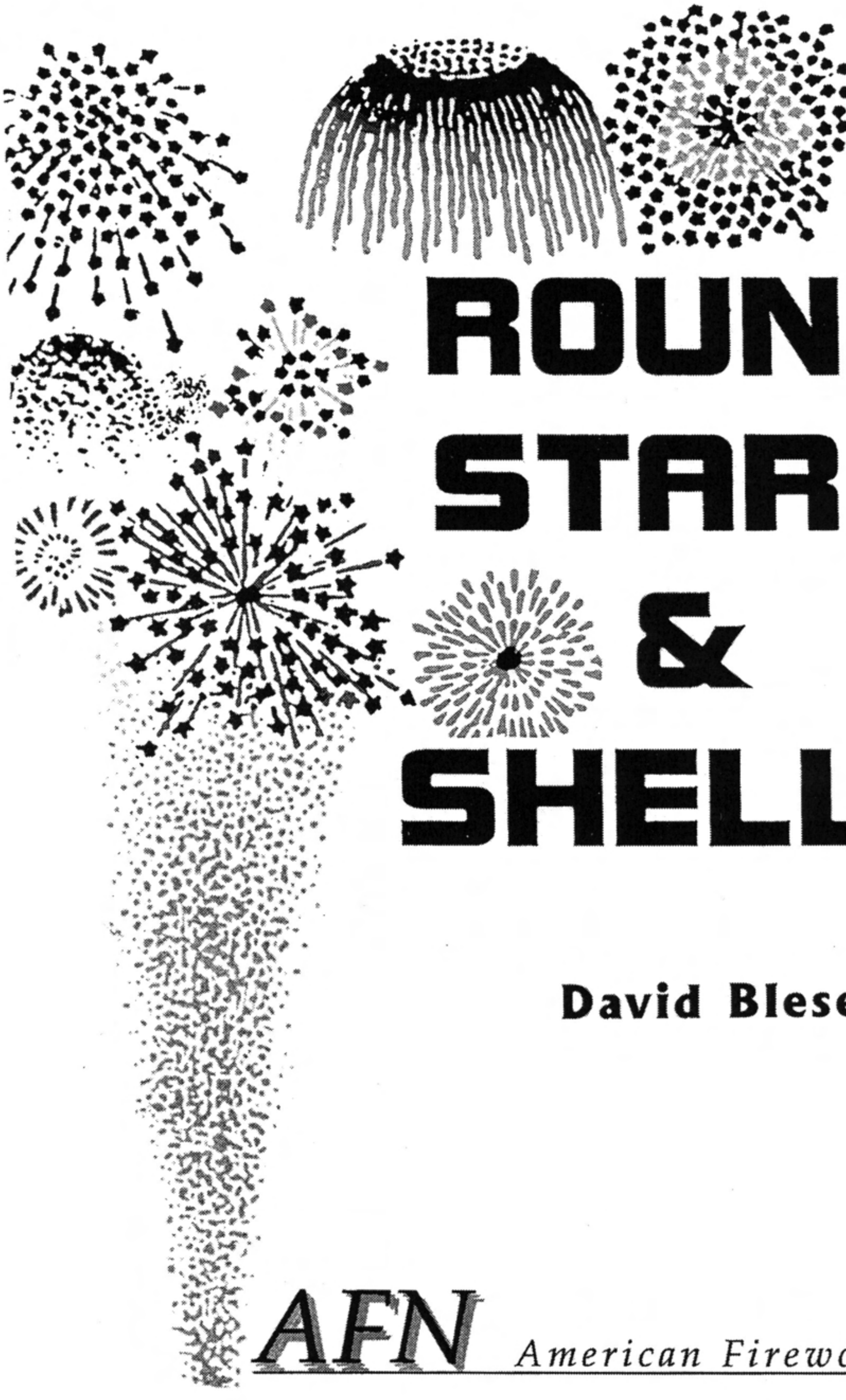

ROUND STARS & SHELLS

David Bleser

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This book is dedicated to

Gail Bleser

without whose support and love
it would not have been possible.

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Preface

This book represents the fruits of a long endeavor into round shell theory and practice. The inspiration for this pursuit evolved from witnessing a Grucci display of fancy Japanese shells in 1982. As I marveled at the beauty and intricacy of those state-of-the-art shells, I began to wonder if it would be possible to create similar devices of my own design. The intent was not to precisely duplicate any specific shells, but to develop a mixed Eastern/Western methodology which would allow me to create shells of equal aesthetic impact.

Available literature on Oriental techniques is scanty. As of this writing, the only sources extant are the works of Takeo Shimizu, which proved invaluable in furnishing me with a point of departure. Although useful information was gleaned from his writings, the path ahead was fraught with difficulties. Round star rolling had to be mastered by constant practice. Some star formulations published by Shimizu were found wanting in color saturation and purity, and had to be augmented with better formulations from American sources. A new, simple technique for paper hemisphere construction was devised.

Once a functional design for paper shells of small diameter was mastered, the pursuit moved into the realm of round plastic shells. No literature on the proper use of these plastic shell cases existed, so construction methods and burst techniques had to be worked out empirically. This distillation of the pyro odyssey is set down here for the benefit of future round shell enthusiasts who wish to be spared some of the mistakes, misinformation and misdirection I experienced.

This book is not written for the absolute novice who is unfamiliar with the uses, dangers and properties of pyrotechnic chemicals. Nor will it be of particular value to the commercial manufacturer, as many methods are not applicable for large scale production without modification. Instead, my purpose is to inspire that small, but growing, group of pyrotechnists interested in the theory and practice of round shells, who have the means available to them for small scale experimentation.

Although special attention has been given to present safe formulations and assembly techniques, one cannot guarantee the absolute safety of any pyrotechnical pursuit. The readers must therefore proceed at his or her own risk, as the author cannot accept responsibility for accident arising from the use or abuse of any of this information.

David Bleser
North Miami Beach, Florida
July, 1988

ROUND STARS AND SHELLS

PART I

ROUND STARS

The beauty of the aerial shell resides in its payload of stars. The shell and its burst charge fix the development of the expansion in space, and the stars determine the expression in time. If the stars are of a single color, the most pleasing effect occurs when the stars burn out at the same time. In more complex stars, simultaneity of color change is required for the optimum effect.

Cut stars are a natural for the beginner due to their ease of construction. Lack of precision of size or shape of the cut star does not diminish the artistic effect in the canister shell. The cut star can also be produced at a faster rate than round stars. The chief stimulus to learning the techniques of round star making resides in the ability to make color changing stars, and to produce stars of good size uniformity which will allow the stars to burn out at the same time. When we speak of color-changing stars, we refer to stars which change from one effect to another, not limited to stars that change from one color to another.

The first skill the beginner must master is to produce a batch of single effect stars of simple composition. After the basic techniques have been discussed, we can move on to more specialized stars, compositions, and color-changing stars.

SELECTION OF CORE

Star composition must form around something and that something is called the *core.* Ideal cores are those which are heavy, perfectly round and of good size uniformity. Lead shot comes very close to this ideal but is often frowned upon by commercial manufacturers because of concern of injury through fallout. Small lead shot such as #8 tends to melt and fuse with the slag of the burned star and does not present the problem that larger shot represents with its greater mass. It is strongly recommended that lead shot be used by the beginner learning to roll as it will present less frustration then other, lighter cores. Later, when the proper feel is developed for the process, a switch can be made to safer cores. If it is planned to have spectators near the fallout area, it is advisable to <u>not</u> use lead shot for cores.

Rape seeds make good cores as powder will stick to them well, and they are round and uniform enough in size to give little trouble. Certain pasta products which consist of tiny spheres of pasta will work. In a pinch, bird seed will function provided the seed is of sufficient size. The Japanese often use tiny grains of sand for cores. It takes a consummate skill to roll compositions on cores as tiny as grains of sand. The smaller the core, the more likely they will stick together in the early stages of rolling. Cut stars will also function as cores although they will take many applications of composition before they become fully round.

SELECTION OF SOLVENT SYSTEM

For dextrin bound stars, the proper solvent to begin with is usually a mixture of equal parts of alcohol and water. Isopropyl can be used but denatured alcohol is best. The solvent is delivered from a simple spray bottle set up to deliver a mist of solvent spray. For stars containing a percentage of red gum higher than 10%, it will be necessary to reduce the percentage of alcohol to 25% to prevent the composition from adhering to the pan. Stars containing parlon in percentages higher than 5% should use a spray bottle containing acetone if water sensitive magnesium is also present in the composition. Magnesium-containing compositions without parlon are best bound with a solution of 3% nitrocellulose lacquer (NC lacquer) in acetone. Higher percentages than 4% will cause the mister to malfunction due to the high viscosity of the solvent.

When using alcohol/water as a solvent, the percentage of alcohol can be reduced as the stars grow in size. The higher the percentage of water, the faster the stars will grow as the tackiness of the dextrin will increase along with an increase in the viscosity of the solvent. The whole purpose of using alcohol is to reduce the surface tension and solubility of dextrin in the solvent to prevent the small cores from sticking together.

PANS AND SHAKER CANS

Stars are rolled easiest in a large stainless steel pan shaped like a salad bowl. Shimizu in his book *Fireworks, the Art, Science and Technique*, remarks that a flat bottom pan will produce stars with bumpy corners. We have found that it makes no difference what the bottom looks like as long as it is smooth and clean. Large plastic cake pans are cheap and very handy to use when the batch of stars becomes too large to handle in the smaller stainless steel pan.

In the beginning phases of star rolling, it is helpful to employ a shaker can filled with composition to help apply small increments. Once the stars get larger, it becomes easier to use a scoop.

GETTING STARTED

Certain compositions are more difficult to roll than others, so it is best to start learning with a composition that will present the fewest problems. Simple Black Powder compositions with ferrotitanium have the property of rolling easily, producing very round stars with good size uniformity. The streamer composition listed below will produce a bright blond tailed star which is quite attractive. The best results are obtained when the potassium nitrate, sulfur, charcoal and dextrin are ball milled for twelve hours. If you lack a ball mill but have some commercial meal powder, try the second formula which is equivalent to the first.

Blond Streamer #1	
Potassium Nitrate	45
Charcoal	29
Sulfur	6
Ferrotitanium 100m	15
Dextrin	5

Blond Streamer #2	
Meal powder	60
Charcoal	20
Ferrotitanium 100m	15
Dextrin	5

The first order of business is to start with a large amount of lead shot as cores which are properly prepared to receive the first increment of composition. Beginners should use #6 lead shot which weighs about 14 gm/100 balls. Make up at least 500 cores by weighing 70 gm of shot. If you start with only 100 or 200 cores, the initial increment size of powder will be so small that it will be easy to overshoot it on your first attempts. The result is a coagulated mess on the bottom of the pan. The cores are so smooth it is difficult for composition to adhere to their surface. Fine (600 mesh) bentonite clay will adhere well and should be used as an initial coat. Dump the shot in the pan and spray with a mist of equal parts of alcohol and water, just a couple of times. Start the shot rolling in a circular motion and sprinkle a little clay on the cores while they are moving. The cores will pick up most of the clay in the pan. It is usually necessary to spray and sprinkle once more to adequately coat the cores. Dump the cores out of the pan and clean the rolling pan thoroughly, as the clay tends to stick quite tenaciously to the pan. Dump the cores back into the clean, dry pan.

Now the cores are ready to accept composition. Set the cores into motion and spray once or twice with solvent. If the cores stick together in clumps, you have over-sprayed. If that happens in this early stage, it is best to start over. The most difficult control of solvent and composition increment size is, unfortunately, at the beginning, and it will take some time to develop a feel for the proper amounts. When the cores are damp, separated and moving, sprinkle a little composition on and see if the cores pick it all up while they are still moving. If they have picked it all up and still appear damp, a second small application can be applied. If you overshoot with composition and there is composition remaining in the pan, I would recommend that you remove it with a paper towel. Composition left in the pan in the early stages of rolling will most likely not be picked up by the cores, and the scum layer will grow thicker with the next application of powder.

Spray once or twice again the (relatively dry) moving cores and apply another increment of powder from the shaker can. If a few cores stick together, they can often be separated by "bouncing" the cores against the pan bottom. This is done by throwing the mass of cores up in the air an inch or so while maintaining a circular, rolling motion. You can ignore cores that are stuck in groups of two or three as they can be removed by hand later if they fail to separate by themselves.

This sequence of dampening and powdering is repeated over and over. As the stars grow in size, it will be necessary to slowly increase the increment size of composition and solvent. If it is necessary to stop rolling for any reason, be sure to do it after you have finished sprinkling with composition. If you stop after the application of solvent, the stars will stick together. The only force keeping them apart is the constant rolling motion.

When the stars grow large enough so that there is no longer a single layer of stars in the bottom of the pan, a new problem presents itself. The smaller stars will tend to distribute themselves on the bottom, and the larger stars will rise to the top layers. This will cause the larger stars to grow still larger at the expense of the smaller stars on the bottom. The only way to control this effect, which deteriorates star size uniformity, is to shake the batch of stars from side to side to keep them well mixed.

Once the stars reach a size of 7 or 8 mm, they will grow quite rapidly, and the shaker can becomes unnecessary. Composition can be applied by shaking powder from a spatula. It is best to avoid dumping the entire increment of powder in at once as it is easy to overshoot. It is best to sprinkle, roll for 5 or 10 seconds and sprinkle again until the stars cannot pick up any more composition. If composition adheres to the bottom of the pan, roll the stars out of the way and spray solvent directly on the patch of scum, and resume rolling. If the scum layer is not too thick, the stars will pick up the scum with little difficulty.

