The Essential Tenney L. Davis

Prometheus Publications

The Essential Tenney Lombard Davis:

selected publications of the late Tenney L. Davis, PhD.

Warren K. Klofkorn
editor

Prometheus Publications

Introduction

Tenney Lombard Davis (1890 - 1949) produced during his 59 years a body of works that marks him as a pioneer in the history of chemistry, and particularly in the history of gunpowder and explosives. By my count, Dr. Davis published no less than 208 articles on scientific and academic subjects, and one landmark textbook, *The Chemistry of Powder and Explosives*. This count *does not include* his articles on the technical aspects of chemistry, which also were numerous.

Tenney Davis had a brilliant academic career from the beginning. He began with undergraduate study at Massachusetts Institute of Technology, from which he graduated in 1912. In 1913 he graduated with the degree of Master of Science from Harvard University. From Harvard Davis also received his Ph. D. in chemistry in 1917 at the age of 27.

The first article he published that I am aware of was a piece called, "Theory as Truth: A Study of the Logical Status of Scientific Theory." This piece appeared in The *Journal of Philosophy, Psychology, and Scientific Methods* in 1916 when Davis was 26. After this date, his articles appeared in rapid-fire succession, on a wide variety of subjects. His inclination toward explosives revealed itself early in his career. Among the first works he published was a series of bibliographical pieces published in 1922 and 1923 in the French journal, *Mémorial des Poudres*.

As Dr. Davis progressed in his career, he published more and more articles aimed at audiences increasingly diverse. He wrote articles that appeared not only in academic journals such as *Isis* and *Journal of Chemical Education*, and *Technology Review*, but also popular science pieces that appeared in periodicals such as *The Boston Globe,* aimed at more down-to-earth readerships. A examination of Davis's work from a chronological perspective reveals shifts in the focus of his writing over the years that seem to represent a methodical progression of interests and perhaps even a strategy. Note that his earlier works include publications of bibliographical materials. At this early stage of his career, this might be expected for several reasons: 1) Writing bibliographies may have been an easy way for a junior chemist to get published. 2) In that age, before computerized indexing of research materials, a handy reference to all the currently published work in the field would likely have been consulted by many other research chemists. This would have put Davis's name in a position of high visibility early in his career. 3) Collecting the materials used to produce the bibliographies would have helped Davis to assemble his own research collection and notes, providing him with a firm foundation for later research.

Toward the middle of his career Davis delved deeply into the history of chemistry, and its beginning in European and Chinese alchemy. During a period of deeply ethnocentric American culture, Dr. Davis broke the mold as a pioneer in cross-cultural studies in the history of science, focusing in the history of science first with respect to Europe, and then with respect to Asian science. In fact, Dr. Davis was a founding editor of *Chymia*, a pioneering journal in the history of chemistry. Davis produced only two volumes of *Chymia* before his death, but his colleagues carried on his work in this regard, making *Chymia* one of the finer ongoing efforts in the history of chemistry. Many of the articles appearing in this volume are taken from Davis's later work, which focused strongly on the history of chemistry and explosives.

Much of this work Davis produced while in retirement due to failing health. One of his obituaries noted that Davis had known for the last ten years of his life that he might die at any time*. Another of his obituaries, from the New York Times in January of 1949, states that Dr. Davis died from cardiac arrest while driving. We might infer that it is likely Davis suffered from heart trouble prior to his death, although the particulars of his condition have not come to light. Despite these difficulties, Davis wrote, edited, and published significant research until his death.

Davis's accomplishments in writing about explosives, the history of chemistry, and all the rest are accentuated by the other achievements of his life. Consider that he spent most of his career as professor of organic chemistry at Massachusetts Institute of Technology -- not only a prestigious position, but surely a demanding job as well. Furthermore, Dr. Davis acted as director of research for the now defunct National Fireworks Company of Boston. Finally, Tenney Davis was a family man -- a husband and father of two sons. Despite all of his competing responsibilities, he produced this tremendous volume of published work.

Unfortunately, aside from a crudely xeroxed collection I assembled and distributed during my undergraduate years at Michigan, there has never been any effort to compile and republish any of the work of Dr. Davis (with the exception of his text *The Chemistry of Powder and Explosives*) since his death in 1949. This volume is an attempt to remedy, at least partially, that state of affairs. There is more material that ought to be anthologized as well, but alas, time and economy argue forcibly against that for the present. Furthermore, some of Dr. Davis's more interesting titles seem to have disappeared altogether. One such title is: "Cultural Relationships of Explosives," which appeared in *National Fireworks Review* of 1944. A long and thoroughly aggravating search has failed to unearth this one, despite finding a record of its having been received at Harvard's Yenching Institute. Another missing work is: "Sugars in Fireworks and Explosives," that was published in 1949 by the Sugar Research Foundation. If any of the present readers have or know of these publications (or others suitable), they would likely be welcome additions to a second volume of Dr. Davis's work. I can be contacted at present at the following address or through the Pyrotechnics Guild International or through *American Fireworks News* of Dingman's Ferry, PA:

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*See Leicester & Klickstein, "Tenney Lombard Davis and the History of Chemistry," *Chymia* 3, 1950, 5.

Mr. Warren Klofkorn
P.O. Box 547
Kirksville MO 63501

Finally, some acknowledgements are in order. First, credit is due to Henry M. Leicester and Herbert S. Klickstein who published an invaluable obituary and bibliography of the work of Dr. Davis in *Chymia* 3 (reprinted in this volume) . Thanks are also due to two people who helped with the present publication: Ms. Sheila Swafford and Ms. Sijia Liu. Ms. Sheila Swafford of Interlibrary Loans at Northeast Missouri State University skillfully tracked down information about Dr. Davis. Ms. Sijia Liu, a student at Northeast Missouri State University who hails from Wuhan, China provided invaluable aid with the Chinese language and helped prepare some of the Chinese text and illustrations which appear in these pages.

Introduction to the Current Edition

During the past five years, *A Davis Chrestomathy*, predecessor to the present volume produced a marvelous response from its readers. The current volume updates the prior volume. This volumes includes, as well as the original material, the two articles I had long sought but not found for that volume. The articles "Sugars in Fireworks and Explosives" and "Cultural Relationships of Explosives" had proven elusive to others before me. As fate would have it, both articles virtually dropped into my lap as indirect consequences of the recent expansion of the data available on the Internet. Both surfaced in 1999. "Sugars" I found with a search of OCLC (On-line Computer Library Center), a library database which continually expands through the efforts of librarians the world over. "Cultural Relationships" turned up through a person I met in the process of conducting an E-Bay on-line auction transaction for a rare book dealing with pyrotechnic history.

Unless I have missed something, this concludes the definitive collection of Davis's published work in the history of explosives and pyrotechnics, neatly complementing the historical materials found in his famous book, *Chemistry of Powder and Explosives*. Of course, in the even that his bibliographers or I missed anything of note, I would welcome its receipt. I hope the readers will find this collection worthwhile. Dr. Davis should be long remembered for his contributions to the history of this field, and to the history of science generally.

Warren Klofkorn
Phoenix, Arizona
USA
November 1999
klofkorn@rocketmail.com

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Chemistry in War: An 18th Century Viewpoint

by
Tenney L. Davis

Army Ordnance 5[1]
[1925]

Chemistry has been so greatly credited in recent print with providing the resources of war, and so greatly blamed for contributing to its horrors, that it is surprising to find the great Dutch physician and chemist, Hermann Boerhaave, giving it the same praise and blame nearly two hundred years ago. After money, Boerhaave considered chemistry to be the chief support of war. But he also arraigned chemistry for making war so destructive to mankind. All the more astonishing to us now is his indictment, for his particular grievance was against black powder.

"It were indeed to be wish'd," writes[1] Boerhaave in his *Elementa Chemiae*, "that our art had been less ingenious, in contriving means destructive to mankind; we mean those instruments of war which were unknown to the ancients, and have made such havoc among the moderns. But as men have always been bent on seeking each other's destructions by continual wars; and as force, the chief support of war, must, after money, be now sought in chemistry.

"*Roger Bacon*, as early as the twelfth century,[2] had found out gunpowder, wherewith he imitated thunder and lightening; but that age was so happy as not to apply so extraordinary a discovery to the destruction of mankind. But two ages afterwards, *Berthold Schwartz*, a German monk and chemist, happening by some accident to discover a prodigious power of expanding in some of this powder which had been made for medicinal uses, he apply'd it first in an iron barrel, and soon after to the military art, and taught it to the *Venetians*. The effect is, that the art of war has since that time turned entirely on this one chemical invention: so that the feeble boy may now kill the stoutest hero: nor is there any thing so vast and solid soever, can withstand it. By a thorough acquaintance with the power of this powder, that intelligent Dutch General Cohorn quite alter'd the whole art of fighting: making such a

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[1]"A New Method of Chemistry: including the History, Theory, and Practice of the Art: translated from the original Latin of Dr. Boerhaave's *Elementa Chemia*, as published by himself. To which are added Notes; and an Appendix showing the necessity and Unity of Enlarging the Bonds of Chemistry. By Peter Shaw, M.D., F.R.S." 3rd edition. London 1753. Vol. 1 pp. 189-191.

[2]The information here is not correct. Roger Bacon was of the thirteenth century, and Berthold Schwartz is generally considered to be a myth.

change in the manner of fortification, that places formerly held impregnable, now want defenders. In effect, the power of gunpowder is still more to be fear'd. I tremble to mention the stupendous force of another powder, prepared of sulphur, nitre, and burnt lees of wine; to say nothing of the well-known power of *aurum fulminans* [fulminate of gold]. Some person taking a quantity of fragrant oil, chemically procured from spices, and mixing it with a liquor prepared from salt-petre, discovered a thing far more powerful than gunpowder itself; and which spontaneously kindles and burns with great fierceness, without any application of fire. I shall but just mention a fatal event which lately happened in *Germany*, from an experiment made with balsam of sulphur terebinthinated [treated with turpentine] and contained in a closed chemical vessel, and thus ignited by fire; God grant that mortal men may not be so ingenious at their own cost, as to pervert a profitable science any longer to such horrible uses. For this reason I forbear to mention several other matters far more horrible and destructive than any of these above rehearsed."

On the foregoing passage, Peter Shaw, translator and editor of Boerhaave's work, has added the following note: "On this occasion we cannot omit to admire an instance of a noble and generous principle, in the late king of *France, Louis XIV*. A Roman chemist, S. Poli, having discovered something of this kind, of prodigious effect, came to France in 1702, on purpose to make an offer of it to that prince; who, tho' he was then going to be engaged in a war against a powerful confederacy; yet voluntarily renounced all the advantages of such a secret: handsomely rewarded the inventor, but enjoin'd him to let it perish."

Primitive men fighting with stones and clubs no doubt felt a resentment against the unsportsmanlike conduct of the first enemy who threw sharpened sticks of wood. But they rapidly adopted the use of spears, and, in due course of time, were again annoyed by an adversary who was not content to throw his pointed sticks, but shot them with a greater velocity by reason of the elastic force of a bended bow. To use the fighting of the golden days seems to have been largely a matter of brawn, but intelligence and skill were really considerable factors in it. To primitive man it would seem to depend but little upon brute strength; it would appear to be largely a matter of the appliances, armor, weapons, and instruments, which were used. The feeble shepherd boy, David, was able to slay the stout hero, Goliath, by means of a simple physical instrument in the use of which his powerful opponent was not skilled. The advantage has always been with the more intelligent, and improvements in method of warfare have been due to advances in scientific knowledge. Except for the smoke pots of the Chinese, and the spouting inextinguishable fires of the Byzantines, improvements in warfare previous to gunpowder were due, not to chemistry, but to physics.

Since the introduction of gunpowder, changes have been in the direction suggested by chemical discovery. Slow burning powder has made rifled artillery possible. The chemistry of steel and that of the compounds of carbon have given us the tank and the engine which propels the airplane. Physical instruments have made use of chemical energies; the powder has propelled the bullet, the airplane has dropped the high explosive, the depth bomb has shaken the submarine as a cat would shake a mouse, the thing to be accomplished by the means provided by chemistry has been, until recently, a physical change, and the damage to the enemy has been physical.

The present revolution in the methods of warfare involves far more than the exploitation of chemistry. War has become more than ever a matter of intelligence. We now attack the enemy, not merely in a physical way, but by every means which an improved understanding of nature has provided for us. We attack him economically and politically, we attack him psychologically by means of propaganda and by other efficacious devices, and we attack him chemically by means of powerful reagents. The resulting horrors are obviously not to be ascribed to psychology and to chemistry, for these are sciences, neither for harm nor good, but simply for the better understanding of certain aspects of the world in which we find ourselves.

It has been said that "an army travels on its stomach.' We cannot have meat unless we have vegetation upon which the animals may feed, and we cannot have vegetation unless there is chemically combined nitrogen in the soil for food for plants. An Army travels upon its nitrogen. While the amount of uncombined nitrogen in the atmosphere is unlimited, the amount of combined nitrogen available for use by plants is frequently meagre. Soils require to be fertilized. The greatest accomplishment of chemistry then would seem to be that it has brought mankind into the present Nitrogen Age and has taught him how to fix the nitrogen of the atmosphere in the form of ammonia and nitrates for use in fertilizers.

Without powder and explosives, serious physical damage cannot be done to an enemy, the powerful reagents of chemical warfare cannot be brought into play, propaganda and other psychological agents cannot be made effective. Since all useful powders and explosives are manufactured from ammonia or from nitrates as raw materials, it appears that an army fights by means of its nitrogen.

Warfare becomes increasingly a matter of intelligence. While admitting the dependence of intelligence upon heredity, stimulating environment, etc., we find nevertheless that there is a chemical something without which there can be no thinking. Since the grey matter of the nerves and brain is made up of carbon compounds of phosphorus and nitrogen, it appears that without nitrogenous foods there can be no thinking -- and an army thinks with its nitrogen.

Whatever may have been the case in Boerhaave's day, in the present Nitrogen Age it is certainly true that "the chief support of was must now be sought in chemistry." It may be that chemistry is more important than money, for without nitrogen we can have no food, no powder, and even no ideas about the matter.

Kunckel's Discovery of Fulminate

by
Tenney L. Davis

Army Ordnance 7[2]
[1926]

After the first use of black powder in a gun, more than five centuries elapsed before anything fundamentally new came into the explosive art, before the principle of high explosive was discovered and applied. Substances now became available which, like nitroglycerine, were exploded by unintentional shock or were made to burn by fire without exploding, which were uncertain and unpredictable in their action. Others, like picric acid, were incapable of exploding from fire or from ordinary shock. It was found that these substances could be exploded regularly by the shock which resulted from the explosion of a small quantity of mercury fulminate. This primary explosive or "initiator" would explode from fire. invariably, whether confined or not, and the great local shock which it would produce would initiate the explosion of the high explosive. The discovery of the peculiar properties of mercury fulminate showed that high explosives were possible. Its use made them tractable.

The preparation of fulminating gold and silver by the action of ammonia on the salt of the corresponding metal is described in what purports to be the writing of Basil Valentine, Dominican monk of Erfurt, in the early part of the fifteenth century. These writings are spurious, for there has never been a Dominican monastery at Erfurt and the records of that religious order do not contain the name of Basil Valentine. They were evidently written in the late sixteenth or early seventeenth century by Johann Thölde (or Thölden) of Hesse who first published them, and constitute altogether an excellent summary of the best chemical knowledge of the time, collected without acknowledgement of the source. Fulminating gold and silver were perhaps discovered by the Dutchman, Cornelis Drebbel (1572-1633). Their composition does note yet appear to have been definitely settled, for they are difficult substances to handle and explode on very slight provocation. For a time after their discovery they attracted considerable attention as toys or chemical curiosities, but they have not been put to practical use. In his diary for November 11, 1663, Pepys describes a conversation with a Dr. Allen who told him about *Aurum fulminans*, "of which a grain -- put in a silver spoon and fired, will give a blow like a musquett and strike a hole through the spoon downward, without the least force upward."

The striking properties of fulminating gold and silver attracted the attention of Johann Kunckel (1630-1703) and led him to the discovery of fulminate of mercury. This man was an exceptionally able experimenter and an acute observer, and contributed many new facts to chemistry. He is best known for his studies on ruby glass and on phosphorus. He was employed by various German princes and finally by Charles XI of Sweden by whom he was made Baron von Löwenstern and Counsellor of Mines for the kingdom. His most important work, the *Laboratorium Chymicum*, was published after his death, under the editorship of Engelleder. On pages 213-214, he says:

"Further evidence that Mercury is cold is to be seen when you dissolve it in *Aqua fortis* (nitric acid), evaporate the solution to dryness, pour highly rectified *Spiritum Vini* (alcohol) over the residue, and then warm it slightly so that it begins to dissolve. It commences to boil with amazing vigor. If the glass is somewhat stopped up, it bursts into a thousand pieces, and, in consequence, it must by no means be stopped up. I once dissolved silver and Mercury together in *Aqua fortis* and poured it over an excess of *Spiritum Vini*, and set the mixture to purify *in fimum Equinum* (in horse manure) after having stopped up the glass with mere sealing wax only. When it happened a few days later that the manure became a little warm, it made such a thunder crack, with the shattering of the glass, that the stable servant imagined, since I had put in a box, either that someone had shot at him through the window or that the Devil himself was active in the stable. As soon as I heard this news, I was able easily to see that the blame was mine, that it must have been my glass. Now this was with Silver and Mercury, 2 *loth* [1 loth = 1/2 ounce] of each. Mercury does the same thing alone, but Silver not at all.

"No *Fulmina* are produced unless hot and cold come together, and have an wholly subtle earth between them. Now Mercury consists for the most part of such a *Terra viscosa* (viscous earth), for otherwise it would have remained water, and it is therefore called also a dry water which does not moisten the hand. Likewise all *Fulmina* which are made artificially must have such an earth, as is seen in the ease of fulminating Gold, and fulminating Mars, Moon, and Saturn (iron , silver, and lead), which all must be precipitated with a *frigidis* (cold), like *Salt of Urine* (ammonia), C.C. (cornu cerri or hart's horn, i.e., ammonia), etc., or otherwise they give no *fulmen*."

This astonishing experiment no doubt became one of the standard exhibits of street fakirs and mountebanks, along with Kunckel's phosphorus. Liebig, who was born in 1803, saw a fakir prepare and exhibit fulminate of Mercury in the marketplace at Darmstadt when he was a boy. He watched the process with interest, recognized by its color the alcohol which was used, went home, and succeeded in preparing the substance for himself. In 1823, when he was working with Gay Lussac at Paris, he studies the fulminates and isolated fulminic acid.

Silver fulminate, as Kunckel says, is not produced by pouring alcohol alone over silver nitrate. Brugnatelli, however, prepared it later by pouring onto one hundred grains of powdered silver nitrate, first an ounce of alcohol, and then an ounce of concentrated nitric acid. After the fulminate had precipitated, the mixture was diluted with water to prevent it from dissolving again, and immediately filtered.

Edward Howard, who described the preparation of mercury fulminate in a paper before the Royal Society of London in 1800, has generally been regarded as the discoverer of the substance. He dissolved mercury in warm nitric acid, and poured the solution after cooling, into alcohol. This mixture was then warmed to excite effervescence, and filtered for removal of the fulminate as soon as precipitation appeared to be complete. Howard's method is essentially the method which is now in use on a factory scale. The use of fulminate caps for priming the black powder charges of muskets soon came in. Sixty years elapsed after Howard's paper before the observation was made by Alfred Nobel and his father that nitroglycerin could be detonated by means of fulminate. After that, the development of high explosives was rapid.

Kunckel and the Early History of Phosphorus

by
Tenney L. Davis
Massachusetts Institute of Technology
Cambridge, Massachusetts

Journal of Chemical Education 4[3]
[1927]

The discovery of phosphorus followed soon after the discovery of the induced phosphorescence of certain calcium salts, and had an enormous effect not only upon the minds of chemists, but upon the imaginations of intelligent people in general. The new substance shone continuously in the dark, inflamed on slight provocation, burned with a flame extraordinarily brilliant, and wasted away entirely unless it was kept under water. It was exhibited at the courts of princes. It was cried up as a remedy for serious ills. And the everlasting wonder of it was set forth in writing and pictorial art.

Phosphorus appears to have been first discovered by the alchemist Brand of Hamburg, who was unwilling for a time to disclose the method of its preparation. Kunckel saw Brand's material but found it impossible to do business with him, and proceeded to discover for himself the manner of preparing it. It came to be known as *Kunckel's phosphorus*. Robert Boyle also seems to have worked out independently the means of producing it, and in 1680 described the method in a paper deposited with the Royal Society but not published until 1682. Ambrose Godfrey had a hint of the process from Boyle and is reported to have supplied Europe with the article. Hence it was frequently known as *English phosphorus*. The whole early history of phosphorus would make an interesting study. The study would be a book, and the book would be an historical romance. The present paper deals merely with Kunckel's part in the history.

Johann Kunckel (1630-1703) was one of the most competent chemists of the seventeenth century. An exceptionally able experimenter and acute observer, he contributed many new facts to chemistry. He discovered mercury fulminate and nitric ester, and is best known for his work on ruby glass and fulminate. His treatise on glass-making remained the best work on the subject until nearly the end of the eighteenth century. He was employed by various German princes and finally by Charles XI of Sweden by whom he was made Baron von Löwenstern and Councillor of Mines for the kingdom. His most important work, the LABORATORIUM CHYMICUM,[3] was published after his death, under the editorship of Engelleder--and was the source from which Karl William Scheele imbibed his first rudiments of chemistry. It is a book to awaken the enthusiasm for chemistry, for it gives a racy

[3]First edition, 1716. The book has a frontspiece portrait of Kunckel, less interesting than the lively portrait, reproduced herewith, which is the frontspiece of his *Ars Vitraria Experimentalis*, published during his lifetime, in 1679.

account of Kunckel's first experiments and adventures.

