CHAPTER III

PYROTECHNICS

The early history of pyrotechnics and the early history of black powder are the same narrative. Incendiary compositions containing saltpeter, and generally sulfur, mixed with combustible materials were used both for amusement and for purposes of war. They developed on the one hand into black powder, first used in crackers for making a noise and later in guns for throwing a projectile, and on the other into pyrotechnic devices. The available evidence indicates that fireworks probably developed first in the Far East, possibly in India earlier than in China, and that they were based upon various compositions of potassium nitrate, sulfur, and charcoal, with the addition of iron filings, coarse charcoal, and realgar (As_2S_2) to produce different visual effects. The nature of the composition and the state of subdivision of its ingredients determine the rate of burning and the appearance of the flame. In Chinese fire, coarse particles of hard-wood charcoal produce soft and lasting sparks; filings of cast iron produce bright and scintillating ones. The original Bengal lights were probably made more brilliant by the addition of realgar.

The manufacture of pyrotechnics from the Renaissance onward has been conducted, and still is practiced in certain places, as a household art or familiar craft. The artificer[1] needs patience and skill and ingenuity for his work. For large-scale factory production, the pyrotechnist has few problems in chemical engineering but many in the control of craftsmanship. His work, like that of the wood-carver or bookbinder, requires manual dexterity but transcends artistry and becomes art by the free play of the imagination for the production of beauty. He knows the kinds of effects, audible and visible, which he can get from his materials. He knows this as the graphic artist knows the appearance of his

[1] In the French language the word *artificier* means fireworks maker, and *artifice* means a pyrotechnic device.

colors. His problem is twofold: the esthetic one of combining these effects in a manner to produce a result which is pleasing, and the wholly practical one of contriving devices—and the means for the construction of devices—which shall produce these results. Like the graphic artist, he had but few colors at first, and he created designs with those which he had—lights, fountains, showers, Roman candles, rockets, etc. As new colors were discovered, he applied them to the production of better examples of the same or slightly modified designs. At the same time he introduced factory methods, devised improvements in the construction of his devices, better tools, faster and more powerful machinery, and learned to conduct his operations with greater safety and with vastly greater output, but the essential improvements in his products since the beginning of the seventeenth century have been largely because of the availability of new chemical materials.

Development of Pyrotechnic Mixtures

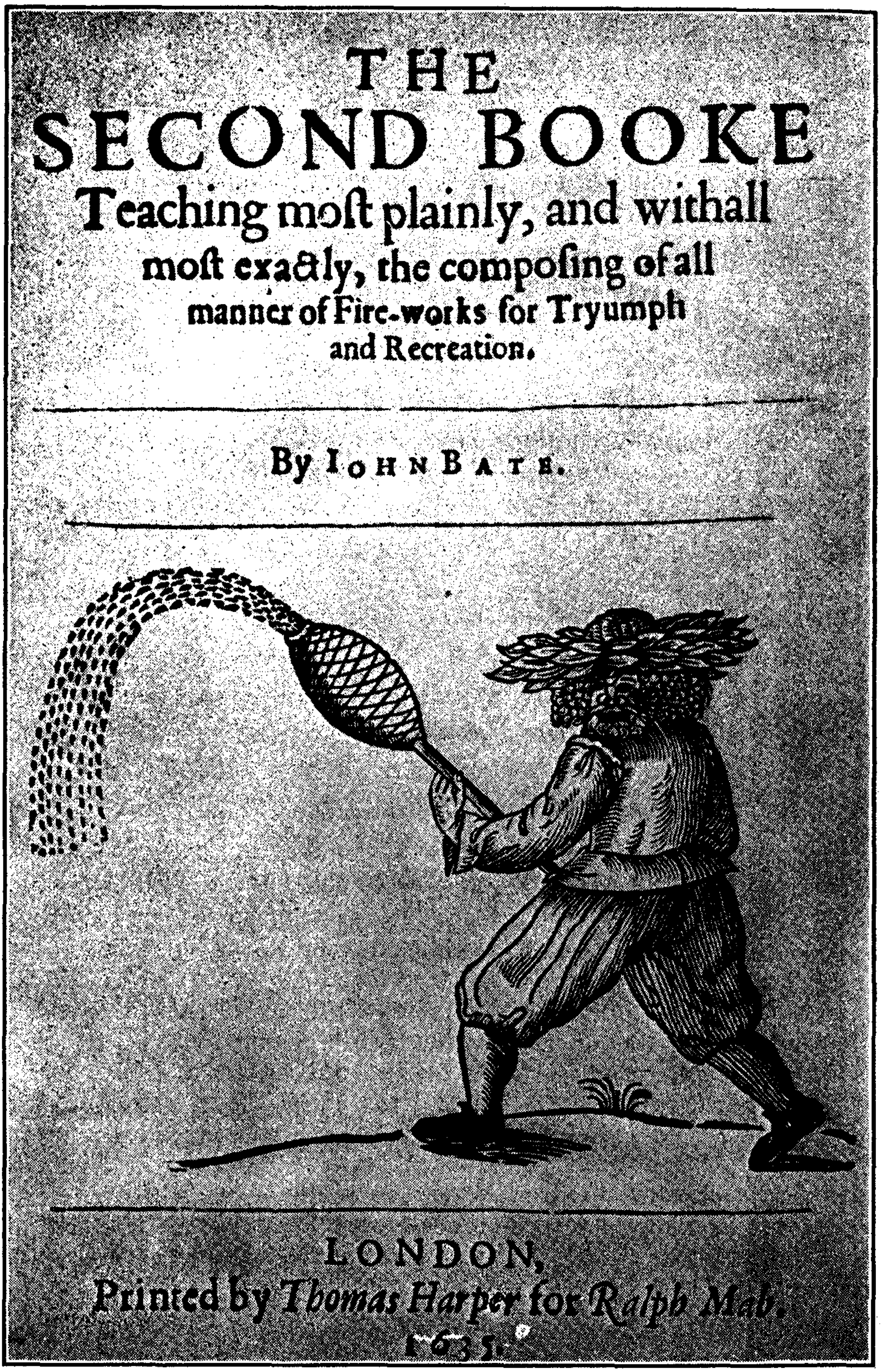
The use of antimony sulfide, Sb_2S_3, designated in the early writings simply as antimony, along with the saltpeter, sulfur, and charcoal, which were the standard ingredients of all pyrotechnic compositions, appears to have been introduced in the early part of the seventeenth century. John Bate's "Book of Fireworks," 1635, containing information derived from "the noted Professors, as Mr. Malthus, Mr. Norton, and the French Authour, Des Récreations Mathématiques,"[2] mentions no mixtures which contain antimony. Typical of his mixtures are the following.

> *Compositions for Starres.* Take saltpeter one pound, brimstone half a pound, gunpowder foure ounces, this must be bound up in paper or little ragges, and afterwards primed.
> *Another receipt for Starres.* Take of saltpeter one pound, gunpowder and brimston of each halfe a pound; these must be mixed together, and of them make a paste, with a sufficient quantity of oil of peter (petroleum), or else of faire water; of this paste you shal make little balles, and roll them in drie gunpowder dust; then dry them, and keepe them for your occasions.[3]

The iron scale which John Bate used in certain of his rocket

[2] F. Malthus (François de Malthe), "Treatise of Artificial Fireworks," 1629; Robert Norton, "The Gunner," 1628.

[3] John Bate, "The Mysteries of Nature and Art," London, 1635, Second Part, p. 101.



THE
SECOND BOOKE
Teaching moſt plainly, and withall
moſt exactly, the compoſing of all
manner of Fire-works for Tryumph
and Recreation.

By IOHN BATE.

LONDON,
Printed by *Thomas Harper* for *Ralph Mab.*
1635.

FIGURE 21. Title Page of John Bate's "Book of Fireworks." A "green man," such as might walk at the head of a procession, is shown scattering sparks from a fire club. The construction of this device is described as follows: "To make . . . you must fill diverse canes open at both ends (and

compositions probably produced no brilliant sparks but only glowing globules of molten slag which gave the rocket a more luminous tail. Hanzelet Lorrain[4] in 1630 showed a more advanced knowledge of the art and gave every evidence of being acquainted with it by his own experience. He described several mixtures containing antimony sulfide and compositions, for balls of brilliant fire to be thrown from the hand, which contain orpiment (As_2S_3) and verdigris.

> *Stars of the only two compositions which are well approved.* Take of powder (gunpowder) four ounces, of saltpeter two ounces, of sulfur two ounces, of camphor half an ounce, of steel filings two *treseaux*, of white amber half an ounce, of antimony (sulfide) half an ounce, of (corrosive) sublimate half an ounce. For double the efficacy it is necessary to temper all these powders with gum *agragante* dissolved in brandy over hot cinders. When you see that the gum is well swollen and fully ready to mix with the said brandy, it is necessary forthwith to mix them in a mortar with the powder, the quicker the better, and then to cut up the resulting paste into pieces. These stars are very beautiful and very flowery. Note that it is necessary to put them to dry in a pastry or baking oven after the bread has been taken off of the hearth.
>
> *Second star composition.* Take of saltpeter in fine and dry flour ten ounces, of charcoal, of sulfur, of powder (gunpowder), of antimony (sulfide), and of camphor each two *treseaux*. Temper the whole with oil of turpentine, and make it into a powdery (mealy) paste which you will put into little cartridges; and you will load them in the same manner as rockets [that is, by pounding in the charge]. When you wish to use them, it is necessary to remove the paper wrapper and to cut them into pieces setting a little black match (*mèche d'estoupin*) in the middle (of each piece) through a little hole which you will pierce there.
>
> *How fire balls are made so white that one can scarcely look at them without being dazzled.* Take a pound of sulfur, three pounds of saltpeter, half a pound of gum arabic, four ounces of orpiment: grind all together, and mix well by hand,

[4] Hanzelet Lorrain, "La pyrotechnie," Pont à Mousson, 1630. The author's name is a pseudonym of Jean Appier.

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of a foot long, or more, or lesse, as you think fit) with a slow composition, and binde them upon a staffe of four or five foot long; prime them so that one being ended, another may begin: you may prime them with a stouple or match (prepared as before). Make an osier basket about it with a hole in the very top to fire it by, and it is done."

FIGURE 22. Seventeenth-Century Fireworks Display, Lorrain, 1630. Flaming swords, shields and pikes, wheel of fire, rockets, stars, candles, serpents, water fireworks. The sun and the moon which are pictured are presumably aerial bombs, and the dragons are probably dragon rockets running on ropes but may possibly be imaginative representations of serpents of fire. The picture is convincing evidence that many of the varieties of fireworks which are now used (in improved form) for display purposes were already in use three centuries ago.

> and moisten with brandy and make into a stiff paste into which you will mix half a pound of ground glass, or of crystal in small grains, not in powder, which you will pass through a screen or sieve. Then, mixing well with the said paste, you will form balls of it, of whatever size you please and as round as you can make them, and then you will let them dry. If you wish to have green fire, it is necessary merely to add a little verdigris to the composition. This is a very beautiful fire and thoroughly tested, and it needs no other primer to fire it than the end of a lighted match, for, as soon as the fire touches it, it inflames forthwith. It is beautiful in saluting a prince or nobleman to have such agreeable hand fire balls before setting off any other fireworks.[5]

Audot, whose little book[6] we take to be representative of the state of the art at the beginning of the nineteenth century, had a slightly larger arsenal of materials.

Iron and steel filings. "They give white and red sparks. It is necessary to choose those which are long and not rolled up, and to separate them from any dirt. They are passed through two sieves, in order to have two sizes, fine filings and coarse filings. Those of steel are in all respects to be preferred. It is easy to procure them from the artisans who work in iron and steel."

Ground and filed cast iron. "Cast iron is used in the fires which are designated by the name of *Chinese fire.* Two kinds, fine and coarse. The cast iron is ground in a cast iron mortar with a cast iron or steel pestle, and then sifted."

Red copper filings. "This gives greenish sparks."

Zinc filings "produce a beautiful blue color; it is a substance very difficult to file."

Antimony (sulfide) "gives a blue flame. It is ground up and passed through a screen of very fine silk."

Yellow amber. "Its color, when it burns, is yellow. It is used only for the fire of lances. It is very common in the drug trade. It ought to be ground and passed through a sieve."

Lampblack. "It gives a very red color to fire, and it gives rose in certain compositions."

Yellow sand or gold powder. "It is used in suns where it produces golden yellow rays. It is a reddish yellow sand mixed with

[5] Hanzelet Lorrain, *op. cit.*, pp. 256-258.

[6] Anon. (L.-E. Audot), "L'art de faire, à peu de frais, les feux d'artifice," Paris, 1818.

little brilliant scales. The paperers sell it under the name of gold powder. It is very common in Paris."[7]

Some of Audot's compositions are as follows:

Common fire: meal powder 16 parts, coarse and fine charcoal 5 parts.

Chinese fire: meal powder 16 parts, cast iron 6 parts.

Brilliant fire: meal powder 16 parts, steel filings 4 parts.

Blue fire for cascades: meal powder 16 parts, saltpeter 8, sulfur 12, and zinc filings 12 parts.

Fixed star: saltpeter 16 parts, sulfur 4, meal powder 4, and antimony (sulfide) 2 parts.

Silver rain for a turning sun or fire wheel: meal powder 16 parts, saltpeter 1, sulfur 1, steel filings 5 parts.

Green fire for the same: meal powder 16 parts, copper filings 3 parts.

Chinese fire for the same: meal powder 16 parts, saltpeter 8, fine charcoal 3, sulfur 3, fine and coarse cast iron 10 parts.

Composition for lances. Yellow: saltpeter 16 parts, meal powder 16, sulfur 4, amber 4, and colophony 3 parts. *Rose:* saltpeter 16 parts, lampblack 1, meal powder 3. *White:* saltpeter 16 parts, sulfur 8, meal powder 4. *Blue:* saltpeter 16 parts, antimony (sulfide) 8, very fine zinc filings 4. *Green:* saltpeter 16 parts, sulfur 6, verdigris 16, and antimony (sulfide) 6 parts.

Bengal flame: saltpeter 16 parts, sulfur 4, and antimony (sulfide) 2 parts. This mixture was to be lighted by quickmatch and burned in small earthenware pots for general illumination.[8]

The Ruggieri, father and son, contributed greatly to the development of fireworks by introducing new, and often very elaborate, pieces for public display and by introducing new materials into the compositions. They appear to have been among the first who attempted to modify the colors of flames by the addition of salts. The compositions which we have cited from Audot are similar to some of those which the elder Ruggieri undoubtedly used at an earlier time, and the younger Ruggieri, earlier than Audot's book, was using materials which Audot does not mention, in particular, copper sulfate and ammonium chloride for the green fire of the palm-tree set piece. The use of ammonium chloride was a definite advance, for the chloride helps to volatilize the copper and to produce a brighter color. But ammonium

[7] Audot, *op. cit.*, pp. 15-19.

[8] Audot, *op. cit.*, pp. 48, 49, 50, 52, 63, 64, 67.

chloride is somewhat hygroscopic and tends to cake, and it is now no longer used; indeed, the chloride is unnecessary in compositions which contain chlorate or perchlorate. In the Ruggieri "we have two pyrotechnists who can be considered to represent the best skill of France and Italy; in fact, it was Ruggieri whose arrival in France from Italy in or about 1735 marked the great advance in pyrotechny in the former country."[9] The elder Ruggieri conducted a fireworks display at Versailles in 1739. In 1743 he exhibited for the first time, at the Théâtre de la Comédie Italienne and before the King, the passage of fire from a moving to a fixed piece. "This ingenious contrivance at first astonished the scientists of the day, who said when it was explained to them that nothing could be more simple and that any one could have done it at once."[10] In 1749 he visited England to conduct, with Sarti, a fireworks display in Green Park in celebration of the peace of Aix-la-Chapelle. The younger Ruggieri conducted many public pyrotechnic exhibitions in France during the years 1800-1820, and wrote a treatise on fireworks which was published both in French and in German.

Potassium chlorate had been discovered, or at least prepared in a state of purity, by Berthollet in 1786. It had been tried unsuccessfully and with disastrous results in gunpowder. Forty years elapsed before it began to be used in pyrotechnic mixtures, where, with appropriate salts to color the flame, it yields the brilliant and many-colored lights which are now familiar to us. At present it is being superseded for certain purposes by the safer perchlorate.