The stars can be rolled to any desired size but it is recommended that the cores not be rolled larger than 15 mm. Stars larger than that size will take too long to dry. The stars can be dried for a few days and rolled larger later. At some point the pan may hold too many stars to mix thoroughly with the rolling and shaking process, so I recommend that you switch to a flat bottomed cake pan for further enlargement. The largest batch that can be easily handled is 1½ to 2 lbs. Some star makers suspend their pan from the ceiling by attaching ropes to the edges of the pan.

When you are working with a large batch of heavy stars, you may notice that some stars are actually getting smaller instead of larger. What is happening is that pieces are being broken off the stars during the rolling process. Larger stars have to be rolled more gently or they will smash themselves to bits! This is especially important if you are rolling fresh composition on large, dry cores. The new damp layer of applied composition can easily flake off the surface of the inner dry core if the stars are rolled and shaken too vigorously. It is recommended that when the star gets larger than 10 mm the solvent be changed to 80% water / 20% alcohol. This will allow the stars to grow larger faster, due to the greater tackiness of the water soluble dextrin binder. The stars will dry harder and be less likely to fragment during the rolling process.

If you used the formulas given above for your stars, they will need no priming. I do recommend finishing the final coat of stars with Black Powder only, as this will help the star burn in a concentric fashion. The Black Powder surface layer will spread the flame quickly around the star, allowing it to burn evenly to the center. This is important in color-changing stars. The last application of Black Powder can be done in excess as it may take five minutes or so for the moisture to diffuse to the surface of a large star. A 1 mm coat of Black Powder should be adequate. When the stars can pick up no more Black Powder after a few minutes of just rolling, they can be dumped in a pan and allowed to dry in the shade for a few days. If the stars are still damp after a couple of days in the shade, they can be thoroughly dried by a few hours in the sun.

It takes practice to get the feel of the increment size needed for each stage of application. Once you get proficient at making stars with #6 lead shot cores, you start practicing with #8 lead shot cores. They are considerably smaller and present less of a fallout danger. Then I would recommend practicing with rape seed or bird seed. Both are lighter and require somewhat greater manipulatory skill. When starting with cores less than 3 mm in diameter, I would start with at least a thousand cores so as to keep the initial increment size of composition large enough to be manageable. Once the cores grow larger than 6 mm, pour some of the stars out of the pan for later use, thus reducing the portion of stars left for further enlargement to a few hundred.

SPIKING PROBLEMS

Certain compositions are subject to an accretion problem which I call spiking. The cores in the pan may start out round but gradually become bumpy as they enlarge. If the problem is not corrected, the bumps will grow to spikes and break off in the pan and create a mess.

Light, finely powdered compositions are most subject to this effect. Finely mealed Black Powder type compositions usually will give problems, especially if they are high in percentage of charcoal. Compositions containing lampblack, a very finely divided, light material, are nearly impossible to roll round if the percentage of lampblack exceeds 20%.

The cause of this problem appears to be related to the property of these finely powdered compositions to shrink when dampened with water. The shrinking "skin" of a newly applied layer around a core causes tiny hills and valleys to form on the surface of the star. One can visualize the intact skin breaking upon shrinking into patches around the surface. The tiny bumps will grow in size as they will preferentially attract newly applied powder. The surface tension of the solvent spray will play a large part in the process. Water has a much higher surface tension than alcohol and will promote greater shrinkage. Acetone, with the lowest surface tension of common solvents, usually will produce little or no shrinkage.

There are three ways to minimize spike formation. The first technique is to adjust the dampening process during rolling. The stars should be made as damp as possible, right up to the point where they are beginning to stick together while rolling in the pan. This softens the surface bumps so that they will naturally roll out round. Smaller stars, i.e., smaller than 7 mm, are usually still too light to respond well to this method. Larger and heavier stars can accept more solvent before sticking, and their heavier weight will assist in smoothing the bumps.

Once they have been rolled for 30 - 60 seconds in this wet state, dry composition can be applied; an improvement in the spiking should be noticed. Repetition of this process will bring the stars into a still rounder shape. One of the reasons a ferrotitanium mix was recommended for beginners is that the heavy metal particles assist the natural surface flattening to such an extent that bumps are rarely noticed. There is a tendency for the beginner to use too small increments of solvent for fear of star agglomeration, and he unknowingly aggravates the problem.

The second approach to reducing the spiking is to lower the surface tension of the solvent. The easiest way to do that is to increase the percentage of alcohol in the spray. It is quite effective but one should not increase the percentage of alcohol above 70% or the binding power of the dextrin will diminish to produce extremely brittle stars.

Since the cause of the spiking problem is related to the average particle size of the composition, one can increase the particle size by dampening the over-fine mix with water, granulate through a 12 mesh screen, dry and mill for an hour or so until the particle size is reduced to 100 - 200 mesh. A composition in this particle size range is optimum for rolling. Particles larger than 80 mesh are difficult to pick up with small cores. Compositions containing perchlorates, chlorates or metal fuels are completely unsafe to ball mill, so this method should be restricted to Black Powder compositions only.

SIZE UNIFORMITY

As noted earlier, the most aesthetic looking shells will have stars that change color at the same time or go out at the same time. Only through tight control of size uniformity of the stars will this be achieved. Color changing stars should have dry cores of good size uniformity before enlarging with a different composition. Each layer of color should have the same thickness to produce the elegant effect of the stars changing color nearly simultaneously.

If one selects for cores, for example, rape seeds with only fair size uniformity, then even the most expert rolling techniques will not result in finished stars of good to excellent uniformity. Bringing all the stars to the same size during the rolling process is best achieved by selective screening.

For the sake of example, let's say that the star maker wants to produce a batch of ½-inch diameter stars of excellent uniformity. This will require a screen which has wire spacing of ½-inch. The Tyler Company makes round brass sieves with various size openings that are carefully calibrated for this purpose. However, they are expensive and not readily available. It is easy to make your own screen by drilling as many ½-inch holes as possible through a flat bottomed plastic pan at least 18-inches in diameter. At some point during the rolling process, some of the stars can be observed to be getting quite close to the ½-inch size as measured by a small caliper. Stop the dusting with powder at this point and pour the stars onto the screen. Most should fall through, and the ½-inch stars will be retained. Pour the retained stars into a holding pan and dampen the rest with solvent as usual, and reapply another increment of powder until the stars cannot pick up any more. Dump the batch again onto the screen and more will be retained. After several cycles of this selective screening process, you will bring all the stars up to the size of the screen holes. It would be possible to use a screen with 3/16-inch holes to produce stars of that size, which could then be enlarged to ½-inch while maintaining good uniformity, for you would be enlarging stars of all the same size. The idea is simply to choose a screen at or close to the desired final size.

STAR BREAKAGE DURING ROLLING

The cohesiveness of the particles that make up a star composition, when they become dampened during the rolling process, plays a major role in assuring that the stars in the pan maintain their physical integrity during rolling. The stars will break up in the pan during rolling if the binding affinity of the wet particles is too low. The stars may enlarge without damage until they reach a certain size, usually around ½-inch, at which point the slamming together of stars in the pan imparts sufficient energy to fracture some of the weakest stars. Compositions high in charcoal percentage and/or low in dextrin are particularly subject to this effect. Again, particle size plays an important role in this problem. Fine particles will bind more strongly than coarse particles as the former have a greater total surface area available for binding. Therefore, compositions with an average particle size of 80 mesh or below should be avoided.

Star fracturing is usually first encountered when one attempts to roll a composition over a fairly large core. For example, suppose a batch of ½-inch red stars is prepared and dried. Then willow mix is applied over the re-dampened cores. When the stars enlarge to 5/8-inch, pieces of the willow "skin" begin to flake off, forming little stars in the pan and ruining the size uniformity. The newly applied willow mix has insufficient cohesiveness due perhaps to insufficient dextrin, too much alcohol in the solvent, or overly large particle size. The willow skin slips off the hard, dry cores, assisted by the bumping action of the stars.

The amount of enlargement of cores is limited by this fracturing tendency which gets more pronounced with star size. It is essential to stop rolling at the first sign of fracturing, and carefully transfer the stars to a tray to dry. The stars can later be further enlarged to any desired size.

THE “DRIVEN IN” PROBLEM

Occasionally it will happen that the stars you roll will not dry thoroughly down to the core, preventing proper functioning. Even when the tray of stars is placed in the sun for many days, the stars will not dry. The simple fact is that the water retained near the center region of the stars cannot pass through the surface to dry out. This can also happen with resin stars bound with just alcohol. This trapped solvent problem is called "driven in".

Stars become driven in when the outside surface dries to form an impervious crust which prevents outward diffusion of solvent. Wet stars immediately placed out in the sun are commonly plagued by this problem. Often the surface will dry and then later crack, with still damp internal composition oozing out of the cracks.

The use of too much dextrin or rice starch binder can also cause stars to become driven in. The dextrin excess causes the stars to become overly gummy and the gummy layer dries hard on the surface only. Stars containing red gum in percentages higher than 10%, and bound with 95% alcohol will become driven in for the same reason. Keeping the percentage of dextrin below 7%, and not attempting to dry a layer thicker than ¼-inch will usually prevent this.

It is always best to dry the stars in the shade first, and then if necessary, place them in the sun for a few hours of final drying.

PART II

STAR FORMULAS

The star formulations given below are from previously published formulas or from my own successful compositions. The beginner is encouraged to start with perchlorate formulations before trying the more sensitive chlorate mixes. Under no circumstances should color compositions be mixed in a ball miller, blender or any mixing machine. They should be screened several times by hand through a 30 to 40 mesh screen. Readers unfamiliar with the basic of star formulas should first read the basic safety and mixing techniques given in Lancaster's book, *FIREWORKS, PRINCIPLES AND PRACTICE*.

Some compositions have specific safety considerations that must be borne in mind by the manufacturer. These will be discussed under the relevant formulations.

Most discussion of specific formulations will be focused on the aspects of their use in round stars only, although it may be useful in meteors, cut stars or other applications. One somewhat overlooked feature of round stars is their favorable safety when compared to cut or pumped stars when using compositions with a tendency to heat up when damp. Certain glitter or flitter compositions can actually ignite when allowed to stand for some time in a wet state. When a large quantity of flitter mix is dampened for use in making cut or pumped stars, it is possible to walk away and forget about the mix. Accidents have resulted from the spontaneous combustion of wet mixes. Luckily, round star makers have a safety advantage as preparation of a batch of dampened composition is unnecessary. The finished damp stars are usually too small to heat up on their own unless they are mistakenly put out in the sun. They usually dry out long before they heat up because of their favorable surface area to mass ratio. We will return to these considerations when specific glitter and flitter mixes are discussed.

RED RESIN FUEL STARS

#1 Red	
Potassium perchlorate	70
Strontium carbonate	15
Red gum	10
Charcoal (airfloat)	1
Dextrin	4

#2 Red	
Potassium chlorate	38
Strontium nitrate	38
Red gum	6
Charcoal (airfloat)	12
Hexachlorobenzene	2
Dextrin	4

Both of these formulas will give a good red color in round stars. Formula #2 burns faster than #1 and gives a slightly purer color but with a somewhat lower surface brightness. The burning speed of the mix can be reduced if desired by decreasing the percentage of charcoal.

The chlorate #2 formula needs very little priming but I routinely prime all color stars with a 1mm coat of Black Powder (meal or ball milled) containing about 2% dextrin. I apply the primer coat *after* the stars have dried or part of the purity of the red color will be lost due to contamination with potassium nitrate diffusing too far into the red core.

These formulas should roll into stars quite nicely but I would recommend using no more than 35% alcohol to prevent the red gum from getting overly sticky. Too little alcohol will cause the stars to start developing bumps. As a general rule the percentage of alcohol can be reduced as the star approaches 3/8-inch.

GREEN AND AQUA RESIN FUEL STARS

#3 Green	
Barium chlorate	72
Red gum	12
Charcoal (airfloat)	8
Barium carbonate	7
Dextrin	4

#4 Aqua	
Barium chlorate	53
Potassium chlorate	12
Copper carbonate	8
Copper oxide	8
PVC	5
Red gum	10
Dextrin	4

The first green formula was given as a cut star formula in Lancaster's book *FIREWORKS PRINCIPLES AND PRACTICE*. It is a good deep green formula intended for cut stars but works fine for making round stars. Barium chlorate is a sensitive compound and should be handled with care. Make sure the mixing screens are clean of any residue of sulfur which should never come in contact with chlorates. The presence of carbonate salts in both formulas reduces considerably any tendency of the compositions to become acidic and therefore sensitive. Formula #3 has no potassium chlorate in it which would serve to increase the burning rate and lower the purity of the color.

Both formulas roll up into stars with ease. Because of the red gum a more aqueous solvent system is recommended such as 40% alcohol in water. Both stars should be primed with a 1 mm thick layer of Black Powder. The prime layer on these chlorate stars will help reduce frictional sensitivity by physically protecting the chlorate core from direct contact with other stars.