In the third part of the LABORATORIUM CHYMICUM, Chapter 34, 649-665, the author gives an account of the two chemical discoveries which he considers to be the most important of the century. They are the discovery of ruby glass, which was developed by Kunckel from the purple of Dr. Cassius, and the discovery of phosphorus. Kunckel's account of the discovery of phosphorus --I include the adventure with Balduin and the phosphorescent calcium nitrate for the sake of completeness -- is as follows.

In the year 1677 there lived at Grossen Hahn in Saxony a certain bailiff of the name Balduin who was a learned, curious, and clever man, and who had company with a certain Doct. Früben who was *Medicus* at that time, for both of them were fallen on the Sproitus Mundi, as they called the material, which they were able to collect and to use by means of a certain magnet. For this purpose they took chalk, dissolved it in spirit of nitre, evaporated to dryness, and left the residuum in the air so that it attracted water to itself. This they abstracted, and they said that the water was a *Spiritus Mundi*. A *loth* of it was valued at 12 *groschen*, and was used by high and low.

Here it can readily be perceived that the belief must have come to fill up of the effect -- for mere rain would have worked as well. In the course of this work it happened by mistake that the spirit of nitre was once evaporated to a hard mass, and consequently that something yellow collected in the neck of the retort. After it had been broken indoors, he threw the neck into a dark corner of the laboratory where he remarked that it glowed like a coal. He observed the phenomenon with wonderment, and remarked further that this light faded again in the dark, and took on light again from the sunlight. With this then he came forthwith to Dresden to the Lord Director of the Privy Council, Baron von Frisen, then to almost all the privy ministers, and finally he came to me. I must acknowledge that I had to marvel greatly at it, but was not able to be so fortunate as to contrive to get any of it into my hands. Finally, impatience drove me to seek him out -- and he treated me in a perfectly couteous manner to agreeable music until evening time, for he excelled on many instruments. I had now discoursed with him a whole day, but his discourse was as orderly as a swarm of bees.

After a light was brought, I asked him if he hadn't observed whether his phosphorus (for so he had baptized it) would not absorb to itself the light from a natural light as well as that from the sun. This was tried, and succeeded when the material was held close to the light. But all the same I couldn't yet get any into my hands. Finally I asked if the light from a greater distance couldn't be thrown into it still better by means of a concave mirror. Full of enthusiasm, he left to fetch one, and in his haste forgot his piece of retort -- which I consequently examined, and I twitched off a little of it, and put it into my mouth. Then he returned with the mirror. I asked if it could be communicated. He said, yes, if I should wish to accept the conditions which they would impose on me and would join their society, then it could be done very well. In sum, I left the matter unsettled, but sent a messenger forthwith to Dresden to the blessed Tutzky, who had been assisting in the laboratory for a long time, and wrote him to make the solution with chalk without delay, to evaporate it directly as strongly as possible, and to let me know the outcome soon by a messenger, while I was still engaged in overtures with him.

This Tutzky, who was also impatient to learn about the matter, speedily smoked off the spirit, put some of the reside on a small capsule under a muffle, cooked off the substance, and produced a yellow crust. There we had the phosphorus. In the meantime I was invited, with the bailiff Balduin, to the mid-day meal at the home of Imperial Privy Councillor von Frisen, who was head bailiff at this place. This gentleman was curious and, as a member of their society, he also knew what sort of conditions they had laid down for me. Among other remarks, the Baron offered the bailiff his spare coach if he had anything to arrange at Dresden. Whereupon I asked if I might not go along with them. Then the head bailiff addressed the bailiff in Latin; he thought we ought first to make a contract. The bailiff made the answer that I should not escape his observation; there was still time enough; I was impatient about it; the Baron ought to be on his guard about me and Tutzky -- we were both shrewd customers. I had to laugh inside that they didn't think I understood as much Latin as that. However, I didn't allow myself to show it, but went forward. When I mounted the coach, the messenger stood there with the phosphorus he had brought me. I forthwith wrote a note for the courtesies which he had shown me and sent my phosphorus to him as a token thanks, while he was even then engaged in a meeting of their society.

The intelligent reader can readily imagine how welcome this letter was. On the strength of it he came to us another time at Dresden and asked if we would still let him have the honor of the discovery, and would not divulge it. This I have made good. We also had to tell him how we prepared it in a test capsule. Then he made a large amount of it, covered it over with glass, and sold it at Leipzig. He also sent emblematic pieces to various courts -- and he had good profit. In this business I didn't meddle with him in the least, although he was inwardly very spiteful to me. He actually made his things larger than he needed it -- because he was so honor-seeking. And all the time I was an obstacle in his way. When he had written his *Aurum aurae*, I asked him how he could have the heart to talk up such things to the world. Didn't he see with his eyes that it was natural verdigris, that the keg or sack of some carrier who had to carry it from Bresslau had become loosened, or a hole might have been worn in it, so that it was thence scattered about in the highway? An intelligent person surely would have asked, why came it only to be on the highway, and not scattered about in the fields and barnyards, if it had fallen with the rain in a thundershower? Now didn't he find for a fact that it gave copper, etc.? Then I suggested the answer: Thus people be made fools of. But I leave it undecided whether that is right. This is now the whole adventure of this phosphorus by which it acquired its name.

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The just-described phosphorus was scarcely a few weeks old when I was obliged to make a trip to Hamburg, and I took one of those glowing fragments along with me. I let someone see it who told me, "There is a man here called Dr. Brand, an unsuccessful merchant who has applied himself to medicine, who has recently made something which glows continuously in the night." This friend also brought it about that I should become acquainted with him. I was curious to see it, but he didn't at that time have any ready except a little stick which he had given to a good friend -- and that I got sight of. Now he had obtained it readily, and in the beginning had done little work on it until he had seen that I was curious about it. I stayed around, but it was always one delay after another. In the meantime, I had written to Herr Crafft at Dresden, and, as soon as he received my letter, took the post, and, unknown to me, came to Hamburg, and sought out this Brand, while he and I were still negotiating, and gave Brand 200 *Reichsthalers* on the condition that he should not inform me about it and should make a few *loth* of the material for him.

Of all this I knew nothing at all, not even that Herr Crafft was in Hamburg. As I now supposed that this Brand would show me all, I went to his chamber -- and Crafft was at the time inside with him. He came outside, and excused himself that he couldn't invite me in; his wife was sick at the time, and he still had someone with him. He said further that he couldn't teach me the art. He wanted to make it again but had been unable to accomplish it. All these pains were spent, so I judged, in order that I might go away empty in consequence. But since he had made it known to a certain woman, and also to me, that it came from urine, I thought that I should accomplish it perfectly well. So I had to go away from Hamburg without success, and was not able to acquire the secret.

But, before I went away, I chanced to meet Herr Crafft and told him the story. He straightaway swore by stone and bone that I would get nothing, for the fellow was very obstinate. I did not know that this B. had finally promised him that he would not disclose it, either to me or to any man, until a certain time, for he had deposited it with the chaplain of the Pest House as a bond. So I had to travel along.

I wrote from Wittenburg and asked him once more, and he gave the same answer as in the first case -- that he could not accomplish the process himself. I persisted. Then he wrote that he had again, by a special dispensation of Providence, discovered the trick (such was the skill of the man), but, because of certain conditions, he couldn't disclose it. Thereupon I again wrote him that I would try my hand at it; and, since could not get it from him, that I should consequently be under no obligation to him if I should discover it for myself. Upon this he wrote me in substance as follows: "I have received the gentleman's letter and see from it that he is half good and half defiant," etc.-- and informed me that he had been under the necessity of meeting the wishes of Crafft who had given him 200 *Reichsthalers*, but after this he had learned that Crafft had already benefitted by it somewhat at the court of Hannover, and, as he had not treated him rightly, he had bidden him farewell and was willing therefore to negotiate with me. But, if I should discover it, then I ought to recall my promise to him, what I had offered him, etc. Wasn't this a sensible request? I had given him as many fine words as I had ever given during my life to any man, but nothing was to be learned from this *Doctor Medicinae et Philosophiae*, as he inscribed himself, and now he wished to obligate me to pay him something if I should discover it myself.

Meanwhile, some weeks elapsed; I grudged neither labor nor expense, and was soon so lucky as to discover it and bring it to the point. The beloved reader has here surmised the true event, that he taught me nothing. Moreover, if he had taught it to me and had at the same time taken 200 *Reichsthalers* from Crafft with a sworn agreement not to teach it to me, then he had behaved like a perjuror to Crafft, and Crafft could indeed have asked back his 200 Reichsthalers. I have heard this Doctor Teutonicus railed at me in a frightful manner, but I don't know whether this is true. Besides, what could be expected from such an impoverished *Doctor*, who had commercialized his study and in consequence knew no word of Latin! Once, when his child's eye was bruised, I told him that he ought to apply a little Oleum Cerae so that it wouldn't turn blue. He replied, "Wat is dat?" "Oil of Wax," I answered. And he said in his good Hamburgish, "*Sü, Sü, dat is ock wahr, ich bedacht mi nicht so balde.*" Hence I have justly styled him *D. Teutonicus*. After his dealings with me, he finally made his secret so common that he accepted 10 *Reichsthalers* for it in his poverty. He taught it to an Italian, who came to Berlin and dealt in processes after the foreign manner, who charged 5 *Reichsthalers* for the secret and taught it to everyone who wanted it. But I have a trick herein, which no one yet knows, which is this, namely, to make this phosphorus perfectly clear like crystal and of greater strength than otherwise. But I don't make any anymore, for a lot of mischief can come from it.

In his OEFFENTLICHE ZUSCHRIFFT, etc., (Open Letter on the Phosphorus Mirabilis and on its Glowing Wonder Pills), published in the year following these adventures, Kunckel describes the properties of phosphorus more fully but comes no nearer to describing the method of its preparation. He had first obtained phosphorus in the form of a "black soap" which glowed in spots and did not shine continuously. He says --

A little of this soap ground up in clear water and shaken about gives a very pleasing light, and some of the particles which remain attached to the glass above the water flash and twinkle like little stars...

This soap has the property that gunpowder put with it and merely left in the warmth of the sun, takes fire of its own accord. Likewise, if only a little is scraped off on the finger and warm gunpowder is touched with it, the powder goes off -- as I have had the very distinguished pleasure of demonstrating to persons of consequence on the principal cities...

A man can write on paper with it, and, if he has a piece only as large as the head of a small pin, he can make unbelievable light back and forth with it on the paper until the little grain is worn off and cannot be seen....

When this Smegma, or the grains, is rubbed with the finger and the hair is striked with it in the night, each hair gives off a glow -- and once seen is a thing to be remembered....

If one writes on paper with it and folds the paper to four thicknesses, it shines through all the leaves. But if one presses them too strongly, the paper takes fire because of the *motum*....

Further, I have something on another subject; a thing which is like an oil and can be used with a pen for writing.--If, in writing, the pen is pressed a little too hard, the paper takes fire. Now this, more than the other, has a wonderful, secret, hidden power, and so must be guarded against the air, or kept under water in order not to waste away entirely.

I have something on still another subject: a thing which is so subtle that, if it is allowed to warm up on the bare hand, it forthwith inflames and gives a furious fire. The *residuum*, which is left behind, shows an orange color and flashes and shines like the *Smegma*.

The last-quoted passage appears to contain the earliest known reference to the red modification of phosphorus.

Kunckel even recommended pills of phosphorus for internal use, and coated them with gold and silver -- evidently by allowing the pills to stand in contact with solutions of these metals. He apparently noticed that this treatment increased the weight of the pills and concluded that it therefore increased their efficacy, for he points out, in passing, that fulminating gold weighs more than the gold from which it is made hence that this same (whether the increase of weight or fulminating power is not clear) comes from the menstruum.

When fulminating gold is made, the same gold comes out heavier than it weighed before, not that the gold is heavier, but that the same comes from the menstruum, as I have already set forth in my earlier treatise.....

I am the first to have devised a method of producing conformance-pills which are gilded and made from the rarest portions of this Wonder-Light, which are proper for the health of man, and compounded with my spirituous gold essence as well as with certain other things. One or two of these pills taken evening and morning will save a man, with the help of God, from all fear of apoplexy or of other sudden sickness during the day. They counteract all noxious and poisoned airs and are a right Antidotum against the pestilential poison. They strengthen and support the vital spirit in man....

If a man has an inner pain and no rest from it, let him take, according to the convenience of the person, one, two, or even three, and, before an hour has gone by, he will perceive the singular effect of them. They will not only allay the pain but, in a singularly remarkable manner, without damage, will supply the needed rest....

They cause no vomiting nor any inconvenience but act in a mysterious manner and are applicable in serious sickness and pain....

To little children a few weeks of age, who frequently cry night and day and have no repose, let there be given a half or, according to the age of the child, a whole, of one of these pills in mother's milk or in clove (?) water, then the singular effect will appear that the pain is allayed and the child comes to repose.

The third chapter of the "Open Letter" describes the Phosphorus Mirabilis or Wonder Stone, which no doubt was the wax-like phosphorus, "perfectly clear like a crystal and of greater strength than otherwise," which Kunckel claimed as his own particular secret. The products were on sale at Leipzig at the apothecary shop of Heinrich Linken who charged 3 *Reichsthalers* for a piece of the "stone" and one *groschen* for a pill.

Although Kunckel did not disclose the method for the preparation of his phosphorus, there seems to be every reason to believe that he accomplished it, as did chemists for some time after him, by evaporating putrid urine to the consistency of a sirup, mixing with sand or brick dust, and distilling at a high temperature from a fortified (coated with clay) retort, the beak of which delivered under water in the receiver. The silicic acid of the sand or brick dust liberated phosphoric acid from the phosphates of the urine, and this was reduced by the carbonaceous material that was present.

Boerhaave in his ELEMENTA CHEMIAE[4] tells a good story about phosphorus, a story which shows the imaginative appeal of the marvelous properties of this substance. As the story also contains a moral, and as a moral is commonly accepted to be the proper ending of a romance, the story may fittingly supply an ending to the present contribution to the romance of the early history of phosphorus.

There is a story of a Tutor, who after all other endeavors to no purpose, by a contrivance borrowed from Chemistry, happily reclaimed a noble youth, who by his dissolute life brought disgrace both upon himself and family, and seemed past all hope of amendment; and this was in the following manner: One night as he lay in the same room with this young gentleman who was fast asleep, he got out of bed softly, and with some English Phosphorus wrote his name in large letters on a board that was at the foot of the bed, and added three words, intimating that if he did not immediately repent, he must expect to die in a very short time. When he had done, without disturbing his pupil he stole gently to his bed again, but then made a great noise on purpose to wake him, and laid himself down as if he was asleep. The youth presently started up in his bed, and listened attentively in order to discover the occasion of his surprize, but heard nothing except the snoring of the other, who feigned himself asleep; but looking accidentally towards the foot of the bed, he saw some letters shining with a blue light which vastly astonished him. Upon this, he calls to his companion, and shews him the writing; who making as if he knew

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[4]Boerhaave, "Elementa Chemiae," Ludguni Batavorum, 1732, vol. I, pp. 106-107. The English is from Dallowe's translation, "Elements of Chemistry: Being the Annual Lectures of Herman Boerhaave, M.D., etc." London, 1735, vol. I, pp. 66-67.

nothing at all of the matter, professed that he did not see anything, which so much the more increased his terrour. The servants who were not in the secret, were then called to bring in some candles, upon which the letters disappearing, they declared, too, that they saw nothing; and indeed the youth himself was astonished to find that the writing was vanished. The servants went away again, but left a candle to shine upon the board; the tutor sets down by his pupil and persuades him to go to sleep, tells him 'twas only a dream, and then goes to bed himself, and puts out the candle. As soon as the room was dark, the youth no sooner looked towards the fatal place, but he again saw the same letters, at which being very frightened, he cries out, and begs his tutor to come to him; who then pretending himself to be afraid, confessed that he did indeed see the writing, and that not without a great deal of astonishment; and then took this occasion to admonish him sincerely to repent, in obedience to this Miracle, and calling for a candle spent the remainder of the night with his pupil, who was under great concern, and was brought by this means to a better way of life.

Roger Bacon's Gunpowder and His Secret Wisdom[5]

by Tenney L. Davis
Massachusetts Institute of Technology

Industrial and Engineering Chemistry[4]
[1928]

The earliest known description of black powder in a European language appears to be that which occurs in a letter of Roger Bacon (1214-1292) "On the Marvellous Power of Art and of Nature and on the Nullity of Magic," a letter evidently written to some high dignitary of the church for the purpose of defending its author against the charge that he was guilty of the practice of magic. Bacon argues that many things reputed magical are really due to the operations of nature. He points to the deceits which are practiced by jugglers and ventriloquists, distinguishes the real psychotherapeutic value of charms from the unreal magical efficacy which is ascribed to them, speaks cautiously of the power of personality and seems to show a slight acquaintance with the phenomena of hypnotism, tells of pulleys and optical devices, and points out that self-propelled vehicles, underwater craft, and flying machines are perfectly possible by natural means without any magic whatsoever. He speaks of other natural wonders "which do not involve particular constructions," of Greek fire, and of a material by which "the sound of thunder may be artificially produced in the air with greater resulting horror than if it had been produced by natural causes." Finally, after discussing the various matters which influence health and the length of life, he says that he wishes to deal with certain special secrets in particular. "But I recall that secrets of nature are not to be committed to the skins of goats and of sheep [that is to vellum and parchment] that anyone may understand them." He speaks of the ignorance of the viulgar crowd and of the manner in which it abuses great truths which it does not understand. "A man is crazy who writes a secret unless he conceals it from the crowd and leaves it so that it can be understood only by effort of the studious and wise." He enumerates seven ways of concealing secrets, by characters and symbols, by enigmatic and figurative expressions, etc., and adds, "I have judged it necessary to touch upon these ways of concealment in order that I may help you as much as I can. Perhaps I shall make use of certain of them because of the magnitude of our secrets." The remainder of the letteris devoted to three descriptions of the Philosophers' Egg, by which name Bacon means blacl powder, and, unlike the earlier portion, is written in an obscure and almost incoherent style. Many have considered it, for this reason, to be spurious. The secret wisdom with which the author of the latter part of the letter was certainly acquainted gives strong support, on the other hand, to the belief that it was really Roger Bacon who wrote it.

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The Philosophers' Egg

The first account of the Philosophers' Egg, if read between the lines, describes a purification of the "aerial stone" by a process of crystallization. "Let it then be dissolved *** with gentle heating***and let it be boiled until its scum has separated *** until it is purged and whitened. ***The distillation is repeated in order that it may sufficiently take on the right degree of goodness until it is rectified *** and the newest signs of the rectification are candor and crystalline serenity. When other things are blackened by the fire, this is whitened, and is purified, and shines with serenity and marvellous splendor. *** When the substance has been whitened in this way, it is frozen -- the true aerial stone, *** and is placed in a pyramid in a warm place." The material crystallizes out and is made into a heap to drain and dry. "Or, if you wish, it is put away in the belley of a horse or ox in acute fever," language which an alchemist would have no difficulty in interpreting to mean that it is put away in a place where a moderately elevated temperature is maintained by artificial heat. The first description of the Philosophers' Egg further disclosesthat two other substances are necessary, one of such sort that "it is not possible that its humidity should be separated by vapor" -- perhaps an obscure reference to charcoal, for charcoal gives off no volatile matter on heating -- and the other of such sort "that it is consumed by quicksilver and is sublimed from it until a powder remains." This latter substance is plainly sulfur, for the power of that material to accomplish the fixation of mercury was well known to the alchemists.

The second description of the Philosophers' Egg make mention of another substance, presumably wood ashes, which is to be used in the crystallization, and devotes considerable attention to the recovery of material from the mother liquors. "If to this, the hot liquor be added four or five times, you will have finally the proposed material *** Then bring together the powder and the residual water, andd squeeze it out thoroughly -- for the unsubstantial water of a certainty will produce a further amount of powder. For this reason, collect the water by itself, for the powder exsiccated from it is suitable to be incorporated in the *** medicine." And again, "Stir it with a pestle, bring the material together as well as you can, separate the water little by little. *** Dry out this water, for it contains both the powder and the water of the medicine which are to be incorporated in the same manner as the original powder." The statement, "If you know how properly to make use of certain parts of burned shrubs or of willow or of many other things, they will hold natural union," is an obvious reference to charcoal. Charcoal from willow and from beech is still preferred for the manufacture of black powder. The sentence, "You must do these things with the vapor of Pearl and with the stone of Tagus," makes other disclosures, for the stone of Tagus is saltpetre, so called because Arabic chemists had found that substance in the city of Toledo on the Tagus River. The expression "vapor of Pearl" evidently refers to the pearly appearance of a sulfur sublimate.

The third account of the Philosophers' Egg contains the following:

> *Sed tamen salis petrae* LVRV VO PO VIR CAN VTRIET *sulphuris, et sic facies tonitruum et coruscationem: sic facies artificium. Videas tamen ultrum loquor in aenigmate, vel secundum veritatem.*

> But however of saltpeter LVRV VO PO VIR CAN VTRIET of sulfur, and so you will make thunder and lightening, and so you will make the artifice (or turn the trick). But you must take note whether I am speaking in an enigma or according to the truth.

Note -- Instead of *sic facies artificium*, some versions read *si scias artificium* -- if you know the trick. The anagram in some versions appears to have been corrupted and read: LVRV MOPE CAN UBRE or LVRA NOPE CUM UBRE, and makes *carbonum pulvere* (powdered carcoal) an obvious and easy solution. The more difficult anagram quoted above is generally accepted as authentic.