James Cutbush, acting professor of chemistry and mineralogy at West Point, in his posthumous "System of Pyrotechny," 1825, tells[11] of the detonation of various chlorate mixtures and of their use for the artificial production of fire. "Besides the use of nitre in pyrotechnical compositions, as it forms an essential part of all

[9] A. St. H. Brock, "Pyrotechnics: The History and Art of Fireworks Making," London, 1922. This is a scholarly and handsome book, bountifully illustrated, which contains excellent accounts both of the history of fireworks and of present manufacturing practice. The author comes from several generations of fireworks makers.

[10] Quoted by Brock, *op. cit.*, p. 124.

[11] James Cutbush, "A System of Pyrotechny, Comprehending the Theory and Practice, with the Application of Chemistry; Designed for Exhibition and for War," Philadelphia, 1825, p. 22.

of them, there is another salt . . . that affords a variety of amusing experiments. This salt is the hyperoxymuriate or chlorate of potassa. Although it has neither been used for fire-works on an extensive scale, nor does it enter into any of the compositions usually made for exhibition, yet its effect is not the less amusing." At a later place Cutbush says: "M. Ruggieri is of opinion, that chlorate, or hyperoxymuriate of potassa may be employed with advantage in the composition of rockets, but we have not heard that it has been used. It is more powerful in its effects, and probably for this reason he recommended it. This salt, mixed with other substances, will produce the *green fire* of the palm-tree, in imitation of the Russian fire."[12]

Ruggieri's Russian fire, as his son later described it, consisted of crystallized copper acetate 4 parts, copper sulfate 2 parts, and ammonium chloride 1 part,[13] all finely pulverized and mixed with alcohol, and placed upon cotton wick attached to spikes upon the thin metal pieces which were the leaves of the palm tree. The resulting display would not be impressive according to modern standards.

Cutbush also knew how to color the flame, for he says:

> We are of opinion, that many of the nitrates might be advantageously employed in the manufacture of fire works. Some, as nitrate of strontian, communicate a red color to flame, as the flame of alcohol. Nitrate of lime also might be used. . . . Muriate of strontian, mixed with alcohol, or spirit of wine, will give a carmine-red flame. For this experiment, one part of the muriate is added to three or four parts of alcohol. Muriate of lime produces, with alcohol, an orange-coloured flame. Nitrate of copper produces an emerald-green flame. Common salt and nitre, with alcohol, give a yellow flame.[14]

According to Brock, the use of chlorate in pyrotechnic mixtures, initiating the modern epoch in the art, first occurred about 1830. Lieut. Hippert of the Belgian artillery published at Bruxelles in 1836 a French translation, "Pyrotechnie raisonnée," of a work by Prussian artillery Captain Moritz Meyer in which one chapter is devoted to colored fires, and listed several com-

[12] Cutbush, *op. cit.*, p. 77.

[13] Ruggieri, "Handbüchlein der Lustfeuerwerkerei," second edition, Quedlinburg and Leipzig, 1845, p. 142.

[14] Cutbush, *op. cit.*, pp. 8 and 20.

positions which contain potassium chlorate. Meyer states, incidentally, that the English at that time used colored rockets for signaling at sea and were able to produce ten distinguishable shades. His descriptions of his compositions give one reason to suspect that he had had little experience with them himself. The first, a mixture of potassium chlorate and sugar, burns, he says, with a red light; but the color is actually a bluish white.

> A powder which burns with a green flame is obtained by the addition of nitrate of baryta to chlorate of potash, nitrate of potash, acetate of copper. A white flame is made by the addition of sulfide of antimony, sulfide of arsenic, camphor. Red by the mixture of lampblack, coal, bone ash, mineral oxide of iron, nitrate of strontia, pumice stone, mica, oxide of cobalt. Blue with ivory, bismuth, alum, zinc, copper sulfate purified of its sea water [*sic*]. Yellow by amber, carbonate of soda, sulfate of soda, cinnabar. It is necessary in order to make the colors come out well to animate the combustion by adding chlorate of potash.[15]

Although Meyer's formulas are somewhat incoherent, they represent a definite advance. Equally significant with the use of chlorate is his use of the nitrates of strontium and barium.

The second German edition of Ruggieri's book (we have not seen the first) contains a *Nachtrag* or supplement which lists nine compositions,[16] of which four contain *Kali oxym.* or potassium chlorate. These are: (1) for red fire, strontium nitrate 24 parts, sulfur 3, fine charcoal 1, and potassium chlorate 5; (2) for green fire, barium carbonate 20 parts, sulfur 5, and potassium chlorate 8 parts; (3) for green stars, barium carbonate 20 parts, sulfur 5, and potassium chlorate 9 parts; and (4) for red lances, strontium carbonate 24 parts, sulfur 4, charcoal 1, and potassium chlorate 4 parts. Ruggieri says:

> The most important factor in the preparation of these compositions is the fine grinding and careful mixing of the several materials. Only when this is done is a beautiful flame to be expected. And it is further to be noted that the potassium chlorate, which occurs in certain of the compositions, is to be wetted with spirit for the grinding in order to avoid an explosion.

[15] Brock, *op. cit.,* pp. 145, 146.
[16] Ruggieri, *op. cit.,* pp. 147, 148.

The chlorate compositions recommended by Ruggieri would undoubtedly give good colors, but are not altogether safe and would probably explode if pounded into their cases. They could be loaded with safety in an hydraulic press, and would probably not explode if tamped carefully by hand.

F. M. Chertier, whose book "Nouvelles recherches sur les feux d'artifice" was published at Paris in 1854, devotes most of his attention to the subject of color, so successfully that, although new materials have come into use since his time, Brock says that "there can be no doubt that Chertier stands alone in the literature of pyrotechny and as a pioneer in the modern development of the art."[17] Tessier, in his "Chimie pyrotechnique ou traité pratique des feux colores," first edition, Paris, 1859, second edition 1883, discusses the effect of individual chemicals upon the colors of flames and gives excellent formulas for chlorate and for non-chlorate compositions which correspond closely to present practice. He used sulfur in many but not in all of his chlorate mixtures. Pyrotechnists in France, with whom the present writer talked during the first World War, considered Tessier's book at that time to be the best existing work on the subject of colored fires—and this in spite of the fact that its author knew nothing of the use of magnesium and aluminum. The spectroscopic study of the colors produced by pure chemicals, and of the colors of pyrotechnic devices which are best suited for particular effects, is the latest of current developments.

Chlorate mixtures which contain sulfur give brighter flames than those which lack it, and such mixtures are still used occasionally in spite of their dangerous properties. The present tendency, however, is toward chlorate mixtures which contain no sulfur, or toward potassium nitrate mixtures (for stars, etc.) which contain sulfur but no chlorate, or toward nitrates, such as those of strontium and barium, which supply both color for the flame and oxygen for the combustion and are used with magnesium or aluminum to impart brilliancy. Magnesium was first used for pyrotechnic purposes about 1865 and aluminum about 1894, both of them for the production of dazzling white light. These metals were used in the compositions of colored airplane

[17] Brock, *op. cit.*, p. 147. Chertier also published a pamphlet on colored fires nearly thirty years earlier than the above-mentioned book.

flares during the first World War, but their use in the colored fires of general pyrotechny is largely a later development.

Tessier introduced the use of cryolite ($AlNa_3F_6$) for the yellow coloring of stars, lances, and Bengal lights. In his second edition he includes a chapter on the small pyrotechnic pieces which are known as Japanese fireworks, giving formulas for them, and another on the picrates, which he studied extensively. The picrates of sodium, potassium, and ammonium crystallize in the anhydrous condition. Those of barium, strontium, calcium, magnesium, zinc, iron, and copper are hygroscopic and contain considerable water of crystallization which makes them unfit for use in pyrotechnic compositions. Lead picrate, with 1 H_2O, detonates from fire and from shock, and its use in caps and primers was patented in France in 1872. Potassium and sodium picrate deflagrate from flame, retaining that property when mixed with other substances. Ammonium picrate detonates from fire and from shock when in contact with potassium chlorate or lead nitrate, but in the absence of these substances it has the special advantage for colored fires that the mixtures give but little smoke and this without offensive odor. Tessier recommends ammonium picrate compositions for producing colored lights in the theater and in other places where smoke might be objectionable. "Indoor fireworks" have been displaced in the theater by electric lighting devices, but are still used for certain purposes. Tessier's formulas, which are excellent, are described later in the section on picrate compositions.

Colored Lights

Colored light compositions are used in the form of a loose powder, or are tamped into paper tubes in torches for political parades, for highway warnings, and for railway and marine signals, in Bengal lights, in airplane flares, and in lances for set pieces, or are prepared in the form of compact pellets as stars for Roman candles, rockets, and aerial bombs, or as stars to be shot from a special pistol for signaling.

Colored fire compositions intended for burning in conical heaps or in trains are sometimes sold in paper bags but more commonly in boxes, usually cylindrical, of pasteboard, turned wood, or tinned iron. The mixtures are frequently burned in the boxes in which they are sold. Compositions which contain no chlorate (or perchlorate) are the oldest, and are still used where the most brilliant colors are not necessary.

	White					Red	Pink		Yellow
Potassium nitrate	5	3	32	8	14	..	12	14	..
Sulfur	2	1	15	2	4	5	5	4	3
Strontium nitrate	..	..	..	..	..	18	48	36	..
Barium nitrate	..	..	..	..	..	..	..	..	36
Sodium oxalate	..	..	..	..	..	..	..	..	6
Antimony metal	..	1	12	..	..	..	..	..	..
Antimony sulfide	1	1	..	..	..	..	..	..	..
Realgar	..	..	..	1	5	..	..	..	..
Minium	..	..	10	..	..	..	..	..	..
Lampblack	..	..	..	..	..	1	..	..	..
Charcoal	..	..	..	..	..	..	4	1	..
Red gum	..	..	..	..	..	..	..	4	5
Dextrin	..	..	1	..	..	..	..	1	..

The chlorate compositions listed below, which contain no sulfur, burn rapidly with brilliant colors and have been recommended for indoor and theatrical uses.

	White	Red	Yellow	Green
Potassium chlorate	12	1	6	2
Potassium nitrate	4	..	6	..
Strontium nitrate	..	4	..	..
Barium nitrate	..	..	..	1
Barium carbonate	1	..	..	..
Sodium oxalate	..	..	5	..
Cane sugar	4	..	..	1
Stearine	1	..	..	..
Shellac	..	1	3	..

The following are brilliant, somewhat slower burning, and suitable for outdoor use and general illumination. The smokes from the compositions which contain calomel and Paris green are poisonous. In mixing Paris green, care must be exercised not to inhale the dust.

	Red			Green		Blue		
Potassium chlorate	10	4	8	4	4	6	8	16
Strontium nitrate	40	10	16	..	..	..	..	..
Barium nitrate	..	..	..	8	8	4	..	14
Paris green	..	..	..	..	..	4	..	12
Shellac	..	..	3	..	3	..	..	1
Stearine	..	..	..	..	..	1	..	2
Red gum	6	3	..	2	..	..	..	..
Calomel	..	..	..	..	..	..	6	2
Sal ammoniac	..	..	..	1	..	1	..	..
Copper ammonium chloride	..	..	..	..	..	..	2	..
Fine sawdust	6	..	..	..	..	..	..	..
Rosin	..	1	..	..	..	..	..	..
Lampblack	1	1	..	..	..	..	..	..
Milk sugar	..	..	..	..	..	..	3	..

Railway Fusees (Truck Signal Lights)

Motor trucks are required by law to be equipped with red signal lights for use as a warning in case an accident causes them to be stopped on the road at night without the use of their electric lights. Similar lights are used for signaling on the railways. The obvious requirement is that the signal should burn conspicuously and for a long time. A. F. Clark recommends a mixture of:

	Parts
Strontium nitrate (100 mesh)	132
Potassium perchlorate (200 mesh)	15
Prepared maple sawdust (20 mesh)	20
Wood flour (200 mesh)	1
Sulfur (200 mesh)	25

The prepared maple sawdust is made by cooking with miner's wax, 10 pounds of sawdust to 1 ounce of wax, in a steam-jacketed kettle. The mixture is tamped dry into a paper tube, 7/8 inch in external diameter, 1/32 inch wall, and burns at the rate of about 1 inch per minute. The fusee is supplied at its base with a pointed piece of wood or iron for setting it up in the ground, and it burns best when set at an angle of about 45°. In order to insure certain ignition, the top of the charge is covered with a primer or *starting fire,* loaded while moistened with alcohol, which consists of potassium chlorate 16 parts, barium chlorate 8, red gum (gum yacca) 4, and powdered charcoal 1. This is covered with a piece of paper on which is painted a *scratch mixture* similar to that which composes the head of a safety match. The top of the fusee is supplied with a cylindrical paper cap, the end of which is coated with a material similar to that with which the striking surface on the sides of a box of safety matches is coated. To light the fusee, the cap is removed and inverted, and its end or bottom is scratched against the mixture on the top of the fusee.

Weingart[18] recommends the first four of the following compositions for railway fusees; Faber[19] reports the fifth. Weingart's mixtures are to be moistened with kerosene before they are tamped into the tubes.

Potassium chlorate	..	..	..	..	12
Potassium perchlorate	..	..	..	5	..
Strontium nitrate	48	36	16	36	72
Saltpeter	12	14	4	..	..
Sulfur	5	4	5	5	10
Fine charcoal	4	1	1	..	..
Red gum	10	4	..	..	4
Dextrin	..	1	..	..	..
Sawdust	..	..	..	2	..
Sawdust and grease	..	..	..	..	4
Calcium carbonate	..	..	..	..	1

Scratch Mixture

Typical scratch mixtures are the pair: (*A*) potassium chlorate 6, antimony sulfide 2, glue 1; and (*B*) powdered pyrolusite (MnO_2) 8, red phosphorus 10, glue 3, recommended by Weingart; and the pair: (*A*) potassium chlorate 86, antimony sulfide 52, dextrin 35; and (*B*) red phosphorus 9, fine sand 5, dextrin 4, used with gum arabic as a binder, and recommended by A. F. Clark.

Marine Signals

Other interesting signal lights, reported by Faber,[20] are as follows.

[18] Weingart, "Dictionary and Manual of Fireworks," Boston, 1937, p. 61.
[19] Faber, "Military Pyrotechnics," 3 vols., Washington, 1919, Vol. I, p. 189.
[20] *Loc. cit.*

	Marine Flare Torch	Pilot's Blue Light
Barium nitrate	16	..
Potassium nitrate	8	..
Potassium chlorate	..	46
Strontium carbonate	1	..
Copper oxychloride	..	32
Sulfur	2	28
Red gum	2	..
Shellac	..	48
Calomel	..	3

Parade Torches

Parade torches are made in various colors; they are of better quality than railway fusees, burn with a deeper color and a brighter light, and are generally made with more expensive compositions. Below are a few typical examples. Parade torches are

	Red			Green		Purple	Amber	Blue
Strontium nitrate	16	5	9	..	..	7	36	..
Barium nitrate	..	..	..	40	30	..	..	..
Potassium chlorate	8	1	..	11	..	..	..	..
Potassium perchlorate	..	..	2	..	6	9	10	5
Sodium oxalate	..	..	..	..	..	..	8	..
Cupric oxide	..	..	..	..	..	6	..	..
Paris green	..	..	..	..	..	..	..	2
Sal ammoniac	..	..	..	1	..	..	..	..
Calomel	..	..	..	..	..	3	..	1
Sulfur	..	..	2	..	3	5	3	..
K.D. gum	..	..	..	6	2	..	..	..
Shellac	3	..	..	..	..	..	5	..
Red gum	..	1	1	..	..	..	..	..
Dextrin	..	..	..	..	..	..	..	1

equipped with wooden handles at the lower ends, and are sealed at their upper ends with a piece of cloth or paper, pasted on, through which a hole has been punched into the composition to a depth of about 1 inch—and through this a piece of *black match*[21]

[21] The match, prepared by dipping a few strands of cotton twine, twisted together, into a paste of meal powder and allowing to dry while stretched on a frame, is called *black match* by the pyrotechnists. When this is enclosed in a paper tube, it burns almost instantaneously and is then known as *quickmatch*. Such *quickmatch* is used for communicating fire in set pieces, Catherine wheels, etc.

has been inserted and fixed in place by a blob of paste of meal powder with gum-arabic water.