BLUE AND PURPLE STARS

#5 Blue	
Potassium chlorate	65
Copper oxychloride	12
Lactose	13
Hexachlorobenzene	5
Dextrin	5

#6 Purple	
Potassium perchlorate	68
PVC	11
Copper oxide	6
Strontium carbonate	9
Dextrin	5

Lactose still seems to be the best fuel for blue stars as it burns cleaner and cooler than red gum, which is an essential condition to obtain a blue color. Formula #6 uses PVC as both fuel and color enhancer.

Formula #5 rolls up very quickly due to the tackiness of the lactose and should be rolled using a 50% alcohol solvent system. Stars of #5 blue should be coated with a 1 mm thick meal layer after drying. Formula #6 may not ignite with just Black Powder because of the lack of chlorate. It is best to use a graduated system of ignition by first making purple cores and letting them dry. After drying make up a small batch of one part #6 and one part Black Powder. Mix together and roll a 1 mm coating on the stars. Finish with a ½ mm thick layer of pure Black Powder.

MAGNESIUM STARS

The formulas below give some of the brightest colors possible in fireworks. Small magnesium stars are the best for cores in color-changing stars. Resin fuel color stars simply do not put out enough light for use as a core if the core is ¼-inch or less. Magnesium stars require special protection against moisture which can not only degrade the color but may even create a fire hazard. Parlon is used in all magnesium stars as it forms the best protection from moisture as well as serving as a color enhancer. PVC tends to produce less ash than parlon so I often use both in the formula.

These stars cannot be bound with water. Use a solvent spray of acetone only. The acetone will partly dissolve the parlon, helping it function as a protector of the magnesium. Acetone bound stars should be made outside and with a special protective face mask which adsorbs solvent vapors.

The only safe place to work with acetone is outside in the shade. If the humidity is higher than 70% and the temperature is above 800 F., the acetone will evaporate rapidly from the pan. This will result in the bottom of the pan becoming cold and very wet with condensed water. Some water will also be incorporated into the stars by the same process, although the layer of heavy acetone fumes in the pan will keep most of the humid air out. The only sensible conditions to work with acetone spray is outside, under conditions of shade, low humidity, little wind and moderate temperatures. (Flash point = minus 4 deg. F; evaporation rate is 95% in 5.5 minutes; fumes concentrate at ground level; only 2.15% concentration in air needed for explosion.)

#7 Red Mag	
Strontium nitrate	55
PVC	7
Parlon	10
Magnesium 100-200 mesh	28

#8 Green Mag	
Barium nitrate	55
PVC	15
Parlon	12
Magnesium 100-200 mesh	18

#9 Yellow Mag	
Potassium perchlorate	45
Cryolite	13
Magnesium 100-200 mesh	30
PVC	10
Charcoal	2

#10 White Mag	
Barium nitrate	53
Potassium nitrate	12
Magnesium 100-200 mesh	28
Parlon	7

These magnesium stars should roll very round with the acetone binder. Their ignition temperature is somewhat high, making it necessary to employ a hot prime. Aluminum flitter and glitter formulas with 8% or more of aluminum can be rolled over the cores without an intermediate igniter layer. All other color changes should be accomplished by using an intermediate acetone bound layer of one part mag mix and one part resin fuel color or charcoal streamer mix. Do not coat strobe cores with magnesium compositions as they do not function well when ignited by an overly hot composition.

Most stars can be bound with alcohol (95%) by adding 5% red gum to the formula, but this will not protect the magnesium from corrosion caused by nitrate-containing compositions layered over it. Only parlon seems to confer the needed protection. Parlon stars bound with acetone will not pick up as large an increment of composition as a water/alcohol bound star of equal size.

Once the igniter layer has dried, it is safe to layer over it with water/alcohol bound compositions. Be sure to dry the stars in the shade. If cracks are noticed on the surface of a color changing star with a mag center, that is a sure sign the magnesium core has started to decompose, and the stars should be discarded in a safe place. I have never had this happen with parlon bound stars, but it remains a possibility.

GLITTER STARS

There are a very large number of formulas which will produce the glitter effect of delayed flashes of aluminum. Both aluminum and magnalium can be used to produce glitter flashes, but magnalium is more sensitive to decomposition, and certain glitter formulas containing it will degrade even after a few weeks in the dry state. A recommended source for more glitter formulas and information is Pyrotechnica II which contains 39 formulas for various successful glitter formulas developed by Robert Winokur. The two formulas given below are modifications of two of his formulas. The first formula is for a star giving a combination charcoal tail and glitter tail which is quite attractive. The second is for a white glitter. Both are stable and should not decompose after time, provided they are stored dry.

#11 Glitter	
Potassium nitrate	50
Charcoal	20
Antimony sulfide	12
Aluminum, atomized 12 µ	9
Barium carbonate	5
Dextrin	5

#12 Glitter	
Potassium nitrate	55
Charcoal	11
Antimony sulfide	5
Sulfur	8
Aluminum, atomized 12 µ	14
Strontium carbonate	3
Dextrin	4

The above formulas should be bound with a solvent of 50/50 alcohol/water. Binding glitter with nitrocellulose lacquer or any organic binder will destroy the glitter effect at the expense of protecting the aluminum. The above formulas should never be dried in the sun as that will accelerate the process of decomposition of the aluminum. Addition of 1% boric acid to the formulas will help slow the rate of decomposition by buffering the pH. Glitter stars do not need any final igniter layer as they take fire as easily as Black Powder. Keep the final percentage of water in the batch of stars as low as possible by dusting with excess glitter composition when the stars have reached the desired size. We dry the stars in the shade on a screen which is placed in front of a fan. The stars should dry for 2 - 3 days under these conditions.

FLITTER STARS

Flitter stars contain a large excess of aluminum flake, using potassium nitrate as an oxidizer or potassium perchlorate. Potassium chlorate can also be used with somewhat less aluminum, but the effect is not as attractive as with the perchlorate, and the sensitivity of chlorate/aluminum mixes makes them undesirable. Potassium nitrate gives a golden colored flitter tail and the perchlorate produces a bright silver flitter.

#13 Flitter	
Potassium nitrate	36
Sulfur	8
Aluminum dark	30
Aluminum bright	19
Boric acid	1
Dextrin	6

#14 Flitter	
Potassium perchlorate	33
Aluminum dark (flake)	61
Dextrin	6

Both of these formulas will roll up quite round and enlarge slower than the previous glitter formulas. A higher percentage of dextrin is included to give the stars sufficient hardness. Since the aluminum in formula #13 is more sensitive to aqueous decomposition, boric acid has been added.

Cores made from these formulas require a hot prime as they are even more difficult to ignite than the magnesium stars given previously. A two-stage ignition system is best for these cores. A plain flitter star with a final desired size of 14 mm will serve as an example. Roll a thousand cores in a pan to a size of 6 mm. Enlarge a portion (200 – 300 stars) from the batch to a final size of 10 mm. The remainder of the stars should be set out to dry in the shade for future use as cores in color-changing stars. Dry the portion of 10 mm stars in the shade. Proceeding further while wet will increase the rate of decomposition, and may create an undesirable driven in condition. Prepare a small quantity of first prime (100 - 150 gm) by mixing two parts formula #14 with one part Black Powder containing 5% dextrin. Enlarge stars to 13 mm. A final prime coat can be applied using Black Powder/dextrin only to bring stars up to a final size of 14 mm. Allow to dry in the shade. Formula #13 is somewhat easier to ignite and will usually succeed with a 1 mm layer of second prime coat, followed by the Black Powder finish.

I would not advise making cores of formula #13 larger than 14 mm in one operation. It is much safer to make small cores and allow them to dry, rather than risk the possible heating up of large stars. Although I have never seen aluminum flitter stars heat up, it is still possible if the stars are dried under conditions of high humidity, and temperatures above 85°.

Colored stars which change to a flitter core are quite attractive and popular. The potassium chlorate and potassium perchlorate colors given above are hot enough burning to require only one intermediate priming coat made up of one part color mix to one part flitter mix. When using flitter formula #13, which contains sulfur, any excess prime mixture should be destroyed if chlorate is present in the color mix. This prevents the possibility of spontaneous ignition through friction or long storage. Naturally, stars which change from flitter to color require no intermediate igniter, even if the core is a magnesium color. Charcoal streamer stars will require a two stage igniter system to function smoothly when using formula #14 as a core. Glitter composition, being hotter, will usually ignite formula #13 without an intermediate prime, but will require a prime of one part glitter to one part #14 flitter to ignite the latter.

CHARCOAL STREAMER STARS

These stars represent the least expensive streamer composition known and are widely used in the Orient. Plain charcoal streamer stars are used in spider web shells, especially in the West. The East prefers to use the composition in color changing stars. The dull reddish orange sparks give a nice contrasting effect when changing to a color core. The formulas given below and their names are taken from Shimizu's book, *Fireworks The Art Science and Technique*. He refers to them as charcoal fire dust compositions.

	Chr. 6	**Chr. 8**	**Tiger tail**	**Willow**
Charcoal Streamer #	**#15**	**#16**	**#17**	**#18**
Potassium nitrate	55	49	44	35
Sulfur	7	6	6	12
Charcoal (airfloat)	33	40	44	45
Dextrin	5	5	6	8

Air float charcoal has been substituted for the pine charcoal in the original formulas as the latter is not readily available. For charcoal to function well as a spark producer, it must be thoroughly saturated with potassium nitrate. Simple mixing of the components and incorporation into stars will not give a dense spark trail. These compositions should be ball milled in a rock tumbler or other type mill in a safe place for at least twelve hours. If possible, ceramic tumbling media should be used in the mill. The media is available from Triple G Tube Supply. After milling, the composition should be dampened with about 20% water and pushed through a 12 mesh screen. After the granules have dried for several days, they can be re-milled for about 3 - 4 hours to give a product which has the optimum particle size distribution for rolling stars (i.e., about 100 - 200 mesh).

The first two formulas, Chrysanthemum 6 and 8 are fast burning and will produce a short, thick tail. The Tigertail and Willow compositions burn quite slowly and with a very cool flame, but will produce a long tail. They are recommended for spider web effects. The percentage of dextrin must go up as the percentage of charcoal increases to give sufficient binding power. The drying time will also increase as charcoal tends to retain moisture.

One of the most common transitions is from charcoal streamer to color. The charcoal mixes given above are hot enough to ignite the potassium chlorate/perchlorate colors but not the magnesium colors which require the graduated prime discussed above.

The Tigertail and Willow formulations will ignite without a prime, but it is best to layer a 1 mm thick Black Powder/dextrin prime to help the star ignite symmetrically over its surface.

AMMONIUM PERCHLORATE COLORED STARS

Stars containing ammonium perchlorate will give some of the best colors possible in pyrotechnics. The excellent color purity is probably due to the lack of hue contamination from smoke particles of potassium compounds. The stars are more difficult to ignite at fast speeds than the potassium chlorate/perchlorate stars; they need a special igniter system to function. If one tries to prime the stars with a prime containing potassium nitrate, ignition failure will invariably result. It is believed that the formation of hygroscopic ammonium nitrate is the mechanism for this failure. Potassium or barium chlorate should never be mixed with compositions containing ammonium perchlorate to prevent the formation of the extremely sensitive explosive ammonium chlorate. No stars should ever be constructed which contains ammonium salts, in any form, with chlorate, even if the two compounds are separated by an intermediate layer.

#19 Crimson	
Ammonium perchlorate	30
Potassium perchlorate	35
Strontium carbonate	18
Red gum	15
Charcoal	2
Dextrin	4

#20 Blue	
Ammonium perchlorate	68
Copper oxychloride	11
Hexamine	17
Dextrin	4

#21 Purple	
Formula #19 Crimson	60
Formula #20 Blue	40

#22 Igniter	
Potassium perchlorate	75
Red gum	12
Charcoal (airfloat)	9
Dextrin	4

Formula #19 is a modification of Sam Bases' crimson given in Pyrotechnica IV. The hue is a much richer red than the colors produced by formulas 1 and 2, which tend to be more reddish-orange or pinkish-red. The burning rate is much lower than the other red formulas, making it necessary to limit the size of the crimson core to 3/8-inch or less (not including the igniter layers).

Formula #20 is a modification of a blue formula offered by Joel Baechle. The burning rate of ammonium perchlorate compositions is greatly accelerated by the presence of copper, copper oxide, or copper oxychloride. This catalytic effect renders the use of potassium perchlorate unnecessary, which was used in formula #19 to increase the burning rate. Still, the burning rate of this ammonium perchlorate is somewhat less than the chlorate blue. The blue flame is accompanied by a reddish tip when a star is ignited on the ground. This reddish tip is not noticed in a star moving through the air.

As of this writing, I have not found any green ammonium perchlorate composition that will burn fast enough to be useful in round stars. The solvent system for these stars is the usual 50/50 alcohol/water. The colored cores should be allowed to dry completely before application of the next layer. For single color stars, the next layer applied should be #22 Igniter using the same solvent with perhaps a higher water percentage due to the large amount of sticky red gum in the formula. The layer should be a minimum of 1 mm thick. After the stars have dried thoroughly, a top coat igniter of Black Powder should be applied with a solvent binder system of 3% nitrocellulose lacquer in acetone. This will require diluting a standard commercial solution of 10% nitrocellulose lacquer with acetone. If the resulting dilution is too syrupy, it may clog the spray bottle. The ideal viscosity is somewhere between water and glycerin. Even with the dissolved nitrocellulose, the lacquer spray will have very low tackiness. The nitrocellulose lacquer-dampened stars will be able to pick up only a small amount of Black Powder, so it is wise to keep the increment size low until you develop the feel for working with this solvent system. The lacquer bound layer of Black Powder should be about ½-mm thick. Potassium nitrate is nearly insoluble in acetone and will not leach through the igniter layer to the ammonium perchlorate core. Incidentally, the ignitability of Black Powder bound with nitrocellulose lacquer seems to be higher than Black Powder bound with dextrin.