Saltpeter and sulfur are now plainly mentioned. The unintelligible letters evidently conceal the third ingredientand perhaps the proportion in which the several ingredients ought to be taken. The Englishman, Lieutenant Colonel Hime[6] has rearranged the letters and offered a solution of the anagram --

R. VII. PART. V. NOV. CORVL. V. ET

the R stands for the imperative, recipe, take, and is the same as the Rx of a physicians prescription. PART, NOV, and CORVL are roots without case endings and represents a method of abbreviation which was common among the Latins. The passage now reads, "But however, of saltpeter take seven parts, of new (or young) willow (charcoal) five, and five of sulfur, and so you will make thunder and lightening," etc.

Hime's solution of the anagram seems plausible enough. Yet it is apparent that alternative solutions are possible. The position of the VII could be exchanged with that of either of the V's to make the formula call for five parts of saltpeter, for seven of one of the other ingredients, the two I's could be distributed and the formula then would require six parts of two of the ingredients and five of the other, or the I's could be placed after NOV and CORVL, respectively, which would make the formula call for equal parts of all three substances. The criterion for determining a choice between the several alternatives, though overlooked by Hime, is to be found in the letter itself. In addition to the anagram, Bacon set forth the composition of his mixture in an enigma by which the solution to the anagram may be tested.

A few lines above the anagram the following passage occurs:

> *Accipiatis igitur de ossibus Adae, & de calce sub eodem pondere, & suni sex ad lapidem petralem* (in some versions this reads ad lapidem Tagi, but in either case saltpeter is signified. All versions agree on the six-five ratio.)*, & quinque ad lapidem unionis, & terantur simul cum aqua vitae ***; deinde ponatum in eadem aqua loco humido, aut suspendaturin vapore aquarum valde calidarum, & liquidarum; deinde congelatur ad Solem.*
> *Take then the bones of Adam and of the Calx, the same weight of each; and there are six of the Petral Stone and five of the Stone of*

[6] J. Roy. Artillery, July, 1911, also the chapter, "Roger Bacon and Gunpowder," in the volume, "Roger Bacon Commeration Essays," edited by Little, Oxford, 1914.

Union. Let them be ground up together with aqua vitae ***. Then it is placed in the same water in a moist place or suspended in hte vapor of hot water or some other liquid, and finally it is congealed in the sun.

The bones of Adam are evidently charcoal, the surviving part of once living matter, and the Calx is perhaps sulfur. But the significance of the latter term is unimportant, for the enigma says in any case that equal parts of charcoal and one of the other six ingredients are to be taken. It is stated further that six parts of saltpeter are to be taken for every five of the Stone of Union. The precise nature of the Stone of Union is not a matter of consequence; it is enough to know that it is one of the ingredients not saltpeter. Since the composition contains three ingredients, the solution of the enigma is easy -- six parts of saltpeter, five of charcoal, and five of sulfur. The correct solution of the anagram then is as follows:

R. VI. PART. V. NOV. CORVLI V. ET

The 6:5:5 formula for black powder does not correspond to very good material. Nevertheless, such powder would be satisfactory for the filling of firecrackers such as Bacon describes in another of his works. Guns were first used in Europe about fifty years after his death, the optimum composition for gunpowder was sought out, the 6:1:1 formula was soon chosen -- and for several centuries no great departure has been made from it. At the present time all black powder for sporting or military purposes approximates to the composition -- 75 per cent saltpeter, 12.5 per cent charcoal, and 12.5 per cent sulfur.

Although Roger Bacon had no knowledge of guns, he seems to have seen the possibilities in his material, for he closes his letter with the statement: "Whoever will rewrite this will have a key which opens and no man shuts: and when he will shut no man opens." The statement is perfectly apt, for there is a finality about the things which are accomplished by means of an explosive. It is further remarkable because it so fittingly describes black powder in the language in which the book of Revalation describes the key of David:

> And to the angel of the church of Philadelphia write. These things saith he that is holy, he that is true, he that hath the Key of David, he that openeth, and no man shutteth; and shuteth and no man openeth. I know thy works: behold, I have set before thee an open door, and no man can shut it. --*Rev*. 3:7,8.

The Three Contraries

After having described the preparation of black powder, Bacon says, "When you have this you have many things simple and equal, and you may accomplish it by means of the three contraries and the several operations that I have earlier called the Keys of the Art." The three contraries are

Note -- The first description of the Philosophers' Egg ends as follows: "The keys of the art are therefore congelation, resolution, inceration, and projection, and this is the end principle. Bur purification, distillation, separation, sublimation, calcination, and inquisition are also used -- and then you may rest."

knowledge and will power. Bacon speaks truly when he says that with these the thing may be accomplished. They are the secret of the winged Sphinx, one of the oldest mysteries.

The intellectual activity of mankind, like that of the individual, had its beginning in the distintion between yes and no, in the perception of what the logicians call the "Law of Contradiction" -- namely, that a given proposition is true or it is not true, that a given object is x or it is not x. The beginning of mental activity isin the perception of two contraries. This dichotomizes the universe, it separates the day from the night, the light from the darkness. In the beginning there was chaos, but presently it was distinguished into contraries -- and classification, thinking, science had commenced. The idea of a pair of contraries was ancient and very well known. So was the idea of the third -- thereby the occult potency of the three -- the mediating third by which the two contraries were neutralized and unified, as the idea of temperature mediates between hot and cold. These things were mysterious, but they were not secret. They were comprehensible, for they are the way the mind works.

The mind does not readily distinguish three contraries; it looks for two. The perception of three terms, each of which is contrary to two others, comes as something of a shock. The observation that knnowledge and will and power actually fulfill thhe conditions is an agreeable surprise, a surprise wich might make a man feel that he had here transcended ordinary human experience and had attained to a special insight into the order of things. Certainly the observation is one which has given to man a splendid rule for the conduct of his like, perhaps the noblest and profoundest ethics which has been conceived. The fourth term, by which knowledge and will and power are mediated and reconciled, was the secret of secrets. It is *intelligent restraint.*

An ancient story tells how the neophyte after days of preparatory fasting, after being bathed and perfumed, was at last conducted through the concluding ceremonies of his initiation into the priesthood. He was led through a colonnade which consisted of three principle archways. Over the first were the words "Be Bold." He was stopped and instructed to reflect upon them. Over the second were the wwords, "Be Bold; Be Bold; and Evermore Be Bold." He was advised to think boldly and to aspire no matter how remote the end. Over the third were the words, "Be Bold; But Not Too Bold." And here he was cautioned that his boldness must be tempered by a wise moderation and intelligent restraint.

When the various qualities of the Sphinx were pointed out, it was usual to enumerate them in a special sequence in order that their lesson might be shaped in a more pointed moral. The man's head symbolizes science, knowledge, intelligence. The eagle's wings symbolize audacity and the power to accomplish. The lion's claws, symbol of will, indicate desire. And the flanks of a bull, symbol of controlled force, mean silence and restraint. The priest who pointed out these things was accustomed to say to the newly initiated member -- "It is necessary to know in order to dare, to dare in order to want, and it is necessary to be silent to have empire."

The three contraries are rarely mentioned in hte books of the alchemists, for they appear to have been known only to a few of the most learned. Bacon's mention of them is evidence that his letter was written to one who understood secrets, to one who would be confidently expected to discover its puzzling contents.

Chemical Flower Gardens

by Tenney L. Davis '13

Technology Review
[1933]

Depression flower gardens which have recently appeared in so many homes, which are being discussed in business offices, in the newspapers, and at teas where the ladies forgather, may be prepared by mixing:

6 tablespoonfuls of salt

6 tablespoonsful of bluing
6 tablespoonfuls of water
1 tablespoonful of ammonia water,

and pouring the mixture , after thorough mixing, over a clinker in a suitable dish. Not quite all of the salt will dissolve, but let the undissolved portion be poured out along with the rest. Instead of a clinker, a piece of coke, or of common brick, or a mass of coal ashes may be used, but a clinker has the best degree of porousity and is probably best. After the clinker has been wet with the liquid, , drop on it a few drops of mercurochrome solution or of red or green ink, or of any other colored liquid which is handy. But do not use iodine, for this reacts with ammonia water to form the dangerously explosive nitrogen iodide, a black powder which is safe so long as it is wet, but exlodes with a loud report from a very slight shock when it is dry. Within 10 or 15 minutes after the materials have been brought together, a coral-like growth begins to appear on the clinker. This increases rapidly; within a few hours the clinker is entirely covered with a growth which is colored in part by the bluing and in part by the mercurochrome or other color which was used. The color of the bluing fades in time and changes to brown because of a chemical reaction with the ammonia. The colors produced by aniline dyes, ink, mercurochrome, and so on are permanent.

The growth also tends to form on the edges of the dish and will climb up and over them unless they have been rubbed with vaseline. The growth will not extend beyond the vaseline.

The "depression flower garden" is a capillary phenomenon involving hte tendency of ammoium salts to "creep." The saturated solution deposits crystals around its edges and upon the clinker where the evaporation is the greatest. The crystals are porous, and act like a wick, sucking up more of the solution by capillary action. The solution thus sucked up evaporates to produce more crystals, more wick, and more growth. The addition of a little more ammonia water to the dish will produce more growth after the first growth has stopped. Or the whole may be allowed to dry and may then be kept without further change.

The idea of the "depression flower garden" is by no means new. In the years 1705, 1706, and 1707, the chemis Nicholas Lemery published in the memoirs of the French academy papers in which he described "vegetations" produced by the spontaneous evaporations of salt solutions. His papers were accompanied by engravings...Lemery secured his vegetations by the use of salts of iron and wrongly concluded from his experiment that iron is therefore necessary for the growth of plants.

One who makes a depression flower garden might be tempted to infer that ammonia is necessary for teh growth of plants. This would be a wrong inference from the experiment, but it would be a correct judgement, for it is true that ammonia is essential to the growth of nearly every kind of vegetable organism.

The "mineral flower garden," which florists sometimes sell or display in their windows, depends upon an entirely different principle, that of osmosis, or of osmotic pressure. A solution of sodium silicate, or "water glass," is poured into a jar or globe, and crystals of readily soluble salts of certain metals which form colored and insoluble silicates are thrown in and allowed to sink to the bottom. Growths resembling marine plants spring up from these crystals and in the course of a few minutes climb rapidly upward through the liquid, often branching and curving, producing an effect which might lead one to believe he sees exotic algae growing in an aquarium. The experiment works best if the solution of water glass is diluted to a specific gravity of about 1.10.

Ferric chloride produces a brown growth; nickel nitrate, grass green; cupric chloride, emerald green; uranium nitrate, yellow; cobaltous chloride or nitrate, dark blue; and manganous nitrate or zinc sulfate, white.

If one of these salts, say feric chloride, were dissolved in water, and the solution were mixed with a solution of sodium silicate, there would be an immediate precipitate of brown ferric silicate. When the crystal of ferric chloride is dropped into the sodium silicate solution, it immediately commences to dissolve, and tends to become surrounded by a solution of ferric chloride. But the solution of ferric chloride at once produces a precipitate at the points where it meets the solution of sodium silicate. The result is that the crystal of ferric chloride, surrounded by a solution of ferric chloride, is enclosed within a little sac or skin of precipitated ferric silicate. More of the crystal dissolves, and the solution within the sac tends to become more concentrated. Water from the silicate solution diffuses through the skin, tending to dilute the concentrated solution of the ferric chloride and building up an osmotic pressure within the sac, a pressure which finally breaks the skin, at the top where the external pressure is least, and releases more ferric chloride solution which comes into contact with the silicate solution to produce a new skin. And the process repeats itself rapidly, producing a growth which is rapid enough for the eye to see.

The experiment wirks best with readily soluble salts, for these dissolve more rapidly and they form more concentrated solutions which have greater osmotic pressures.

The middle "flower gardens" may be kept indefinitely if they are protected from the air and not shaken or disturbed. The carbon dioxide which is present in teh air, if it has access to the silicate solution, would make the solution become milky in the course of a few weeks.

Much-Maligned TNT

by Tenney L. Davis

The Technology Review[5]
[1932]

"The things that can claw, and the things that can gore,
Are very untrustworthy things;
And a man with a sword in his hand, furthermore,
And rivers, and women, and kings."

So Bhartrihari warned about 1500 years ago. According to popular opinion, TNT and high explosives in general ought to be added to the list, for these, too, are commonly thought to be among the most dangerous things there are. The word, high, when used in connection with explosives, seems to many to convey the idea of high-strung and quick-tempered. TNT, in the movies and in the daily press, has become symbolic of all that is powerful and hazardous, dangerous and uncertain, of all that must be handled with circumspection if the direst of consequences are to be avoided. But its evil reputation is not entirely deserved. It is powerful, to be sure, but it is not unreliable, and it is not so tremendously powerful when all things are considered. The explosion of a pound of TNT liberates an amount of energy of the same order of magnitude as that which a pound of sugar used as food in the human body. It acquired its reputation by doing precisely the thing which was expected of it, promptly and without waste of effort. It is as trustworthy in its action as opium or alcohol.

TNT is one of the safest of the high explosives, and for military purposes is the most important. In appearance it is a buff-colored crystalline powder resembling brown sugar. If a bottle containing TNT should be dropped upon a concrete floor, the bottle would be broken, but the TNT would not explode. TNT loaded in a tin canister is not exploded by the impact of a high-power rifle bullet. Tetryl, the high-explosive which is universally preferred for boosters, ios exploded under the same conditions, but it is not exploded by the impact of any rifle bullet if it is loaded in a pasteboard carton. Cyclonite is exploded even in a pasteboard box.

Thus, TNT is but little sensitive to shock. If loaded into a shell, it will stand the "setback" which occurs at the moment that the projectile starts to move in the barrel of the gun. Dynamite will not stand such shaking up. It is too sensitive for military use, and would, if loaded into a shell, blow the gun to pieces before the projectile could get started on its way. TNT will stand the impact of the shell against ordinary structural materials, and in practice the shell is made to explode by means of a fuse and relay device, after it has penetrated the target. TNT will not, however, tolerate the shock of impact against the heavy armor plate of battle cruisers, and armor-piercing shells are loaded with explosives which are even less sensitive in order that they may explode, not when they strike the ship, but after they have reached the inside of it.

TNT melts at a temperature below the boiling point od water, and is generally loaded into shells by pouring. If a small quantity of TNT is heated carefully in a test tube, it vaporizes and the vapors condense again in the form of crystals on the upper and cooler portions of the tube. Unless great care is exercised in this experiment, the TNT "puffs off" and disappears in a small cloud of smoke by a rapid decomposition which is hardly an explosion and does not injure the tube. TNT burns with a smoky flame which is easily blown out if the amount of the substance is small. If the amount is large, as in a warehouse filled with the explosive, the situation is entirely different. Increased temperature increases the rate of chemical reactions. The heat of the burning raises the temperature of the material which is about to burn, the combustion becomes more and more rapid, and finally detonation sets in. It may be that the heat shakes up the molecules until they attain the velocity of detonation of TNT. It is also true that all high explosives are most sensitive to shock when they are warm.

TNT has a velocity of detonation of about 17,300 feet per second. That is, if a long tube is loadedloaded with the explosive, and if detonation is started at one end by the firing of a blasting cap, then the explosion, or the explosive wave, travels along the column of TNT with a velocity of about three miles per second. It is this brissance which makes TNT so damaging.

At the present time there is no real need for more powerful explosives. TNT is powerful enough for such needs as now exist or can be forseen. We could get along with less powerful explosives. Stronger ones would break our shells into fragments too small to produce the havoc which shells are designed to accomplish. Cheaper explosives are needed, explosives which can be manufactured from raw materials of which the supply is abundant or unlimited, and explosives which are more insensitive than TNT but equally certain in their functioning.

Notes on Gunpowder

by Tenney L. Davis

The Technology Review[6]
[1932]

Since the World War we have heard little about advances in military science, particularly ordnance. In an effort to fill the gap we have lately been asking questions about gunpowder and, happily enough, Professor Tenney L. Davis, '13, one of our contributing Editors, has answered them, he being an authority on explosives.

What are the disadvantages of ordinary black powder?

Black powder burns to produce a voluminous white smoke, which of course helps to show the enemy the position of the battery, but the smoke has another more serious disadvantage. The smoke constitutes about 54% of the weight of the original powder. It consists of finely divided solid matter, not gas, and it is the gas from the powder which causes the motion of the projectile. The smoke, therefore, represents, out of 100 pounds of powder, about 54 pounds of weight which is not convertible into projectile velocity. Black powder burns quickly. In an exceedingly short interval of time it changes from a compact solid to a voluminous and hot mass of smoke and gas. There is a large and sudden rise of pressure behind the projectile. The projectile starts to move under the force of this pressure, the gas expands and the pressure drops, and the projectile when it reaches the muzzle is actually moving less rapidly than it was a moment earlier further back in the barrel of the gun.

The sudden pressure produced by the burning of black powder is well-known to everyone who has felt the kick of an old-fashioned shot-gun. The effect upon the projectile is that of a sudden and powerful but momentary blow from behind, not the effect of a persisting push. Cannon which used this black powder were heavy and unwieldy weapons, built to withstand the high and sudden pressure, very thick at the breach, and tapering, but still very thick at the muzzle.

Black powder is stable and will last forever if it is kept dry and is left to itself. During the Great War the French used, in the igniter bags of their modern artillery, black powder which had been made for Napoleon's army and had long been in storage. Indeed they regarded this old powder as something very special and choice, perhaps because of their habit of dealing so generally with a commodity which really does improve with age. But the powder had been kept dry.

What are the characteristics of modern powders and how have they been improved?

Smokeless powder produces a small amount of thin grey smoke, but otherwise it burns completely into hot gas which pushes the projectile. It is very much more powerful than black powder. Its history is the story of making it slower, making it stable, making it cool-burning, making it water-proof or indifferent to moisture. Our present smokeless powder is probably stable enough to last for 20 years, no more. And we have special smokeless powder which is so cool that it gives no visible flash from the muzzle of the gun.

When nitrocellulose or guncotton was discovered, its explosive power was recognized at once and it was tried in cannon, in the sturdy cannon of the time which were designed for use with black powder. But the nitrocellulose burned so rapidly that it blew the cannon to pieces before there was time for the projectile to be started.

By converting the nitrocellulose into a homogenous colloid and shaping this into grains, a powder was secured which burned more slowly, more slowly even than black powder. English Cordite and Italian ballistite are colloids of nitrocellulose with nitroglycerine. They are indifferent to moisture because of the oily nature of the nitroglycerine which they contain, and they are powerful and hot and erosive in the gun. French, Russian, and United States powders are "straight nitrocellulose" colloids. They are cooler and less erosive than the nitroglycerine based powders. They take up moisture from damp air, and must be shipped in sealed containers. The powder for our military rifles consists of small, short, cylindrical grains, thinner than the lead of a lead pencil, each grain having a single perforation. The larger grains for the larger guns have seven perforations. A single grain of the powder for the 12 inch gun, for example, is a multi-perforated cylinder about three quarters of an inch in diameter, about an inch and three-quarters long, and weighing about three-quarters of an ounce. It almost seems unreasonable to call such a thing a "grain."

Colloided powder burns slowly. It is possible to hold a grain of convenient size, say a grain of powder for the 75mm gun, between the thumb and forefinger and to light it with a match and then blow it out, and the process may be repeated two or three times without burning the fingers. The grains are "progressive burning," that is, they burn from the point at which they are lighted. When the flame from the primer or igniter sweeps into the chamber of the gun, the grains begin to burn all over their surface. They burn from the outside inward, and from the perforation outward. A single perforated grain thus has a constant burning surface until it is entirely consumed -- a simple matter of geometry -- and a multi-perforated grain has a burning surface which increases as the burning progresses. The production of heat in the chamber further increases the rate of burning. In consequence, the powder gases *push* the projectile and continue to push it with an ever-increasing pressure until it emerges from the muzzle of the gun, at which moment, if everything has been designed correctly, the powder is burned completely. Lighter guns are possible, and rifling which imparts a rotary motion to the projectile and greater stability in flight. High velocities are attained. The bullets from our military rifles have a velocity at the muzzle of something over a half a mile a second.

The gases which follow the projectile from the muzzle are white hot and dazzlingly brilliant at a temperature of 2,700° to 2,900° C. The flash from a 16 inch gun has been known to singe the fibers of a rope 150 feet distant from the muzzle. Although the sound from such a gun is not audible more than 6 miles away, the flash may be seen at a distance of 30 miles.

By the introduction of suitable materials into the nitrocellulose colloid it is now possible to produce powder which is as powerful, weight for weight, as the standard service powder, but which is entirely flashless in many of the guns. Two best ways of accomplishing the result are by the admixture of a cool explosive like nitroguanidine (which alone explodes to produce temperature of 907° C.) which gives a larger volume of gas at a lower temperature, and by introducing some carbonaceous material into the colloid in such manner that, while the nitrocellulose alone would produce one molecule of carbon dioxide, the nitrocellulose plus the carbonaceous material now produces two molecules of carbon monoxide, or more gas at a lower temperature. Nitroguanidine is soluble in water, but the second method is applicable to nitroglycerine-nitrocellulose powders and yields a powder which is both flashless and entirely indifferent to moisture.

Flashless powders produce somewhat more thin grey smoke than does ordinary smokeless powder, but they produce no visible flash and, being cooler, are less erosive and give longer life to the gun. At night they give a dull red glow in the neighborhood of the muzzle, similar to the glow of a cigarette, and the glow is not visible for more than a hundred yards or so. The glow is entirely without actinic power and does not affect a photographic plate.

We have powder which is smokeless, flashless, cool, and indifferent to moisture, but the powder is not yet stable and can probably not be depended upon to last longer than two decades. The best opinion appears to be that a smokeless, flashless, non-hygroscopic, and perfectly stable powder, when it is made, will not be made from nitrocellulose.