Aluminum and Magnesium Flares

When barium and strontium nitrates are used in colored lights, these substances serve the twofold purpose of coloring the flame and of supplying oxygen for its maintenance. The materials which combine with the oxygen to yield the flame, in the compositions which have been described, have been sulfur and carbonaceous matter. If, now, part or all of these materials is substituted by magnesium or aluminum powder or flakes, the resulting composition is one which burns with an intensely bright light. A mixture of potassium perchlorate 7 parts, mixed aluminum powder and flakes 5 parts, and powdered sulfur 2 parts burns with a brilliant light having a lilac cast. A balanced mixture of barium and strontium nitrates, that is, of green and red, gives a light which is practically white. Such lights are used in parade torches and signals, but are so bright as to be trying to the eyes. They find important use in aviation for signaling and for illuminating landing fields and military objectives.

Magnesium is attacked fairly rapidly by moisture, and pyrotechnic mixtures containing this metal do not keep well unless the particles of magnesium are first coated with a protecting layer of linseed oil or similar material. Aluminum does not have the same defect and is more widely used. An excellent magnesium light, suitable for illumination, is described in a patent recently granted to George J. Schladt.[22] It consists of a mixture of 36 to 40 per cent barium nitrate, 6 to 8 per cent strontium nitrate, 50 to 54 per cent flake magnesium coated with linseed oil, and 1 to 4 per cent of a mixture of linseed and castor oils.

The airplane wing-tip flares which were used for signaling during the first World War are good examples[23] of aluminum compositions. They were loaded in cylindrical paper cases 4¼ inches in length and 1⅝ inches in internal diameter. The white light composition consisted of 77 parts of barium nitrate, 13 of flake aluminum, and 5 of sulfur intimately mixed and secured by a binder of shellac, and burned in the cases mentioned, for 1

[22] U. S. Pat. 2,149,314, March 7, 1939.

[23] Faber, *op. cit.*, Vol. 2, pp. 223, 225-227.

minute with an illumination of 22,000 candlepower. The red light was made from 24 parts of strontium nitrate, 6 of flake aluminum, and 6 of sulfur with a shellac binder and burned for 1 minute with an illumination of 12,000 to 15,000 candlepower. The compositions were loaded into the cases by means of a pneumatic press, and filled them to within 5/16 inch of the top. The charge was then covered with a ⅛-inch layer of starting fire or *first fire composition,* made from saltpeter 6 parts, sulfur 4, and charcoal 1, dampened with a solution of shellac in alcohol, and this, when the device was used, was fired by an electric squib.

Lances

Lances are paper tubes, generally thin and of light construction, say, ¼ to ⅜ inch in diameter and 2 to 3½ inches long, filled with colored fire composition, loaded by tamping, not by ramming, and are used in set pieces, attached to wooden frameworks, to outline the figure of a temple or palace, to represent a flag, to spell words, etc. When set up, they are connected by quickmatch (black match in a paper tube) and are thus lighted as nearly simultaneously as may be. They are often charged in such manner as to burn with a succession of color, in which event the order of loading the various colors becomes important. Green should not be next to white, for there is not sufficient contrast. And green should not burn after red, for the color of the barium flame appears to one who has been watching the flame of strontium to be a light and uninteresting blue. The order of loading (the reverse of the order of burning) is generally white, blue (or yellow or violet, green, red, white. In the tables on page 70 a number of lance compositions are listed, illustrative of the various types and corresponding to considerable differences in cost of manufacture.

Picrate Compositions

Ammonium picrate is used in the so-called indoor fireworks which burn with but little smoke and without the production of objectionable odor. On page 71 some of the compositions recommended by Tessier[24] for Bengal lights are tabulated.

[24] *Op. cit.,* second edition, pp. 383-396.

WHITE	Potassium nitrate	33	5	9	8	11
	Antimony sulfide	5	..	2	..	1
	Antimony metal	..	1	..	..	3
	Realgar	..	..	..	1	..
	Sulfur	11	2	1	2	3
	Meal powder	2	1	..	..	..
RED	Potassium chlorate			10	6	36
	Strontium nitrate			..	..	54
	Strontium carbonate			3	2	..
	Sulfur			..	..	13
	Lampblack			..	..	2
	Shellac			2	..	12
	Paraffin			..	1	..
YELLOW	Potassium perchlorate		..	..	..	24
	Potassium chlorate		8	4	4	..
	Barium nitrate		1	..	22	..
	Sodium oxalate		..	2	..	8
	Sodium bicarbonate		2	..	..	..
	Cryolite		..	..	2	..
	Sulfur		4	..	5	..
	Lampblack		..	..	1	..
	Shellac		..	1	..	3
GREEN	Potassium chlorate		..	..	7	..
	Barium nitrate		12	4	7	..
	Barium chlorate		9	5	..	6
	Lampblack		1	..	..	..
	Shellac		10	1	2	1
BLUE	Potassium perchlorate			16	..	..
	Potassium chlorate			..	32	5
	Copper oxychloride			..	..	2
	Paris green			6	10	..
	Calomel			1	6	..
	Shellac			1	..	1
	Stearine			..	3	..
LILAC	Potassium chlorate					26
	Strontium sulfate					10
	Basic copper sulfate					6
	Lead nitrate					5
	Sulfur					4
	Shellac					1
	Stearine					1
VIOLET	Potassium chlorate					25
	Strontium sulfate					20
	Basic copper sulfate					1
	Sulfur					20

To be burned without compression, in the open, in trains or in heaps:

	Red		Green		Aurora	Yellow	White
Ammonium picrate	5	10	8	5	10	20	5
Strontium nitrate	25	40	..	..	31	12	..
Barium nitrate	..	..	32	25	..	58	30
Cryolite	..	..	..	..	3	7	..
Antimony metal	..	..	..	..	..	..	5
Lampblack	1	2	1	..	2	4	1
Paraffin	1	1	1	1	1	2	1

To be compressed in paper cartridges, 25-30 mm. internal diameter, to be burned in a horizontal position in order that the residue may not interfere with the burning:

	Red		Green			Aurora	Yellow		White	
Ammonium picrate	1	20	5	5	11	20	20	24	6	5
Strontium nitrate	1	60	..	..	..	60	10	3	..	..
Barium nitrate	..	..	6	28	36	..	60	20	4	30
Cryolite	..	..	..	..	..	7	7	4	..	..
Calcium fluoride	..	7	..	..	..	..	..	..	..	..
Antimony metal	..	..	..	..	..	..	..	..	..	4
Antimony sulfide	..	..	..	..	..	..	..	..	3	1
Lampblack	..	4	..	1	1	4	4	..	..	1
Paraffin	..	2	..	1	1	2	2	..	..	1

Picric acid added in small quantities to colors deepens them and increases their brilliancy without making them burn much faster. Stars containing picric acid ought not to be used in aerial shells, for they are likely to detonate either from the shock of setback or later from being ignited in a confined space. Mixtures which contain picric acid along with potassium chlorate or salts of heavy metals are liable to detonate from shock.

Weingart[25] lists two "smokeless tableau" fires which contain picric acid, as follows:

[25] *Op. cit.*, p. 60.

	Red	Green
Strontium nitrate	8	..
Barium nitrate	..	4
Picric acid	5	2
Charcoal	2	1
Shellac	1	..

The picric acid is to be dissolved in boiling water, the strontium or barium nitrate added, the mixture stirred until cold, and the solid matter collected and dried. The same author[26] gives picric acid compositions for stars, "not suitable for shells," as follows:

	Red		Green
Strontium nitrate	8	..	..
Strontium carbonate	..	3	..
Barium chlorate	..	..	12
Potassium chlorate	4	10	8
Picric acid	1.5	1.5	2
Calomel	..	..	6
Shellac	1.5	0.75	2
Fine charcoal	1	1	..
Lampblack	..	..	1.5
Dextrin	0.5	0.75	0.5

Picrate Whistles

An intimate mixture of finely powdered dry potassium picrate and potassium nitrate, in the proportion about 60/40, rammed tightly into paper, or better, bamboo tubes from ¼ to ¾ inch in diameter, burns with a loud whistling sound. The mixture is dangerous, exploding from shock, and cannot be used safely in aerial shells. Whistling rockets are made by attaching a tube of the mixture to the outside of the case in such manner that it burns, and whistles, during the flight—or by loading a small tube, say ¼ inch in diameter and 2½ inches long, into the head of the rocket to produce a whistle when the rocket bursts. The mixture

[26] *Op. cit.*, pp. 114, 115.

is used in whistling firecrackers, "musical salutes," "whistling whizzers," "whistling tornados," etc. The effect of a whistle as an accompaniment to a change in the appearance of a burning wheel is amusing. Whistles are perhaps most effective when six or eight of them, varying in size from the small to the large, are fired in series, the smallest caliber and the highest pitch being first.

Non-Picrate Whistles

Non-picrate whistles, made from a mixture of 1 part powdered gallic acid and 3 parts potassium chlorate, are considered to be safer than those which contain picrate. The mixture is charged into a ½-inch case, 5/16 inch in internal diameter. The case is loaded on a 1-inch spindle, and the finished whistle has a 1-inch length of empty tube which is necessary for the production of the sound. Whistles of this sort, with charges of a chlorate or perchlorate explosive at their ends, are used in "chasers," "whizzers," etc., which scoot along the ground while whistling and finally explode with a loud report.

Rockets

The principle of the rocket and the details of its design were worked out at an early date. Improvements have been in the methods of manufacture and in the development of more brilliant and more spectacular devices to load in the rocket head for display purposes. When rockets are made by hand, the present practice is still very much like that which is indicated by Figure 23. The paper casing is mounted on a spindle shaped to form the long conical cavity on the surface of which the propelling charge will start to burn. The composition is rammed into the space surrounding the spindle by means of perforated ram rods or *drifts* pounded by a mallet. The base of the rocket is no longer choked by crimping, but is choked by a perforated plug of clay. The clay, dried from water and moistened lightly with crankcase oil, is pounded or pressed into place, and forms a hard and stable mass. The tubular paper cases of rockets, *gerbs*,[27] etc., are now often made by machinery, and the compositions are loaded into them automatically or semi-automatically and pressed by hydraulic presses.

[27] Pronounced *jurbs*.

John Bate and Hanzelet Lorrain understood that the heavier rockets require compositions which burn more slowly.

> It is necessary to have compositions according to the greatness or the littleness of the rockets, for that which is proper for the little ones is too violent for the large—because the fire, being lighted in a large tube, lights a composition of great amplitude, and burns a great quantity of material,

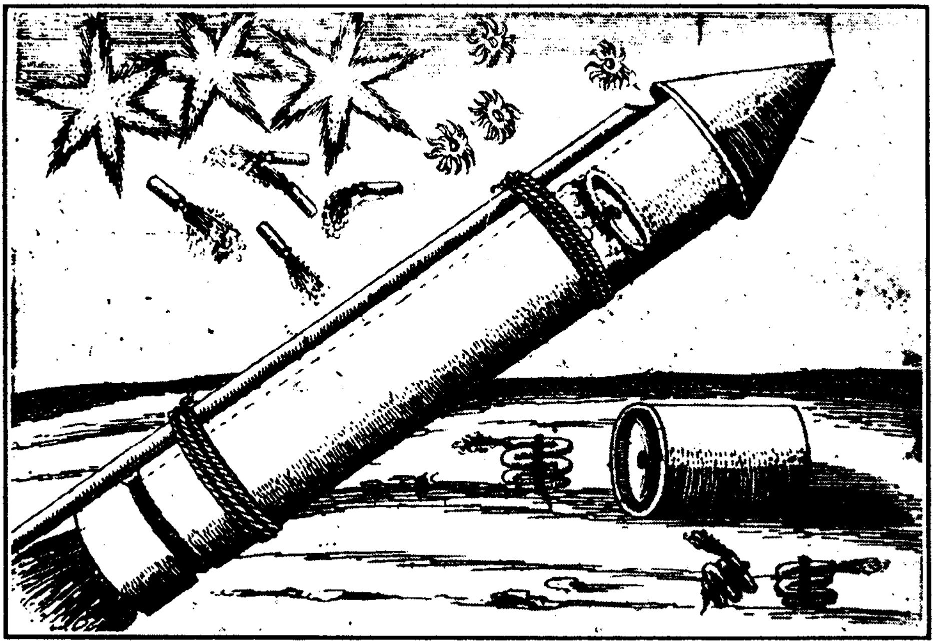

FIGURE 23. Rocket, Lorrain, 1630. Substantially as rockets are made today. After the propelling charge has burned completely and the rocket has reached the height of its flight, the fire reaches the charge in the head which bursts and throws out large and small stars, serpents and grasshoppers, or English firecrackers. The container, which is loaded into the head of the rocket, is shown separately with several grasshoppers in the lower right-hand corner of the picture.

> and no geometric proportionality applies. Rockets intended to contain an ounce or an ounce and a half should have the following for their compositions.
>
> Take of fine powder (gunpowder) passed through a screen or very fine sieve four ounces, of soft charcoal one ounce, and mix them well together.[28]
>
> *Otherwise.* Of powder sieved and screened as above one pound, of saltpeter one ounce and a half, of soft charcoal

[28] The charcoal makes the powder burn more slowly, and produces a trail of sparks when the rocket is fired.

one ounce and a half. It does not matter what charcoal it is; that of light wood is best, particularly of wood of the vine.

For rockets weighing two ounces. Take of the above-said powder four ounces and a half, of saltpeter one ounce.

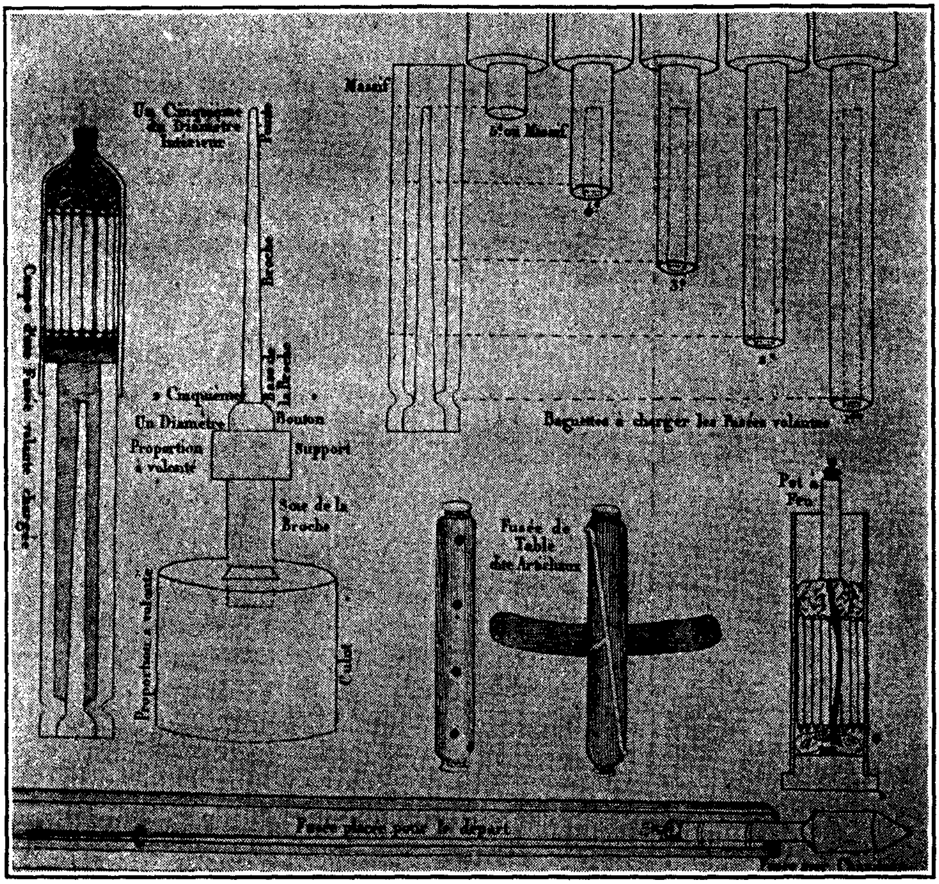

FIGURE 24. Details of Construction of Rocket and of Other Pieces, Audot, 1818. The rocket case, already crimped or constricted, is placed upon the spindle (*broche*); the first portion of the propelling charge is introduced and pounded firmly into place by means of a mallet and the longest of the *drifts* pictured in the upper right-hand corner; another portion of the charge is introduced, a shorter drift is used for tamping it, and so on until the case is charged as shown at the extreme left. A tourbillion (table rocket or artichoke) and a mine charged with serpents of fire are also shown.