Color-changing stars which start with one effect that changes to an ammonium perchlorate color require some thought due to the incompatibility problem. As an example, let's assume one wants a glitter star to change to an ammonium perchlorate blue. The blue core will require the usual 1 mm thick layer of perchlorate igniter. Then a 1 mm layer of nitrocellulose bound glitter mix can be applied. After drying of this layer, more glitter can be applied with a water/alcohol dextrin bound solvent. Or the igniter layer itself can be bound with nitrocellulose lacquer which is somewhat tricky because of the high solubility of red gum in acetone. With skillful control of the rolling process this is not overly difficult. Then the glitter layer can be applied with water/alcohol, with the lacquer bound igniter layer preventing diffusion of the potassium nitrate.

For another example, let's say that a flitter star changing to an ammonium perchlorate red is desired. First, a potassium perchlorate flitter, such as formula #14, is selected. This can be layered directly on the red core, serving as an igniter. If the flitter layer is at least 2 mm thick, it will be possible to layer over it the usual Black Powder/flitter igniter described above with water/alcohol. The flitter layer should be dry before the application of the igniter, to minimize diffusion. When designing color changing stars, as long as one remains aware of the chlorate/nitrate incompatibility, many attractive combinations exist.

FLASH CORE COMPOSITION

Another common Oriental effect is the transition to flash core. Color stars will finish their burning with a very bright white flash climax. Other flash compositions containing chlorate, sulfur and aluminum have been reported, but they are considered too sensitive and dangerous for consideration here. Barium nitrate probably gives the brightest light compared to other oxidizers with the fuel aluminum.

#23 Flash	
Barium nitrate	66
Aluminum, German black	27
Boric acid	1
Dextrin	6

#24 Flash Igniter	
Potassium perchlorate	33
Barium nitrate	34
Aluminum, German black	10
Red gum	8
Antimony trisulfide	9
Boric acid	1
Dextrin	5

Composition #23 is one of the most difficult to ignite that will be found in this book. The #24 igniter composition has been especially formulated by Shimizu to ignite the flash core. Flash cores should be rolled with the usual alcohol/water 50/50 solvent system. For the best rapid flash effect, do not make the cores larger than 5 mm. One to two thousand cores can easily be made up at one time and allowed to dry. Over this core is layered a 1 mm thick coating of #24 igniter. For its own ignition, this igniter will require a relatively hot burning mixture primed over it. Color formulas, glitter, and flitter mixtures are suitable to ignite #24. But if you plan to use the cool burning charcoal streamer mixes given above to make the transition, you should employ as an intermediate prime a ½-mm layer of one part charcoal streamer, one part #24.

Stars made with flash cores should certainly be tested by shooting a small batch out of a star gun to assure proper function. The stars cannot be tested by burning on the ground as they will accumulate too much heat by burning in still air and will give a false successful impression.

STROBE STARS

These are the newest stars to appear in commercial shells. The stars burn by producing flickering or strobing flashes with little or no light between the flashes. The three most useful strobe colors are white, green, and red; formulas are given below. The green and white strobes can be bound with dextrin. A good red strobe which can be dextrin bound does not exist because magnalium, when substituted for water sensitive magnesium, will give a pink, rather than a red strobe.

#25 Green Strobe	
Barium nitrate	53
Sulfur	17
Magnalium 100 mesh	12
Hexachlorobenzene	13
Dextrin	5

#26 White Strobe	
Barium nitrate	51
Sulfur	19
Magnalium 100 mesh	18
Potassium nitrate	7
Dextrin	5

#27 Red Strobe	
Ammonium perchlorate	48
Magnesium 100 mesh	28
Strontium sulfate	19
Potassium dichromate	5

#28 Strobe Igniter	
Potassium perchlorate	74
Red gum	12
Charcoal	6
Aluminum dark	3
Potassium dichromate	5

Formula #25 gives a good green flickering strobe and has the advantage of a dextrin binding system. The same applies to the white formula #26. Stars made from these compositions should be made no larger than 8 mm or they will strobe all the way to the ground. They are best used as cores for color changing stars.

The white and green strobe formulas require a moderately hot prime, not as hot as mag star mixes nor as cool as willow. Resin fuel color compositions will serve to ignite the strobe cores without an intermediate prime. For a transition from willow to green strobe, the most appropriate prime would be the strobe igniter; it can be applied ½-mm thick onto the dry strobe cores.

The frequency of flashes of strobe stars cannot be judged by burning the star on the ground. The star needs to burn while flying through the air, as the cooling effect of the air will slow down the flash frequency. This is especially noticeable with the ammonium perchlorate red strobe formula #27.

Formula #27, which was devised by Shimizu, produces the deepest red strobe I have seen. Some pyrotechnicians have modified the formula slightly with the addition of PVC or parlon in an attempt to boost further the color intensity. I have not noticed any improvement myself with these chlorine donors. This is not surprising as ammonium perchlorate decomposes in the flame to hydrogen chloride gas, which reacts with the strontium to produce strontium chloride, a strong red emitter, from its molecular band spectra.

Calcium sulfate can be substituted for strontium sulfate to give an orange strobe. The strobe frequency will be altered somewhat, but the use of calcium instead of strontium will present no special problems.

The type of magnesium used in this strobe formulation is important. It functions best with atomized or spheroidal magnesium powder in the 100 - 200 mesh size. Granular magnesium is extremely reactive compared to the atomized variety, and if used will not strobe but will burn continuously. The strobe frequency for this formula with atomized magnesium is about 2 Hz, but this will also be dependent somewhat on the mesh size and type of atomization of the magnesium.

Cut or pumped stars will function best, giving the highest ignitability and the most perfect strobing. When the igniter layers are applied in the rolling pan, they will gradually become round. The formula is still satisfactory for producing small round stars as cores or as single effect strobe stars up to 12 mm in diameter.

Ammonium perchlorate is highly reactive with magnesium in the presence of moisture. A small amount of degradation will bleach the red color, and more extensive degradation will cause the star to become unignitable and produce an easily noticeable ammonia smell resulting from the aqueous reduction of the ammonium perchlorate. The stars must be bound with a 3% solution of nitrocellulose lacquer in acetone. The potassium dichromate [corrosive to human tissue] serves as an oxidation inhibitor for the magnesium. Roll outside in the shade, using a solvent mask. Roll cores up to 10 mm in size. Allow the cores to dry - about 5 – 6 hours. The strobe igniter can be layered on with 95% alcohol or you can use the lacquer spray. In either case, wipe off any primer scum that may form on the bottom of the pan. Keep rolling until a 1 mm layer of prime has been applied, then allow the stars to dry again. The final top coat prime of Black Powder should be applied with the lacquer spray to avoid any diffusion of potassium nitrate through the igniter layer and into the core. The Black Powder should be applied 1 mm thick.

Chlorate color should never be applied over the strobe core as chlorates should never be used in the star containing ammonium salts, as previously mentioned. An ammonium perchlorate color, such as formulas #19, 20, or 21 can be layered directly on the strobe core and will serve as an igniter. If a flitter to red strobe color-changing star is desired, then #14 flitter can be layered over the star. Remember that whenever mix is layered over the star, be sure it contains no potassium nitrate or chlorates, and be sure that the final Black Powder prime is put on with nitrocellulose lacquer. These constraints make it difficult to mass produce these stars for commercial production, but small amounts can be made by amateurs to good effect. The barium nitrate/magnalium strobes are commonly manufactured for Class B shells.

A few years ago I fired a shell of color-changing strobe stars which has an attractive effect. They were made simply by layering red strobe #27 on green strobe #25. This could not be done with white strobe because it contains potassium nitrate.

CRACKLE STARS

Round stars made with an explosive center are called crackle stars. Commercial crackle stars are made in China and use an extremely dangerous and sensitive realgar/potassium chlorate explosive core. They are made by a wet method, avoiding the use of highly sensitive dry powder. The inherent safety problems of this type of core preclude its use for amateurs.

It is much safer to use pistol primers for crackle cores; they are readily available at gun shops. They are expensive, but the effect is well worth the cost.

The primers contain lead styphnate which is a primary explosive. It is protected from shock by being enclosed in a tiny metal crimped can. The surface of the can is polished metal and may cause difficulty picking up star composition. It may be necessary to coat them with a very thin clay layer first as they will adhere easier.

Primer cores will explode the loudest when a hot, fast burning composition is rolled on top. I recommend using the magnesium colors or #14 flitter which gives a nice crossette effect with each individual crackle. A water bound composition cannot be layered on these primers as the enclosed cavity will not properly dry out. This problem can be circumvented by initially spraying the cores with aluminum spray paint which will protect the cores and treat the smooth surface of the core at the same time. Or the primer cores can be sprayed directly with a solution of nitrocellulose lacquer in acetone, thus avoiding the water altogether.

It will take an application of about 2 mm of composition applied to the core before the stars start becoming round. Shortly after this size is reached, it is best to stop and allow the stars to dry. Another composition can be applied using a water/alcohol binder over the crackle cores for a nice color changing star with a crackle finish.

PART III

THE ROUND SHELL

The vast majority of fireworks shells made in the United States are of the paper canister type. It also remains a favorite design for small scale amateur construction, as evidenced by the preponderance of canister shells entered in the shell competition at the Pyrotechnics Guild International convention. In the Orient however, nearly all manufactured shells are of the round paper type. Nearly all good fireworks displays will feature both shell types.

Certainly each shell type possesses its own unique advantages. For multibreak shells which consist of single break shells stacked on top of each other, the canister design offers the only sensible choice. The canister shell also provides the best geometry for loading specialized shell inserts, such as salutes, tourbillions, box stars, serpents, etc. The round shell excels in its ability to deploy its stars in a perfectly spherical burst, referred to in the Orient as a flower. With the use of color-changing stars in the round shell, a vast variety of flowers can be created.

The emphasis on canister shell production in the West is due to several key factors. For starters, most of the available pyro literature focuses on the construction techniques of Italian canister shells. The only source for information on the Japanese round shell construction techniques has been the published works of the indefatigable Japanese pyro-scientist, Takeo Shimizu. Unfortunately, his major work, *FIREWORKS, THE ART, SCIENCE AND TECHNIQUE* is out of print, although it is possible that a reprint is being planned. His more recent work on the physics and chemistry of star compositions and shell design, *FIREWORKS FROM A PHYSICAL STANDPOINT*, is available from Pyrotechnica Publications.

Another primary reason for the paucity of round shell production is the difficulty of learning the manufacture of round stars, a necessary component for the round shell. The overwhelming majority of stars made by amateurs are cut stars. Cut stars can be made quickly in large quantities, and with simple techniques that novices can learn in a day or so. Too often a novice's first attempt at rolling round stars results in a sticky, coagulated mess of stars in the pan that winds up getting discarded, with a concomitant loss of enthusiasm for the whole procedure. However, the economic and technical difficulties of round star production are being overcome on the commercial scale by the increased use of star rolling machines capable of turning out large quantities of stars at a cost that is competitive with cut stars. Whereas discussion of star rolling machines is outside the scope of this book, and probably outside the budget of the majority of the readers, this book was written on the premise that round star rolling by hand is quite easy to learn by anyone and is even fun to do.

Probably the major reason more paper round shells are not made in the West is the greater hand labor that goes into finishing the shells versus the canister shell. Paper round shells must be pasted over with many cut strips of Kraft paper, which takes a great deal more time than the rapid roll up of a long, single sheet of Kraft paper on a canister shell. The pyro novice in the U.S. finds this strip pasting process tedious at best. It is for this reason that this book will focus primarily on the use of plastic hemispheres which are now readily available in sizes up to six inches. Clearly, the plastic shells can be assembled even quicker than the canister paper shells, with a fraction of the time required for drying. The low labor costs of plastic construction has resulted in the recent adoption of round shell production by firms that had previously produced only canister shells.

This book will try to remedy many of these deficiencies by outlining a clear, proven method of construction of round shells and stars for readers interested in making attractive round shells which will perform properly the first time they are fired. Readers unfamiliar with the basics of pyrotechnics are highly recommended to gain experience with pumped and cut stars, mixing techniques, safety considerations, and simple canister shell construction techniques by consulting basic books such as Lancaster's *FIREWORKS, PRINCIPLES AND PRACTICE*, before proceeding to round shell construction.

STRAWBOARD AND PAPER HEMISPHERES

Round shells can be constructed with strawboard, paper or plastic hemispheres. The Japanese almost exclusively use the strawboard hemispheres which are made by machine in a press. These hemispheres are exported to the west in sizes from 2 inches to 12 inches in diameter, and ranging from about 1/8-inch thick to 3/8-inch thick. They are not cheap and sometimes are difficult to obtain from suppliers. Handmade hemispheres can be made for next to nothing from Kraft paper and paste. Plastic hemispheres are currently available in sizes from under 2 inches to 6 inches in diameter, at prices considerably below the cost of imported hemispheres. The chief drawback with plastic hemispheres is the danger and mess of fallout. Sharp pieces of shattered plastic drift to the ground after a burst, leaving a minefield of sharp-edged litter. For some situations where only a few shells are fired, or the fallout area is a body of water, plastic hemispheres will be the best choice for their ease and simplicity of shell construction. The reader should not choose to ignore paper hemisphere construction as they are essential in the building of double petalled chrysanthemums, which will be discussed later.