The New Bomb Bogey

by Tenney L. Davis

The Technology Review[7]
[1938]

A war-jittery world, fooled even by a radio play describing an attack from Mars, has read with horrified acceptance news reports of a dreadful new liquid-air bomb devised and used in Europe. To get the facts about this type of bomb, The Review went to an authority on explosives, and here are his comments. **The Editor.**

If a mass of absorbent combustible material, say a paper cylinder filled with wood pulp or powdered cork or spongy aluminum, is dipped into liquid air, the liquid air is absorbed by the combustible material -- as water is absorbed by blotting paper -- and the resulting mass is a powerful and sensitive high explosive. The paper cylinder becomes a cartridge of dynamite. It may be made to explode conveniently by means of a blasting cap. But since it is rather sensitive to shock, it may also be made to explode accidentally by improper handling. Liquid-air explosives, or liquid-oxygen explosives, have clear cut advantages and disadvantages and have definite limitations to their usefulness.

Liquid-oxygen explosives are so sensitive that they cannot be safely transported from place to place. They are conveniently used by loading the non-explosive combustible material into the place where the explosive charge is desired and then by pouring upon it as much liquid air as it will absorb. Thus, the explosive is manufactured in the very place which it is to explode. Another reason why it is not desirable to move liquid-oxygen explosives from place to place is that they are transitory. The liquid air evaporates, and the material ceases to be an explosive. This property of the explosives gives them a great advantage for certain purposes. If a stick of dynamite fails to explode after it has been loaded, it is thereafter decidedly unsafe for a workman to go into the place with pick and drill. But an unexploded cartridge of a liquid-oxygen explosive retains its explosibility only for an hour or two and thereafter may be battered by pick and drill as safely as any other inert material.

The facts that liquid-oxygen explosives must be prepared immediately before they are used, that they will not keep, and that they are readily sensitive to shock render them unfit for strictly military uses. If they could be loaded into shells, the shock of shooting them from a gun would make them explode before they had left the barrel. The gun would be destroyed, and the artillerymen would be killed.

Subject to their limitations, liquid-oxygen explosives are still useful (and cheap) for civil purposes and for the pseudo-civil purposes of the military engineer. During the World War the German military engineers used them behind the lines for demolition purposes. The liquid-air was brought into the place in large steel, vacuum-jacketed cans, built like huge thermos bottles, in which the liquid air -- kept cold by its own evaporation -- could be preserved for a long time. Nothing, of course, could prevent its ultimate evaporation. Sometimes the liquid air was prepared where it was to be used, by portable liquefying machines transported by motor truck.

Liquid oxygen constitutes about one-fifth of freshly prepared liquid air and a larger proportion of older material from which part or all of the more volatile liquid nitrogen has been allowed to evaporate. Liquid air and liquid oxygen, however, are to all intents and purposes the same thing as far as the preparation of liquid-oxygen explosives is concerned. Liquid oxygen boils at -182.5 degrees C. at atmospheric pressure. At higher pressures it boils at higher temperatures (at about 50 atmospheres it boils at -118.8 degrees C.), and it cannot be kept in the liquid state above -118.8 degrees C. no matter what the pressure which is put upon it. If a quantity of liquid air at a very low temperature is confined in a strong, closed vessel and allowed to warm up, the vessel at ordinary temperature will contain compressed air, not liquid air. The pressure of the air will be enormous, and the vessel will have to be exceedingly strong to hold it. Such a vessel would evidently not make a practicable shell to shoot from a gun or a bomb to drop from an airplane.

If liquid-oxygen explosives could be loaded into bombs and if such bombs could be carried by airplane, they would still not be suitable for military use because of their great sensitivity to shock. An enemy bullet striking the bomb would certainly cause the destruction of the airplane which was carrying it. The only conceivable way in which liquid oxygen could be used practically in an explosive drop bomb is one in which the liquid oxygen is added to the combustible material, that is, one in which the actual explosive is formed, after the bomb is in flight.

During the World War the French had drop bombs which contained no explosive at all while the airplane was carrying them. Within the bombs were two compartments. One was filled with liquid nitric oxide, an oxidizing agent which liquifies readily and remains liquid at ordinary temperatures when confined under slight pressure; the other compartment contained a combustible liquid, ordinarily either gasoline or carbon disulphide. An enemy bullet striking the bomb would destroy it, of course, but would not make it explode. When the bomb was released from the airplane, the little propeller on its nose, actuated in flight, caused a valve to open and the two liquids to mix. The bomb was thus filled with a sensitive and powerful high explosive. The bombs exploded upon impact against the slightest obstacle and were therefore more useful against personnel than for the destruction of buildings, for which purpose a bomb loaded with an insensitive explosive is needed -- a bomb which will not explode upon impact with the roof, but is exploded by means of a detonator after it has penetrated to the basement.

A recent news dispatch reports that the Spanish Insurgents are using against the Loyalist infantry airplane drop bombs which contain liquid air in accordance with an invention which is said to have been made in Germany. Such bombs would be practical if the liquid air were not mixed with the combustible component of the explosive, either solid or liquid, until after the bomb had been released from the airplane. The compartment containing the liquid air could not, while the plane is carrying the bomb, be kept closed to the outer atmosphere. The liquid air must be free to evaporate in order that it may keep itself at low temperature. It would have to be introduced into the compartment of the bomb shortly before the bomb is to be used, which would be a time-consuming nuisance in wartime, and the bombs would not retain their vigor for many hours because the liquid air would evaporate away. The effective life of the bomb could, of course, be increased by building the liquid-air compartment after the model of a thermos bottle. It is doubtful whether the tight little bombs which the French used more than 20 years ago would not be better, more convenient, and probably just as cheap.

Annual Meeting

The Technology Review[8]
[1940]

Presentation of new officers of the Alumni Association [of Massachusetts Institute of Technology] andd of regular annual reports engaged the Alumni Council at its 214th meeting on the last Monday in May, which concluded the year's work. Raymond Stevens, '17, retiring Vice-President, was chairman in the absence of Frank B. Jewett, "03. Technology's share in present programs for national defense was described by President Compton.

Tenney L. Davis, '13, Professor of Organic Chemistry, gave a brief talk on modern explosives, illustrated by demonstration experiments; and Stephen G. Simpson, '16, Assistant Professor of Chemistry, noted for his practice of prestidigitation, presented a series of tricks of magic which were regarded as a fitting conclusion to the year's activities.

Fireworks for Fun:
Amusing Explosives Appeal to Something Deep Down in Human Nature

by Tenney L. Davis
The Technology Review[9]
[1940]

Fireworks were before firearms. Pyrotechnic devices were in use for the pleasure that they gave before black powder had yet been put to service for throwing a projectile or for doing useful mechanical work. The spontaneous and long-drawn "ah-h-h!" and "oh-h-h!" which arise when a crowd of people is watching a display of rockets is evidence that fireworks appeal profoundly to something in us. Man in his innermost heart is still truly a fire-worshiper. Civilization surely commenced at the place where man first controlled a fire. Here pottery was made, ores were smelted, and metal objects were first fashioned, better suited to human needs than is stone. Here social and political institutions arose, the storyteller and the minstrel exercised their magic, and here the medicine man practiced his primitive science. And from long-forgotten time an atavistic residue of religious feeling in the presence of visible combustion has survived in all of us. No man can be so old that he fails to recall the thrills of the pyrotechnic exhibitions which he witnessed as a boy nor so old that he will not experience them again and yearn for the fun of shooting off Roman candles and firecrackers.

Roger Bacon in the Thirteenth Century was probably the first man in North Europe to describe the preparation of gunpowder. He recommended it for the construction of petards, which, unhappily, he did not conceive to be devices for amusement. In the *Opus tertium* he says: "From the flashing and flaming of certain igneous mixtures and the terror inspired by their noise wonderful consequences ensue. As a simple example may be mentioned the noise and flame generated by the powder, known in divers places, composed of saltpeter, charcoal, and sulphur. When a quantity of the powder no bigger than a man's finger is wrapped up in a piece of parchment and ignited, it explodes with a blinding flash and a stunning noise. If a larger quantity is used, or if the case is made of some solid material, the explosion will, of course, be much more violent, and the flash and din altogether unbearable..."

Marcus Graecus, probably a Byzantine of the Eighth Century and presumably much earlier than Bacon, described both rockets and crackers "for flying and for making thunder": "Note that the envelope for flying ought to be thin and long, and well-filled with powder tightly packed, while the envelope for making thunder ought to be short and thick, only half-filled with powder, and tightly tied up at both ends with iron wire. Note that a small hole ought to be made in each envelope for the introduction of the match. The match ought to be thin at both ends, thick in the middle, and filled with the powder. The envelope intended to fly in the air has as many thicknesses as one pleases; that for making thunder, however, has a great many....Another flying fire may be made from saltpeter, sulphur, and grapevine or willow charcoal. These materials, mixed and introduced into a papyrus tube, and ignited, will make it fly rapidly." The quotation is from Liber ignium ad comburendos hostes (Book of Fire for Burning the Enemy). Descendants of Greek fire, which was by no means intended for amusement, these are early forms of devices which we use for entertainment now. Stickless rockets, ignited and released from the hand, are still used in certain countries in Europe. It is considered to be funny to send them skittering among the crowd of carnival makers.

Although Roger Bacon had no knowledge of guns, her saw the possibility of getting useful and irrevocable mechanical work from his powder. In his letter *De nullitate magiae* he concealed the composition of the powder in an anagram but gave the reader an opportunity to check its solution by means of a problem in algebra, and concluded his account of it with the prophetic words: "Whoever will rewrite this, will have a key which opens and no man shuts: and when he will shiut, no man opens." Interesting is the similarity of this passage to Revelations 3:7-8: "And to the angel of the church in Philadelphia write; These things saith he that is holy, he that is true, he that hath the key of DAvid, he that openeth, and no man shutteth; and shutteth, no man openeth; I know thy works: behold, I have set before thee an open door, and no man can shut it..."

Practically all pyrotechnic compositions are derived from black powder, either by altering the proportions of its ingredients, by adding others, or by substituting different substances for saltpeter (potassium nitrate), the sulfur, and the charcoal. In his work on The Mysteries of Nature and Art (London, 1635), "The Second Booke Teaching most plainly, and withall most exactly, the composing of all manner of Fireworks for Tryumph and Redreation," John Bate says: "All kindes of gunpowder are made of these ingredients impasted, or incorporated with vinegar, or aquavitae, and afterwards grayned by art. The Saltpeter is the Soule, the Sulphur the Life, and the Coales the Body of it." This is correct, and it shows that John Bate really understood how gunpowder works. The saltpeter supplies oxygen for the combustion of the sulfur and the charcoal. The powder will burn under water -- as well as in the absence of air as in the presence of it. The best black powder for use in guns has been found to be that whose composition lies somewhere between the formula 75 parts of saltpeter, 12.5 parts of sulphur, and 12.5 parts of charcoal (6:1:1) and that using 75 parts of saltpeter, 10 parts of sulphur, and 15 parts of charcoal. By these two formulas, or by formulas intermediate between them, practically all the black powder for military and sporting purposes is made. Any considerable deviation fromthese proportions causes reduction in the strength of the powder. The sulphur, as John Bate knew, serves to make the powder lively, to make it inflammable, and to make the fire quick-spreading. The charcoal by its combustion largely produces the gas which causes the explosion. A typical blasting powder -- which is slower than powder for guns -- contains 62 per cent saltpeter, 20 per cent sulphur, and 18 per cent charcoal. A slow blasting powder contains the materials in the proportions 40:30:30.

At the beginning of the Seventeenth Century the art of pyrotechny had already attained a state of high development in France and England. Nearly all of the devices which are now in common use were made at that time -- display rockets bursting with showers of stars, serpents, and crackers, aerial bombs and petards, Catherine wheels, fountains, water fireworks, flying pigeons, and grasshoppers (saucissons or English crackers, as they used to be called). The design and the details of construction were essentially the same then as now. The fireworks were made by hand, as many fireworks are still made. Paper tubes and pasteboard cases are now rolled, glued, and cut by machinery, but the manufacture of fireworks remains an art which requires the utmost of dexterity and skill. Three hundred years ago rockets were made in wooden molds, on wooden spindles, with wooden rammers pounded by mallets. Steel tools, of the same form as the wooden ones, later came into use. In modern factories rockets are loaded by means of a hydraulic press. Rocket cases are no longer choked by hand crimping or constricting of the tubes but are choked by means of perforated clay plugs which are pressed into place. American flash crackers -- the case, the fuse, loading, and crimping, and so on --are manufactured completely by automatic machinery. The art of the pyrotechnist during the past three hundred years has changed about as much, and has undergone about the same kind of improvement, as has the art of the bookbinder during the same interval of time.

The advance of chemistry, however, has given the pyrotechnist new materials with which he can procure new and more brilliant effects: metallic salts for colors of all varieties, potassium chlorate to increase the vigor of combustion and to give sharper explosions, magnesium and aluminum for dazzling brightness. Chemistry has also supplied children's toy torpedoes, Pharoah's serpents, black snakes, snakes in the grass, whistling crackers, sirens, and whizzers. The brilliancy, the variety, and the sharp detonation of a fine fireworks displayare due to the development of chemical knowledge and are relatively new, but the form of the show is old, and the fundamental machinery of the performance is actuated by the same old materials.

In rockets the propelling charge is a mixture of the three ingredients of black powder in a proportion which makes them burn more slowly. They are not so finely powdered or so intimately mixed. Large rockets require a slower-burning propelling charge than do small ones. In a typical case, one- and two-ounce rockets are loaded with a mixture 36 parts saltpeter, 6 parts of sulphur, 12 parts coarse charcoal, and 7 parts of dust of willow charcoal, whereas eight-pound rockets are loaded with 13 of coarse charcoal, and 13 od dust of willow charcoal. The coarse charcoal produces the sparks which give the rocket its tail. The propelling charge, burning over the whole surface of the conical cavity, produces hot gas which rushes out through the constricted lower end of the case and drives the rocket upward. The rocket approaches the top of its flight by the time the charge is completely burned. The fire, however, is carried by a short powder train to the head of the rocket, where it ignites a bursting charge of black powder which blows out the head and sets fire to the stars, serpents, and crackers with which the head is filled.

Stars are pellets of combustible material. There is nothing in their appearance to suggest the magic which is in them. Lampblack, or Japanese, stars are commonly made either from lampblack and potassium chlorate or from lampblack and black powder dust and antimony sulphide. The materials are mixed intimately, moistened with a solution of an adhesive, formed into cylindrical pellets or small cubes -- three-eighths of an inch to three-quarters of an inch on hte side -- and allowed to dry. Thrown out by a bursting rocket or an aerial bomb, they fall like glowing coals of fire and produce the beautiful willow-tree effect. As rockets start their flight slowly and accelerate after they are in the air, they may safely be charged with chlorate stars. But chlorate stars are sensitive to shock and are considered to be dangerous for use in bombs which are shot violently from mortars. Aluminum stars, made from powdered aluminum and potassium chlorate or perchlorate, burn with a dazzling white light. Indeed, the brilliancy of modern fireworks, of aerial displays, of airplane landing flares, and even the flash which accompanies the explosion of a toy firecracker, is due to the use of aluminum and chlorate or perchlorate. A silver shower is produced by stars which are made from saltpeter, sulphur, charcoal, and realgar (red arsenic sulphide) -- hte materials which Hanzelet Lorrain (1630) used for the same purpose -- and golden streamers are made by stars containing saltpeter, sulphur, and sodium oxalate. Steel stars, like penny sparklers, contain steel filings and scvintillate when they burn. Steel gerbs (pronounced jurbs), or fountains, are made by loading a mixture, say of saltpeter, steel filings, and shellac, into a choked tube and packing it tightly into place. When the mixture burns, the fire rushing out from the constricted orifice carries with it the burning particles of steel. Electric spreader stars contain zinc dust and potassium dichromate along with chlorate and granular charcoal. They break up when they burn, and throw bright sparks over a space sometimes as lage as 15 feet. Colored stars owe their color to mineral salts which give characteristic colors to the flame: strontium red, calcium pink, barium green, copper blue, and sodium yellow. A good blue fire composition is perhaps the most difficult to make, but satisfactory mixtures have been worked out which contain Paris green and calomel (mercurous chloride), the latter substances serving to impart volatility to the copper compounds.

Lances are paper tubes filled with colored-fire compositions, burned usually in a horizontal position, and are used to make letters and designs in set pieces. Charcoal gerbs for soft sparks or steel gerbs for hard, scintillating ones are used in large display pieces and in such garden or lawn pieces as the "Mikado's Fan," "Golden Blossoms," "Diamond Star," "Pyric Fountain," and "True-Lover's Knot."

To make Roman candles, gunpowder and stars, and a modified black-powder mixture which is known as a Roman candle composition (or candle comp) are necessary. The candle composition is a mixture of powdered saltpeter, sulphur, and charcoal which has been moistened with a solution of dextrin, passed through a sieve, and dried. It burns more slowly than black-powder and gives luminous sparks. The case is a long, narrow, strong tube of pasteboard plugged at the bottom with clay. Next to the clay is a small quantity of gunpowder; on top of this is a star; and on top of this, a layer of candle composition. 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 filled with candle composition. When the three materials have been introduced, they are rammed tightly into place. Then gunpowder, a star, and candle composition again are loaded into the tube and rammed down, and so on until the tube is filled. When a Roman candle is lighted, the candle composition begins to burn and to throw out a fountain of sparks. The fire soon reaches the star, ignites it, and burns along the side of the star to light the gunpowder, which blows the burning star, like a projectile, out of the tube.

The tubes which make the wheels go round in many pyrotechnic display pieces are known as drivers and are loaded with a composition essentially the same as that which is used in rockets. They are built like rockets, except that the conical depression where the burning commences is not nearly so deep, and they are choked with perforated plugs of clay. Coarse charcoal, steel filings, and sometime other substances, such as realgar or granulated aluminum, are incorporated in hte driver composition to produce various effects. Drivers attached to the periphery of a wheel or to the sides of a square or triangle which is pivoted at its center cause the device to rotate in reaction to the rapid stream of fire which they eject. They are used in Catherin wheels and in such larger pieces as the "Revolving Cascade," "Dragon Wheel," "Wheel of Fortune," "Chromatic Circle," "Brilliant Sunrise," and "Morning-Glory."

After the time of Hanzelet Lorrain no important improvements were made in the pyrotechnic art for about two centuries. Soon after 1800, strontium and barium nitrates -- for red and green flames, respectively -- began to be used in colored fire compositions in place of part of all of the saltpeter which ws the usual oxidiing agent. About 1830, potassium chlorate began to be used. This powerful but dangerous oxidizing agent produced brighter flames and led to a study of the effects of mineral salts of all sorts in pyrotechic compositions and to the development of a great variety of colors. The study culminated in the work of Tessier, whose *Chimie Pyrotechnique ou Traité Pratique des Feux Colorés* (Paris, first edition, 1859; second edition, 1883) remains the best book on the subject. Tessier also studied the picrates and developed compositions containing ammonium picrate, "tableaux lights," which gave but little smoke and were useful in he theater but have now been replaced entirely for that purpose by electric lighting. Chlorate mixtures which contain sulphur give brighter flames than those which lack it, and such mixtures are still used occasionally in spite of their easy inflammability and dangerous sensitivity to shock. The present tendency, however, is toward chlorate mixtures which contain no sulphur, or toward potassium nitrate mixtures which contain sulphur 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. The less dangerous potassium perchlorate is coming into use as a substitute for chlorate. Magnesium was first used in fireworks around 1865 and aluminum about 1894, each of them for the production of a dazzling white light. Magnesium is oxidized fairly rapidly by moisture -- much more rapidly than aluminum, by which it has been superseded for use in commercial compositions. Powdered magnesium, however, may be used satisfactorily if the particles have first been covered with a film of linseed oil.

The airplane wing-tip flates which were used for signalling during the world war are good examples of aluminum compositions. They were loaded in cylindrical pasteboard cases four and a quarter inches in length, and one and five-eighths in internal diameter. The white-light composition consisted of 77 parts of barium nitrate, 13 parts of flake aluminum, and five parts of sulphur intimately mixed and secured by a binder of shellac, and burned, in the cases previously mentioned, for one minute with an illumination of 22,000 candle power. The red light was made from 24 parts of strontium nitrate, 6 parts of flake aluminum, and 6 parts of sulphur with a shellac binder, and burned for one minute with an illumination of 12,000 to 15,000 candle power.[7] Thus fireworks, intrinsically for pleasure and benefit, and turned to purposes of war, as so many benevolent and valuable things -- men, food, paper and ink, human ingenuity, and high ideals -- are likewise uselessly perverted.

Fireworks are for fun. The fireworks enthusiast loves to see them, to talk about them, to visualize them in retrospect; from fireworks catalogs he gets the same pleasure that

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[7]H.B. Faber, *Military Pyrotechnics* (Washington:Government Printing Office, 1919) II, 223, 225-226.

a gardener gets from the seed catalogues which act so powerfully upon his imagination. Such passages as these quoted from current catalogs are representative of descriptions which delight him.

"Sheba's Brooch Set piece. When this device breaks open, brilliant and sparkling golden and diamond effects are reproduced in one of Sheba's beautiful and costly brooches. This comes in mammoth size and is one of the devices that will bring applause."[8]

"Victor Jerome Battle in the Clouds Shell. A spectascular 12-inch battle shell that opens with showers of signal lights, followed by six precision-timed heavy battle reports, and a seventh and final detonation of terrific force, bringing the exhibition to an end with a mighty bang."[9]

Courtesy of Wallace Clark

Making Chinese firecrackers into bunches by braiding the fuses together, French Indo-China, January, 1939

[8]Illinois Fireworks Company, Inc., *Catalogue*, 1939.

[9]Liberty Display Fireworks Company, Inc., *Catalogue*, 1939.