Otherwise for the same weight. Take powder two ounces, of soft charcoal half an ounce.

Composition for rockets weighing from 4 to 8 ounces. Take powder as above seventeen ounces, of saltpeter four ounces, of soft charcoal four ounces.

Otherwise and very good. Of saltpeter ten ounces, of sulfur one ounce, of powder three ounces and a half, of charcoal three ounces and a half.

To make them go up more suddenly. Take of powder ten ounces, of saltpeter three ounces and a half, of sulfur one ounce, of charcoal three ounces and a half.

For rockets weighing one pound. Take of powder one pound, of soft charcoal two ounces, and of sulfur one ounce.

Otherwise. Of saltpeter one pound four ounces, of sulfur two ounces, of soft charcoal five ounces and a half.

For rockets weighing three pounds. Of saltpeter 30 ounces, of charcoal 11 ounces, of sulfur 7 ounces and a half.

For rockets weighing four, five, six, and seven pounds. Of soft charcoal ten pounds, of sulfur four pounds and a half, of saltpeter thirty one pounds.[29]

Present practice is illustrated by the specifications tabulated below for 1-ounce, 3-ounce, and 6-pound rockets as now manufactured by an American fireworks company. The diameter of

		Ounce	Ounce	Pound
Size		1	3	6
Composition of charge	Saltpeter	36	35	30
	Sulfur	6	5	5
	No. 3 charcoal	..	5	12
	No. 5 charcoal	12	..	..
	Charcoal dust	7	17	12
		Inch	Inch	Inch
Length of case		3	4 1/4	13
Outside diameter		1/2	11/16	2 3/8
Inside diameter		5/16	7/16	1 1/2
Overall length of spindle		2 3/4	4	12 3/4
Length of taper		2 1/2	3 23/32	12
Choke diameter		5/32	1/4	3/4

the base of the spindle is, of course, the same as the inside diameter of the case. That of the hemispherical tip of the spindle is half the diameter of the choke, that is, half the diameter of the hole in the clay plug at the base of the rocket. The clay rings and plugs, formed into position by high pressure, actually make grooves in the inner walls of the cases, and these grooves hold them in place against the pressures which arise when the rockets are used. The propelling charge is loaded in several successive small portions by successive pressings with hydraulic presses

[29] Lorrain, *op. cit.*, pp. 236-237.

which handle a gross of the 1-ounce or 3-ounce rockets at a time but only three of the 6-pound size. The presses exert a total pressure of 9 tons on the three spindles when the 6-pound rockets are being loaded.

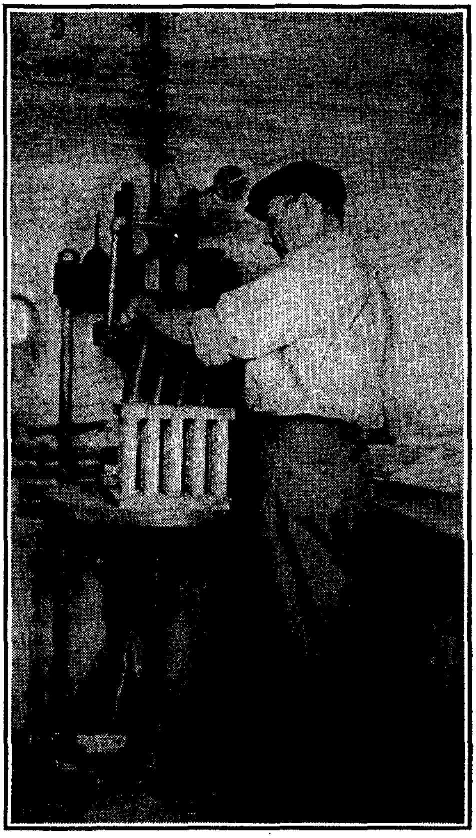

FIGURE 25. Loading Rockets by Means of an Hydraulic Press. (Courtesy National Fireworks Company.)

Rockets of the smaller sizes, for use as toys, are closed at the top with plugs of solid clay and are supplied with conical paper caps. They produce the spectacle only of a trail of sparks streaking skyward. Rockets are generally equipped with sticks to give them balance and direct their flight and are then fired from a trough or frame, but other rockets have recently come on the market which are equipped with vanes and are fired from a level surface while standing in a vertical position.

Large exhibition rockets are equipped with heads which contain stars of various kinds (see below), parachutes, crackers (see grasshoppers), serpents (compare Figure 23), and so on. In these, the clay plug which stands at the top of the rocket case is perforated, and directly below it there is a *heading* of composition which burns more slowly than the propelling charge. In a typical example this is made from a mixture of saltpeter 24 parts, sulfur 6, fine charcoal 4, willow charcoal dust 1½, and dextrin 2; it is loaded while slightly moist, pressed, and allowed to dry before the head of the rocket is loaded. When the rocket reaches the top of its flight, the heading burns through, and its fire, by means of several strands of black match which have been inserted in the perforation in the clay plug, passes into the head. The head is filled with a mixture, say, of gunpowder, Roman candle composition (see below), and stars. When the fire reaches this mixture, the head blows open with a shower of sparks, and the stars, which have become ignited, fall through the air, producing their own specialized effects.

In another example, the head may contain a charge of gunpowder and a silk or paper parachute carrying a flare or a festoon of lights or colored *twinklers*, the arrangement being such that the powder blows the wooden head from the rocket, ejects the parachute, and sets fire to the display material which it carries. In order that the fire may not touch the parachute, the materials which are to receive the fire (by match from the bursting charge) are packed softly in cotton wool and the remaining space is rammed with bran.

The very beautiful liquid fire effect is produced by equipment which is fully assembled only at the moment when it is to be used. The perforation in the clay plug at the top of the rocket is filled with gunpowder, and this is covered with a layer of waterproof cloth well sealed, separating it from the space in the empty head. When the piece is to be fired, the pyrotechnist, having at hand a can containing sticks of yellow phosphorus preserved under water, removes the wooden head from the rocket, empties the water from the can of phosphorus, and dumps the phosphorus, still wet, into the head case, replaces the wooden head, and fires. The explosion of the gunpowder at the top of the rocket's flight tears through the layer of waterproof cloth, ignites the phosphorus, blows off the wooden head, and throws out the liquid fire. A similar effect, with a yellow light, is obtained with metallic sodium.

Roman Candles

Roman candles are repeating guns which shoot projectiles of colored fire and send out showers of glowing sparks between the shots. To the pyrotechnists of the seventeenth century they were known as "star pumps" or "pumps with stars."

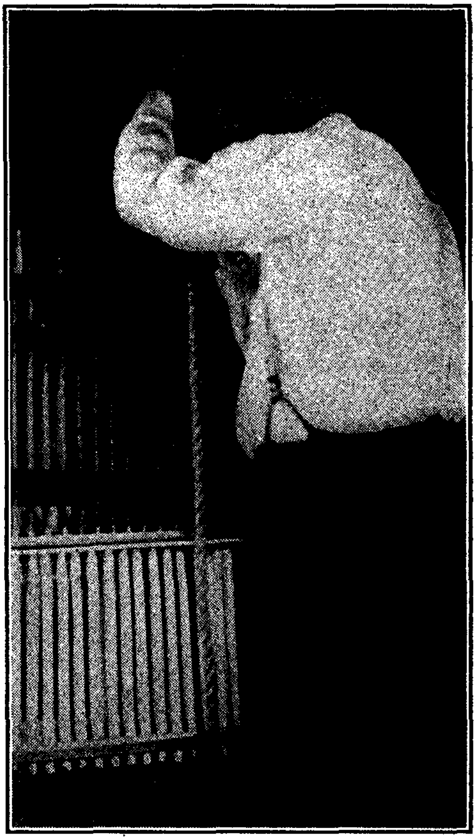

FIGURE 26. Ramming Roman Candles. (Courtesy National Fireworks Company.)

For the manufacture of Roman candles, gunpowder and stars and a modified black powder mixture which is known as Roman candle composition, or *candle comp*, are necessary. The candle comp is made from:

	PARTS	
Saltpeter	34	(200 mesh)
Sulfur	7	(200 mesh)
No. 4 Charcoal (hardwood)	15	(about 24 mesh)
No. 3 Charcoal (hardwood)	3	(about 16 mesh)
No. 2 Charcoal (hardwood)	3	(about 12 mesh)
Dextrin	1	

The materials are mixed thoroughly, then moistened slightly and rubbed for intimate mixture through a 10-mesh sieve, dried quickly in shallow trays, and sifted through a 10-mesh sieve.

FIGURE 27. Matching a Battery of 10 Ball Roman Candles. (Courtesy National Fireworks Company and the *Boston Globe*.)

Candle comp burns more slowly than black powder and gives luminous sparks. The case is a long, narrow, strong tube of paper plugged at the bottom with clay. Next to the clay is a small quantity of gunpowder (4F); on top of this is a star; and on top of this a layer of candle comp. The star is of such size that it does not fit the tube tightly. It rests upon the gunpowder, and the space between the star and the wall of the tube is partly filled with candle comp. When the three materials have been introduced, they are rammed tightly into place. Then gunpowder, a star, and candle comp again are loaded into the tube and rammed down, and so on until the tube is charged. Damp candle comp, with a piece of black match leading to it and into it, is loaded at the top, pressed tightly into place, and allowed to dry. When a Roman candle is lighted, the candle comp begins to burn and to throw out a fountain of sparks. The fire soon reaches the star, ignites it, and flashes along the side of the star to light the gunpowder which blows the burning star, like a projectile, out of the tube.

Stars

Stars are pellets of combustible material. Those which contain neither aluminum nor magnesium nor Paris green have nothing in their appearance to suggest even remotely the magic which is in them. They are, however, the principal cause of the beauty of aerial pyrotechnic displays.

The components of star composition are mixed intimately and dampened uniformly with some solution which contains a binder, perhaps with gum-arabic water, perhaps with water alone if the composition contains dextrin, perhaps with alcohol if it contains shellac. Several different methods are used for forming the stars.

To make *cut stars,* the damp mixture is spread out in a shallow pan, pressed down evenly, cut into cubes, say ¼ to ¾ inch on the side, allowed to dry, and broken apart. Because of their corners, cut stars take fire very readily and are well suited for use in rockets and small aerial bombshells. Cylindrical stars are preferred for Roman candles.

For the preparation of a small number of stars, a *star pump* is a convenient instrument. This consists of a brass tube with a plunger which slides within it. The plunger has a handle and, on its side, a peg which works within a slot in the side of the tube—in such manner that it may be fixed in position to leave at the open end of the tube a space equal to the size of the star which it is desired to make. This space is then tightly packed with the damp mixture; the plunger is turned so that the peg may move through the longitudinal slot, and the handle is pushed to eject the star.

For large-scale production, a *star plate* or *star mold* assembly is best. This consists of three flat rectangular plates of hard wood or metal, preferably aluminum. One has a perfectly smooth surface. The second, which rests upon this, has many circular holes of the size of the stars which are desired. The damp mixture is dumped upon this plate, rubbed, pressed, and packed into the holes, and the surface of the plate is then wiped clean. The third

FIGURE 28. A Star Plate or Star Board in Use. (Courtesy National Fireworks Company.)

plate is supplied with pegs, corresponding in number and position to the holes of the second plate, the pegs being slightly narrower than the holes and slightly longer than their depth. The second plate is now placed above a tray into which the stars may fall, and the stars are pushed out by putting the pegged plate upon it. In certain conditions it may be possible to dispense with the pegged plate and to push out the stars by means of a roller of soft crêpe rubber.

Box stars are less likely to crumble from shock, and are accordingly used in large aerial bombshells. They are also used for festoons and for other aerial tableaux effects. Short pieces of

4-ply manila paper tubing, say ¾ inch long and ½ inch in diameter, are taken; pieces of black match long enough to protrude from both ends of the tubes are inserted and held in this position by the fingers while the tubes are pressed full of the damp composition. Box stars require a longer drying than those which are not covered.

White stars, except some of those which contain aluminum, are generally made with potassium nitrate as the oxidizing agent. Various white star compositions are tabulated below. The last three are for white *electric stars*. The last formula, containing perchlorate, was communicated by Allen F. Clark.

Potassium nitrate	70	28	180	20	42	14	28	..
Potassium perchlorate	..	..	..	..	..	..	..	30
Barium nitrate	..	..	..	..	..	..	..	5
Aluminum	..	..	..	..	..	3	5	22
Antimony sulfide	20	..	10	..	..	3	7	..
Antimony metal	..	5	40	..	..	..	..	..
Zinc dust	..	..	..	..	6	..	..	..
Realgar	..	..	..	6	6	..	..	..
Meal powder	..	..	..	..	12	6	3	..
Sulfur	20	8	50	6	23	..	8	..
Charcoal dust	..	..	3	..	..	..	..	..
Dextrin	3	1	6	1	..	1	1	..
Shellac	..	..	..	..	..	..	..	3

Stars which contain aluminum are known as electric stars because of the dazzling brilliancy of their light, which resembles that of an electric arc. Stars which contain chlorate and sulfur or antimony sulfide or arsenic sulfide or picric acid are dangerous to mix, likely to explode if subjected to too sudden shock, and unsafe for use in shells. They are used in rockets and Roman candles. Perchlorate compositions, and chlorate compositions without sulfur, sulfides, and picric acid, will tolerate considerable shock and are used in aerial bombshells.

The following star compositions which contain both chlorate and sulfur are among those recommended by Tessier.[30] Mixtures which contain chlorate and sulfur have a tendency to "sour" with the production of sulfuric acid after they have been wetted,

[30] *Op. cit.*, pp. 338, 343, 344, 345, 347, 349.

and to deteriorate, but the difficulty may be remedied by the addition of an anti-acid, and some of these compositions do in-

FIGURE 29. Aluminum Stars from a Single Rocket.

deed contain carbonates or basic salts which act in that capacity. Tessier recommends that the mixtures be made up while dampened with small quantities of 35 per cent alcohol.

	Red	Lilac	Lilac Mauve	Violet	Blue	Green
Potassium chlorate	167	17	17	56	24	48
Strontium carbonate	54	9	9	..	..	..
Strontium sulfate	..	..	..	16	..	..
Barium nitrate	..	..	..	..	..	80
Copper oxychloride	..	2	4	..	..	..
Basic copper sulfate	..	..	..	8	12	..
Lead chloride	..	1	1	3	2	10
Charcoal dust (poplar)	..	..	..	3	..	..
Sulfur	35	7	7	20	8	26
Dextrin	7	1	1	3	1	3
Shellac	16	..	..	..	..	2
Lampblack	..	..	..	..	..	2

Weingart[31] reports compositions for cut, pumped, or candle stars which contain chlorate but no sulfur or sulfides, as follows:

	Red		Blue	Green	Yellow	
Potassium chlorate	12	48	48	12	32	16
Strontium nitrate	12	..	..	..	..	..
Strontium carbonate	..	8	..	..	..	..
Barium nitrate	..	..	16	12	12	..
Paris green	..	..	18	..	..	..
Calomel	..	..	..	1	..	..
Sodium oxalate	..	..	..	..	2	7
Fine charcoal	4	8	..	4	8	1
Dextrin	1	3	3	1	3	1
Shellac	2	6	10	2	6	3

For the following perchlorate star formulas the author is indebted to Allen F. Clark.

	Rose	Amber	Green		Violet	
Potassium perchlorate	12	10	..	44	12	41
Potassium nitrate	6	..	..	..	..	..
Barium perchlorate	..	..	32	90	..	..
Calcium carbonate	..	..	..	..	..	12
Strontium oxalate	1	..	..	..	9	3
Copper oxalate	..	..	..	..	5	..
Sodium oxalate	..	4	..	..	..	..
Calomel	..	..	..	..	..	3
Sulfur	..	..	..	..	..	14
Lampblack	1	..	..	..	..	..
Dextrin	1	..	..	6	..	..
Shellac	..	2	3	15	3	..

Illustrative of electric star compositions are the following; those which contain potassium chlorate are reported by Faber,[32] the others, containing perchlorate, were communicated by Allen

[31] *Op. cit.*, p. 114.
[32] *Op. cit.*, Vol. 1, p. 188.