A hemispherical form is required for the construction of thin walled hemispheres. Forms for a four inch set can be made from a polished sphere of metal or plastic, 3½-inches in diameter, cut exactly in half. A set of commercial four-inch diameter hemispheres will also suffice as forms, and are certainly easier to obtain. Commercial strawboard hemispheres are about ½-inch less in outside diameter than their stated diameter, to allow for the external pasted wraps. The strawboard hemispheres first must be wrapped tightly in plastic film to prevent the pasted wraps from sticking. Each hemisphere is placed in the center of a sheet or plastic bag. The bag is tightly twisted to form a neck on the inside center of the hemisphere. The excess film is cut off and the neck is taped down with a wide piece of plastic tape, as in figure 1.

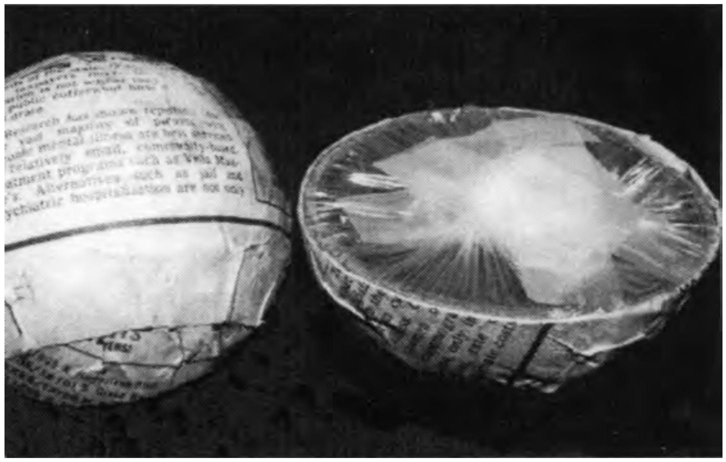

Figure 1

The two hemispheres are assembled to form a sphere, and held together with several small pieces of tape around the equator, as seen in figure 2.

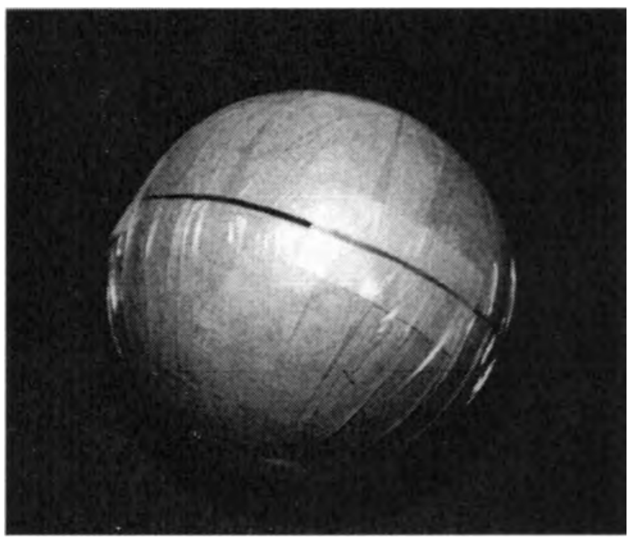

Figure 2

The hemispheres are pasted like a baseball with strips of 40 lb. Kraft paper, using two pieces per layer, overlapped somewhat. A four-inch hemisphere set will require two pieces of Kraft paper, 2¾ x 8½-inches, per layer. A five-inch hemisphere set will require 4 x 11-inch strips. I find that Elmers-type white glue, slightly diluted with water, is best for pasting. The two strips are placed at 90° angles, as in figure 3, which cover nearly the entire area of the plastic-wrapped sphere.

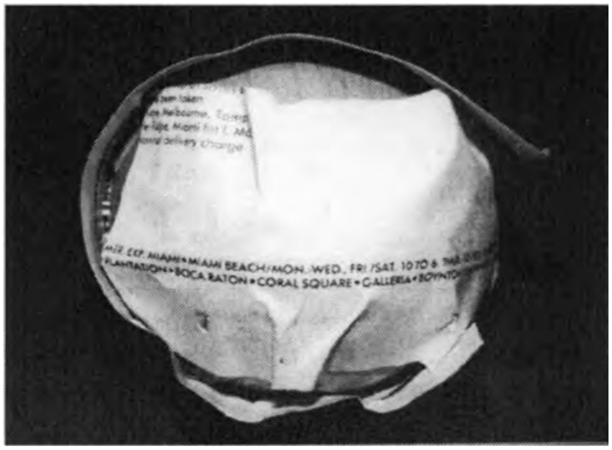

Figure 3

After rolling the sphere on a hard surface to smooth out the first layer, the next layer is applied. The second layer's strips should be applied at an angle to the first so that any areas of the sphere not covered by the first layer will be covered by the second. The process of pasting and rolling is repeated until five layers have been applied. Hemispheres can be internally inserted in double petalled shells to hold an inner spherical layer of stars. They should be made only three layers thick, out of strips of newspaper.

Now comes the most difficult part in the entire operation. It is necessary to find the equatorial seam hidden below the layers of pasted paper. Feel around with your thumb until you detect the equatorial ridge, which is slightly raised. Take a sharp razor blade and cut through the gap, as shown in figure 4. Cut all the way around and separate the sphere into two hemispheres. Allow to dry overnight; this will keep the hemispheres in spherical shape before they are removed from the forms.

Figure 4

Once dry, the hemispheres can easily be peeled from the forms to give the finished product as shown in figure 5. Homemade 4-inch hemispheres will hold somewhat more stars than commercial strawboard hemispheres because their internal diameter is nearly ¼-inch larger.

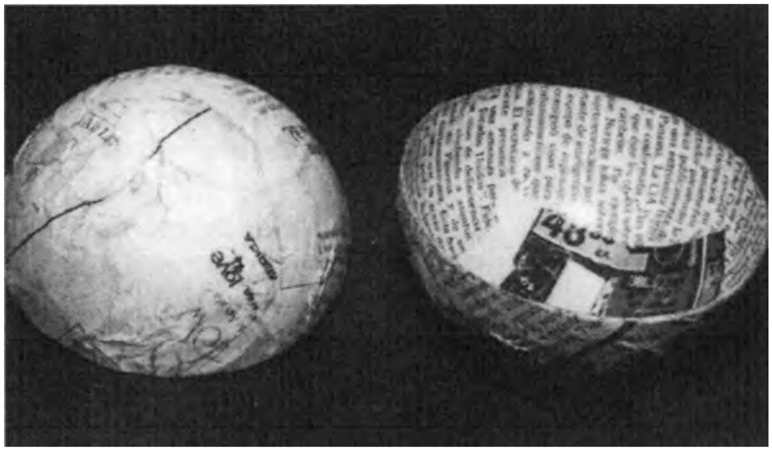

Figure 5

INSERTION OF FUSE

The most appropriate time fuse for a round shell is a piece of ¼-inch diameter Japanese commercial time fuse. This fuse is usually available in coils of 30 meters from pyrotechnic suppliers. Other commercial fuses of the Bickford type can be used provided they burn at the desired rate of three seconds per inch. For large shells over eight inches in diameter, sometimes a larger fuse, such as 3/8 or ½-inch can be used. Homemade time fuses of the spoulette type can also be used; these are ¼-inch i.d. cardboard tubes with a wall thickness of at least 1/16-inch, in which Black Powder is rammed in small increments. These fuses are tedious to make and are only recommended for use in special shells that require them, as they are prone to blow through if not correctly made, with resultant flowerpotting of the shell.

The fuse should be cut with a sharp knife or razor to 1¾-inches long. Holes about 1/8-inch diameter are punched through the fuse, ¼-inch from each end for insertion later of the crossmatch pieces. The two punched holes should be 1¼-inches apart for shells up to six inches in diameter. It is easier to make perfectly perpendicular holes when you use a punch set for ¼-inch time fuse. Fuse crossmatching sets are available from Rich Wolter's Pyro Tools.

With paper or strawboard hemispheres you will need to drill a hole the exact size of the o.d. of the time fuse . Plastic hemispheres already have the hole built in but in some cases the hole may need to be reamed or drilled out slightly to accommodate a too tightly fitting fuse. The fuse is inserted through the hole with about a ¾-inch segment protruding on the outside. The end of the fuse and the crossmatch hole protruding outside should be covered with a small piece of masking tape to protect the fuse from damage until it is finished. The fuse should be cemented in place with a bead of glue on the outside and the inside of the hemisphere, to prevent blow through of the fuse from the lift charge. With plastic hemispheres, the use of an electric glue gun is very popular. Be sure to use sticks of translucent white glue in the gun as the melting point is lower than the opaque yellow types, and is therefore safer. Figure 6 shows a properly installed fuse in a plastic hemisphere.

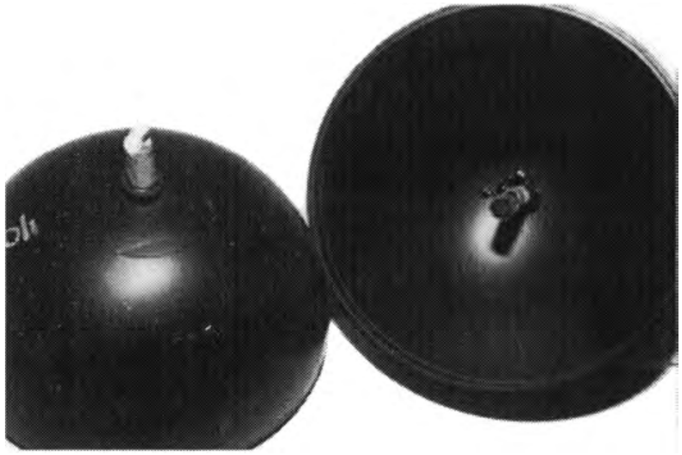

Figure 6

There is a school of thought that says it is important to ignite the central burst charge the exact center of the shell. I am not convinced of this necessity, especially in shells of 4 inches or smaller where the time fuse almost reaches the center. For shells of 5 inches of larger, it is necessary to slip a tube over the fuse to extend it to the center, otherwise the stars in larger shells will be at the same level as the crossmatch. It is simple to construct a fuse tube from a piece of cut off lance tube, which will easily slip over the time fuse.

Cross match the inner fuse hole by slipping a 1-inch piece of Thermolite (be careful when cutting Thermolite as it has occasionally been known to ignite while being cut) through the punched hole. Bend the Thermolite along the sides of the fuse and slip a piece of lance tube cut to a length that will allow it to end just below the center of the shell.

Glue the fuse tube to the bottom of the shell. Fill the fuse pipe up to the top with 2Fg or 4FA Black Powder. Paste a tiny piece of newspaper over the end to seal the powder in place. Your time fuse is now complete and the shell is ready for filling.

LOADING OF STARS

There are actually only two ways to load stars in a round shell. They can simply be dumped in the hemisphere, or they can be placed along only the inner wall. The former procedure will produce what is known in Japan as a Poka shell. Crysanthemums and peony shells belong to the latter method. (Shells with payloads of color stars without tails are called peonys and those with tailed stars giving a burst with radial spokes which may or may not end in color are called chrysanthemums). Beginners tend to experiment with the Poka design first, owing to its simplicity. The novice soon discovers that the burst of the Poka shell is not much different than the wide bouquet breaks of a canister shell.

The dynamics of the burst of a Poka are such that the velocity imparted by the explosion to the stars varies from a maximum for stars near the periphery, to nearly zero for stars located at the center. The stars near the center are propelled primarily by gravity and fall slowly in descending arcs. In a peony or chrysanthemum type, all stars in a perfect break leave with the same velocity, giving an aesthetically pleasing spherical expansion. The size of stars used can vary according to the desired star density. The practical limits of star size range from 5 to 15% of the shell diameter. Shimizu has given us the formula for determining the number of stars required to fill a round shell. I have reproduced it below from *FIREWORKS FROM A PHYSICAL STANDPOINT* (Pyrotechnica Publications).

$$n = 3.63 (Di/d) ((Di/d) -2)$$

where: Di is the inner diameter of the shell case
d is the diameter of the spherical star

For ease of loading the hemispheres I usually rest them on 4-inch salute cases which serve as a steady base. A small cup is filled with stars and the stars are poured out into the shell while the shell is slowly rotated. This method is much less tedious than placing the stars one or two at a time along the inner shell wall. Don't fill the stars all the way to the top edge as they will tend to fall down to the bottom when you are manipulating the burst bag.

THE BURST CHARGE

The purpose of the burst charge in any shell is to break open the shell casing with the proper amount of force to propel the stars outward at the desired velocity. The heat and flame of the burst charge also serves to ignite the stars. The velocity imparted to the stars is a function of the quantity, rate of burn, and volume of gas produced per unit weight of the burst charge. To obtain the desired symmetrical break of the round shell, one has to pay close attention to these variables.

Both paper and plastic round shells have hard shell walls which require a burst system of the proper energy. Too weak a burst charge will result in the shell opening with a soft pop in which only a small portion of the stars will ignite. The ignited stars will be ejected with a small velocity, producing a drooping, bouquet-type appearance of the burst. The flame of the burst charge jets out of a crack in the shell, igniting only the stars in the immediate vicinity of the crack.