Chao Hsüeh-min's *Outline of Pyrotechnics*
A Contribution to the History of Fireworks

By Tenney L. Davis and Chao Yün-Ts'ung [趙雲從][10]

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[1943]

The history of fireworks is very obscure. It is generally believed that pyrotechnic mixtures of saltpeter with sulfur and charcoal, or with other materials, were invented in China at an early time and were used for entertainment, for purposes of magic as in the exorcising of demons, and later in the military art. A knowledge of these mixtures presumably found its way to Europe over the trade routes to Byzantium. The celebrated *Liber ignium ad comburendos hosles* of Marcus Graecus, which was probably written in Greek in the eighth century, describes Greek fire and other incendiaries as well as black powder and the use of the latter material in firecrackers and in primitive rockets without sticks. The writings of Roger Bacon in the thirteenth century, which contain what is supposed to be the earliest reference to black powder in Latin Europe, make mention of the fact that toy firecrackers were already in use by the children of the time. Modern improvements, the use of chlorate and perchlorate in colored fire compositions, strontium and barium salts to color the flame, and magnesium and aluminum to impart brilliancy, have come in since 1800; they are recent enough to be dated, and certain of them may probably be set down as the inventions of particular men. But it is not known who invented the Roman candle, the rocket, the flying pigeon, the catherine wheel and the saxon, and it is not known when or by whom such familiar and much-used substances as arsenic sulfide, antimony sulfide, verdigris, calomel, and iron and steel filings were introduced into pyrotechny.

The literature of fireworks is meager. Contemporary books in European languages are few and far between, and are issued in such small editions that they quickly become out of print. Books before 1800 are rare without exception, but they are especially valuable to students of the history of pyrotechnics for the reason that they antedate modern improvements and indicate the state of the art during a time when it was advancing with exceeding slowness. Fireworks in the eighteenth century were but little advanced over those of the seventeenth century. The latter showed considerable improvement over those of Marcus Graecus in the mechanical devices in which they were applied but very little in the materials from which the compositions were made. During seven or eight centuries the addition of each new substance to the list of the pyrotechnist's materials must have represented a real achievement.

The Chinese text which is under discussion in the present paper is the only Chinese text on civil pyrotechnics[10] which we have been able to find. It represents an art which is more highly developed in some respects than the pyrotechnic art of eighteenth century Europe, an art which apparently grew up entirely independently in China. It lacks certain things which were common in European treatises, and it mentions certain things which would certainly have been copied in Europe if they had been known. It appears to be wholly Chinese.

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[10]Dr. A. W. Hummel, Chief of the Division of Orientalia, Library of Congress, has kindly directed our attention to two earlier texts on military pyrotechnics, and has made it possible for us to procure microfilms of them. We hope to report upon these shortly.

The *Huo-hsi lüeh* [火戲略] (Outline of Pyrotechnics) by *Chao Hsüeh-min* [趙學敏] is printed in the collection, [昭代叢書][11] where it had a postscript by *Yang Fu-chi* [楊復吉] which is dated 1753. It was therefore in existence at that date. A short biography of its author is included in the *Hang-chou fu chih* [杭州府志] (Record of the District of *Hang-chou*) 150.16 b-17a (1923 ed.), and considerable information about him and about his father, his brother, and his own work in medicine is given in his two prefaces to his famous Supplement [拾遺] to the *materia medica, Pên-ts'ao kang-mu* [本草綱目].[12] The prefaces are dated 1770 and 1765, but they contain no reference to their author's age at the time when they were written.

Chao Hsüeh-min, whose *tzû* was *Shu-hsien* [恕軒], was a native of *Ch'ien-t'ang* [錢塘] in *Hang-chou* (Chehkiang Province). He lived during the *Ch'ien-lung* [乾隆] era (1736-1796). His father was Salt Commissioner of *Hsia-sha* [下砂] county. The story goes that his father longed for sons. One day, when he was in *Ching-k'ou* [京口], he met a stranger who said to him, "According to your physiognomy, you will not have any successor, but, if you do beneficial relief work, you may get sons." There was an ocean flood which caused the death of hundreds of thousands of people. He did his best to rescue them and to bury the dead. In the autumn a plague followed, and he again contributed his

[11]Volume 170 of the edition of the Library of Congress.

[12]We wish to make grateful acknowledgment to Dr. A. W. Hummel for giving us references to this material, to Dr. *Ch'iu K'ai-ming* [***] for finding it for us in the Library of the Harvard-Yenching Institute, to the Harvard-Yenching Institute for the useof its text of the *Huo-hsi lüeh* and for the use of the Chinese type which has been employed in the present printing, and to Professor James R. Ware of Harvard University for reading the manuscript and for valuable criticism and suggestions.

salary to help, to procure medicines and the services of physicians. Thousands of lives were saved in consequence. He also suggested to the government a plan for the building of a dike. The officers in charge allowed the plan to be heard by the Emperor, and it was approved. Before any action was taken, many fields were badly damaged by the ocean tides, and seven counties, *Hsia-sha, Shih-yen* [石堰], *Ch'uan-shan* [穿山], *Ming-hao* [鳴鶴], *Lung-t'ou* [龍頭], etc., were inundated. He managed however to build the dike himself, and when it was finished he named it *Li-chi* [利濟] (Beneficial Relief). In the autumn of that year the ocean tides came again, but they were stopped by the dike and no damage was done. Later he was moved from this post to hold office in *Yu-ch'i* [尤溪]. And so it came about that his sons, *Hsüeh-min* and *Ch'iai* [楷] were born, and were given the baby names of *Li* [利] (Beneficial) and Chi [濟] (Relief). When the father retired for his post, he also gave his hall the same name of *Li-chi*.

The father wished one of his sons to study Confucius and the other to study medicine. *Ch'iai*, the younger, studied the teachings of Confucius but also studied the canons on typhoid and on fevers. In his leisure time he was taught "to draw the copper man diagrams" [study acupuncture] for fun. From spring to winter the brother studied in the Nourishing Essence Garden [養素園], which was fifty *mou* [畝] of land (more than six acres) devoted to the cultivation of medicinal grasses. *Hsüeh-min* encouraged his brother to specialize in medicine (*Ch'i-Huang* [岐黃]) in accordance with the wish of his father. Although *Ch'iai* did not have confidence enough in himself to practice medicine publicly, relatives and friends who called upon him for diagnosis and who took his medicine were all cured of their diseases. He wrote a work entitled "Mirror of Herbs" [百草鏡] in 8 *chüan*

[卷] and another, "Saving Lives from the Ocean of Sorrows" [救生苦海] in 100 *chüan*.

Chao Hsüeh-min was a great reader. It was his custom to continue his reading into the night. He says that he liked especially to read about the stars and the calendar, about medical subjects, and about divination and alchemy. When he found anything which interested him, he was so pleased that he forgot fatigue; he copied it or summarized it, and filed the material in packages. In this way he accumulated several thousand *chüan*. In the first of the prefaces which accompany his Supplement [拾遺] to the *Pên-ts'ao kang-mu*, he says that he almost became tired of this kind of work, and that once, when he had the time available to look them over, he picked out those which he thought to be useless and threw them in the furnace. He wrote *Li-chi shih-êuh chung* [利濟十二種] (Twelve Books from Li-chi Hall), as follows-

1. The Best Works of the Medical World [醫林集腋], 16 *chüan,*
2. Transmitted Trustworthy Formulas from the Nourishing Essence Garden [養素園傳信方], 6 *chüan,*
3. Proofs of Exorcism [祝由錄驗], 4 *chüan,*
4. Collections [集] under the Names of *Nang* and *Lu* [囊露] (herbs), 4 *chüan,*
5. Observations [詁] on the *Pen-ts'ao*, 32 *chüan,*
6. A Gathering of Selected Formulas (of the author and others) [串雅], 8 *chüan,*
7. A Report on the Short Names of Certain Herbs [花藥小名錄], 4 *chüan,*
8. The Secrets of Rising and Sinking [升降秘要], 2 *chüan,*
9. Leisure Readings on the Maintenance of the Health [攝生閒覽], 4 *chüan,*

10. Explanations of the Properties of Medicines [藥性元解], 4 *chüan*,

11. References to Strange Medicines [奇藥備考], 6 *chüan*, and

12. Supplement to *Pen-ts'ao kang-mu*, 10 *chuan*.

The twelve titles were published in the book catalogue of the *Pao* [鮑] family, and the manuscripts were circulated. At the end of the *Chia-ch'ing* [嘉慶] era (1796-1821) only the manuscripts of Nos. 6 and 12 survived, and these texts were preserved in the *Hang i lien pao* [杭醫連] (The United Treasure of Hangchow Medical Doctors). *Chang Ying-ch'ang* [張應昌] reorganized the material in these two texts, corrected the mistakes, and edited and published them in the middle of the *T'ung-chih* [同治] era (1862-1875). The other ten texts have been lost. The manuscripts of the family are said to have been destroyed about 1860 in the Taiping Rebellion.

Of the two prefaces by *Chao Hsueh-min* which now accompany his Supplement to the *Pên-ts'ao kang-mu*, the second is properly a preface to the Supplement and describes his reasons for writing it. The first is really a preface to the whole collection of Twelve Books on Beneficial Relief, and tells something of the circumstances surrounding the writing of each of the treatises. The author says-

"Of the twelve books which I wrote, the manuscripts of two, namely, of the 'Proofs of Exorcism,' and the 'Gathering of Selected Formulas,' were set aside last year to be put on the fire, but the manuscripts were saved by the children. The treatise, "The Best Works of the Medical World,' was completed a year ago. Once I happened to have a chance to read the books in the library of my neighbor, *Huang Fan-wêng* [黃昄翁], in which the collection of books on medicine amounted to more than ten thousand *chüan*, and I compared them with my old collection of confidential papers of the Kiangsu and Fukien authors. I selected from them the formulas which had always proved effective to form a treatise entitled 'Best Works.' It was my experience that the selection was not easy. Some of my relatives and friends happened to test the formulas, and told me of improvements. The treatise was then revised, and enlarged from year to year, and its name was changed to 'Transmitted Trustworthy Formulas.'

In the spring of the year *i-hai* [乙亥] (1755), *Wang Ttu-shih* [汪子師] of Human Province paid me a visit and made a short stay in my home. I saw on his desk a volume on exorcism, the formulas of which he was testing. I then borrowed the book and copied it myself, and later secured other manuscripts, those of the *Chang* [張] family, of the *Wan* [萬] family, and of the *Hsieh* [薛] family. I tested some of the formulas from them, removed the false ones, saved the effective ones, and wrote the book, 'Proofs of Exorcism.'

"I was addicted to the reading of books. The daytime was not enough for my study, and I continued it by the burning of fat. I disliked to yawn in the study hall, and so I built a box for the lamp and brought it into the mosquito net in order to carry on my reading at night. After some time the soot from the lamp blackened the beautiful net. In the year *ping-tzu* [丙子] (1756) I had eye disease. The disease was so serious that I had almost become blind; after six months of sightlessness it was finally cured. For this reason I wrote another book entitled 'Collections under the Names of *Nang* and *Lu*'[13] . . .

[13] *Nang* and *Lu* are herbs which are used in the treatment of eye disease.

"Someday if I can devote my time to studying the canons on the impulse of the blood, on typhoid, on fever, etc., and can organize the material into treatises, I shall write ten more books. These, together with the two books written by my brother, I shall put into a 'Later Twelve Books from Li-Chi Hall.' The year *kêng-yin* [庚 寅] (1770), the second month of spring, the sixth day of the month. *Chao Hsüeh-min, Shu-hsien.*"

The *Huo-hsi lüeh* (Outline of Pyrotechnics) is probably one of the earlier works of *Chao Hsüeh-min*, for the note of commendation appended to it by a reader is dated 1753, more than a decade earlier than the dates (1765 and 1770) which Chao Hsüeh-min has himself given his own prefaces to the Supplement to the *Pên-ts'ao kang-mu*. The treatise appears to be one of those collections of notes, or summaries of readings, of which *Chao* says that he accumulated several thousand *chüan*. It shows an acquaintance with the materials of the pyrotechnist, and with their properties and uses, and leads one to believe that its author had handled them himself. It appears to consist essentially of the notes and observations of a skillful worker in the art, addressed to one who is already familiar with the principles. It omits many details. It does not, for example, tell how saltpeter is prepared, but it indicates a true understanding of the unfavorable effect of sea salt which may be present in it as an impurity. It shows an interest in the theoretical basis or explanation of the observed facts. It contains no mention of antimony sulfide which was widely used in eighteenth century European pyrotechnics, and conversely it refers to materials and techniques which had not yet been applied in European practice. Many of its points of interest are discussed in the notes which follow the Translation and Abstract and which are numbered with the same numbers as the paragraphs of the Translation and Abstract to which they refer.

Translation and Abstract

Huo Hsi Lüeh [火戲略] An Outline of Pyrotechnics

By Chao Hsüeh-min [趙學敏]

Extraction of Saltpeter

1. [1a-2a] *Hsiao* [硝] (saltpeter) is produced in salty places (salt marshes). The districts in *Ch'ing-yang* [慶陽] (in Kansu) and in *Ho-pei* [河北] (in Honan Province) and the interior of *Shu* [蜀] (*Ssu-ch'uan* [四川] Province) have an abundance of this substance. During the autumn and wintertime the ground is covered with a white material which is swept up with a broom and refined by boiling (its solutions), and *hsiao* is thus obtained. In *Ts'ui Fang's* [崔昉] (exterior *tan*), and in the *Pen ts'ao* [本草] (Book of Medicines), it is called *yin shih* [陰石] [stone of *yin* (陰)]. In *Fu hung t'u* [伏汞圖] (Diagrams of Conquering Mercury) of *Hu-kang-tzu*, [狐剛子] it is also named *pei ti yüan chu* [北帝元珠] (the primary pearl of the Northern God).

2. *Hsiao* (saltpeter) gets its name, I suppose, from the fact that is the essence of *T'ai yin* [太陰] (the Grand *yin*, synonym of the moon) and will fly away on meeting fire. At the extremity of *yin* [陰], *yang* [陽] begins to appear. *Hsiao* pertains to *li* [離] (a *kua* [卦], namely - -, standing for *yin*), and has the property of being able to soften the five metals and to change the seventy-two stones into water.

3. The word *hsiao* means to dissolve (to vanish). It (*hsiao*) must be refined for use as an internal medicine. The same is true for use in making fireworks. It is thought that *hsiao* is formed by the influence of the ethereal essence of the salty sea, since it becomes wet in contact with a humid atmosphere. Dryness is essential for *huo yao* [火藥] (fire powder, black powder). If unpurified (1b) *hsiao* is mistakenly used to make the powder, the charcoal of the powder will become moist very easily during humid weather. The iron filings (in the powder) will be surely rusted from the effect of the *lu ch'i* [鹵氣] (ethereal essence of salt) caused by the wet charcoal. It is unlikely that such a powder can produce any good result in *hua p'ao* [花砲] (flower cannon, flower rocket). Consequently, the *hsiao* must be purified to get rid of the *lu chi'* (ethereal essence of salt) before it is compounded in the fire-powder.

4. For the method employed in the preparation: *hsiao* is put in a large iron kettle, covered with clear water until the water rises one or two *ts'un* [寸] (inches) above the *Hsiao*, two *liang* [两] (ounces) of water glue (glue solution) is added and the contents is boiled for a period of two incenses (the time needed for burning consecutively two pieces of incense). When the liquor boils, foam may form and, in such case, is skimmed off. Remove from the fire and let the liquor stand until clarified. On the next day the supernatant liquor is decanted off and is replaced by fresh water. About three or five white turnips are then added and the contents boiled for another two incenses. Again, remove from the fire, remove the white turnips, and let the liquor clarify as before. Next morning, replace (the

supernatant liquor) with fresh water, add new white turnips, and boil the whole again for two incenses. The *Lu ch'i* (ethereal essence of salt) is completely removed by such treatment. The *Hsiao* is taken out and dried in the sun light.

5. If one wishes to prepare roasted *hsiao*, good *shao chiu* [燒酒] (distilled spirit, samshoo) is added slowly in the kettle to the purified *hsiao* mentioned above, and the contents is roasted to dryness to get the product. Another method for manufacturing hsiao is given in *Shui shu pen fang* [水鼠本方] (Original Methods of Making Water-Mice)[14].

Preparation of Sulfur

6. [2a-b] Huang [黃] (yellow, sulfur) consists of the essence of pure *yang* [陽] of fire-stone. It is formed by condensing the *ch'i* [氣] (ethereal essence) of the sun. Workers in *Wai tan* (Exterior tan), call it *huang ya* [黃芽] (yellow sprout). It is probable that the essence of the sun (sulfur) acquires its body by the influence of wind and wood. The branches of wood (the element wood, sulfur) grow out sideways. Therefore, when they are mixed with charcoal, the flames shoot out sideways. Wood appears blue, therefore its flame (the flame of sulfur) is also blue.

7. Sulfur of light yellow color is named *K'un lun huang* [崑崙黃] (the yellow of *K'un lun* [崑崙]); that of red color, *shih t'ing chih* [石亭脂] (the fat of *Shih't'ing*, red sulfur); that of blue color, *tung chieh shih* [冬結石] (stone of shocking spirits). They are produced everywhere, in the East, the West, the South, and the North. The grade for making rocket powder must be of deep yellow color. If the bluish

[14] Water-mice are small fireworks intended for use under water.

grey material is used, there will be a hazard of explosion due to its uncleanness. If one wishes to treat it with distilled spirit, do not roast it, but stir it and expose it for drying in the sunlight. If it catches fire on roasting with other ingredients, then by using your mouth spray vinegar onto it to stop the fire. If you wish [2b] to remove the odor, make a hollow chamber in a white turnip, fill the chamber with the pulverized sulfur, put the white turnip, into a heap of burning rice-hulls until it is cooked, and the odor is gone.

8. If you wish to change sulfur into a liquid, fill a bamboo cylinder with your sulfur, bury the cylinder in house dung for one month and you will get the liquid sulfur. This liquid has the characteristic properties of turning the five metals black, of turning mercury red, of giving a purpler color with magnetic stone, of making a disturbance with saltpeter, and of becoming quiet with pig fat. One should understand these properties and be able to utilize the sulfur well.

The Use of Charcoal

9. [2b-3b] Charcoal is the soul [魄] of fire. Fire resides in (the element) wood, and wood comes from (the element) water. Whenever wood dies, it turns black to show that it has returned to its original form. The properties of charcoal are to fly away and to give out light easily. It is used in accordance with its properties. The charcoal which is usually used for the making of powder is that from the extreme ends of fir branches. Other varieties are bamboo shoot charcoal which is violent and spreading, bamboo knot charcoal which is violent and powerful, bamboo root charcoal which is hard and side-bursting, calabash vine

charcoal which is quick and side-running, bamboo leaf charcoal which gives a hissing sound, coconut [3a] shell charcoal which produces splashing noises, melon skin charcoal which is quick and violent, eggplant charcoal which makes clear crackling sounds, horn charcoal which is permeable to flame, snake skin charcoal which gives flashing light, and grasshopper charcoal which possesses the property of flying away and running. The quick acting powders have the property of destroying and bursting. Charcoal from glutinous rice can be used to make bird-gun powder. Willow and fir charcoals are the lightest of all and can be used to make powders for *Shou hua* [手花] (hand flowers). *P'ao* [砲] (cannon) using ashes of hemp stalk (in the powder) produce no noise. If the flinty skin of bamboo is used, plenty of smoke results. Other effects can be produced by applying your knowledge.

10. Charcoal must be prepared by burning (the raw material) until the last trace of smoke is driven off. It is then taken out and put into an earthenware jar which has a tight cover. After cooling it is pulverized to the finest degree for use in powder. This substance is much disposed to become moist, and so it must be burned (prepared) just before use. If too much of it has been made, the unused portion must be wrapped in a piece of paper and put into a jar containing (burnt) lime.

11. If the charcoal has been exposed to moist air, it will be unreliable in its effect upon the slowness and quickness of the finished powder, and also it will make the finished powder fail to burn out (produce) colors and flowers. Furthermore, the iron filings will not be completely melted (if used) with such a charcoal.

12. However, there is a wet method for making powder. For instance, in the preparation of *chu êrh yao* [珠兒藥] (bead powder), saltpeter is boiled with the

charcoal and the (resulting) mass is pulverized when it is still moist. In the preparation of *hsüeh têng yao* [雪燈藥] (snow-lantern powder), [3b] camphor is boiled with charcoal and the product is also pulverized while in the moist conditions.

13. Another method is the cast-charcoal dry method. If you want it (the product) to appear as a silvery thread, (the material) is cast with lacquer and dried in the sunlight whereupon the properties of the powder are stabilized. If you want to change its color, you can drop it (into a kettle), roast it, and cast it. It depends upon yourself how much of the subject you can understand.

The Use of Iron Filings

14. [3b-4a] *Sha* [砂] (sand, powdered iron) consists of broken cast iron having grains as large as sand, and hence its name. Its old name was *t'ieh ê* [鉄鋨] (iron ants). It also has another name, *t'ieh hsieh* [鉄屑] (iron filings). Without it, *t'ung hua* [筒花] (cylinder sparks, cylinder flowers, fountains, or gerbs) will no longer produce flowers (sparks).

15. It should be prepared at the time when it is used. It can not be stored for a long time because it has a tendency to rust. Once rusted, it will produce no more sparks. Old, broken, cast-iron kettles are usually employed (as the material) for making *sha*. The broken kettles are heated to a red heat in order to remove adhering grease and dirt. After cooling somewhat, they are pulverized in an iron mortar while they are still warm. The product is then sieved and separated into four grades. The fines are called upper *sha*; the coarser ones,

medium *sha*; the still coarser grade, coarse *sha*; and the coarsest ones are called large *sha*. [4a] Besides these, there is another kind of *sha* which is known as needle *sha*; it consists of drillings for the boring out of needles' eyes. After the *sha* is sieved, it is wrapped in paper and put in the lime jar to prevent it fro m rusting. Powdered iron is not to be touched with the hands, otherwise it becomes sparkless rust. Oil can also spoil powdered iron as it makes it melt into beads without producing sparks when burnt in powder (compositions). Powdered iron, when weighed, is to be handled with a copper spoon to avoid contact with the hands.