	Red		Gold	Green			Blue	
Potassium perchlorate	..	12	..	..	..	6	..	14
Potassium chlorate	24	..	6	8	..	..	32	..
Barium perchlorate	..	..	..	..	12	12	..	..
Barium chlorate	..	..	4	16	..	..	..	..
Barium nitrate	..	..	..	16	..	..	..	..
Strontium chlorate	..	3	..	..	..	..	..	..
Strontium carbonate	4	..	..	..	..	..	..	..
Aluminum	8	3	4	12	5	8	8	6
Sodium oxalate	..	..	2	..	..	..	..	..
Calcium carbonate	..	..	..	..	..	..	..	1
Magnesium carbonate	..	..	1	..	..	..	..	..
Paris green	..	..	..	..	..	..	16	10
Calomel	..	..	..	..	..	..	..	2
Fine charcoal	1	..	..	3	..	..	..	..
Dextrin	2	1	..	2	..	1	2	1
Red gum	..	..	..	4	..	..	..	..
Shellac	2	1	2	..	1	2	1	2

F. Clark. The last-named authority has also supplied two formulas for magnesium stars. The compositions are mixed while

	Amber	Green
Potassium perchlorate	4	..
Barium perchlorate	..	12
Magnesium	1	2
Sodium oxalate	2	..
Lycopodium powder	..	1
Shellac	1	2

dampened with alcohol which insures that the particles of magnesium are covered with a protective layer of shellac.

Lampblack stars burn with a rather dull soft light. Discharged in large number from a rocket or aerial shell, they produce the beautiful willow-tree effect. They are made, according to Allen F. Clark, by incorporating 3 pounds of lampblack, 4 pounds of meal powder, and ½ pound of finely powdered antimony sulfide with 2 ounces of shellac dissolved in alcohol.

Stars compounded out of what is essentially a modified black powder mixture, given a yellowish or whitish color by the addition of appropriate materials, and used in rockets and shells in the same manner as lampblack stars, produce *gold* and *silver showers*, or, if the stars are larger and fewer in number, *gold* and *silver streamers*. The following formulas are typical.

	Gold	Silver
Potassium nitrate	16	10
Charcoal	1	2
Sulfur	4	3
Realgar	..	3
Sodium oxalate	8	..
Red gum	1	1

Twinklers are stars which, when they fall through the air, burn brightly and dully by turns. A shower of twinklers produces an extraordinary effect. Weingart in a recent letter has kindly sent the following formula for yellow twinklers:

Meal powder	24
Sodium oxalate	4
Antimony sulfide	3
Powdered aluminum	3
Dextrin	1

The materials are mixed intimately while dampened with water, and the mixture is pumped into stars about ¾ inch in diameter and ⅞ inch long. The stars are dried promptly. They function only when falling through the air. If lighted on the ground they merely smolder, but when fired from rockets or shells are most effective.

Spreader stars contain nearly two-thirds of their weight of powdered zinc. The remaining one-third consists of material necessary to maintain an active combustion. When they are ignited, these stars burn brightly and throw off masses of burning zinc (greenish white flame) often to a distance of several feet. Weingart[33] gives the two following formulas for spreader stars, the first for "electric spreader stars," the second for "granite stars," so called because of their appearance.

[33] *Op. cit.*, p. 118.

Zinc dust	72	80
Potassium nitrate	..	28
Potassium chlorate	15	..
Potassium dichromate	12	..
Granulated charcoal	12	..
Fine charcoal	..	14
Sulfur	..	5
Dextrin	2	2

The first of these formulas is the more difficult to mix and the more expensive. All its components except the charcoal are first

FIGURE 30. Spreader Stars from a Battery of Rockets.

mixed and dampened; the granulated charcoal, which must be free from dust, is then mixed in, and the stars are formed with a pump. They throw off two kinds of fire when they burn, masses of brightly burning zinc and particles of glowing charcoal. Weingart recommends that the second formula be made into cut stars ⅜ inch on the side. Spreader stars because of the zinc which they contain are much heavier than other stars. Rockets and aerial bombs cannot carry as many of them.

Gerbs

Gerbs produce jets of ornamental and brilliant fire and are used in set pieces. They are rammed or pressed like rockets, on a short nipple instead of a long spindle, and have only a slight depression within the choke, not a long central cavity. They are choked to about one-third the diameter of the tube. The simplest gerbs contain only a modified black powder mixture, say meal powder 4 parts, saltpeter 2, sulfur 1, and charcoal dust 1 or mixed charcoal 2; and are used occasionally for contrast in elaborate set pieces. Similar composition is used for the starting fire of steel gerbs which are more difficult to ignite. If antimony sulfide is used in place of charcoal, as in the mixtures:

Meal powder	2	3
Saltpeter	8	8
Sulfur	3	4
Antimony sulfide	1	2

the gerbs yield compact whitish flames and are used in star and floral designs. Gold gerbs appropriately arranged produce the sunburst effect. Colored gerbs are made by adding small cut stars. In loading the tube, a scoopful of composition is introduced and rammed down, then a few stars, then more composition which is rammed down, and so on. Care must be exercised that no stars containing chlorate are used with compositions which contain sulfur, for an explosion might occur when the charge is rammed. The following compositions are typical. The steel filings

	Steel		Colored Steel	Gold	Colored Gold
Meal powder	6	4	8	40	40
Potassium nitrate	2	..	7	..	..
Sulfur	1	..	..	..	..
Fine charcoal	1	1	2	..	..
Steel filings	1	2	5	..	..
Stars	..	..	5	..	5
Sodium oxalate	..	..	..	6	6
Antimony sulfide	..	..	..	8	9
Aluminum	..	..	..	4	..
Dextrin	..	..	..	..	4

must be protected from rusting by previous treatment with paraffin or linseed oil.

Prismatic fountains, floral bouquets, etc., are essentially colored gerbs. Flower pots are supplied with wooden handles and generally contain a modified black powder composition with lampblack and sometimes with a small amount of granulated black powder. In the charging of fountains and gerbs, a small charge of gunpowder is often introduced first, next to the clay plug which closes the bottom of the tube and before the first scoopful of composition which is rammed or pressed. This makes them finish with a report or *bounce.*

Fountains

Fountains are designed to stand upon the ground, either upon a flat base or upon a pointed wooden stick. They are choked slightly more than gerbs, and have heavier, stronger cases to withstand the greater pressures which eject the fire to greater distances.

The "Giant Steel Fountain" of Allen F. Clark is charged with a mixture of saltpeter 5 parts (200 mesh), cast-iron turnings 1 part (8 to 40 mesh), and red gum 1 part (180 to 200 mesh). For loading, the mixture is dampened with 50 per cent alcohol. The case is a strong paper tube, 20 inches long, 4 inches in external diameter, with walls 1 inch thick, made from Bird's hardware paper. It is rolled on a machine lathe, the paper being passed first through a heavy solution of dextrin and the excess of the gum scraped off. The bottom of the case is closed with a 3-inch plug of clay. The composition will stand tremendous pressures without exploding, and it is loaded very solidly in order that it may stay in place when the piece is burned. The charge is rammed in with a wooden rammer actuated by short blows, as heavy as the case will stand, from a 15-pound sledge. The top is closed with a 3-inch clay plug. A ⅞-inch hole is then bored with an auger in the center of the top, and the hole is continued into the charge to a total depth of 10 inches. The composition is difficult to light, but the ignition is accomplished by a bundle of six strands of black match inserted to the full depth of the cavity and tied into place. This artifice produces a column of scintillating fire, 100 feet or more in height, of the general shape of a red cedar tree. It develops considerable sound, and ends suddenly with a terrifying roar at the moment of its maximum splendor. If loaded at the hydraulic press with a tapered spindle (as is necessary), it finishes its burning with a fountain which grows smaller and smaller and finally fades out entirely.

Wheels

Driving tubes or *drivers*, attached to the periphery of a wheel or to the sides of a square or hexagon of wood which is pivoted

FIGURE 31. Matching Display Wheels. (Courtesy National Fireworks Company and the *Boston Globe*.)

at its center, by shooting out jets of fire, cause the device to rotate and to produce various ornamental effects according to the compositions with which they are loaded. When the fire reaches the bottom of one driver, it is carried by quickmatch to the top of the next. Drivers are loaded in the same manner as gerbs, the compositions being varied slightly according to the size as is done with rockets. A gross of the 1-ounce and 2-ounce sizes in present American practice is loaded at one time by the hydraulic press. Typical wheel turning compositions (Allen F. Clark) for use in 1-ounce and 2-ounce drivers are reported below, the first for a *charcoal spark effect*, the second for an *iron and steel effect*. The speed of the mixtures may be increased by increasing the proportion of gunpowder.

Saltpeter (210 mesh)	10	46
Sulfur (200 mesh)	2	19
Meal powder	6	..
Charcoal dust	..	16
Charcoal (80 mesh)	1	..
6F gunpowder	6	..
7F gunpowder	..	24
Cast-iron turnings (16 mesh)	..	30
Dextrin	..	8

Wheels, gerbs, and colored fires are the parts out of which such display pieces as the "Corona Cluster," "Sparkling Caprice," "Flying Dutchman," "Morning Glory," "Cuban Dragon," "Blazing Sun," and innumerable others are constructed.

Saxons

Saxons are strong paper tubes, plugged with clay at their middles and at both ends, and filled between the plugs with composition similar to that used in drivers. A lateral hole is bored through the middle of the tube and through the central clay plug, and it is around a nail, passed through this hole and driven into a convenient support, that the artifice rotates. Other holes, at right angles to this one, are bored from opposite sides near the ends of the tube, just under the end plugs, through one wall of the tube and into the composition but not through it. A piece of black match in one of these holes ignites the composition. The hot gases, sparks, etc., rushing from the hole cause the device to turn upon its pivot. When the fire reaches the bottom of the charge, it lights a piece of quickmatch, previously connected through a hole at that point and glued to the outside of the case, which carries the fire to the other half of the saxon.

Saxons are generally matched as described, the two halves burning consecutively and rotating it in the same direction. Sometimes they burn simultaneously, and sometimes one half turns it in one direction and the other afterwards "causes the rapid spinning to reverse amid a mad burst of sparks." This effect "is very pleasing and is considered one of the best to be obtained for so small an expenditure."

Pinwheels

To make pinwheels, manila or kraft paper tubes or *pipes*, about 12 inches long and 3/16 inch in diameter, are needed. One end is closed by twisting or folding over. The tubes are filled with composition, the other ends are closed in the same way, and the tubes are wrapped in a moist towel and set aside until they are thoroughly flabby. In this condition they are passed between rollers and flattened to the desired extent. Each tube is then wound in an even spiral around the edge of a cardboard disc which has a hole in its center for the pin, and the whole is placed in a frame which prevents it from uncoiling. Four drops of glue, at the four quarters of the circle, are then brushed on, across the pipes and onto the center disc, and the device is allowed to dry.

Weingart[34] recommends for pinwheels the compositions which are indicated below. The first of these produces both steel and

Meal powder	..	10	8	2
Gunpowder (fine)	8	5	8	..
Aluminum	..	..	3	..
Saltpeter	14	4	16	1
Steel filings	6	6	..	..
Sulfur	4	1	3	1
Charcoal	3	1	8	..

charcoal effects, the second steel with much less of the charcoal, the third aluminum and charcoal, and the fourth a circle merely of lilac-colored fire.

Tessier thought highly of pinwheels (*pastilles*). They were, he says,[35]

> formerly among the artifices which were called *table fireworks*, the use of which has wholly fallen away since the immense apartments have disappeared which alone provided places where these little pyrotechnic pieces might be burned without too much inconvenience.
>
> The manner of use of these pastilles calls only for small calibers; also their small dimensions make it possible to turn them out at a low price, and the fireworks makers have always continued to make them the object of current manufacture. But what they have neglected, they still neglect: and that is, to seek to bring them to perfection. Those that

[34] *Op. cit.*, p. 98.
[35] *Op. cit.*, p. 393.

they confine themselves to making serve only for the amusement of children.

However, pastilles may become charming pieces of fireworks, fit to refresh all eyes. They can be made to produce

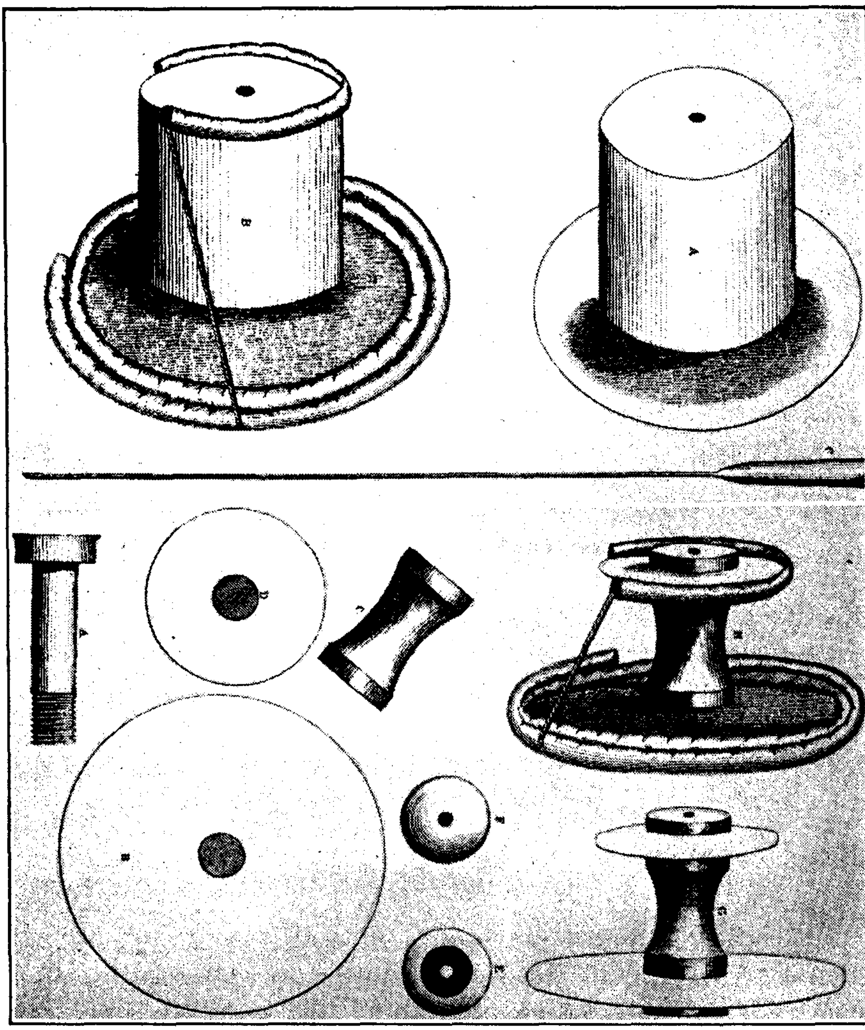

FIGURE 32. Pinwheels, Tessier, 1883. Wheels which show an inner circle of colored fire. Plate 1 (above) pictures pinwheels which are intended to be sold as completely consumable. The instrument represented at the bottom of the plate is the ramrod for tamping the charges in the pipes. Plate 2 (below) represents pinwheels which are intended to be exhibited by the pyrotechnist himself: the wooden parts are to be recovered and used again.

truly marvellous effects, considering the conditions imposed by their size, effects all the more remarkable in as much as, by the very reason of these same conditions, they have no need of a vast theater in which to be fired. The least little garden suffices for them. They burn under the very eye of the spectator, who loses nothing of their splendor, whereas, in general, large pieces of fireworks can be enjoyed only at a distance from the place of firing. Finally, they have over these last the advantage of their low price and the advantage that they can be transported without embarrassment and set in place at the moment of being fired.

Tessier describes ordinary pastilles, diamond pastilles, and pastilles with colored fires. The shorter and more central tubes (Figure 32), wound part way around discs 40 mm. in diameter, hold the colored fire compositions. The longer tubes, forming the larger circles around discs 72 mm. in diameter, are the turning tubes. The latter, it will be seen, are so arranged that they burn for a time before the fire reaches the colored compositions. "The charging of the tubes is commenced, up to a height of about 17 cms., with the four compositions, Nos. 142, 126, 128, and 129, in the order named. The rest of the tube is charged entirely with composition No. 149, or with No. 152, both of which produce scintillating aureoles."[36] The charges are tamped tightly in the tubes by means of a long, thin ramrod and mallet. The compositions in question, designated by Tessier's own numbers, are indicated below.