At the other extreme, too hard a break will also result in poor ignition as many of the stars are moving too fast to stay lit, or the stars are fractured into dust from the excessive violence. The use of too much burst charge can result in an explosive compression of the shell so rapid that the shell opens before the internal flame and heat touch all the stars. Even the most vigorous star priming will not mitigate the problem. In plastic shells, it is not uncommon for the stars in only one hemisphere to ignite after an overly hard break. The reason for most, if not all of these ignition problems in shells with properly primed stars is simply that some of the stars lining the shell wall are moving outward ahead of the flame front from the burst.

There are probably as many different burst charges and burst configurations as there are round shell builders. The selection of the proper type and quantity of burst charge for a specific shell is critical in achieving the desired symmetrical break radius. Let's begin by examining some of the most common burst compositions in use today.

H3 Burst Charge	
Potassium chlorate	75
Charcoal (airfloat)	25
Dextrin	5

Whistle Burst	
Potassium perchlorate	70
Sodium or potassium benzoate	30

KP Burst Charge	
Potassium perchlorate	75
Charcoal (airfloat)	15
Sulfur	10
Dextrin	5

Flash Burst	
Potassium perchlorate	64
Aluminum dark pyro	27
Sulfur	9
Dextrin	5

I have omitted from the formula list above the most common burst charge used in canister shells: 2FA Black Powder. Commercial Black Powder has a low ignition temperature, moderate burning speed and a gas production per unit weight less than chlorate or perchlorate based burst charges. These properties render it suitable for large round shells over 5 inches in size, but the smaller shells will require a more energetic burst. The cost and availability of commercial 2FA Black Powder limit its popularity.

H3 is a popular burst charge for small round shells and is used extensively. It will function most effectively if made into granular form, pasted on rice hulls. The latter form will give the shell maker the greatest control over the quantity and burning rate of the H3. The use of granular burst charges is recommended for shells with a radius of 2 inches or smaller. The burning rate of granular bursts can vary tremendously as it is a sensitive inverse function of the average particle size.

The ingredients of H3 should be mixed by careful screening with due respect for the sensitivity of mixtures containing chlorates. Ball milling of the dry ingredients is almost certainly going to result in a horrendous explosion. It is safe to ball mill the chlorate alone before mixing with the other ingredients, but the mill should be thoroughly washed before further use with other loads. One needs to take particular care to prevent the chlorate burst charge from coming into contact with stars with a Black Powder-primed surface to avoid the notorious chlorate/sulfur contact sensitivity.

PREPARATION OF H3 COATED RICE HULLS

The preparation of H3 coated rice hulls described below is straightforward, and can be applied to the process of coating of hulls with any composition.

The first step is to select the desired ratio of the weight of rice hulls to H3. This can vary anywhere from 3 to 5 parts of H3 to 1 part of rice hulls. The 4:1 ratio is good for shells of 4 or 5 inches in radius. Six-inch shells will function well with a 3:1 ratio. Shells over 6 inches should not use H3 as it will produce an overly hard break.

About 150 grams of rice hulls are weighed out and placed in a large plastic cake pan. The pan is filled with warm water and the hulls stirred, then left to soak for about half an hour. The water is then drained off by pouring through a colander or screen. Fifteen to thirty minutes are allowed for full draining. The hulls are then returned to the cake pan and approximately one half of the weighed load of H3 is dumped in the pan, on top of the hulls. The operator closes the lid and swings the pan around for 10 - 15 seconds. Then the pan is opened and the remaining H3 is added. The lid is closed and the pan rotated as before. If the hulls have been previously properly drained, the hulls should be thoroughly coated and easily separable. A spatula is used to clean the composition from the sides of the pan, then the load is dumped into shallow pans for drying, which should be done in the shade for at least two days. After drying, masses of coated hulls may stick together in lumps, but they can usually be easily separated by breaking them apart with the hands.

KP BURST

The KP burst formula shown above is often used in large shells, 5 inches or greater. The burning rate of this burst is less than the H3 or Black Powder burst. Potassium dichromate (5%) can be added as a catalyst to increase the burn rate. The standard KP burst pasted on rice hulls is not energetic enough to give a break of sufficient hardness for small shells.

WHISTLE COMPOSITION

The whistle composition shown is becoming widely used in the West for breaking both round and canister plastic shells. Only a small amount is required to create a nicely symmetrical break. Whistle composition has a higher ignition temperature than the previously mentioned break powders. It is necessary to assure its rapid ignition by mixing it with Black Powder, granulated or pasted on rice hulls. For whistle composition to function, it must be well mixed. The ingredients are carefully screened five or six times through a 40 mesh screen. Ball milling is avoided because of sensitivity. Properly mixed whistle composition should have a burning rate of 5.5 mm/second when packed in a narrow gauge cardboard tube. The use of the sodium salt of benzoic acid is not recommended for those living in a damp climate.

Whistle composition seems to work best when mixed with meal coated rice hulls. Ball milled Black Powder made from fertilizer grade potassium nitrate can be pasted on rice hulls according to the method shown above. A ratio of 5 parts of Black Powder to 1 part by weight of hulls seems optimal. The finished hulls should be screened after drying to remove all small particles of meal powder.

Whistle composition can be placed in powder form directly on top of the crossmatched fuse, and the remaining area in the center of the shell can be filled with meal coated rice hulls. However, a better method, giving more reproducible results, is recommended. The approximate weight of rice hulls needed to fill the central region of both hemispheres is determined. A four inch round shell, for example, will require about 80 gm of meal coated rice hulls. The exact amount of coated hulls will depend on the size of the stars used in the shell. Six or seven grams of whistle composition is added to Whistle composition can be placed in powder form directly on top of the crossmatched fuse, and the remaining area in the center of the shell can be filled with meal coated rice hulls. However, a better method, giving more reproducible results, is recommended. The approximate weight of rice hulls needed to fill the central region of both hemispheres is determined. A four inch round shell, for example, will require about 80 gm of

meal coated rice hulls. The exact amount of coated hulls will depend on the size of the stars used in the shell. Six or seven grams of whistle composition is added to the weighed portion of hulls and then shaken in a container. The rice hulls will be overcoated with the white whistle composition. This can be used to fill the center of the shell. There will be some loose whistle composition with the hulls that will tend to settle out. The presence of the loose powder seems to present no difficulties. For shells from 5 to 8 inches, the amount of whistle composition is kept constant at 6 or 7 grams, but the quantity of coated rice hulls will increase accordingly. The novice tends to believe that the larger the shell, the greater the burst charge needed, not realizing that the increased amount of coated rice hulls automatically increases the burst charge.

FLASH POWDER

The flash powder burst shown above is somewhat more energetic than the whistle composition. It can be used in the same way as the whistle composition system described above. Some shell builders place the flash in a tiny bag attached to the end of the time fuse. The remaining space is filled with meal coated rice hulls. There is no particular advantage to be gained by this more laborious procedure. Coating rice hulls with flash powder has been tried and will work well for quite small shells, but often it produces too hard a burst in shells 5-inches or larger. As usual, it will take some experimentation to find the correct quantity of flash appropriate for the shell size and type you are using.

ASSEMBLY OF SHELL - PLASTIC

A set of four-inch plastic hemispheres loaded with stars is shown in figure 7. Note that the star are not loaded to the very top where they would be likely to fall in. A small hole is cut in the center of a piece of tissue paper and slid over the fuse, taking care not to knock the stars down from the sides. A short piece of fast burning Thermolite is passed through the hole in the time fuse. It is recommended that some of the fabric coating of the Thermolite be removed before insertion to assure intimate contact with the powder train. Another square of tissue paper is placed in the other hemisphere.

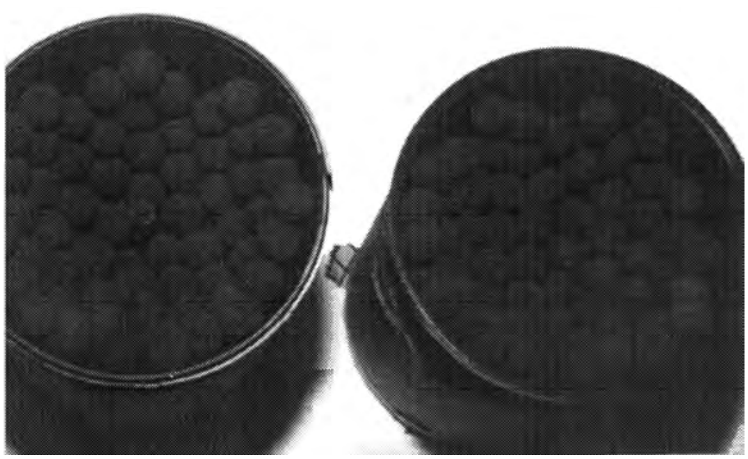

Figure 7

Six grams of whistle composition are added to 80 gm of meal coated rice hulls and shaken to coat the hulls and distribute the powder. The coated rice hulls are added to each hemisphere, nearly filling to the top as shown in figure 8.

Figure 8

The rest of the stars can be added in carefully by lifting the tissue. Care must be exercised not to overfill by allowing stars to protrude above the edge of the hemisphere. Any excess tissue paper is trimmed away. The rice hulls are packed in well and more are added, being pressed down with a flat piece of cardboard or plastic sheet until each hemisphere is filled flush, as in figure 9.

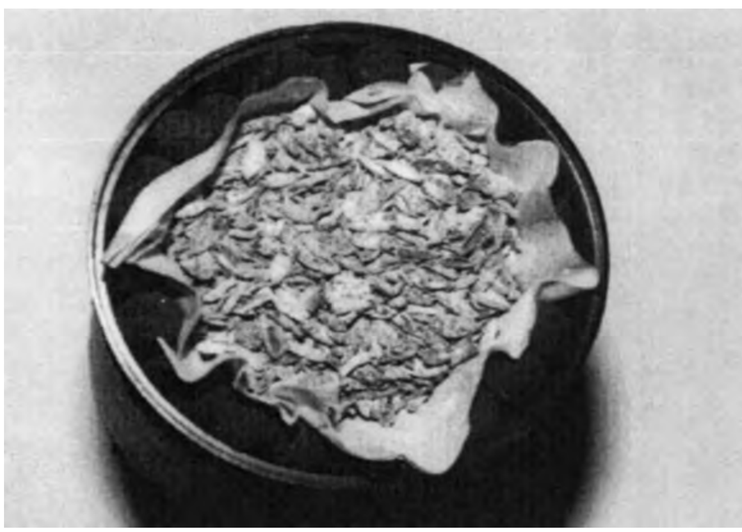

Figure 9

With fingertips placed on the plastic sheet to prevent the contents from spilling out, the operator flips one hemi over and places on top of the other, as shown in figure 10.

Figure 10

Holding the two hemispheres together, he slowly pulls out the divider, as shown in figure 11. Any pieces of tissue paper protruding from the seam are pushed inside with a razor blade. Any tissue left in the crack will interfere with the seam bonding, and even allow solvent to seep into the shell. The shell is then snapped together.

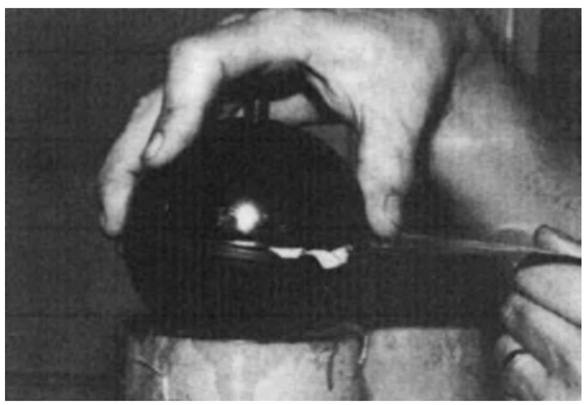

Figure 11

To weld the hemispheres together a solvent is applied in a thin stream into the crack as shown in figure 12 (view of white plastic 6-inch shell). The hemispheres should be pulled apart slightly to allow access to the lips of the seam. Several applications of solvent will be required to thoroughly soften the seam. The best solvents are chloroform or methylene chloride. It is necessary to wear a solvent absorbing dust mask to protect yourself from the vapors. Some workers use Duro contact cement instead of solvent.

Figure 12

The shell is now snapped closed. A clamp can be used to give a tight fit, as shown in figure 13. Note the use of collars at the jaws of the clamp which slip over the fuse and the raised collar at the opposite end.

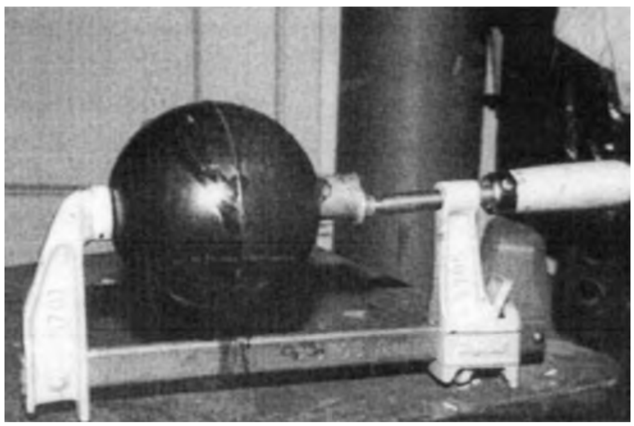

Figure 13

The solvent is allowed to partially dry for fifteen minutes or so. There should be a raised lip around the equator of the shell if the seam was sufficiently softened with solvent.