16. At the present time, powdered iron is all purchased from *Su-chou* [蘇州] (near Nanking). It should have a glistening lustre like that of tin.

The Match (Fuse)

17. [4a-b] Large match is called double-wick match and small match single wick match. All kinds come from *Hui-chou* [徽州] (*An- hui* province, lower Yang-tze valley) (where they are manufactured) for use as open-lead igniters for *hua-p'ao* (cannon). However, in fireworks there are still other igniters which are known as piped match. Matches are of two kinds, the slow ones and the quick ones. Quick matches are made with charcoal of calabash, the slow one with charcoal of willow or fir. T'ao hua [桃花] (peach flower) paper is used as the wrapping paper and should be treated beforehand with a solution of saltpeter and dried in the summer time. [4b] The powder is wrapped in by twisting the paper around it, and burns readily through a crimp.

18. Matches are packed in bundles of 500 pieces each with the two ends of the bundle tied by paper threads. They are stored in a lime jar for use at the time needed.

19. The powder for matches should be loaded on the paper with a match-spoon in order to get it even. The match spoon is made from a piece of bamboo by cutting the bamboo to a size as small as a scallion leaf and to a length of about one foot in a thin (spoon) shape. When powder is loaded on paper with this spoon, there will be an even distribution of the powder and match of uniform size will thus result.

Use of Piped Match (Abstract)

20. [4b-5b] Piped match is a match enclosed in a paper tube, the tube being about the size of a wheat straw and fireproofed with alumn. In a display of fireworks, piped match is used for connecting the different pieces in order to prevent all of the matches, which cross each other, from burning together at one time, so that the display can be shown in systematic order. Furthermore, the fire of the match is enclosed within the tube and is not visible. After the matches have burned, hundreds of flowers of fire appear suddenly, and the display is made much more amusing. The ends of the match are not piped, with the results that the tube, after the match has burned, finds no support for itself and drops away.

Treatment of Papers (Abstract)

21. [5b-6b] There are four kinds of papers used in making fireworks, fire-proof paper, inflammable paper, paper for a sharp, crackling explosion, and paper for strength. Fire-proof paper is used in making the inner cylinders of fireworks, and is itself made by

treating paper with alum solutions. In wrapping fuses, the paper must be inflammable; this result is secured by soaking it in saltpeter torn into small pieces by the explosion to produce loud, cracking reports with small fragments of paper filling the air. Bamboo or mulberry-bark paper will be suitable for this purpose. For a certain kind of lower cylinder (fountain), the outer layer of the cylinder must be made of strong paper to prevent the bursting of the cylinder, and for this purpose a layer of thick paper or *yüan-shu* [元書] paper is usually used.

22. [6a-8] Dyed paper must not be used in fireworks, because the color is likely to be destroyed by the powder. If color must be applied, the pigments which are used for ordinary painting will produce satisfactory results and will not be changed by contact with the sulfur fumes.

The Containers

23. [6b-7a] Containers are of three different sorts, namely, the clay cylinder, the paper cylinder, and the iron cylinder. For *p'ao* (cannon, firecrackers), only the first two are in use while all of the three are employed in flower cylinders (fountains). The mouth and the bottom of a cannon cylinder are equal in size, but in a fountain cylinder the mouth is small and the bottom is large forming a horn-shaped (or conical) space in between. (The conical container) will direct the force of the powder upward without being itself burst.

24. To test fountain powders there is a simple method for making the container. A small bamboo cylinder is cut off so that one of its ends retains the knot and the other is left

open. The powder is packed into the cylinder until it is almost full. The open end is then blocked tightly with a choke of ashes wrapped in paper. [7a] A hole is made through the knot of the other end for inserting a fuse. This method obviously saves the laborious effort of making a paper container. However, before packing in the powder, the cylinder must be packed with paper to make an inner horn-shaped (or conical) cavity with the tip (apex) against the knot. This removes the trouble of cracking or side-bursting. If a horn-shape cavity is made in a piece of dry clay and the clay is used (in the place of the paper) for packing the bamboo cylinder, the result will be the same.

The Compounding

25. [7a-8b] The most essential materials used in the compounding (of the powder) are the saltpeter, sulfur, and charcoal which have been discussed in detail previously. Others are auxiliary substances. However, one has to know the art of compounding. For instance, if *hsiung huang* [雄黃] (male yellow, realgar) or *shih huang* [石黃] (stone yellow, orpiment) is used, (the mineral) must be first stirred with *shao chiu* (distilled spirit) and dried in the sunlight. It will give a yellow smoke. If it is used together with saltpeter, the smoke will be very intense with a yellow light which will not be overshadowed by the light of the burning powder. If sulfur, which has an odor, is employed, it must be roasted with vinegar beforehand in order [7b] to remove the odor. By being admixed with *tsao chio kao*

[皁角膏] (a fat from the pods of *gleditschia sinensis*), the powder acquires slowness. By being mixed with *fu jung chih* [芙蓉汁] (the juice of lotus flowers), the powder becomes quick acting. Shreds of cotton give a violet light: *t'ung ch'ing* [銅青] (copper green, verdigris, basic acetate of copper) produces a green light; *yin chu* [銀硃] (vermilion, cinnabar), a red light (smoke?); *ch'ien fen* [鉛粉] (lead powder, white lead, carbonate of lead), a white light (smoke?); *hsiung ching*[雄精] (realgar), a yellow light (smoke?); and *sung mei* [松煤] (pine soot), a black light (smoke?). The above contain the five colors of light (smoke?).

26. *Shih huang* [石黃] (orpiment) produces a yellow smoke; *ch'ing tai* [青黛] (lapis lazuli) a green smoke; *chu sha* [硃砂] (cinnabar) a red smoke; *ni fên* [膩粉] (greasy powder, calomel) a white smoke; and *li ch'ing* [瀝青] (pitch, resin) a black smoke. The addition of gold or silver foil makes a light similar to that of gold fragments. The addition of tin foil makes a light resembling that of broken red clouds. Sulfur alone makes it (the light) blue, while the addition of *tan fan* [膽礬] (bluestone, blue vitriol, copper sulfate) makes the light still stronger. Saltpeter alone renders the light violet. *P'i shih* [砒石] (white arsenic, arsenious acid) produces a still longer light (flame). *Shih nao yu* [石腦油] (rock oil, bitumen, asphalt), *chang nao* [樟腦] (camphor), and *ti sou* [地溲] (earth-extract) all can produce fire from water (liquid). The thorns of *gleditschia sinensis*, spring-willow branches, bamboo shoots, etc., all are able to produce something else in the fire. The presence of impurities in the root (the powder) is due to the incomplete extraction of the

saltpeter. The feebleness of the flowers (sparks) is caused by the use of unfresh (deteriorated) iron filings.

27. If one wishes the powder to produce fruits, the spraying of water should be so plentiful as to be comparable to that of spring time. If you want the light to be controllable, (the powder) should be stirred with a bath of plums. Earthworm powder and snake skin are used according to their properties. [8a] Boiling in a solution and drying in the sunlight will bring out the efficacy. The persons who are able to do the job will not be limited by a single rule. The followers (students) should be able to derive everything from the above (discussion).

28. The proportions (quantities) must be accurate and the mixing must be thorough. Iron filings are of coarse and fine grades. (The addition of) charcoal has its own order. When the roasting method is used, the ingredients must be roasted separately. If the wet method should be chosen, the procedures would not be the same. The crushing and grinding apparatus should be in good condition and efficient. During the sieving, precautions must be taken with respect to wind and fire. Follow these rules and you will have over one-half of your thought (more than half of the expected results).

The Roasting of Powder

29. [8a-b] In making powder there is an excellent method of combining the advantages of water and fire. For example, *ch'iang yao* [鎗藥] (gunpowder) is made by boiling saltpeter and sulfur with water, roasting (the product) with charcoal and

stirring to form the beads. *Huo chiu* [火酒] (fire spirit, alcohol) is sometimes used in the roasting. According to *Shui shu fang* [水鼠方] (Water and Mice Methods) of *Yün ch'i* [雲溪] (Cloud-spring) floating (upper) saltpeter, jumping saltpeter, and settled (bottom) saltpeter are recommended. In *Jên yüan fang* [仁源方] (Spring of Kindness Methods), alcoholic saltpeter is employed to make the five-color butterfly. A certain one roasts (the powder) with oil, lacquer, snake-blood, or juice of *fu jung* [芙蓉] (lotus flowers). Again, another roasts in the dry state or roasts with addition of other substances. Probably, the advantage of dry roasting is to absorb the power of fire for assisting the rising property (of the powder), while that of admixing with other substances is to make use of the power of those substances to conform to the will of the *shên ming* [神明] (spirits).

30. There is no definite method. If you want to minimize the yellow flame, *tan fan* [胆礬] (bluestone) will be mixed in. If you want to retain the light of saltpeter, (the powder) is to be boiled with rosin oil. If you want the powder whirling around, tails of grubs will be added during the roasting. If you want the powder to be spreading, earthworm blood will be added during the roasting. When silver foil is roasted for use in powder, ash of lotus leaves is to be added. When copper foil is roasted for use in powder, walnut ashes are to be incorporated. The reason is for controlling (the effect).

31. [8b-10a] Common people know only that substances which are inflammable can be incorporated into fire powder. However, the non-inflammable materials, when used properly, produce wonderful results. This has been stated in the Books of *Tan*, that all substances can produce light. It is the substance of inflammable material and the spirit of non-inflammable which are effective. For instance, minerals such as *huang tan* [黄丹] (minium, red lead oxide), *mi t'o sêng* [蜜陀僧] (litharge) and *hei hsi hui* [黑锡灰] (black tin ash, lead), all are heavy and are able to suppress the power of the powder. *Ku ch'ing ch'ien* [古青钱] (old copper coins, old brass), *t'ieh hua fên* [铁華粉] (acetate of iron) and silver rust are able to split fire to give flowers. *Lu kan shih* [爐甘石] (zinc bloom, zinc carbonate), *pu hui mu* [不灰木] (non-ashing wood, asbestos) and *shih chih kao* [石脂膏] (stone fat, siliceous clay) can be used to treat paper and to separate fire. *Ch'ing fên* [軽粉] (calomel), *chung ju* [鍾乳] (stalactites, chiefly calcite), and *shih t'an* [石炭] (graphite) are able in certain cases to produce particular effects. *Yü shih* [礜石] (arsenolite, white arsenical ore), *huang fan* [黄礬] (yellow-colored alum), and *lei mo* [雷墨] (meteorites) all are able to invert the light. *Nao sha* [硇砂] (sal ammoniac), *p'êng sha* [蓬砂] (borax), and salt assist saltpeter and sulfur in the powder to burn out.

32. As for vegetable materials, (the charcoal of) rush stalks can change a small fire into a large one. Rosin can concentrate spreading light into spot light. (Numerous other effects of various vegetables and animal materials are also mentioned.)

The Use of Powders (Abstract)

33. [10a-11a] If you want the piece to fly, the addition of mice-powder is necessary. If you want it bright, moon-lantern-powder should be added. Powders for filling soft containers are usually fine and are not quick-acting. If quick-acting powder is used (in this case), the container will be shattered and your hand may be injured. The flowers of soft pieces must shoot out sidewise and open slantingly, otherwise the choke will be blasted out and random burning result from the straight-upward shooting. With a large proportion of saltpeter, the force of the powder is tremendous. With plenty of charcoal, the light of the powder becomes scattering. Powders rich in sulfur make loud sounds, while those rich in powdered iron give obscure (unclear) flowers. The shaking of the container (unevenness of firing) is caused by the formation of obstructions in the mouth. The formation of beads on top of the flowers is caused by the use of rusted iron filings.

The Coatings and Pastes

34. [11a-b] It is necessary to know the use of coatings and pastes, for, by means of these, results from the powder are made much more wonderful and changeable. They are comparable to the color designs of a painter and to the pattern designs of a textile-maker. If a powder does not have a coating or paste, it will not be able to trace out its flight, and the weak and intense colors are not to be distinguished. It will also fail to concentrate the light,

and the wonders of the changes will not be magnificent. This subject, therefore, ought to be discussed.

35. Whenever the grains of a powder have no particular shapes, the grains are called beads. Those which have corners, are called prisms. They may have the shape of grain-awns, chelae, hair, the scars of the moon, a broken wall, a broken sword, fractured calcite, or a heap of hooks. They may contain eight corners, a trident, a conical shape, or a shape of a bowl-head.

36. Some of these grains are shaped (molded) with open fire, with greenish fire, with explosion-powder, or with ignition-powder. It has been stated that powders which have a shape, can put on clothes. Red clothes (coating) consists of *chu sha* [硃砂] (cinnabar); green coating, of sulfur; blue coatings, of *t'ung lü* [銅綠] (verdigris, green copper); white coating, of *ch'ien fên* [鉛粉] (lead powder, white lead); and coatings of other colors will be made up in a comparable manner.

37. Some people use a paste. For example, when cotton is coated with a sulfur paste, (and is used in the powder), the fire with purple-green balls will fly out. When tin foil treated with a saltpeter-sulfur paste is used, one can see the fire spitting out colored light (flames). If wick-grass is used in the powder, the paste-method must be applied. Sometimes powdered iron is also coated or pasted. when this is used in fountains, the flowers are much more deceptive and marvelous. Again, some one uses powder to coat upon the coat, a paste upon the coat, one side with coat while the other with paste, or coating and paste in the center. In another method, the grains of the powder are dressed (coated), made into shape, wrapped together, and coated again. This is called the seven-star coating. The method of

using one layer of coating, then one layer of powder, and son on, layer after layer, is called case-coating. Sometimes, the pipe of a piped match is also coated or pasted. This kind of trick is not understood by those who have not specialized in the art.

The Packing in of the Powder (Abstract)

38. [12a-b] To save labor, the powder for firecrackers is loaded into 300-500 small, colored cylinders at one time, all of the cylinders being made up into an hexagonal bundle with the openings facing upward, and the powder is then run in from a long spoon (funnel). In packing fountains, the powder, after loading, must be stirred to prevent the settling down of the powdered iron, and is not to be shaken, otherwise, the ingredients will be separated from each other with the charcoal on top, and the saltpeter and sulfur at the bottom. The powder for crackers must be packed loosely but the powder for fountains is pressed hard.

Auxiliary Shows (Special Pieces) (Abstract)

39. [12b-13b] The Hundred Sons, The Three Ranks, The First of All, Lucky Clouds, Butterflies, Rockets, Flowers of the Moon, Brick Flowers, The Nine Dragons, the Eight *Hsien* [仙] (immortals), etc., are auxiliary shows (special pieces). They may be fired singly or may make up a part of a play. They go up in the air, jump on the ground, and fly to the one side or dance on the other. These furnish motions in front of a stationary

spectacle. Rockets are the eyes of fireworks, and are fired before the main display in order to quieten the audience.

40. There are some fireworks for display in the day time. They are called smoke-plays, and make use of smokes. They may be so constructed as to display colored buildings, towers, human beings, mountains, waters, and various spectacles. The auxiliary shows (special pieces) may be earth mice (ground mice), water mice, snow crackers, smoke crackers, incense lanterns, falling pearls, smoke horns, foggy orchids (orchids of mist or smoke), colored wheels, colored wings, etc., while colored rockets are used as the first fire. The flower shells are shells filled with powder for enlarging the shows and are to be reckoned as special pieces. Shells of fruits, nuts, fir cones, calabash, paper, clay, wood, etc., are also used.

Flexible Pieces (Abstract)

41. [13b-14b] Flexible articles are constructed by using folding frames on which images of men and other things, buildings, towers, etc., can be mounted at will to form a spectacle. The frames are made of bamboo, hemp-rope, and paper. There are self-illuminated figures and figures to be illuminated. Fire wheels, fountains, crackers, rockets, flower moons, flying rates, etc., may also be mounted on the same frames. Fireproof materials are always procured by treating with alum solutions.

Fireproof Screens (Abstract)

42. [14b-15b] When three or four spectacles or displays are mounted and folded up into one package, the bottom spectacle must be separated from the upper one by means of a screen of fireproof paper in order to prevent them from burning together. After the display has been exhibited, the screen is dropped off automatically. If alum alone is not sufficient to make the paper fire-proof, *lu kan shih* [爐甘石] (zinc bloom, zinc carbonate), *shih chih fên* [石脂粉] (fuller's earth) or lime may also be used in combination with it.

Head Fuses (Abstract)

43. [15b-16a] If a fire show is lighted at the bottom, the fire goes upward slowly. The difficulty is reduced by lighting it at the top also, so that it takes fire all over. This is done by means of head fuse or top match.

Rigid Pieces (Abstract)

44. [16b-17a] A rigid piece is used when there is only a single spectacle which does not need to be folded up.

Changing Shows or Transformations (Abstract)

45. [17a-b] The appearance of one thing which will change into another in a show, is called a changing show or transformation. Examples are: a fish changing into a dragon, a copper coin changing into a butterfly, the two *hsien* (immortals) giving *tao* [道], the two dragons playing with the ocean (the latter two items have two things change into one), the flat peach, and the god of longevity, and others.

Multiple Pieces (Abstract)

46. [17b-18a] In fireworks displays two or more sets of articles are sometimes fired separately and at the same time in adjacent scenes to make up one spectacle. They are called combinations.

Flying Pieces (Abstract)

47. [18a-b] *Liu hsing* [流 星] (flying star, rocket), flying rat, flower-moon, etc. are the small flying pieces. In plays, for instance, the *hsien*-people (immortals) hailing the crane, the envoy *Hsiao* [蕭] riding on the phoenix's back, the golden lotus bursting out from the ground, the five old men going back to heaven, etc. are the flying articles of larger designs.

Water Fireworks (Abstract)

48. [19a] Powder is put in pig's intestines, paper swans, bamboo cylinders, etc. to make fireworks which are fired on the surface of water. Colored smokes and water-mice are fired under the water.

Moving Pieces for Banquets (Abstract)

49. [19a-b] Small articles such as jumping grasshoppers, wandering fish, running snakes, galloping deer, etc., all of these being small pieces about an inch in length, are fired after a banquet. It is supposed that their smoke facilitates recovery from over-indulgence.

Folding Frames (Abstract)

50. [19b-20a] Folding frames in the form of leaves are made of iron wires. They can be folded over for the mounting of fireworks.

Assembling the Display (Abstract)

51. [20a-b] Pieces are fastened onto the frame with bamboo fibers or paper-wrapped iron wires, but not with hemp rope, for the latter slips.

52. [20b-21b] There are internal connections and external connections. The internal ones use powder while the external ones use match.

TABOOS

53. [22a] Essentially, no precautions are needed in the use of *huo hsi* [火戲] (fire-plays, fireworks), but, because of their violent character and light producing ability, wherein they resemble the sun shine on all the devils, they are not to be treated carelessly. Although *ni yün* [尼褌] (woolen cloth) and *ching pu* [縱布] (muslin) can stop the shooting of a candle, and iron shots and magnetic stones are able to control sulfur, these are the specific properties of the substances, but human actions also accomplish their effects.

54. The compounding must not be done in a family which is in mourning. It is especially prohibited in the house where a funeral has been held or where a man has died, for there the misfortune of accidental fire is certain to happen.[15] In case the mourning is for someone outside of the immediate family, and in case the family wishes to buy powder and must use it, a piece of red silk-cloth may be hung in the compounding room to release (the family) from the prohibition of using powder. In a house where fireworks are being made,

[15] Fireworks, especially crackers, are used in China solely for celebrations or for the purpose of expressing joy, and are avoided in times of sadness. They are supposed to have the power of driving devils away.

one must not burn *ts'an sha* [蠶沙] (grass?) or bamboo leaves lest by this means the essence of the saltpeter is weakened.

55. During the packing of powder, if a drum is beaten to strike power into the powder, the fire flowers will be brighter. However, during the compounding, the sound of a drum must not be heard lest the powder in consequence acquire the defect of bursting. The ashes on the charcoal must be removed before use. If [22b] a charcoal with adhering ashes is used, the resulting powder will usually be impeded. Probably the ashes are the ghosts of charcoal and the charcoal is afraid of the.

56. Women are not allowed to handle the powder. If the powder is packed by women, the crackers will change into fountains and vice versa. Smoking is forbidden in the powder room. The room should be kept quiet and neat, and noisy talk forbidden in order that the soul of the powder may be soothed. Care must be taken to prevent any changes in the powder. The testing of powder must not be carried out at any place near the powder house. The filling of the cylinders must not be done near any fire or smoke. The apparatus for handling the powder must be closed tightly, and the access of wind must be prevented. After long standing in the wind, the powder takes fire spontaneously. Artifices after being loaded with powder, must not be heated again (for drying), for there is danger that the powder may show its behavior spontaneously after long continued warming. The tamping or pounding of the powder must be neither too heavy nor too light, and the amount of the powder may not freely be increased or decreased. The packing of powder by lamplight is not permissible. The opening of the powder container on a rainy day is not permissible.

Those who hold established formulas will be limited by them; who understands elemental changes?

Skill of Craftsmanship (Abstract)

57. [22b] The various operations, the fastening of the artifices, the connecting of the fuses, the preparation of the powder, the tamping in of the charges, etc., all require special tricks of manipulation.

The Spare Pole (Abstract)

58. [23b] A stick or pole is useful in case some of the hanging pieces misfire or burn improperly.