	142	126	128	129	149	152
Meal powder	16	16	16	32	..	..
Potassium nitrate	1	1	1	4	..	..
Oak charcoal	1	..	..	..	..	..
Litharge	..	2	..	..	..	..
Powdered mica	..	..	2	..	..	..
Antimony sulfide	..	..	..	5	..	..
Plumbic powder No. 1	..	..	..	..	17	17
Cast-iron filings	..	..	..	..	3	..
Steel wool	..	..	..	..	..	3

No. 142 is a composition for ordinary pastilles. Tessier says that it produces "numerous sparks forming a feeble aureole. As this composition is not lively, and as it is not able to make the

[36] *Ibid.*, p. 419.

pastilles turn conveniently, care is taken not to load more of it than a length of 15 mm. in the tube."[37]

Nos. 126, 128, and 129 are also for ordinary pastilles. No. 126 "has not much force; it is incapable alone of making a pastille turn with the necessary rapidity. Hence care is taken in charging it to introduce only a small quantity into the tube." It burns with a white flame "forming a crown, more or less lacy-edged, from which rays and sparks are thrown out."[38]

The two compositions, Nos. 142 and 126, evidently burn while the pastille is turning from the initial twirl given it by the hand. When the fire reaches the next composition, No. 128, the pastille accelerates by its own power. This gives "reddish rays, very straight and very numerous," and No. 129 gives "a white flame around the disc, and numerous and persistent sparks which fall down forming a sort of cascade on each side of the pastille."[39]

Neither No. 128 nor 129 is bright enough to make much of a show if the colored fire is also burning. When they burn to an end, the fire is communicated to the colored composition; at the same time the bright diamond composition, either No. 149 or 152, commences to burn. No. 149 produces "a splendid aureole of silver-white flowers. These flowers are less developed than those produced by steel wool and make a different effect from the latter."[40] No. 152 produces a "splendid effect—no inflamed disc, no reddish sparks—numerous jasmine flowers of all dimensions forming a vast aureole of a striking white."[41]

Plumbic powder No. 1 is made from lead nitrate 12 parts, potassium nitrate 2 parts, and black alder charcoal 3 parts.[42] The materials are powdered and mixed, and then rolled in a wooden ball-mill with balls of hard lead (Pb 5, Sb 1) or brass or bronze.

Tessier[43] gives credit to the earlier French pyrotechnist, Chertier, for the introduction into pyrotechny of lead nitrate (which had been used before his time only for the preparation of slow-

[37] *Ibid.*, p. 408.
[38] *Ibid.*, p. 403.
[39] *Ibid.*, p. 404.
[40] *Ibid.*, p. 411.
[41] *Ibid.*, p. 412.
[42] *Ibid.*, p. 281.
[43] *Op. cit.*, p. 118.

match or fire wick), for the invention[44] of plumbic powder by which a silver shower (*pluie d'argent*) is produced, and for originating[45] the idea of the diamond pastille with colored fires which Chertier called the *dahlia pastille* but for the making of which he did not give precise directions.

Mines

Mines are paper mortars—commonly strong paper tubes each standing vertically on a wooden base into which it is countersunk and glued—arranged to throw into the air a display of stars, serpents, etc. They are often equipped with fountains, Roman candles, etc., which make a display on the ground before the final explosion occurs.

A *serpent mine* (*pot à feu*) is represented in Figure 24. This starts with a steel fountain. When the fire has reached the bottom of the fountain, it is carried by quickmatch to a charge of gunpowder in the paper bag, *a*. Immediately above the paper bag are the serpents. These are small paper tubes, rammed with a mixture of meal powder, gunpowder, saltpeter, sulfur, and mixed charcoal, crimped or plugged with clay at one end, supplied with match (as in the diagram) or merely left open-ended at the other. The lower, matched or open, ends of the serpents take fire from the burning of the gunpowder, which also blows them into the air where they dart and squirm about like little tailless rockets leaving a trail of sparks. In Audot's diagram, directly below the fountain and above the closed ends of the serpents, is a mass of wadding. This tends to offer a slight resistance to the force of the gunpowder, with the result that the serpents receive the fire more surely and are shot farther into the air before they begin to go their several ways.

Saucissons are constructed in the same way as serpents, but are larger, and have, next to the closed end, a small charge of gunpowder which makes them end with a bang. They are used in mines and in rockets.

Mines which discharge serpents, stars, English crackers, etc., are often made by loading these materials into the same paper bags which contain the blowing charges of granulated gunpowder. About two level teaspoonfuls of blowing powder is used

[44] *Ibid.*, p. 281.
[45] *Ibid.*, p. 414.

per ounce of stars. For making the bags, a board is taken which has had holes bored into it slightly smaller than the internal diameter of the mine case and of a depth suited to the caliber of the mine. A disc of tissue paper is placed over a hole and then punched down into it by a wooden punch or rod with slightly rounded edges which fits rather loosely in the hole. This makes a paper cup into which one end of the fuse is inserted, and around it the stars and blowing charge. The edges of the paper cup are then gathered together and tied with string or wire.

Mines are often made up with a single Roman candle, lacking the plug of clay at the bottom, mounted in the center of the mine case. The fuse leading from the charge in the paper bag is thrust into the bottom of the Roman candle. A mine with a large and short case, carrying a charge of tailed stars, serpents, and English crackers, and having one Roman candle in its center and four others, matched to burn simultaneously, attached to the outside of the case, is known as a *devil among the tailors.*

Comets and Meteors

These are virtually mines which shoot a single large star. A pumped star 1½ inches in diameter is fired, for example, from a tube or mortar 10 inches long and 1¾ inches in internal diameter. A piece of quickmatch (wrapped black match) about 6 inches longer than the mortar is taken; an inch of black match is made bare at one end, bent at right angles, and laid against the base of the star; and the star, with the quickmatch lying along its side, is then enclosed in the middle of a paper cylinder by wrapping a strip, say 4 inches wide, of pasted tissue paper around it. A half teaspoonful of granulated black powder is put into the cup thus formed on the (bottom) side of the star where the black match has been exposed, and the edges of the paper cylinder are brought together over it and tied. The other (upper) end of the paper cylinder is similarly tied around the quickmatch. In using this piece, and in using all others which are lighted by quickmatch, care must be taken that a few inches of the quickmatch have been opened and the black match exposed, before the fire is set to it; otherwise it will be impossible to get away quickly enough. This, of course, is already done in pieces which are offered for public sale.

Comets burn with a charcoal or lampblack effect, meteors with an electric one. The two comet star compositions given below are due to Weingart;[46] that of the green meteor to Allen F. Clark.

	Comets		Green Meteor
Potassium nitrate	6	..	..
Barium perchlorate	..	..	4
Barium nitrate	..	..	2
Meal powder	6	3	..
Sulfur	1	..	..
Fine charcoal	3	1	..
Antimony sulfide	3	1	..
Lampblack	..	2	..
Aluminum	..	..	1
Dextrin	..	..	1

Some manufacturers apply the name of meteors to artifices which are essentially large Roman candles, mounted on wooden bases and shooting four, six, eight, and ten stars 1½ inches in diameter. They are loaded in the same way as Roman candles except that a special device is used to insure the certain ignition of the stars. Two pieces of black match at right angles to each other are placed under the bottom of the star; the four ends are turned up along the sides of the star and are cut off even with the top of it. The match being held in this position, the star is inserted into the top of the case and pushed down with a rammer onto the propelling charge of gunpowder which has already been introduced. Then coarse candle comp is put in, then gunpowder, then another star in the same manner, and so on. The black match at the side of the star keeps a space open between the star and the walls of the tube, which space is only partly or loosely filled with candle comp. The black match acts as a quickmatch, insuring the early ignition of the propelling charge as well as the sure ignition of the star. Electric stars, spreader stars, and *splitters* are used in meteors. Splitter stars are made from the same composition as snowball sparklers (see below); the composition for stars, however, is moistened with much less water than for sparklers. They split into bright fragments while shooting upward and burst at the top to produce a palm-tree effect.

[46] *Op. cit.*, p. 121

Bombshells

Bombshells are shot from mortars by means of a charge of black powder and burst high in the air with the production of reports, flashes, showers, and other spectacular effects. The smaller ones are shot from paper mortars; the larger, most commonly from mortars of iron. In the past they have often been made in a spherical shape, wood or paper or metal hemispheres pasted heavily over with paper, but now in this country they are made almost exclusively in the form of cylinders. For the same caliber, cylindrical bombshells will hold more stars or other display material than spherical ones, and it is much easier to contrive them in a manner to procure multiple bursts. The materials of construction are paper, paste, and string. The shells are supplied with *Roman fuses* timed to cause them to burst at the top of their flight. The success and safety of bombshells depend upon carefully constructed fuses.

Roman fuses are made by pounding the fuse powder as firmly as is possible into hard, strong, tightly rolled paper tubes. These are commonly made from Bird's hardware paper, pasted all over before it is rolled, and are dried carefully and thoroughly before they are loaded with ramrod and mallet. "When a number of these cases are rolled," says Weingart,[47] "they must be dried in the shade until they are as hard as wood and rattle when struck together." He recommends the first of the following-listed compositions, the Vergnauds the others:[48]

Potassium nitrate	2	4	2
Sulfur	1	2	1
Meal powder	4	6	3
Antimony sulfide	..	1	..

The length of the column of composition determines the duration of the burning. The composition in the fuse must be as hard and as firmly packed as possible; otherwise it will blow through into the shell when in use and will cause a premature explosion. Some manufacturers load the tubes and cut them afterwards with a fine-tooth hack saw. Others prefer to cut them to the desired lengths with a sharp knife while they are prevented from collapsing by a brass rod through them, and afterwards to load

[47] *Ibid.*, p. 130.

[48] A. D. and P. Vergnaud, "Nouveau manuel complet de l'artificier. Pyrotechnie civile." (Ed., G. Petit) (Manuels Roret), Paris, 1906.

the short pieces separately. Different size tubes are often used for the fuses of different size shells; those for a 4-inch shell (that is, for a shell to be shot from a 4-inch mortar) are commonly made from tubes 5/16 inch in internal diameter and ⅝

FIGURE 33. Bombshells for 4- and 6-inch Mortars. (Courtesy National Fireworks Company and the *Boston Globe*.)

inch in external diameter. Fuses are generally attached to the front end of the bombshell. The forward-pointing end of the tube, which is outside the shell and receives the fire, is filled flush with the composition. The other backward-pointing end, inside the shell, is empty of composition for ¾ inch of its length; a bundle of stiff 2-inch pieces of black match is inserted into this space and is held in position by a rolled wrapper of paper, glued to the fuse case and tied with a string near the ends of the match, in order that it may not be dislodged by the shock of setback. The match serves to bring the fire more satisfactorily to the bursting charge within the shell.

The preparation of the bombshell is hand work which requires much skill and deserves a fairly full description. We describe the construction of a 4-inch shell to produce a single burst of stars. A strip of bogus or news board paper is cut to the desired length and is rolled tightly on a form without paste. When it is nearly all rolled, a strip of medium-weight kraft paper, 4 inches wider than the other strip, is rolled in and is rolled around the tube several times and is pasted to hold it in position. Three circular discs of pasteboard of the same diameter as the bogus tube (3½ inches) are taken, and a ⅝-inch hole is punched in the center of two of them. The fuse is inserted through the hole in one of them and glued heavily on the inside. When this is thoroughly dry, the disc is glued to one end of the bogus tube, the matched end of the fuse being outside; the outer wrapper of kraft paper is folded over carefully onto the disc, glued, and rubbed down smoothly; and the second perforated disc is placed on top of it.

The shell case is now turned over, there being a hole in the bench to receive the fuse, and it is filled with as many stars (½-inch diameter, ½ inch long) as it will contain. A mixture of 2F gunpowder and candle comp is then added, shaken in, and settled among the stars until the case is absolutely full. A disc of pasteboard is placed over the stars and powder, pressed down against the end of the bogus body and glued, and the outer kraft paper wrapper is folded and glued over the end.

At this point the shell is allowed to dry thoroughly before it is wound with strong jute twine. It is first wound lengthwise; the twine is wrapped as tightly as possible and as firmly against the fuse as may be; each time that it passes the fuse the plane of the winding is advanced by about 10° until 36 turns have been laid on, and then 36 turns are wound around the sides of the cylinder at right angles to the first winding. The shell is now ready to be "pasted in." For this purpose, 50-pound kraft paper is cut into strips of the desired dimensions, the length of the strips being across the grain of the paper. A strip of this paper is folded, rubbed, and twisted in paste until it is thoroughly impregnated. It is then laid out on the bench and the shell is rolled up in it. The cylinder is now stood upright, the fuse end at the top, and the portion of the wet pasted kraft paper wrapper which extends above the body of the shell is torn into strips about ¾ inch wide; these, one by one, are rubbed down carefully and smoothly, one overlapping the other, upon the end of the shell case. They extend up the fuse tube for about ½ inch and are pressed down firmly against it. The shell is now turned over, the fused end resting against a tapered hole in the bench, and a corresponding operation is performed upon the other end. The body of the shell is now about ¼ inch thick on the sides of the cylinder, about ⅜ inch thick at the top end, and about ½ inch at the base end. It is dried outdoors in the sun and breeze, or in a well-ventilated dry-house at 100°F., and, when thoroughly dry, is ready to be supplied with the propelling or *blowing charge.*

A piece of *piped match* (black match in a paper tube) is laid along the side of the bombshell; both are rolled up without paste in 4 thicknesses of 30-pound kraft paper wide enough to extend about 4 inches beyond the ends of the cylinder, and the outer wrapper is tied lightly in place by two strings encircling the cylinder near the ends of the shell case. The cylinder is turned bottom end up. About 3 inches of the paper pipe of the quickmatch is removed to expose the black match, a second piece of black match is inserted into the end of the paper pipe, and the pipe is tied with string to hold the match in place. The propelling charge of 2F gunpowder is next introduced; the two inner layers of the outer kraft paper wrapper are folded down upon it and pressed firmly, then the two outer layers are pleated to the center of the cylinder, tied, and trimmed close to the string. The cylinder is then turned to bring the fuse end uppermost. The end of the fuse is scraped clean if it has been touched with paste. Two pieces of black match are crossed over the end of the fuse, bent down along the sides of the fuse tube, and tied in this position with string. The piped match which leads to the blowing charge is now laid down upon the end of the cylinder, up to the bottom of the fuse tube, then bent up along the side of the fuse tube, then bent across its end and down the other side, and then bent back upon itself, and tied in this position. Before it is tied, a small hole is made in the match pipe at the point where it passes the end of the Roman fuse, and a piece of flat black match is inserted. The two inner layers of the kraft paper wrapper are now pleated around the base of the fuse and tied close to the shell. The two outer layers are pleated and tied above the top of the fuse, a 3-foot length of piped match extending from the upper end of the package. A few inches of black match is now bared at the end and an extra piece of black match is inserted and tied in place by a string about 1 inch back from the end of the pipe. The black match, for safety's sake, is then covered with a piece of lance tube, closed at the end, which is to be removed after the shell has been placed in the mortar and is ready for firing.

Maroons

Bombs which explode with a loud report, whether they are intended for use on the ground or in the air, are known as maroons. They are called *marrons* in French, a name which also means large chestnuts in that language—and chestnuts sometimes explode while being roasted.

Maroons are used for military purposes to disconcert the enemy by imitating the sounds of gunfire and shell bursts, and have at times been part of the standard equipment of various armies. A cubical pasteboard box filled with gunpowder is wound in three directions with heavy twine, the successive turns being laid close to one another; an end of miner's fuse is inserted through a hole made by an awl, and the container, already very strong, is made still stronger by dipping it into liquid glue and allowing to dry.

For sharper reports, more closely resembling those of a high-explosive shell, fulminating compositions containing chlorate are used. With these, the necessity for a strong container is not so great; the winding may be done with lighter twine, and the successive turns of twine need not make the closest possible contact. Faber reports two compositions, as follows:

Potassium chlorate	4	1
Sulfur	1	..
Soft wood charcoal	1	..
Antimony sulfide	..	1

"It is to be noted," he says,[49] "that, while the first formula affords a composition of great strength, the second is still more violent. It is also of such susceptibility that extraordinary care is required in the handling of it, or a premature explosion may result."