The strength of the seal may be improved by an additional step in a solvent bath. The bottom of a small bowl is filled with solvent to about ½-inch deep. The shell is removed from the clamp, and grasping the two ends of the shell, the operator lowers it into the solvent and rotates fairly rapidly for 45 seconds to one minute, as shown in figure 14.

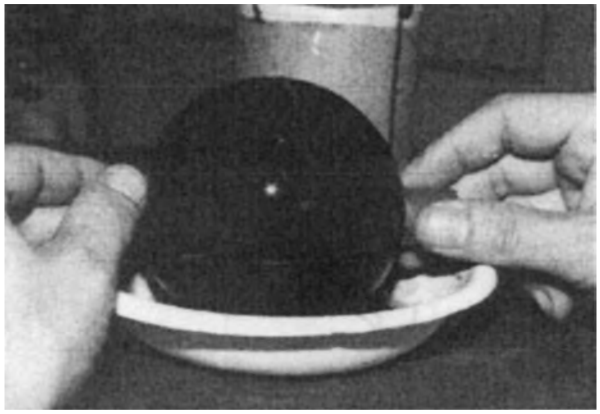

Figure 14

The shell is then removed from the bath and kept rotating for another thirty seconds or so until solvent no longer runs on the surface of the shell. Then it is re-clamped. The shell can be removed from the clamp after an hour or so, but it will take overnight to completely dry. A shell is dry when the fingernails are incapable of scratching it. After drying, the fuse loop can be soaked in solvent and pushed into the top hole. The shell is now ready for attachment of lift charge and leader.

SHELL ASSEMBLY - PAPER

The paper hemispheres are filled exactly the same way as the plastic described above. We pick up the procedure where the cardboard or plastic divider is about to be removed from the joined hemisphere. The hemispheres are examined until the two indexing marks are located, then they are rotated until the marks line up. This brings them back to their original orientation. The divider is pulled out and the junction is sealed with strips of masking tape or glued Kraft paper. The shell is now ready for pasting. If commercial strawboard hemispheres are being used, assembly and pasting up are the same.

There are several schools of thought on the pasting process. Some folks believe that the use of a large number of layers of thin Kraft paper, say 30 or 40 lb., pasted with wheat paste, is important for a good symmetrical break. There is no question that Kraft paper soaked in wheat paste dries hard and brittle. Unfortunately, no one, to my knowledge, has ever studied the effect of different glues on break symmetry. Some claim to achieve excellent results by wrapping the shell in masking tape, or fiber reinforced tape. Whereas tape represents a rather expensive choice, there is no evidence that it gives an inferior result. Evidence gleaned from my own studies on this problem supports the view that the essential consideration is to simply provide a shell wall of the proper strength for the burst charge that is used. The material selected to construct the shell wall has little influence on the break. Were this not the case, it would be nearly impossible to achieve a symmetrical break from a plastic shell, which is certainly not the case. With all these various pasting strategies in mind, I will elaborate on one which has proved inexpensive and efficient.

Kraft paper of 50 - 60 lb. weight, obtained from grocery bags, offers the best compromise between the thinner stock requiring more layers, and the 70 lb. or heavier stock which is difficult to manipulate. The Kraft paper is cut into strips of the proper length and width so that eight pieces will cover the surface. For example, for a four inch shell, the paper should be cut into 1¼ x 4½-inch strips. A five inch shell will require 1½ x 5½-inch strips.

Wheat paste, although the cheapest paste one can use, requires excessive drying time, and when applied to homemade Kraft hemispheres, softens the shell to such an extent that dents will form during the rolling process. White glue seems ideal, with its excellent tackiness and fast drying time. The glue should be diluted with about 10% water to lower its viscosity.

Eight strips are set out on a piece of newspaper and rapidly pasted with a glue brush. Four strips are applied, starting from the fuse end of the shell, as shown in figure 15.

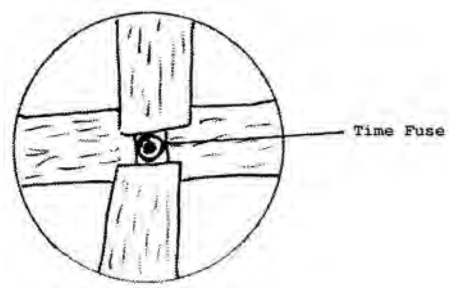

Figure 15

The other four strips are applied to the opposite pole of the shell to fill in the four open quadrants. Not all of the surface area will be covered, but the coverage is symmetric. The shell is rolled on a hard surface to smooth over the layer. Another layer of eight strips is applied in the same way, at a 90 degree orientation. Again, the shell is rolled and smoothed. A third layer is applied at right angles to the previous layer. The fourth layer is applied with the same orientation as the first. If the shell is not getting too soft, an additional layer can be applied. The partially finished shell is allowed to dry overnight. More layers are applied in the same manner until a total of nine or ten layers is applied. A five inch shell will require eleven or twelve layers. For every inch increase in diameter, the number of layers is increased by two. These specifications are for shells made with homemade hemispheres, as described earlier. If strawboard hemispheres are used, the number of layers may be decreased by two for each size stated, to give allowance for the greater strength of the strawboard.

If the break of the paper shells is judged to be weak, it is better to increase the strength of the burst charge, rather than to increase the wall thickness. An overly thick wall will produce a disturbed break, regardless of the burst charge used.

THE LIFT CHARGE

In the vast majority of commercial shells, the lift charge used is 2FA Black Powder. The grain size of this powder is overly large for round shells with a diameter of 6 inches or less. 4FA Black Powder or 2Fg gives a more efficient lift, requiring less to do the job. 2FA is preferred for canister shells as it gives a more gentle push, respecting the increased propensity of canister shells to flowerpot. The table below gives the approximate lift charges for shells of various diameters.

Shell Diameter	Wt. of 2Fg
2-inch	8 grams
3-inch	17 grams
4-inch	25 grams
5-inch	45 grams
6-inch	80 grams

The amount of lift required will vary depending on the tightness of fit of the shell, the length of the mortar (assumed 36 inches for the table), and to a small degree, the weight of the shell. Is it important that the lift charge be accurate? The answer is yes, if one wants to achieve a perceived perfect symmetry. If a shell breaks at the top of its trajectory, when it is motionless with respect to the ground, then a time lapse photograph will look like figure 16 (stars ejected out of plane of paper are omitted for clarity).

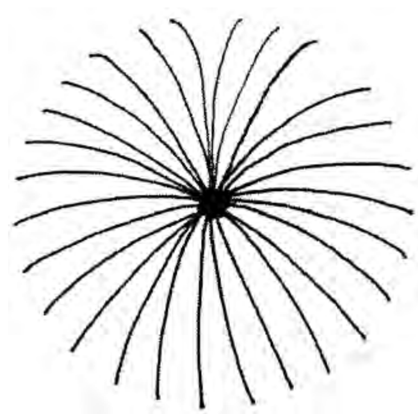

Figure 16

If the shell explodes on the way down, a component of motion will be added to the star trajectories to give an appearance like that shown in figure 17. A shell exploding on the way up will look like the inverse of figure 17. Obviously, one has the option of changing the burn time of the time fuse instead of changing the lift charge, to place the break of the shell at the zenith of flight.

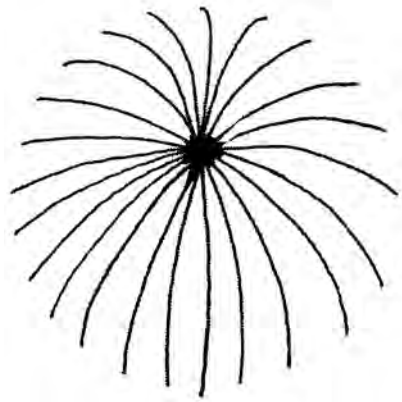

Figure 17

Ball milled Black Powder which is subsequently granulated can be used as a lift charge and works well. It will be necessary to use about three times the amount stated in the above table. The big drawbacks of using the homemade product is the lack of consistency of the product, and the necessity of cleaning out the mortar much more often, due to its much increased residue.

An easy way of forming the lift charge is to pour the weighed powder in a paper cup. The sides of the cup are trimmed so that the powder is ½-inch below the rim. The fuse protector is removed, the fuse is crossmatched with a piece of Thermolite, and then the fuse end is stuck into the cup. The edges of the cup are fixed to the shell with hot glue. A slit is made into the cup and the quickmatch leader is threaded through the top fuse loop, with the bare match end penetrating the cup. The end of the leader which contacts the lift cup is taped securely with several pieces of masking tape. Figure 18 shows a completed 4-inch plastic shell, ready for firing.

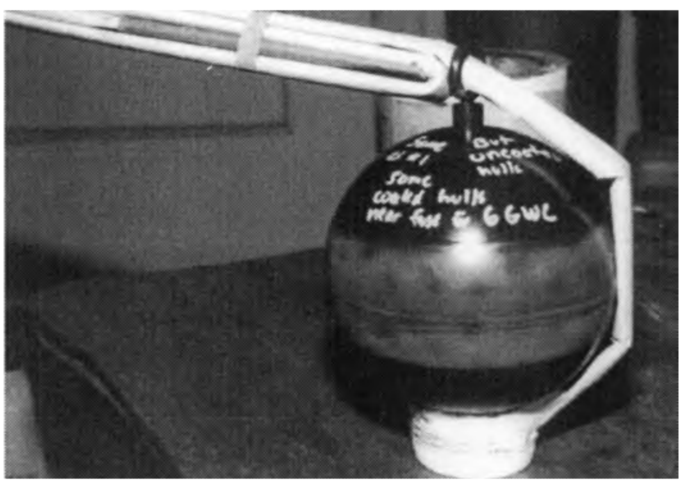

Figure 18

THE DOUBLE PETALLED ROUND SHELL

The double petalled peony or chrysanthemum represents the next stage of refinement of the basic round shell. Simply put, the double petalled round shell consists of a small shell concentrically positioned inside a larger shell. The artistic intent is to produce a burst in which a perfectly symmetric inner sphere of stars ignites, filling the central region of a larger outer sphere of stars. Usually, but not always, there is a slight delay before the outer color stars ignite. The aesthetic effect is most pleasing when the inner radius is one third to one half the outer radius. With the judicious use of carefully made color changing stars in both layers, both the inner and outer layers of stars can be made to change color simultaneously. The construction of these elegant shells presents the greatest challenge to the pyrotechnist.

The Japanese commonly denote the inner petal stars as the pistil stars. There is some confusion in the nomenclature on this point as pistil stars are also taken to mean those stars which are placed in the center of a single petalled round shell, i.e., stars mixed with the burst charge. Pistil stars of that type will not be ejected radially outward, but will fall downward in a bouquet formation. It is not uncommon for the Japanese to use pistil stars mixed with the inner burst charge in a double petalled shell for a triple layered effect. A true triple layered effect can only be achieved with a triple petalled shell. Such shells are quite large (10 inches or more in diameter), and are rarely seen in this country.

One of the most common aberrations in the burst of these shells is marked asymmetry in the inner petal. Assuming that the observed burst symmetry mirrors the geometry of the star positions in the shell, one can speculate that the inner layer should be made as spherical and as concentric with the outer star layer as possible. This can be readily achieved with the use of an inner newspaper hemisphere to arrange the stars against. The thin, brittle hemispheres easily fragment, and offer no impediment for the ignition of the outer layer.

Construction of a six inch plastic double petalled chrysanthemum is easier than one might think, and should take only a few minutes longer than a single petalled six-inch. Shells smaller than six inches can be made but will require more skill and dexterity to work in the cramped inner spaces.

First one needs to prepare the inner set of hemispheres. These are made from three layers of newspaper strips pasted on a plastic wrapped set of four inch hemispheres, as described earlier.

A piece of ¼-inch Japanese time fuse is hot glued in a six inch plastic hemisphere. A length of 5/16" i.d. cardboard tube is slipped over the crossmatched fuse; it should end within ½-inch of the exact center of the shell. The fuse tube is filled with granulated Black Powder and pasted over on top with a thin piece of newspaper to prevent the powder from falling out. Hot glue is used to fasten the base of the tube. See figure 19.

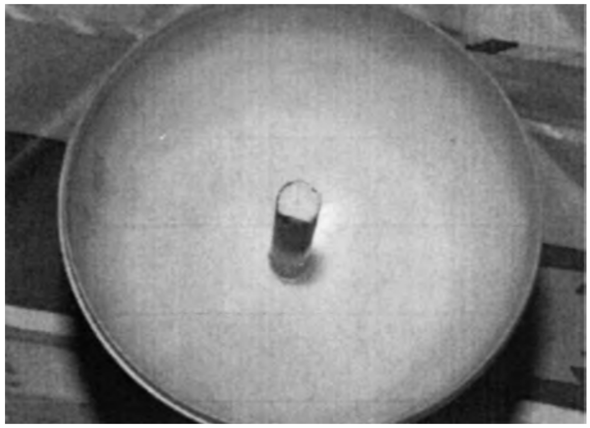

Figure 19

The outer petal stars can now be loaded into both hemispheres nearly to the edge. By using 15 mm outer stars and 10 mm inner stars, a good balance in the perceived star density of the burst was achieved. Note that the stars are not filled to the edge of the hemispheres where they would be likely to fall down. A hole is cut in the center of a piece of tissue paper and slipped over the fuse tube. Another piece of tissue paper is placed over the stars in the other hemisphere. A small amount of uncoated rice hulls is placed around the fuse tube, on the tissue paper. Coated rice hulls are unnecessary, nor will uncoated rice hulls block the ignition of the outer stars if the design is followed through. A hole is cut in the exact center of one of the newspaper hemispheres, just big enough to fit over the fuse tube. Then the hemisphere is slid over the fuse tube until it rests on the rice hulls. The edges of the newspaper hemi should be flush with the edges of the plastic hemispheres. The other news-paper hemi is placed on top of the rice hulls in the other plastic hemi, in the same manner. Rice hulls may have to be added or subtracted to bring the inner hemi flush. More rice hulls are added between the tissue liner and the newspaper hemi to about the level of the outer stars, as in figure 20.