A NOTE ON READING THE TREATISE

HUO HSI LÜEH

By Yang Fu-chi [楊復吉]

[24b] An account of fireworks has rarely been published. The only available information appears in *Yüeh ling kuang i* [月令廣義] (The Yüeh-ling Expanded, by Fêng Ying-ching: [馮應京]) and in *Wan shu chih* [宛署記] (Memoranda of Wan-shu), both of which were written in the Ming [明] dynasty. These contain only a

few words (on fireworks), and are of little use. *Chao Hsüeh-min* [趙學敏] of *Ch'ien-t'ang* [錢塘], giving himself to relating in detail the formulas for manufacturing fireworks, has prepared a book. Although the subject is trifling, much energy and patience has gone into the collecting and assembling of materials. The work really occupies a place which has never before been filled. By no means should we laugh a bit at this composition as useless. *Yang Fu-chi* of *Chên-tsê* [震澤], in the late summer of the year *kuei-yu* [癸酉] (1753).

NOTES

1. Chao's description of the purification of saltpeter is so incomplete that one is tempted to infer that he had had no experience with the process. No effort appears to have been made to supply the deficiency of potassium in the crude material, or to replace the calcium which is commonly present, as is done in Europe by the use of wood ashes.

2. It is interesting to find that saltpeter, the oxidizing agent, is related in Chinese chemistry of the eighteenth century to the negative principle, yin, as oxygen in Europe was considered to be dephlogisticated air, and that sulfur in China was the embodiment of the positive principle, phlogiston, the essence of pure yang.

3. Unpurified saltpeter containing sea salt is more hygroscopic than the purified material. Impure saltpeter encourages charcoal (with which it is mixed) to take up moisture, and iron filings to rust.

4. The clarification by means of glue would work. White turnips boiled in the solution of impure saltpeter would absorb a certain amount of the dissolved salts, and conceivably might, as the suggests remove the chlorides faster than the nitrates-but we have no information on this point.

8. The process which of here described for the preparation of liquid sulfur might well yield a solution of ammonium polysulfide which would have several of the characteristic properties of sulfur. It would, for example, blacken the common metals including mercury, and would also convert mercury into cinnabar by suitable manipulation. The other reactions which are enumerated are not so evident, the purple color with magnetic stone and the disturbance with saltpeter, for ammonium polysulfide solution does not react with saltpeter. With pig fat it would emulsify to form a salve or ointment.

10. Charcoal is hygroscopic. Chao recommends that it be kept, as we would say, "in a desiccator over lime."

11. Charcoal which has taken up water makes the compositions which contain it unreliable in their performance.

12. The wet method of making black powder, particularly sulfurless gunpowder, is at present in use in this country. The text apparently refers to sulfurless gunpowder. Particles of charcoal impregnated with camphor (snow-lantern-powder) would produce an interesting effect when used in gerbs or fountains.

13. The powder is mixed with lacquer and cast; the resulting mass is not affected by moisture, and is stable in its properties. No analogous method was in use in Europe.

14, 15. Powdered cast iron and steel dust were used in Europe at this time, and mixtures containing powdered cast iron were generally called Chinese fire. Lieutenant Robert Jones, contemporary with *Chao*, reports the following formulas.

"For a Brilliant Fire. Meal powder twelve pound, saltpeter one pound, brimstone four ounces, and steel dust one pound and a half.

"Chinese Fire. Saltpeter twelve ounces, meal powder two pound, brimstone one pound two ounces, and beat iron twelve ounces.

"For Gerbes. Meal powder six pound, and beat iron two pound one ounce and a half."[16]

The same author gives six compositions "for standing or fixed cases" (fountains) of which two contain steel dust. Needle steel (drillings from the manufacture of needles) are used in gerbs in this country at present.

Cutbush states that "D'Incarville, a missionary at Pekin, obtained the process for making Chinese fire; and observes, that the pulverized cast iron they employ is called *iron-sand*, of which they have six numbers or varieties.[17] . . .

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[16] Jones, "Artificial Fire-Works, Improved to the Modern Practice, From the Minutest to the Highest Branches," etc., 2nd ed., London, 1766, pp. 43, 44.

[17] James Cutbush, "A System of Pyrotechny, Comprehending the Theory and Practice," etc., Philadelphia, 1825, p. 202.

"The Chinese have long been in possession of a method of rendering fire brilliant, and variegated in its colours. Cast-iron, reduced to a powder more or less fine, is called iron-sand, because it answers to the name given to it by the Chinese. They use old iron pots, which they pulverize, till the grains are not larger than radish seed; and these they separate into sizes or numbers, for particular purposes."[18]

Chao's text indicates a real understanding of the properties of powdered iron, and mentions several wise precautions to be exercised in its handling. The practice of wrapping the powder in paper and keeping in a desiccator over lime is a good one, but it does not guarantee the keeping qualities of the mixtures in which the iron is subsequently used. Cutbush however recommends a somewhat similar method of storage. "As the goodness of iron or steel dust, in fire-works, depends greatly on its being dry, and not oxidized or rusted; its preservation must be accordingly attended to. The usual preservative is to put it in a box, lined with oiled paper, and covered with the same, or in tin canisters, with their mouths well closed.[19]

"It should be observed, that rockets, into the composition of which, iron filings and iron sand enter, cannot long be preserved, owing to the change which the iron undergoes in consequence of moisture."[20]

On the subject of preserving steel and iron filings, Jones says- "it sometimes may happen, that fire-works may be required to be kept a long time, or sent abroad; neither of which could be done with brilliant fires, if made with filings unprepared; for this reason, that the saltpeter being of a damp nature, it causes the iron to rust, the consequence of which is, that when the works are fired, there will appear but very few brilliant sparks, but instead of them a number of red and drossy sparks, and besides, the charge will be so much weakened, that if this should happen to wheels, the fire will hardly be strong enough to force them round; but to prevent such accidents, prepare your filings after the following manner."[21]
He then describes the process of coating the filings with sulfur by stirring them up with melted brimstone. This method was commonly used in Europe as late as the first half of the nineteenth century, but it is more usual now to coat the filings with beeswax, paraffin, or linseed oil.

17. Different kinds of charcoal for quick and for slow match.

18. The match is kept dry be means of lime.

20. The trick of leaving the ends of the match unpiped, and thus of causing the match tube or pipe to fall away from the piece after the match has burned, is one which does not appear to have been use din Europe. The piped match burns almost instantaneously, but the portion of the match which is not enclosed within the tube burns slowly.

21. The use of alum for fireproofing was ancient and widespread. Archelaos, one of the generals of Mithradates in the war with Rome in 87 BC fireproofed a wooden tower by means of alum, and the wooden siege engines which the Romans used in the war of Constantine and the Persians in 296 AD were similarly treated.[22]

22. Many kinds of dyed paper are bleached by the sulfur which is used in the compositions, but the common pigments are generally not affected.

23, 24. The Chinese technique in the making of fountains is described. The conical shape of the interior of the container provides what amounts to the choke or constricted exit for the gases in European practice.

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[18] *Ibid.*, p. 371.

[19] Cutbush. *op cit.*, p. 202.

[20] Jones, *op. cit.*, p.83.

[21] *Ibid.*, pp. 371-372.

[22] Partington, "Origins and Development of Applied Chemistry," London, New York, Toronto, 1935, p. 148.

25. Orpiment and realgar, sulfides of arsenic which occur naturally as minerals, were used in European compositions at an early date. They are combustible and burn with a bright, white light. They are also volatile, and yield yellow smokes to the extent that they escape combustion. The intent of the statement that shreds of cotton give violet light is not clear. Verdigris does impart a greenish or bluish color to the flame, especially if chlorides are present; lead compounds tend to give a lilac color; but black *light* from pine soot is obviously impossible. It is probable that the word, light, applied to the effects of verdigris, vermilion, white lead, and pine soot, is in error and that the appearance, like a smoke puff, of a cloud of the finely powdered material, blown about by the force of the burning composition, is really intended.

26. The lapis lazuli, cinnabar, and calomel are evidently intended to be used in the state of fine powders to produce colored clouds of dust, and the metal foils, gold, silver, and tin, to be blown out in the same way as the colored powders to produce interesting visual effects. Pitch burns to produce soot or black smoke. Calomel is volatile and will produce a white smoke; it is used occasionally at present, particularly in blue lights, to supply chlorine which enhances the blue color which copper compounds give to the flame. Potassium nitrate (saltpeter) mixed with combustible materials gives a violet flame, sodium nitrate a yellow one.

29. The wet method of making black powder is described, and explanations given of the effects of dry roasting and of wet roasting with the admixture of other substances.

30. A copper compound to reduce the yellowness of the flame. If the powder is boiled with rosin oil (possibly turpentine), its flame will be smaller in size but more lasting in time.

31. There are certain incombustible substances which are useful in the pyrotechnic art for the production of various effects.

32. Rosin can "concentrate spreading light into spot light" by preventing an explosive expansion of the mixture in which it is incorporated.

33. Mice-powder and moon-lantern-powder are special powders for use in particular fireworks. The author makes practical observations which suggest that he has had an extensive experience with pyrotechnics; he mentions the effects of the saltpeter, of the sulfur, of the charcoal, of the iron sand, etc., and the fact that obstructions in the choke cause the piece to shake or to jump about.

34-37. The coated and composite grains evidently represent a technique of Chinese origin and indicate that certain of the effects of the fireworks are intended to be observed in the daytime. The burning grains of powder trace out their flight both by their flame and by their smoke. A compact mass or grain of burning composition, thrown out from a rocket, Roman candle, gerb, fountain, or flower pot, is called a *star* in our present practice. Composite stars are made in this country in such manner that the stars change color while they are burning or that the single stars burst into several stars of the same or of different colors. But daylight fireworks have not been popular, and we have not known of stars being coated with materials which produce colored smokes as is described in the Chinese text. The use of iron sand would produce an effect similar to that of penny sparklers or of electric spreader stars.

38. It is a good practical observation that the powder for crackers must be packed loosely but that the powder for fountains is pressed hard. The hard-pressed mixture burns from its surface; the flame from the burning cannot penetrate into its mass. If it were loosely packed, like granular gunpowder, the mixture would burn rapidly throughout its mass and an explosion would result. The tendency of mixtures containing iron sand to lose their uniformity is also correctly noted. These mixtures must be stirred constantly while they are being loaded and then pressed, tamped, or pounded so firmly into place that they can no longer separate.

39. The Chinese names for the various pieces of fireworks are no more bizarre and fantastic than American catalogues list such pieces as "jeweled cascade," "devil among the tailors," "golden sunrise," "whistling pigeon," " wheel of fortune," "illuminated surprise," "yellowstone wonders," "fountain of youth," "jack in the box," "horn of plenty," "diamond necklace," "Hawaiian frolic," "dance of the fairies," and "messenger to Mars."

42. The fireproofing of paper with alum, or, if this is insufficient, by the use of an additional dusting with zinc carbonate, fuller's earth, or lime.

54. Sympathetic magic: the bad effects upon the powder of mourning, death, funerals, etc., but, if the mourning is for someone outside of the immediate family, then its effects may be counteracted by magical means.

55. Magical effects on the powder of the beating of a drum. Wood ashes mixed into the powder make it burn more slowly.

56. An intermingling here of magic with sound good sense: several sage precautions to be observed in the handling or powder are mentioned. The statement that the powder takes fire spontaneously after long standing in the wind appears to be in error, but may perhaps contain a certain element of truth. The several components of the powder, differing in density, would be more or less separated by the wind, and the blowing about and settling of the dust would introduce new hazards which might result in easy, if not actually spontaneous, ignition.

Traps, But Not For Boobies

by Tenney L. Davis
The Technology Review 47
[1945][11]

A BOOBY is defined as a dunce, a stupid fellow, also an awkward lubberly fellow, but the definition provides no satisfactory basis for understanding what a booby trap is. Booby traps are not designed particularly for the entrapping of boobies, nor is their efficiency for that purpose any measure of their excellence. The best booby traps indeed are designed to ensnare intelligent persons by an appeal to their curiousity and interest. The appeal must be definite. Traps into which a wayfarer blunders by accident are traps to be sure, but not booby traps. Booby traps must be innocent appearance, showing no hint of their harmfulness, and they must be attractive or interesting, apparently desirable or useful. They are intended to be actuated by the person to whom they are intended to be injurious.

When used for purposes of war, booby traps fight for a general in places where the men of his army are absent. This is one of the ways in which explosives are now being used on the beaches of Europe, in the forests, and in the villages. Booby traps containing snakes, poisons, and so forth, were probably known to the unrelenting Romans, to the wily Greeks, and to the ingenious Chinese, and it may be that the latter made early use oftraps loaded with gunpowder. At any rate, booby traps containing explosives were used in Europe early in the Seventeenth Century. Two such devices are described in the Pyrotechnie of Hanzelet Lorrain, which was published at Pont-à-Mousson in 1630.

Lorrain was able by means of a wheel lock to produce fire almost instantly at the slightest touch. The device consisted of a toothed wheel of steel, wound up against the tension of a spring and held wound by means of a ratchet. When a pull on a trigger or a string released the ratchet, the wheel started to rotate rapidly, striking its teeth against a piece of flint and producing a stream of sparks for the ignition of gunpowder. It probably worked as well as a modern cigar lighter.

Lorrain describes his first booby trap as:

"Another invention of an instrument which when used rightly can make a disagreeable job for an enemy.

"Since a common osier basket such as everyone uses can be carried anywhere without suspicion, take two wooden bowls plenty strong and thick which fit closelyone within the other; bind them with good iron wire well tightened in many places; then attach and fasten very near to them a harquebus wheel lock, and make a hole in one of the bowls at the position of the pan of said wheel lock to serve as a passageway to the primer; you will make a hole on the top of the said bowls to fill them with good powder, then you will plug up the hole; and afterwards take some black pitch, a little turpentine, and some sifted cement fromwhich you will make a paste with which you will cover the said bowls to the thickness of half a finger, and in the said paste while it is still hot you will set a good quantity of harquebus balls, and you will tie an end of match cord to the ratchet of said wheel lock: this done you will bind your wheel lock and set the dog on the primer and tie it to the bottom of the said basket in such a manner that it does not move. The cord will be made into a coil which you will set in the said basket and one of its ends will be attached to the ratchet of the wheel lock; and the rest you will fill up with eggs, fruit, and other foods. And when the person who wishes to steal the said coil will sieze it, he will release the ratchet, and the fire will take hold with marvellous assault upon those who are near by. The thing can be brought by the food peddlars to the troops of the enemy when they bring food to them."

The second one, TB Mk 2-30, Trap, booby, Mark 2, model of 1630, is described as a "chest of fireworks." It appears to have been invented to meet a particular situation and to have been used in it to good purpose. One suspects that Lorrain may perhaps have built it for a peddlar friend.

"How necessity makes means to be found to avenge one's self on one's enemies. A French merchant was accustomed to peddle his goods among the troops as much from the side of the open forts as from other places, and as there were garrisons at all of the strong points, some of the one side, some of the other, which laid a toll upon all who passed, this merchant was robbed from three or four directions at once and suffered great losses both in merchandise and in the ransoms which he was constrained to pay. Seeing himself stripped of all livelihood and as in despair, complaining to a friend of his, he asked him what means he could find to be avenged on those who had thus ruined him. The invention was suggested to him to fix up a cart similar to that in which he was accustomed to peddle his merchandise; equipping it with a chest similar to that in which he carried bolts of silk, and in place of the said cloth the chest should be filled with fire barrels, grenades, fire pots, powder, and other fireworks; and to announce the time of a fair where he was accustomed to go in order to bring the said cart near the places where he had been robbed. Soon the cart was built and the chest accomodated to it within which there was placed a charge of grenades, fire barrels, fireballs, and a good quantity of powder. After the whole was set up, he caused wheel locks made especially for the purpose to be fixed within the said box, one worked from the lock which connected with the key of the chest and released the ratchet when it was opened, and the other was attached in another place within the said chest and its ratchet was released as soon as one lifted the cloth which covered whatever was packaged in the form of bolts of silk. The said cart was brought to the accustomed place and there it was taken and siezed just as the others had been. The soldiers wishing to take the booty and opening said chest, they were either killed or burned to the number of 20 or 30. This invention can serve in some ambuscade to attract an enemy which has given itself over to pillaging and not to fighting."

Among the many military andpyrotechnic contrivances which Lorrain describes there is one other which ciomes close to being a booby trap but which fails to conform to the definition because it is actuated by a soldier who wishes to injure those who are opposed to him. It is of innocent appearance and involves the principles of deceit and camouflage. A donkey carries four or five harquebuses or chevrettes set up to be fired by a train from a wheel lockto which a cord is attached by which it may be released at will. The guns may be covered by a cloth so that the donkey appears to be loaded with baggage and then, when the donkey has been maneuvered into a favorable position, the cord is pulled. Lorrain's ingenuity included also a cart loaded with sticks of wood, bored out like muskets and arranged to shoot bullets or pieces or iron.

The Early Use of Potassium Chlorate In Pyrotechny

Dr. Moritz Meyer's Colored Flame Compositions

by
Tenney L. Davis

Chymia I[12]
[1948]

The history of fireworks divides itself naturally into two principal periods, the period before the introduction of potassium chlorate, and the period after the introduction of that substance. The first period includes the development of practically all of the pyrotechnic devices which are known today, fire balls, signal flares, smokes, gerbs, Roman candles, rockets, wheels, table fireworks, aerial bombs and exhibition pieces, all of which employed pyrotechnic mixtures combining potassium nitrate along with sulfur and charcoal and certain other combustible materials. The variety of the ingredients was small, but the variety of the contrivances in which they were used, and of the mechanical effects which they produced, had already largely exhausted the possibilities of diversification. The period since the introduction of potassium chlorate has seen the application of many new chemicals to pyrotechny, and such new and improved effects, louder and sharper explosions, brilliant colored and dazzling lights, as can be produced by the new ingredients.

Berthollet in 1786 first recognized potassium chlorate as a new compound, prepared it in a state of purity, and described its properties. Its extraordinary activity as an oxidizing agent attracted Lavoisier, Fourcroy, and Vauquelin to take part in the study of it. "It is especially in the violent manner in which this substance reacts with combustible bodies," said Fourcroy, "that its most singular properties reside, and these may indeed be considered surprising if they are compared with those which all other known saline substances exhibit. The superoxygenated muriate of potash seems to contain the elements of the thunderbolt in its molecules. The chemist can produce almost miraculous effects by means of it. Nature seems to have concentrated all her power of detonation, fulmination, and inflammation in this terrible compound."[23]

Experiments undertaken by the French Government in an effort to manufacture a new and stronger gunpowder from potassium chlorate resulted in the death of two persons from the accidental explosion of the stamp-mill at Esson, 27 October, 1788.[24]

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[23]Raoul Jagnaux, "Histoire de la chimie," Paris, 1891, Vol. 2, p. 91.

[24]The dramatic account of the accident which was published in the *Journal de Paris* of 31 October 1788 is quoted at length by Jagnaux, op. cit. pp. 91-92, and with slight abbreviation by Ferdinand Hoefer, "Histoire de la chimie," 2nd edition, Paris, 1869, vol. 2, p. 554.

Experiments were carried out at the Arsenal at Paris, 27 April, 1793, in which chlorate powder (6:1:1) was tested in ballistic mortars, eprouvettes of Darcy and Regnier, and was found to be considerably stronger than ordinary black powder.

Powdered chlorate can be mixed with powdered sulfur and other materials if proper precautions are taken, but it cannot be ground up with sulfur and charcoal, and incorporated intimately with them without the greatest danger and an overwhelming probability of an explosion. A mixture of chlorate with sulfur and charcoal takes fire from shock or friction, and deflagrates, behaving more like an explosive than a propellant powder. The sensitivity of chlorate mixtures can be reduced by adding other salts or combustibles less easily inflammable than sulfur such as rosin, shellac, starch, or sugar, as is done in various fireworks compositions, but efforts to use these mixtures as propellant powders have never been successful.

As chemist became better acquainted with the properties of chlorate, they found use for it in various spectacular demonstrations, many of which are still standard lecture experiments, and in such inventions as dip splints, friction matches, and percussion primers.[25]

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[25]The first matches, *dip splints*, are reported to have been manufactured in Vienna as early as 1812. They consisted of wooden splints, dipped in sulfur at one end, the sulfur covered with a composition of chlorate and sugar, mixed with glue and colored with a little vermillion. They were ignited by bringing the head into contact with strong sulfuric acid which was kept, usually absorbed on an asbestos pad, in a small glass bottle or leaden vial.

The first real friction matches or *Congreves*, were made in 1832, sulfur-tipped splints with heads made from a mixture of potassium chlorate with about twice its weight of antimony sulfide along with gum or glue. They were ignited by pressing strongly between two pieces of sandpaper, but the ignition was accompanied by a sharp report or small explosion, and the heads often flew off burning without setting fire to the splint.

In 1805 Rev. Alexander Forsyth of Belhelaive in Aberdeenshire, Scotland, invented a lock for firearms which operated by percussion and without flint and steel. It was charged with a mixture of potassium chlorate and sulfur, enough for forty primings, and used for each shot as much powder as contained one-eighth grain of chlorate.

Pauly's priming powder, described in the *Archives de découverte* for 1812, p. 158, and ibid. for 1814, p. 174, as reported by James Cutbush, "A System of Pyrotechny..." Philadelphia, 1825, p. 578, consisted of potassium chlorate 8 parts, sulfur 3 parts,and charcoal of light wood 2 parts.

Frederick Accum, "Chemical Amusements, Comprising a Series of Curious and Instructive Experiments in Chemistry..." 4th ed., London, 1819, p.229, describes a powder which takes fire when rubbed in a mortar, "To six grains of chlorate of potash (hyperoxymuriate of potash),reduced to a fine powder, add three of finely pulverized charcoal; mingle them together, by the greatest possible friction, on a piece of paper. If to this mixture two grains of sulfur be added, the whole, when forcibly rubbed with a pestle in a mortar inflames with a rapid flash, like fired gunpowder. The hand should be covered with a glove or handkerchief when performing this experiment."