Chlorate compositions are not safe for use in maroons. Black powder is not noisy enough. Allen F. Clark has communicated the following perchlorate formulas for reports for maroons. For

Potassium perchlorate	12	6	32
Sulfur	8	2	..
Antimony sulfide	..	3	..
Sawdust	1	..	..
Rosin	..	..	3
Fine charcoal	..	..	3

a *flash report* he uses a mixture of 3 parts of potassium permanganate and 2 of aluminum.

Toy Caps

Toy caps are commonly made from red phosphorus and potassium chlorate, a combination which is the most sensitive, dangerous, and unpredictable of the many with which the pyrotechnist has to deal. Their preparation ought under no conditions to be attempted by an amateur. Powdered potassium chlorate 20 parts is made into a slurry with gum water. It is absolutely essential that the chlorate should be wetted thoroughly before the red phosphorus is mixed with it. Red phosphorus, 8 parts, is mixed with powdered sulfur 1 part and precipitated calcium carbonate 1 part, and the mixture is made into a slurry separately with gum water, and this is stirred into the other until thoroughly mixed. The porridgelike mass is then spotted on paper, and a piece of pasted tissue paper is placed over the spotted surface in a manner to avoid the enclosure of any air bubbles between the two. This is important, for, unless the tissue paper covers the spots snugly, the composition is likely to crumble, to fall out, and to create new dangers. (A strip of caps, for example, may explode between the fingers of a boy who is tearing it.) The moist sheets of caps are piled up between moist blankets in a press, or with a board and weights on top of the pile, and are pressed for an hour or so. They are then cut into strips

[49] *Op. cit.*, Vol. 1, p. 166.

of caps which are dried, packaged, and sold for use in toy repeating pistols. Or they are cut in squares, one cap each, which are not dried but are used while still moist for making Japanese torpedoes (see below). The calcium carbonate in this mixture is an anti-acid, which prevents it from deteriorating under the influence of moisture during the rather long time which elapses, especially in the manufacture of torpedoes, before it becomes fully dry.

Mixtures of potassium chlorate and red phosphorus explode from shock *and from fire.* They do not burn in an orderly fashion as do black powder and most other pyrotechnic mixtures. No scrap or waste ought ever to be allowed to accumulate in the building where caps are made; it ought to be removed hourly, whether moist or not, and taken to a distance and thrown upon a fire which is burning actively.

Silver Torpedoes

These contain silver fulminate, a substance which is as sensitive as the red phosphorus and chlorate mixture mentioned above, but which, however, is somewhat more predictable. They are made by the use of a *torpedo board,* that is, a board, say ⅞ inch thick, through which ¾-inch holes have been bored. A 2-inch square of tissue paper is placed over each hole and punched into the hole to form a paper cup. A second board of the same thickness, the *gravel board,* has ½-inch holes, bored not quite through it, in number and position corresponding to the holes in the torpedo board. Fine gravel, free from dust, is poured upon it; the holes are filled, and the excess removed. The torpedo board, filled with paper cups, is inverted and set down upon the gravel board, the holes matching one another. Then the two boards, held firmly together, are turned over and set down upon the bench. The gravel falls down into the paper cups, and the gravel board is removed. A small amount of silver fulminate is now put, on top of the gravel, into each of the paper cups. This is a dangerous operation, for the act of picking up some of the fulminate with a scoop may cause the whole of it to explode. The explosion will be accompanied by a loud noise, by a flash of light, and by a tremendous local disturbance damaging to whatever is in the immediate neighborhood of the fulminate but without effect upon objects which are even a few inches away.

In one plant which the present writer has visited, the fulminate destined to be loaded into the torpedoes rests in a small heap in the center of a piece of thin rubber (dentist's dam) stretched over a ring of metal which is attached to a piece of metal weighing about a pound. This is held in the worker's left hand, and a scoop made from a quill, held in the right hand, is used to take up the fulminate which goes into each torpedo. If the fulminate explodes, it destroys the piece of stretched rubber—nothing else. And the rubber, moreover, cushions it so that it is less likely to explode anyway. The pound of metal is something which the worker can hold much more steadily than the light-weight ring with its rubber and fulminate, and it has inertia enough so that it is not jarred from his hand if an explosion occurs. After the fulminate has been introduced into the paper cups, the edges of each cup are gathered together with one hand and twisted with the thumb and forefinger of the other hand which have been moistened with paste. This operation requires care, for the torpedo is likely to explode in the fingers if it is twisted too tightly.

Torpedoes, whether silver, Japanese, or globe, ought to be packed in sawdust for storage and shipment, and they ought not to be stored in the same magazine or shipped in the same package with other fireworks. If a number of them are standing together, the explosion of one of them for any reason is practically certain to explode the others. Unpacked torpedoes ought not to be allowed to accumulate in the building in which they are made.

Japanese Torpedoes

The so-called Japanese torpedoes appear to be an American invention. They contain a paper cap placed between two masses of gravel, and in general require to be thrown somewhat harder than silver torpedoes to make them explode. The same torpedo board is used as in the manufacture of silver torpedoes, but a gravel board which holds only about half as much gravel. After the gravel has been put in the paper cups, a paper cap, still moist, is placed on top of it, more gravel, substantially equal in amount to that already in the cup, is added to each, and the tops are twisted.

Globe Torpedoes[50]

Small cups of manila paper, about ¾ inch in diameter and ⅞ inch deep, are punched out by machine. They are such that two of them may be fitted together to form a box. The requisite amount of powdered potassium chlorate is first introduced into the cups; then, on top of it and without mixing, the requisite

FIGURE 34. Manufacture of Globe Torpedoes. Introducing gravel and closing the paper capsules. (Courtesy National Fireworks Company and the *Boston Globe*.)

amount, already mixed, of the other components of the flash fulminating mixture is added. These other components are antimony sulfide, lampblack, and aluminum. Without disturbing the white and black powders in the bottoms of the cups, workers then fill the cups with clean coarse gravel and put other cups down upon them to form closed ¾ by ¾ inch cylindrical boxes. The little packages are put into a heated barrel, rotating at an angle with the horizontal, and are tumbled together with a solution of water-glass. The solution softens the paper (but later

[50] U. S. Pats. 1,199,775, 1,467,755, 1,783,999.

hardens it), and the packages assume a spherical shape. Small discs of colored paper (punchings) are added a few at a time until the globes are completely covered with them and have lost all tendency to stick together. They are then emptied out of the

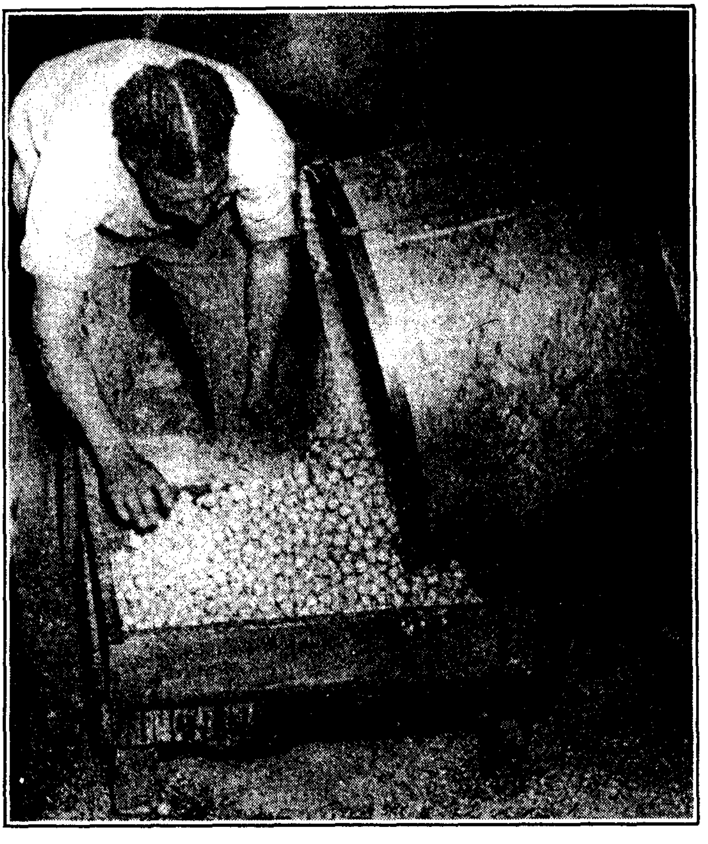

FIGURE 35. Manufacture of Globe Torpedoes. Removing the moist spheres from the tumbling barrel. (Courtesy National Fireworks Company and the *Boston Globe*.)

tumbler, dried in steam-heated ovens, and packed in wood shavings for storage and shipment.

Railway Torpedoes

A railway torpedo consists of a flat tin box, of about an ounce capacity, filled with a fulminating composition and having a strip of lead, soldered to it, which may be bent in order to hold it in place upon the railroad track. It explodes when the first wheel of the locomotive strikes it, and produces a signal which is audible to the engineer above the noise of the train. Railway torpedoes were formerly filled with compositions containing chlorate and red phosphorus, similar to those which are used in toy caps; but these mixtures are dangerous and much more sensitive than

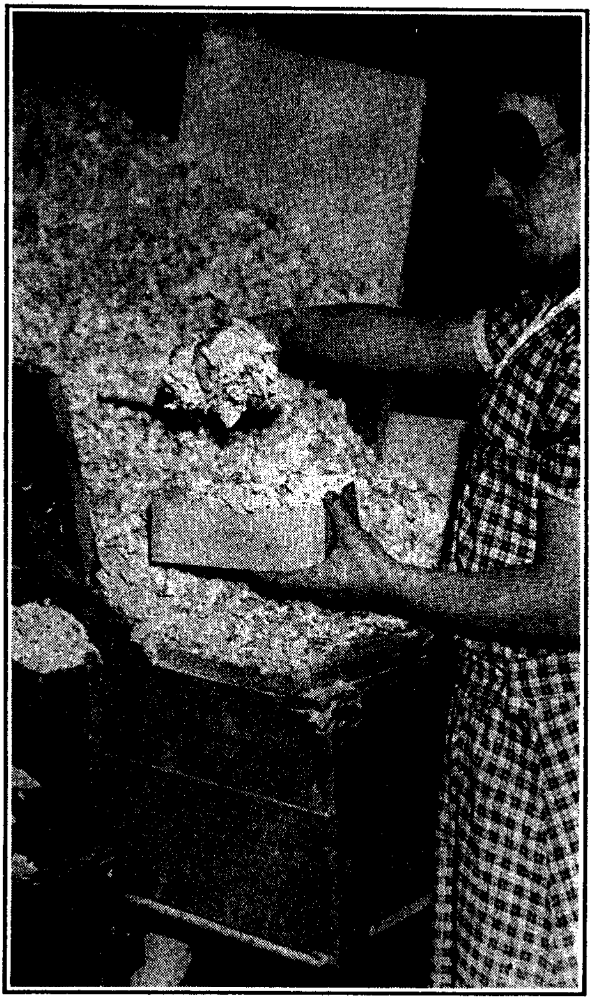

FIGURE 36. Packing Globe Torpedoes in Wood Shavings. (Courtesy National Fireworks Company and the *Boston Globe*.)

is necessary. At present, safer perchlorate mixtures without phosphorus are used. The following compositions (Allen F. Clark) can be mixed dry and yield railway torpedoes which will not explode from ordinary shock or an accidental fall.

Potassium perchlorate	6	12
Antimony sulfide	5	9
Sulfur	1	3

English Crackers or Grasshoppers

These devices are old; they were described by John Bate and by Hanzelet Lorrain. English crackers are represented in the lower right-corner of Figure 23, reproduced from Lorrain's book of 1630. They are used in bombshells and, as Lorrain used them, in rockets, where they jump about in the air producing a series of flashes and explosions. Children shoot them on the ground like firecrackers where their movements suggest the behavior of grasshoppers.

English crackers are commonly loaded with granulated gunpowder, tamped into paper pipes like those from which pinwheels are made. The loaded pipes are softened by moisture in the same way, passed between rollers to make them flatter, folded in frames, and, for the best results, tied each time they are folded and then tied over the whole bundle. They are generally supplied with black match for lighting. They produce as many explosions as there are ligatures.

Chinese Firecrackers

Firecrackers have long been used in China for a variety of ceremonial purposes. The houseboat dweller greets the morning by setting off a bunch of firecrackers, for safety's sake in an iron kettle with a cover over it, to keep all devils away from him during the day. For their own use the Chinese insist upon firecrackers made entirely of red paper, which leave nothing but red fragments, for red is a color particularly offensive to the devils. Firecrackers for export, however, are commonly made from tubes of cheap, coarse, brown paper enclosed in colored wrappers. Thirty years ago a considerable variety of Chinese firecrackers was imported into this country. There were "Mandarin crackers," made entirely from red paper and tied at the ends with silk thread; cheaper crackers plugged at the ends with clay (and these never exploded as satisfactorily); "lady crackers," less than an inch long, tied, and no thicker than a match stem; and "cannon crackers," tied with string, 6, 8, and 12 inches long, made of brown paper with brilliant red wrappers. All these were loaded with explosive mixtures of the general nature of black powder, were equipped with fuses of tissue paper twisted around black powder, and were sold, as Chinese firecrackers are now sold, in bunches with their fuses braided together. The composition 4 parts potassium nitrate, 1 of charcoal, and 1 of sulfur has been reported in Chinese firecrackers; more recently mixtures containing both potassium nitrate and a small amount of potassium chlorate have been used; and at present, when the importation of firecrackers over 1¾ inches in length is practically[51] prohibited, flash powders containing aluminum and potassium

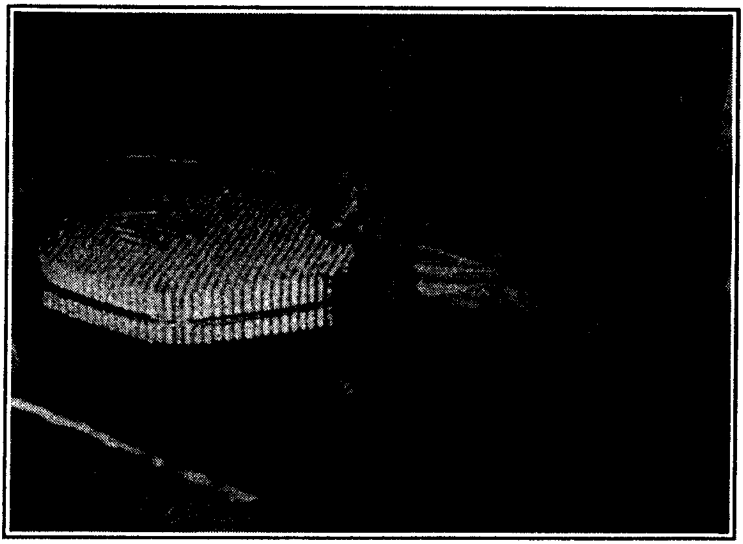

FIGURE 37. Chinese Firecrackers. Tying the Tubes into Bundles. (Courtesy Wallace Clark.)

chlorate are commonly used, for they give a sharper explosion than black powder.

The Chinese firecracker industry formerly centered in Canton but, since the Japanese occupation, has moved elsewhere, largely to French Indo-China and Macao in Portuguese territory. Its processes require great skill and manual dexterity, and have long been a secret and a mystery to Europeans. So far as we know, they had not been described in English print until Weingart's book[52] published an account of the manufacture of clay-plugged crackers based upon information received from the manager of a fireworks company at Hong Kong. His account is illustrated with three pen sketches, two of them of workmen

[51] Firecrackers not exceeding 1¾ inches in length and 5/16 inch in diameter carry a duty of 8 cents per pound. For longer crackers the duty is 25 cents per pound, which practically prohibits their importation.

[52] *Op. cit.*, pp. 166–170.

carrying out manual operations and a third which shows some of the tools and instruments. The brief account which follows is

FIGURE 38. Crimping the Back Ends of the Tubes. (Courtesy Wallace Clark.)

based upon conversations with Wallace Clark of Chicago and upon still and moving pictures which he took at a large factory in French Indo-China in January, 1939.

FIGURE 39. Punching Holes for Loading. (Courtesy Wallace Clark.)

The tubes for the firecrackers are rolled and cut to length in outlying villages, and are brought to the factory for loading.