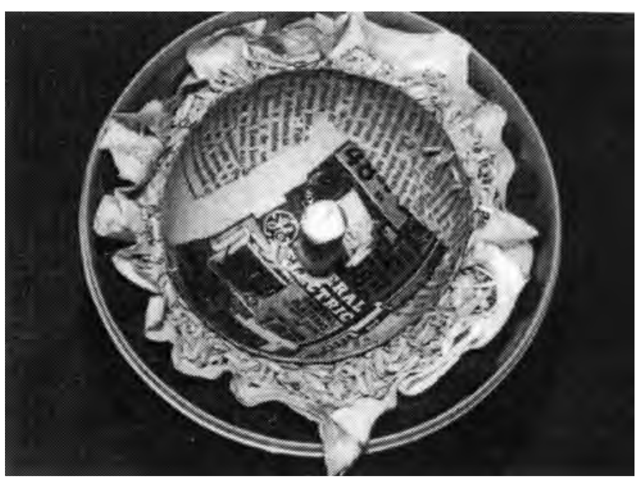

Figure 20

With both newspaper hemispheres nestled in proper position on their bed of rice hulls, the inner stars can now be added, as shown in figure 21.

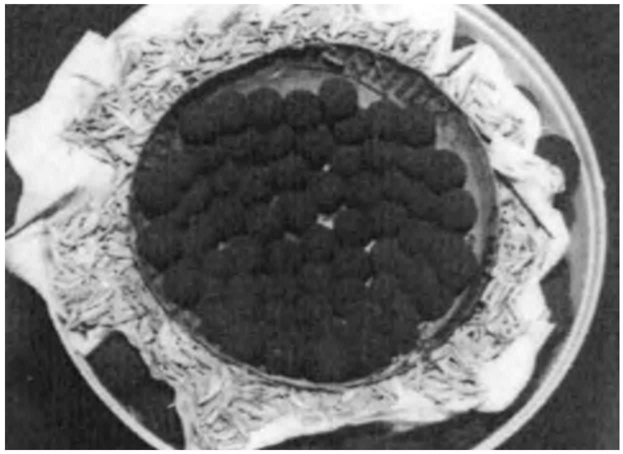

Figure 21

Another set of tissue papers is placed over the inner stars, and the excess tissue is trimmed away with scissors. Approximately 80 grams of rice hulls, coated with meal powder and shaken with 7 grams of whistle composition, are added to this inner tissue bag. At this point, more inner and outer stars may be inserted to bring the star layers flush with the edge. The remaining burst spaces are filled with uncoated and coated rice hulls until also flush.

Figure 22 shows the hemispheres fully packed with stars and burst, ready for assembly. The directions for final assembly are the same as given previously for plastic shells. A properly constructed shell will have no rattle evident when shaken.

Figure 22

RING AND INTERSECTOR SHELLS

Only a slight modification of procedure is required to produce a ring shell. The challenge is to produce a shell in which the ring of stars emerging from the burst is symmetric. The orientation of the ring in the sky is not readily controllable, as it will depend on the shell's attitude at the moment of the burst, relative to the observer on the ground. The appearance of the ring will most frequently assume the shape of an ellipse, but it can vary from nearly an edge-on line of stars to a perfect circle. A poorly made ring shell will produce a distorted pattern of stars that will not even be recognizable as a ring. Distortion in commercially made ring shells is far from uncommon. The key to the problem is to burst the shell hard enough to create a symmetrical spread. Overly hard breaks will invariably distort the shape of the ring, with some of the stars not igniting, leaving gaps in the perceived pattern.

The stars selected for a ring shell should be highly uniform in size. The initial velocity imparted to a star is a function of the weight of star, making it necessary to choose stars of equal mass. A fast way of assembling a ring shell is to use hot glue to lock the stars in the proper pattern in each plastic hemisphere. A four-inch ring shell will require at least twenty 11 mm stars to make a complete ring. Place a small drop of hot glue in the bottom center of the hemisphere without the fuse. Press the star into the glue drop to fix it in place. Another drop of hot glue is placed in position directly above the bottom star and the next star is glued in. The stars should butt right up against one another. More stars are added by this method until the semicircular row of stars reaches the top edge of the hemisphere. The completed row of stars should exactly bisect the hemispherical inside surface of the shell.

The same procedure is followed in the other hemisphere which contains the time fuse, covered with its central fuse tube. The fuse will bisect the arc of stars in its hemisphere. Eyeball the row of stars to assure they have been glued down in a "straight" line. Since each hemisphere contains one half of the ring, it is necessary to mark the outside of each hemisphere, along the top edge, corresponding to the position of internal ring stars. It is quite embarrassing to assemble the hemispheres only to realize that there is no way of orienting the hemis to assure that the ring segments are lined up!

After the rows of stars have been glued in place, and the outside edges marked, simply pack each hemisphere with meal-coated rice hulls, previously shaken with 5 grams of whistle composition. A tissue liner is not really necessary. One hemisphere can now be flipped over, using a thin piece of cardboard to hold the stars and burst from falling out, and placed on top of the other hemisphere. Before sliding out the cardboard, rotate the hemispheres with respect to one another so that the ring marks line up. Now the light weight shell can be finished in the manner previously described.

Intersector shells are made in the same way as ring shells except another line of stars of contrasting color is arranged perpendicular to the first ring. Each hemisphere, when viewed from the top, will have an "X" shaped pattern of stars which will combine into two intersecting rings in the finished shell.

It is possible to construct a triple intersector shell in which a third ring of stars is arranged at a 90 degree angle to the other two rings. The third ring of stars can be positioned just under the edge lip of one or the two hemispheres. These shells are made in Japan and a few are sold in the United States with the epithet "atomic pattern". A six inch shell is about the smallest that can be considered to give a good effect. Again, perfect symmetry is required to easily perceive the three rings.

RISING TAILS

A comet star can be attached to a round shell which will give an attractive ascending effect. Prepare a small quantity of dampened streamer composition such as willow or glitter. Fill a one-inch i.d. star pump with this composition, and place the pump flush on the outside of a completed four, five, or six inch plastic shell. Press down on the piston while holding the outside sleeve tightly against the shell. Remove the pump from the shell and push out the star. The star will have a concave surface that exactly matches the curvature of the shell. After drying, the star can be hot glued directly on the shell, very close to the top leader loop. The star should be no more than ¾-inch high and should be wrapped with one layer of masking tape, with just the top flat surface exposed. This surface will readily take fire from the flame of the lift charge. The incandescent streaming tail will spiral upwards as the shell rotates in its ascent.

METEOR SHELLS

An even more attractive effect is to coat the shell with streamer composition, turning it into a single huge meteor with a fat tail. At the peak of its ascent, the internal shell breaks, furnishing an attractive climax. These shells are tricky and time consuming to make, but are worth the effort.

To function properly, the internal shell must have a very short time fuse. The most effective way of achieving this is to employ a specially made spoulette. A piece of 1/16" wall, ¼-i.d. cardboard tube is cut to length of about 1½-inches. Place the tube on a hard surface and ram small increments of Black Powder, using a ¼-inch dowel as a rammer. Stop ramming when a Black Powder plug is formed which is 1/4-inch deep. Fill the remaining space above the plug with pieces of black match. Use a drill to enlarge the ¼-inch time fuse hole in a 3 or 4-inch plastic round shell hemisphere to 3/8". Any "lip" of plastic remaining after drilling should be sanded away to make the 3/8" hole exactly flush with the outside plastic surface.

The spoulette is now inserted into the hole and hot glued on the inside surface. The plug of Black Powder should be facing outwards and flush with the plastic. The shell can now be filled with stars and burst and cemented together using the procedure previously described.

The shell can be held with the hand protected by a rubber glove, and wiped rapidly with solvent to soften the surface. Lower the shell into a plastic cake pan containing a ½-inch deep layer of streamer composition. The glitter formula #11 is a good choice. The glitter will adhere to the outer surface in a thin layer. The layer will make it possible for more composition to adhere to the surface in the next step.

The fuse plug needs to be protected against influx of moisture by smearing a paste, made from meal mixed with 10% nitrocellulose lacquer, over the end of the time fuse. When this is dry, the coating process can begin. Grasp the shell with a rubber glove-protected hand and rapidly dunk it in a container of water containing about 20% alcohol. Pull it out immediately and drop it into the cake pan containing the glitter or streamer mix. Roll the shell around until it cannot pick up any more composition. Carefully pick up the shell and allow it to dry overnight.

The usual method of star enlargement, using cycles of dampening and dusting, cannot succeed in this case. The "star" is so big that even with the most careful rolling procedure, the increments of composition will slough off the surface. The "skin" of dampened composition is extremely sensitive to damage from banging into the sides of the pan. Increasing the thickness by adding another layer will further reduce the integrity of the surface. Therefore, each layer of applied composition must be allowed to dry before re-dampening.

The shell, with its dried crust of streamer composition, is re-dunked in the water and rolled again in the pan containing the meteor mix. The shell will grow in diameter about 1/16" per coating cycle.

If you have used a four inch internal shell, stop the coating when the diameter of the shell reaches 4¾-inches. It is now ready to fire after drying. Be sure it slides into a 5-inch mortar with no resistance.

The entire shell can be placed in a paper bag containing the lift charge and the shell leader pipe, positioned appropriately for proper function. The readily flammable surface of the shell should not be exposed. The timing of the inner shell is dependent on the rate of burn of the streamer mix. This has been found to give the correct four second delay when the glitter mix is used as recommended.

SATURN SHELL

The best firework displays will feature at least a few of these shells, also called *planet with ring*. They are sold in sizes of 6 inches and up by Onda, a company in Japan. A Saturn shell appears in the sky as a simple peony sphere of single color stars surrounded by an outer ring of larger stars. Occasionally these outer ring stars will have a streamer composition which changes to a colored core. As with all ring-type shells, the orientation of the "planet" and ring is not controllable, due to the spin of the shell at is leaves the mortar. They are quite attractive in nearly every orientation except the one in which the ring appears edge on.

The Saturn shell is nothing more than a special case of the double petalled shell described earlier. A six-inch shell will use ring stars of approximately 5/8-inch diameter, and inner petal stars, which are the planet stars, of ½-inch diameter or less. As with the double petalled shell, the construction begins with the placement of the outer petal stars. In this case, the stars are placed in the ring. The ring of outer stars can be glued in position directly underneath the rim of one of the hemispheres, (which gives a ring slightly out of the plane of equator of the inner planet) or the stars can be placed with one arc in each hemisphere. After the ring stars are in place, a tissue paper liner can be inserted, if desired. Meal coated rice hulls are added to fill the hemispheres to the level of the bottom of the four-inch newspaper hemisphere, which is placed over the fuse tube. The shell is completed in exactly the same manner as the double petalled shell.

There exists a certain fancy type of Saturn shell which in the sky starts out looking like an ordinary Saturn shell, but finishes up looking like a double petalled peony. The planet stars will extinguish and the outer petal stars will suddenly ignite, producing a large climactic flower. There is nothing mysterious about the design of these shells as the outer petal stars are simply not seen immediately after the break. This is because the colored core of these stars is coated with a dark composition, i.e., a composition producing very little flame and sparks.

The exact formulation of this dark composition is not known to me. However, Dr. Shimizu has provided me with the formulation given below that works quite well *(personal communication).*

Dark Composition	
Potassium nitrate	75
Potassium perchlorate	7
Antimony sulfide	3
Red gum	2
Charcoal	8
Dextrin	5

This composition is layered over a colored core of approximately 5/16-inch in diameter. The exact size will depend on the precise timing of the effect. The finished star should have a Black Powder prime and a diameter of 5/8-inch for a six-inch shell. The construction of the shell begins with the placement of the ring stars, as mentioned previously. The remaining space of the wall of the plastic hemispheres is filled in with a layer of the dark stars with the colored core. The shell is then finished in the same manner as described for the 6-inch double petalled shell.

About the author ...

Dave Bleser was born in Schenectady, New York, and graduated from Albany College of Pharmacy in 1970. He moved to Miami in 1971 to practice pharmacy. His intense interest in chemistry led him to change his occupation from pharmacist to chemist in 1972, when he became chief environmental chemist for Florida Power and Light. Later earning his master's degree in organic chemistry, he pursued employment in cancer research for the University of Miami. He began studying pyrotechnic chemistry in 1980 and had been active in the Pyrotechnic Guild International, serving as 2nd vice president in 1985. His wife Gail, a retired registered nurse, is also a fireworks enthusiast. David is currently working at Douglas Gardens Community Mental Health Center in Miami Beach. His current interests are in astrophotography using a Celestron l l-inch telescope.

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