They are tied in hexagonal bundles, Figure 37, each containing 1006 tubes. Since the twine tied tightly around the bundle

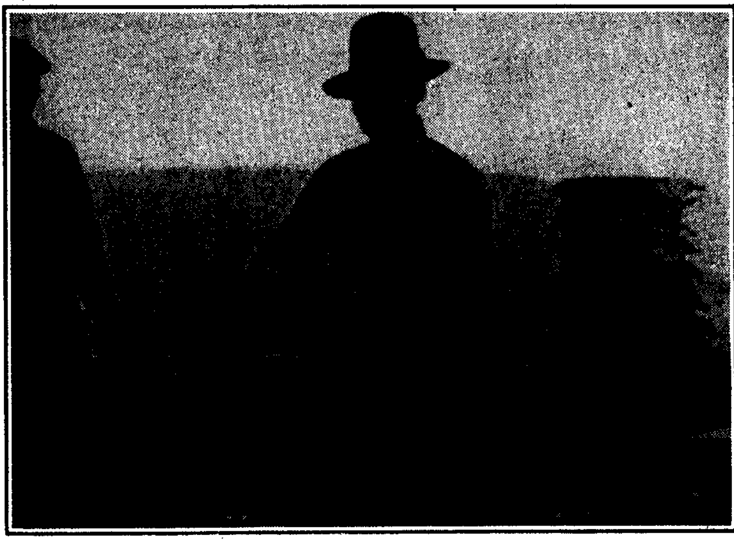

FIGURE 40. Loading. Filling the Tubes with Powder. (Courtesy Wallace Clark.)

crushes the 6 tubes at the corners of the hexagon, and since these are discarded, each bundle contains tubes for 1000 finished crackers.

FIGURE 41. Fusing and Crimping. (Courtesy Wallace Clark.)

The back ends of the crackers are then crimped; Figure 38. A bamboo stick is placed against the end of the tube and is struck a sharp blow; this forces some of the paper down into the tube and closes it effectively. The operation, like all the other

FIGURE 42. Making the Fuse. (Courtesy Wallace Clark.)

operations in the manufacture of the crackers, is carried out very rapidly.

FIGURE 43. Making the Crackers into Bunches by Braiding Fuses Together. (Courtesy Wallace Clark.)

A sheet of paper is then pasted over the other side of the hexagonal bundle of tubes, closing the ends which are later to carry the fuses. When this is dry, holes corresponding to the tubes are punched in the paper. The operation is carried out by young girls who punch the holes four at a time by means of four bamboo sticks held in one hand while they hold the bundle of tubes steady with the other; Figure 39. The edges of the paper are then bent slightly upward, giving it the form of a shallow saucer with 1000 holes in its bottom. The powder for charging the crackers is then introduced into this saucer, and the whole is

FIGURE 44. Wrapping the Bunches. (Courtesy Wallace Clark.)

shaken gently until all the tubes are full; Figure 40. Then, by a deft movement of the worker's hands and wrists, the excess powder in the saucer, and a portion of the powder in each of the tubes, is emptied out quickly, each of the tubes being left partly full of powder with enough empty space at the top for the fuse and the crimp. This operation, of all those in the manufacture, is considered to be the one which requires the greatest skill. Day after day the average consumption of powder per 1000 or per 100,000 crackers is remarkably constant.

The paper is then torn off from the hexagonal bundle, and the fuses, cut to length, are put in place by one workman while another with a pointed bamboo stick rapidly crimps the paper around them; Figure 41. The fuse is made from narrow strips of tissue paper about 2 feet long. While one end of the strip is clamped to the bench and the other is held in the hand, the strip is shaped by a motion of the worker's other hand into the form of a trough which is then filled with a narrow train of powder, and, by another motion of the hand, the fingers being moistened, is twisted into the finished fuse; Figure 42. This is set aside to dry and is cut into lengths for use in the crackers. The fuses of the finished crackers are braided or pleated together, Figure 43, making the crackers into bunches, and the bunches are wrapped and labeled, Figure 44.

Flash Cracker Composition

Chinese firecrackers and American machine-made salutes are loaded with compositions which contain powdered aluminum and potassium chlorate or perchlorate. They produce a bright flash and an extremely sharp report when they explode. The compositions listed below are typical. The first four in the table have been used in Chinese firecrackers. For the last four the author is indebted to Allen F. Clark.

Potassium perchlorate	..	..	..	..	6	1	7	..
Potassium chlorate	2	3	..	7	..	..	..	..
Potassium nitrate	..	..	5	..	..	..	..	..
Barium nitrate	..	..	..	..	3	1	..	4
Aluminum (fine powder)	1	4	2	1	5	1	5	2
Sulfur	1	3	3	2	..	1	..	1
Antimony sulfide	..	..	..	1	..	..	..	..

The compositions which contain barium nitrate produce a green flash, the others a white one. All of them burn with great rapidity in the open. It is debatable whether the phenomenon of the burning is not really an explosion, or would be one if the material were not allowed to scatter while being burned. With the exception of the third and the last, they are all fulminating explosives when confined. All the mixtures which contain sulfur along with chlorate or perchlorate can be exploded on an iron anvil by a moderately strong blow with an iron hammer.

Sparklers

Snowball sparklers (Allen F. Clark) are made from:

Potassium nitrate	64
Barium nitrate	30
Sulfur	16
Charcoal dust	16
Antimony sulfide	16
Fine aluminum powder	9
Dextrin	16

The ingredients are all powdered to pass a 200-210 mesh sieve. The dry materials are mixed thoroughly and sifted, then moistened little by little with water with thorough mixing until the mixture attains the consistency of heavy molasses. Iron wires (20 gauge) of convenient length are dipped in the mixture and are hung up to dry for 24 hours. These are dipped a second time for size, and allowed to dry for another 24 hours. The sparklers burn with a bright white light and throw out "soft sparks" from the charcoal and occasionally scintillating sparks from the burning of the iron wire.

Other mixtures which produce similar effects are as follows:

Potassium nitrate	64	..
Potassium perchlorate	3	16
Barium nitrate	..	6
Sulfur	18	4
Lampblack	5	..
Red gum	4	4
Fine aluminum powder	6	6
Coarse aluminum powder	..	4

The first of these burns with a lilac-colored flame as contrasted with the flame of the second which appears white. These compositions are applied by adding the intimately mixed dry ingredients to a liquid known as "black wax," procured by melting together 3 pounds of rosin and 1 gallon of liquid roofing-paper tar. The iron wires are dipped two or three times in the resulting slurry, and allowed to dry between dips.

The use of iron and steel filings in the compositions produces a more brilliant display of scintillating sparks. The following formulas are typical. Water is used for applying the compositions. The iron and steel filings which are used in these compositions are coated, before the mixing, with paraffin or linseed oil to protect them from rusting.

Barium nitrate	48	48	..
Potassium perchlorate	..	..	6
Fine aluminum powder	7	7	1
Fine iron filings	24	18	..
Fine steel filings	..	9	12
Manganese dioxide	2	1	..
Dextrin	12	12	2
Glucose	..	1	..

Wire Dips and Colored Fire Sticks

These devices are made in the same way as sparklers, by dipping wires or twisted narrow strips of iron or thin sticks of wood, and generally burn with a tranquil flame except for the sparks that come from the burning of the iron wire or strip. Several typical compositions are listed. Alcohol is used for applying the

	Red			Green	White
Potassium chlorate	..	2	3	..	..
Potassium perchlorate	..	..	..	..	10
Strontium nitrate	5	6	16	..	..
Barium chlorate	..	..	..	16	..
Fine aluminum powder	..	..	..	..	7
Coarse aluminum powder	..	6	..	24	..
Shellac	1	1	..	3	..
Red gum	..	..	4	..	..
Dextrin	..	..	3	..	3

compositions which contain shellac; water, for applying the others which contain dextrin.

Pharaoh's Serpents[53]

Wöhler in 1821 first reported the remarkable property of mercurous thiocyanate that it swells up when it is heated, "winding out from itself at the same time worm-like processes, to many times its former bulk, of a very light material of the color of graphite, with the evolution of carbon disulfide, nitrogen, and mercury." Mercuric thiocyanate, which gives better snakes than the mercurous compound, came early into use for this purpose in pyrotechnic toys. When a heap or pellet of either of these compounds is set on fire, it burns with an inconspicuous blue flame, producing sulfur dioxide and mercury vapor. The resulting pale brown or pale gray snake, if broken, is found to be much darker in the interior, and evidently consists of paracyanogen and mercuric sulfide, the mercury having been burned and vaporized from the outer layer.

Mercuric thiocyanate is prepared by adding a solution of

[53] Cf. Davis, article entitled "Pyrotechnic Snakes," in *J. Chem. Education*, 17, 268-270 (1940).

potassium, sodium, or ammonium thiocyanate to a solution of mercuric nitrate, a ferric chloride or ferric alum indicator being used to indicate by a red color when enough of the former solution has been added. This is necessary since mercuric thiocyanate is soluble in an excess of either of the reagents by the interaction of which it is produced. The precipitate is collected, washed, dried, powdered, moistened with gum-arabic water in which a little potassium nitrate is dissolved, and made into small pellets by means of a device like a star board or by a pelleting machine. The small pellets are known as *Pharaoh's serpent's eggs.*

Snakes-in-the-grass, volcano snakes, etc., depend upon the use of ammonium dichromate. If this material in the form of a powder is made into a conical heap, and a flame applied to the top of it, a visible but not violent "combustion" proceeds through the mass, which "boils up" to form a large volume of green material resembling tea leaves.

$$(NH_4)_2Cr_2O_7 \longrightarrow N_2 + 4H_2O + Cr_2O_3$$

In practice, more flame is desired than ammonium dichromate alone will give. Weingart[54] recommends a mixture of 2 parts of ammonium dichromate with 1 of potassium nitrate and 1 of dextrin. Tinfoil cones are made from circles of tinfoil shaped on a former, and are introduced by means of the former into conical cavities in a block of wood; they are then about half filled with the powdered mixture, a Pharaoh's serpent's egg is pressed in, and the edges of the tinfoil are turned down upon it to form the base of the cone.

While the fumes from burning mercuric thiocyanate are offensive because of their sulfur dioxide, the small amount of mercury vapor which they contain probably presents no serious danger. The possibility, however, that children may swallow the pellets, with fatal consequences, is a real hazard. For this reason, the sale of mercury snakes has been forbidden by law in many states, and black non-mercury snakes, which are essentially non-poisonous, have come into general use.

Black Non-Mercury Snakes[55]

These are used in the form of *barrel snakes, hat snakes* (black

[54] *Op. cit.*, p. 152.
[55] Davis, *loc. cit.*

pellets affixed to black discs of pasteboard to form what look like miniature broad-brimmed black hats), *colored fire snakes*, etc. The best which we have seen are prepared from naphthol pitch by a process described by Weingart.[56] The naphthol pitch is a by-product in the manufacture of β-naphthol. The method of "nitration by kneading" is so unusual that it appears worth while to describe the process in detail.

Preparation of Black Non-Mercury Snakes. Thirty grams of powdered naphthol pitch is mixed intimately with 6 grams of linseed oil, and the material is chilled in a 200-cc. Pyrex beaker surrounded by cracked ice. Twenty-one cubic centimeters of fuming nitric acid (*d.* 1.50) is added in small portions, one drop at a time at first, and the material is stirred over, kneaded, and kept thoroughly mixed at all times by means of a porcelain spatula. The addition of each drop of acid, especially at the beginning of the process, causes an abundance of red fumes, considerable heating, and some spattering. It is recommended that goggles and rubber gloves be worn, and that the operation be carried out in an efficient hood. The heat of the reaction causes the material to assume a plastic condition, and the rate of addition of the acid ought to be so regulated that this condition is maintained. After all the acid has been added, the dark brown, doughlike mass becomes friable on cooling. It is broken up under water with the spatula, washed thoroughly, and allowed to dry in the air. The product is ground up in a porcelain mortar with 10.5 grams of picric acid, made into a moist meal with gum-arabic water, pelleted, and dried. A pellet ½ inch long and ⅜ inch in diameter gives a snake about 4 feet long, smooth-skinned and glossy, with a luster like that of coke, elastic, and of spongy texture within.

The oxidized linseed oil produced during the nitration appears to play an important part in the formation of the snakes. If naphthol pitch alone is nitrated, ground up with picric acid, and made into pellets after moistening with linseed oil, the pellets when fresh do not yield snakes, but do give snakes after they have been kept for several months, during which time the linseed oil oxidizes and hardens. Weingart states in a letter that he has obtained satisfactory results by using, instead of naphthol pitch, the material procured by melting together 60 parts of Syrian asphalt and 40 of roofing pitch. Worked up in the regular way this "yielded fairly good snakes which were improved by rubbing

[56] *Op. cit.*, p. 153.

the finished product up with a little stearine before forming into pellets." The present writer has found that the substitution of β-naphthol for naphthol pitch yields fairly good snakes which, however, are not so long and not so shiny, and are blacker and covered with wartlike protuberances.

Smokes

Smoke shells and rockets are used to produce *smoke clouds* for military signaling and, in daylight fireworks, for ornamental effects. The shell case or rocket head is filled with a fine powder of the desired color, which powdered material need not necessarily be one which will tolerate heat, and this is dispersed in the form of a colored cloud by the explosion of a small bag of gunpowder placed as near to its center as may be. Artificial vermilion (red), ultramarine (blue), Paris green, chrome yellow, chalk, and ivory black are among the materials which have been used, but almost any material which has a bright color when powdered and which does not cake together may be employed.

Colored smokes strictly so called are produced by the burning, in *smoke pots* or smoke cases, of pyrotechnic compositions which contain colored substances capable of being sublimed without an undue amount of decomposition. The substances are volatilized by the heat of the burning compositions to form colored vapors which quickly condense to form clouds of finely divided colored dust. Colored smokes are used for military signaling, and recently have found use in colored moving pictures. Red smokes, for example, were used in the "Wizard of Oz." Colored smoke compositions are commonly rammed lightly, not packed firmly, in cases, say 1 inch in internal diameter and 4 inches long, both ends of which are closed with plugs of clay or wood. Holes, ¼ inch in diameter, are bored through the case at intervals on a spiral line around it; the topmost hole penetrates well into the composition and is filled with starting fire material into which a piece of black match, held in place by meal powder paste, is inserted. According to Faber,[57] the following-listed compositions were used in American airplane smoke-signal grenades during the first World War.

[57] *Op. cit.*, Vol. 1, p. 219.

	Red	Yellow	Green	Blue
Potassium chlorate	1	33	33	7
Lactose	1	24	26	5
Paranitraniline red	3	..	..	..
Auramine	..	34	15	..
Chrysoidine	..	9	..	..
Indigo	..	..	26	8

The following (Allen F. Clark) are illustrative of the perchlorate colored smoke compositions which have come into use more recently.

	Red	Green	Blue
Potassium perchlorate	5	6	5
Antimony sulfide	4	5	4
Rhodamine red	10	..	..
Malachite green	..	10	..
Methylene blue	..	..	10
Gum arabic	1	1	1

Many other dyestuffs may be used. Paranitraniline Yellow gives a canary yellow smoke, and Flaming Red B gives a crimson-colored smoke by comparison with which the smoke from Paranitraniline Red appears to be scarlet. None of the colored smoke compositions are adapted to indoor use. All the smokes are unpleasant and unwholesome.

White smoke is produced by burning a mixture of potassium chlorate 3 parts, lactose 1, and finely powdered ammonium chloride 1. The smoke, which consists of finely divided ammonium chloride, is not poisonous, and has found some use in connection with the study of problems in ventilation.

For use in trench warfare, for the purpose of obscuring the situation from the sight of the enemy, a very satisfactory dense *white* or *gray smoke* is procured by burning a mixture of zinc dust and hexachloroethane. The mixture requires a strong starting fire. The smoke consists largely of finely divided zinc chloride. For a grayer smoke naphthalene or anthracene is added to the mixture. Torches for *black smoke* have also been used, charged with a mixture of potassium nitrate and sulfur with rosin or pitch and generally with such additional ingredients as sand, powdered chalk, or glue to modify the rate of their burning.

When shells are loaded with certain high explosives which produce no smoke (such as amatol), *smoke boxes* are generally inserted in the charges in order that the artilleryman, by seeing the smoke, may be able to judge the position and success of his fire. These are cylindrical pasteboard boxes containing a mixture of arsenious oxide and red phosphorus, usually with a small amount of stearine or paraffin.