The colored flame compositions which revolutionized the art of fireworks owed their invention in part to chlorate, in part to new compounds, particularly to those of strontium and barium, and in part to new knowledge concerning the flame colorations produced by various materials. As has happened repeatedly in the history of fireworks, the invention was in use before it was discussed. When information concerning it was finally published, the publication had only a small circulation, the practice still remained largely secret, and knowledge about it spread with amazing slowness. The earliest important publication on colored flame compositions appears to be that of Dr. Moritz Meyer, a captain in the Prussian War Ministry who described many improvements, "Die Feuerwerkerei in ihrer Anwendung auf Kunst, Wissenschaft, und Gewerbwe," an octavio brochure of 55 pages, published in Leipzig in 1833.[26] According to Brock,[27] a French translation, Pyrotechnie raisonée," by Lieut. Hippert of the Belgian artillery, was published at Brussels in 1836. We take it that 1833 is approximately the date of introduction of chlorate colored flame compositions into practical military and recreational fireworks.

The yellow color imparted by sea salt to the flame of watch fires and military incendiaries was known to the ancient Greeks, and the green, blue, and peacock colors produced by copper and its compounds have been known so long that no date of discovery can be assigned to them. Margraf in 1758 commented upon the yellow color imparted to the flame by sodium salts, and the lavender by potassium salts, but the facts were probably already well-known. The discovery of the carmine-red color which strontium compounds give to the flame did much to stimulate an interest in flame coloration. This color appears to have been mentioned publicly for the first time by Thomas C. Hope in a paper which he read at Edinburgh, 4 November, 1793,[28] in which he states that it was first mentioned to him "by an ingenious gentleman, Mr. Ash, who was then studying physic at Edinburgh." Hope stated that strontium nitrate deflagrates with combustibles and gives a bright red flame or light. He also noticed the green flame color of barium and the red of calcium, and was able to distinguish the latter from the more brilliant red of strontium. Lithium was discovered in 1818, and its red flame coloration was reported in the same year, although the red color which the mineral, spodumene, imparts to the flame had been noted before that.

Teachers and demonstrators of chemistry had means of producing colored flames before the introduction of chlorate, but the flames were regarded rather as curiosities than as

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Thenard, "Traité de chimie," 6th ed., Paris, 1834, Vol.2, pp. 295-296, gives an improved formula for a priming powder adapted to the percussion lock -- potassium chlorate 1.00 part, potassium nitrate 0.55, sulfur 0.33, sifted raspings of black alder wood, 0.17, and lycopodium powder 0.17.

[26]I wish to make grateful acknowledgement to the Edgar F. Smith Memorial Collection for the use of the only copy of this work which I have seen. T.L.D.

[27]A. St. H. Brock, "Pyrotechnics, The History and Art of Firework Making," London, 1922, pp. 145, 183.

[28]Thomas C. Hope, *Trans. Roy. Soc. Edinburgh*, 4, (2), 3-39 (1798).

useful fireworks. They are of interest to us because they indicate the state of the art before 1833. Cutbush in his posthumous "System of Pyrotechny," 1825, says:

> We are of the 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.[29]...
>
> 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 also 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.[30]...
>
> Again, we know that a mixture of nitrate of strontia and charcoal will burn with a rose-coloured flame; one part of boracic acid, and three of charcoal with a green flame; one of nitrate of barytes, and four of charcoal, with a yellow flame; and equal parts of nitrate of lime and charcoal powder, with an orange flame. We also know, that cotton dipt in oil of turpentine, or ardent spirit, rosin, & camphor, &c. will burn extremely beautiful.[31]

Cutbush was acquainted with some of the remarkable properties of potassium chlorate which he says, "affords a variety of amusing experiments...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."[32] He describes several experiments with the salt, but mentions no fireworks which contain it. He states that "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."[33]

Unknown to Cutbush, chlorate red fire appears to have been in use for theatrical illumination as early as 1821. Ure's "Dictinary of Chemistry," published at Philadelphia that year, contains the following passage:

> The beautiful red fire which is now so frequently used at the theatres, is composed of the following ingredients: 40 parts of nitrate of strontian, 13

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[29]James Cutbush, op. cit., p. 8.

[30]Ibid., p. 20. Accum, op. cit., pp.105-9, a few years earlier described the same flame colors with alcohol.

[31]Cutbush, op. cit., p. 435, quoting from an unnamed author in the "Dictionaire de l'industrie," Vol. 3 p. 365.

[32]Ibid., p. 22.

[33]Ibid., p. 77.

parts of finely powdered sulphur, 5 parts of chlorate of potash (hyperoxymuriate), and 4 parts of sulphuret of antimony. The chlorate of potash and sulphuret of antimony should be powdered separately in a mortar, and then mixed together on paper; after which they may be added to the other ingredients, previously powdered and mixed. No other kind of mixture than rubbing together on paper is required. Sometimes a little realgar is added to the sulphuret of antimony, and frequently when the fire burns dim and badly, a small quantity of very finely powdered charcoal or lampblack will make it perfect.[34]

The same formula for "*red fire* employed at theatres" is given in Gray's "Elements of Chemistry," 1842[35] where we find also the statement that barium nitrate "is used...in *pyrotechny*, to impart a green color to the flame." The book gives a formula for "green fire" designed according to the same principles as the formula for red fire, and hence probably coeval with it and earlier than 1833. "The *green fire* is composed of 13 parts sulphur, 77 nitrate of baryta, 5 chlorate of potassa, 2 of arsenic, and three of charcoal."[36] Both of these compositions are compounded according to a different principle from Meyer's, and may be taken as pertaining to a different tradition.

Captain Dr. Moritz Meyer appears to have been acquainted with the properties of potassium chlorate, but was no more impressed than many of his contemporaries by the dangers of manipulating it, and appears to have thought the manufacture of gunpowder-like mixtures from it to be perfectly feasible. He was a shrewd observer, and noted many points which are still of interest because they concern matters which every pyrotechnist is required to know.

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[34]Andrew Ure, "A Dictionary of Chemistry," 1st Amer. Ed. with additions, notes, etc., by Robert Hare assisted by Franklin Bache, Philadelphia, 1821, vol. 2, article, "Strontia."

[35]Alonzo Gray, "Elements of Chemistry; Containing the Principals of the Science, both Experimental and Theoretical," 4th ed., New York and Boston, 1842, pp. 296 fn., 297 fn. The author taught chemistry and natural history at the Teachers' Seminary, Andover, Massachusetts. This is one of the very few early textbooks of chemistry which mention *pyrotechny* and list the word in the index.

[36]The use of metallic arsenic in fireworks is unusual. The same book, p. 255, describes several experiments with chlorate and arsenic which we have not found in earlier textbooks, except Ure's "Dictionary of Chemistry," Vol. 1, article, "Arsenic," where the following passage occurs: "...but if three parts of chlorate of potash be mixed with one part of arsenic in fine powder, which must be done with great precaution, and a very light hand, and a very small quantity of this be placed on an anvil, and struck with a hammer, will explode with flame and considerable report; if touched with fire it will burn with considerable rapidity; and if thrown into concentrated sulphuric acid, at the instant of contact a flame rises into the air like a flash of lightening, which is so bright as to dazzle the eye."

Meyer believed that fireworks depend upon "the combustion of certain substances in pure oxygen gas, accompanied by the simple heating of substances with such materials as evolve oxygen when ignited" -- and that the fireworks art is the technical application of such combustion.[37] Two oxygen-evolving substances were available, saltpeter which had been used before and potassium chlorate (*chlorsaures kali*), new to the art, which Meyer in his book proposes to call by the shorter name of *Chlorkali*.[38] These two, with sulfur and charcoal, are the prime materials. If color is desired, some non-burning material appropriate to produce it must be added to the mixture. Besides sulfur and charcoal which are the most important combustibles, others are sometimes used, realgar, colophony, various oils, fats, and gummy substances, and antimony sulfide which, as mentioned later, serves a special purpose in certain color compositions.[39]

Meyer recommended four primary compositions for use in the manufacture of fireworks, as follows:

1. Black powder: saltpeter 75, sulfur 12, charcoal 13.
2. *Saltpeterschwefel* (saltpeter-sulfur): saltpeter 75, sulfur 25.
3. *Chlorkalipulver* (chlorate powder): potassium chlorate 79, sulfur 10, charcoal 11.
4. *Chlorkalischwefel* (chlorate-sulfur): potassium chlorate 79, sulfur 11.

He knew the relative advantages of these compositions for particular purposes, and understood how to use them practically, but had incorrect ideas concerning the chemistry of their burning.[40] The second, *Saltpeterschwefel*, is not as easily ignited as black powder,

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[37]This definition, of course, is not satisfactory. The reactions of combustion in most pyrotechnic mixtures do not take place in the gas phase at all, but in a fixed and residual phase which is probably fused or sintered. Some pyrotechnic compositions, such as black powder, colored fire mixtures, etc., maintain their own combustion without need for the oxygen of air; others require it.

[38]This is quite in harmony with the practice of today's fireworks makers, who commonly refer to it simply as potash.

[39]Meyer, *op. cit.*, pp. 4-6.

[40]He believed for example, *ibid.*, p. 7, that black powder on combustion yields 50% of its weight in carbon dioxide gas, 10% of nitrogen gas, and 40% of solid potassium sulfide, smoke, and residue, which contained all of the original potassium and sulfur. Actually it yields about 56% solid material containing about 61% potassium carbonate, and about 15% each of sulfide and sulfate. He thought, *ibid.*, p. 10, that *Chlorkalipulver* yields 42% of its weight of carbon dioxide gas, 22% of chlorine gas, and 36% solid potassium sulfide. Actually, the chlorine remains combined in the solid, though, if water is present in the powder, there may be hydrogen chloride present in the gases.

either by spark or by percussion. "Although sulfur is much more easily lighted than charcoal, it does not, on its first burning in the atmosphere, evolve enough heat to warm the saltpeter to the point where it evolves oxygen." External heat ignites it, such as that from the burning of black powder, and it burns at a moderate rate, without explosion, and with a brilliant white light. For use in fireworks it requires the addition of some black powder to insure its kindling properly. In fact, its principle use is to make black powder burn more slowly. *Chlorkalipulver* is stronger than black powder, and takes fire at a lower temperature. *Chlorkalischwefel* is very readily ignited, burns more slowly than mixtures which contain charcoal, and gives a less bright light than *Saltpeterschwefel*.

> It is well adapted to the production of colored lights since it takes on different colors readily, does not burn too fast, and yet acts strongly enough on a non-burning component to volatilize it into the flame. It is more easily kindled by a blow than *Chlorkalipulver*, and likewise is more readily extinguished.[41]

By mixing the four primary compositions Meyer found it possible to control the velocity of burning, the gas production, and the temperature or brilliancy of the light. Another extremely important advantage, the use of these compositions made it possible to get along without the dirty and troublesome preparation and manipulation of charcoal, "the most uncertain, the most time-consuming, and the most thankless job of the pyrotechnist." Charcoal has a tendency to absorb moisture from the atmosphere, but this undesirable property is largely lost from charcoal which has been made into black powder. *Chlorkalipulver* can be made without manipulating charcoal by mixing the chlorate with the residue of sulfur and charcoal which remains after leaching out black powder with water.

Meyer still preferred to use saltpeter compositions for white lights. Such lights, he says, had been made from saltpeter and sulfur, antimony sulfide, realgar, charcoal, rosin, and sawdust. The latter substances do no harm if they are present in excess, except that they give a little reddish flame. Turpentine, sal ammoniac, quicksilver, talc, and petroleum, which are also used, have a similar effect. Common white fires are:

> Bengal fire: saltpeter 100, sulfur 29, antimony sulfide 14, and
> Indian fire: saltpeter 100, sulfur 29, realgar 8.

The first of these is approximately the same as a mixture of 116 parts *Saltpeterschwefel* (75/25) and 27 parts *Antimonsaltpeter* (50/50). Meyer believed that a better white light, giving a brighter flame with less smoke, could be made from Saltpeterschwefel with 10 or 20 percent of meal powder. This composition was safe to load, remained unaltered after loading, and packed to a mass hard as stone, which could be made up in the form of balls and coated with rosin.

For colored lights Meyer preferred to use chlorate compositions containing the new color-producing substances, which, apparently, he was the first to use with success.

[41]Meyer, *op. cit.*, p. 11.

> For the preparation of colored lights there are needed a strongly burning mixture of salts, which ought itself to be colored as little as possible, and a non-burning substance which is made to glow when it is vaporized by the flame and which has the property, by this glowing, of giving a colored light. Two distinctly different parts therefore pertain to every colored light composition; the coloring substance, as mentioned, is the element which has been lacking.
>
> As a combustible mixture, Saltpeterschwefel with black powder gives a light which is too white and a temperature which is not high enough.[42] Nevertheless, it has been employed, more or less mixed with other substances, as a basis for colored light compositions which however were only moderately bright.
>
> *Chlorkalischwefel* is much to be preferred, and is indeed the best primary composition yet known for mixtures of this sort.It gives no dazzlingly bright light, burns without black powder or charcoal quickly and energetically, and has all the properties which are needed for this purpose...In larger quantities, where the burning becomes rapid, Saltpeterschwefel up to 5 percent may be added. More gives too white a light.[43]

With the single exception of boric acid, it is the base-forming elements which give color to the flame. With borax, the yellow sodium color completely masks any color which might be caused by the boric acid. Among salts of the same base, the choice is determined by considerations of cost.

> A phenomenon which is not yet wholly explained is this, that the same substances do not give the same color in all flames. Thus, copper salts, which give a beautiful green flame with alcohol, rosin, or sawdust, give a blue with *Chlorkalischwefel*. Calcium chloride gives an orange color to the alcohol flame, a rose color to *Chlorkalischwefel*, and so on.[44]

The carbonates, except potassium carbonate, are not hygroscopic as are many of the nitrates and chlorides, and are to be preferred for that reason. Sodium carbonate, which requires

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[42]Meyer was mistaken in thinking that potassium nitrate mixtures are not hot enough. One effect of chlorate is to form chlorides of the color-imparting elements, chlorides which are more easily volatile than oxides, sulfates, etc., and which give brilliant color to the flame. Nitrate mixtures are hot enough if chlorine compounds are present. George J. Schladt, US Patent 2,362,502 (1944), describes a modern non-chlorate composition which burns with a rich, brilliant green flame: barium nitrate 40%, magnesium powder 28%, hexachloroethane 30%, linseed oil 2%.

[43]Meyer, *op. cit.* pp. 26, 27.

[44]*Ibid.*, p. 27.

water of crystallization requires to be dehydrated. Crystallized boric acid can be used without dehydration. The carbonates have the further advantage that they contain larger amounts of the color-producing elements than do the other salts, sulfates, nitrates, etc.

> An investigation of the purity of the various substances would be a matter of considerable detail. It is therefore more convenient to weigh out about 1/4 *Loth* of *Chlorkalischwefel*, to mix it with 20 percent of the finely powdered substance which is being tested, to burn the composition, and to observe whether the desired color appears pure and of the usual brilliancy. If the test has once been made with the practically pure substance, then one cannot be deceived any more about the purity of another sample.
>
> The substances must be very finely powdered before being mixed with the combustible composition, dried if it seems necessary before weighing, and then very intimately mingled with the composition -- with *Saltpeterschwefel* by grinding, with Kalischwefel only by mixing.[45]
>
> A certain difficulty is involved in the fixing of the correct proportions of the several ingredients in order to obtain a light as brilliantly colored as possible and one which does not burn too rapidly.
>
> *Chlorkalischwefel* by itself is too fast; it must be therefore slowed down, and this is readily accomplished in most cases by the admixture of the coloring substance alone. Five percent admixture generally gives a notable light and a sufficiently lengthened burning, but in many cases the admixture must be increased up to 20 or 30 percent before the color attains the greatest degree of intensity. As long as the blinding white light still predominates, the admixture is still too small. If the combustion is too fast even after larger admixture, as happens only in rare cases (for example, with the red flame of chalk), then 5 to 10 percent of *Saltpeterschwefel* is added. But if the composition while having the proper intensity is too slow, if it leaves a very large residue, if the flame is always threatening to go out again, then *Chlorkalipulver* or black powder is to be added. But is it should be a blue or green flame, in which case the red color of the burning charcoal would affect it, then antimony sulfide is used which plays a role similar to that of sulfur and charcoal and which gives a white light when it burns. It is used along with *Chlorkali* and 10 or 15 percent of the mixture (50 parts antimony sulfide, 50 parts potassium chlorate) is used...If the composition burns brightly enough, and without going out, but if it is difficult to ignite, then the difficulty can be remedied by covering it with some one of the compositions which is rich in *Chlorkalischwefel* or with *Chlorkalischwefel* alone. The covering is easily lighted.[46]

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[45] *Ibid.*, p.28.

[46] *Ibid.*, p. 29.

> Not all of the substances which give very beautiful colors with *Chlorkalischwefel* will serve, even if used in the largest proportions, to give color to *Saltpeterschwefel* compositions. With these, one has to be limited to less and less intense colors. In recent French writings, lights of this sort which have been known heretofore, have been designated merely as reddish, greenish, and bluish. To make them, one starts at best with a mixture of 50 parts black powder with 100 of *Saltpeterschwefel*, and increases the proportion of black powder until a sufficiently clear color results from the addition of 20 or 30 parts of the non-burning substance. There is never need here of an additional ingredient to slow down the burning.[47]

Meyer discusses the various color producing substances at considerable length. Strontium nitrate has been used before for purple-red, but it is hygroscopic. The carbonate is preferable, as it occurs naturally in strontianite, or, better, precipitated, washed, and dried. Precipitated chalk gives a purplish-red which is almost equally good, but its use is limited to chlorate mixtures. It gives no good colors with *Saltpeterschwefel*. Mixtures of *Chlorkalischwefel* with strontium and calcium carbonates can be made slower burning by the addition of *Saltpeterschwefel*, but considerable additions change colors toward orange. Lithium carbonate gives a very beautiful purple-red, but it is too expensive to use technically. Gypsum gives a rose-red which is a new color, and flourospar a paler rose mixed with green, but neither of these substances gives any color with *Saltpeterschwefel*.

Sodium nitrate or, better, sodium carbonate which has been ignited strongly, gives with *Chlorkalischwefel* a pure yellow light which is suitable for use in the theatre. With *Saltpeterschwefel* or with black powder the color is not quite so good, tending toward reddish. Other sodium salts, borate, chloride, give less pure color, as do also, orpiment, cinnabar, bone charcoal, boxwood sawdust, pyrite, etc., which have been used earlier in saltpeter compositions.

> Heretofore the best blue has been scarcely better than the color produced by antimony. It has been our good fortune with *Chlorkalischwefel* to obtain a blue light which is not inferior in brilliancy to those described above. Copper oxide, verdigris, and copper carbonate give with *Chlorkalischwefel* a blue light, but the blue light is not brilliant enough. If, on the other hand, the ammoniated basic copper sulfate (*das Schwefelsaure Kupferoxyd-Ammoniak*) is taken, which is to be had at the apothecary's, and if this is mixed with half its weight of potassium sulfate, a beautiful blue light is produced by a composition of 60 to 80 parts of this mixture with *Chlorkalischwefel*. The ammoniate copper salt decomposes within a few days in the air, and must therefore be ordered just before it is to be incorporated in the composition, or, if it is desired to keep it longer, it must be kept in tightly closed vessels. The copper compounds mentioned above, which are unaltered in the air, are satisfactory

[47]*Ibid.*, p. 29, 30.

for compositions where such a brilliant color is not required. Ammoniated basic copper sulfate gives no blue light with *Saltpeterschwefel*.[48]

The light blue color produced by a mixture of well-burned alum or potassium sulfate with *Chlorkalischwefel* is not brilliant enough for reflections from it to be useful in the theatre. The blues which are based upon saltpeter with antimony, zinc, alum, bismuth oxide, bone meal, or copper oxide are dull.

The orange light from *Chlorkalischwefel* with the carbonates of sodium and calcium can be brought nearer to yellow or nearer to red by increasing the relative amount of one or the other carbonate. It is suitable for use in the theatre.

Violet is a new color. With *Chlorkalischwefel* mixtures it may be procured from various potassium salts, magnesium carbonate, ammonium carbonate, and most readily from a mixture of burned alum or potassium sulfate with calcium carbonate.

Apple green can be obtained from barium carbonate with *Chlorkalischwefel*, but the color is dull and not serviceable in the theatre. If more than 20 or 21 percent of barium carbonate is used, it is necessary to strengthen the composition by adding a mixture of antimony sulfide and potassium chlorate. Barium carbonate gives no green with *Saltpeterschwefel* and is not suitable for use in saltpeter compositions.

Crystallized boric acid gives a green light with *Chlorkalischwefel*. Five percent gives a distinct color which 10 or 15 percent does not make proportionally stronger. If 25 percent is used, it becomes necessary to strengthen the mixture with antimony sulfide and potassium chlorate. The light is bright enough for recreational fireworks and for signalling, but is too weak for the theatre. Boric acid does not give a green light with Saltpeterschwefel.

> A very brilliant green light which is notably more reflecting is obtained by mixing barium nitrate with as much sulfur as is needed for the decomposition of its nitric acid, that is to say, 132 parts barium nitrate with 32 sulfur: 13:3 1/5; of this mixture, which is non-burning by itself, to 100 parts 30 or 40 parts of *Chlorkalischwefel* is added whereby it becomes readily kindled. The color is nearly the same as that of copper salts burned with alcohol. In order that it may burn with the same deep green throughout, the later-burning portion of the composition ought to contain less *Chlorkalischwefel* than that which is first lighted. For lighting the loose composition, the surface of it is strewn with *Chlorkalischwefel*.
>
> It is peculiar that one is not always successful in bringing out with saltpeter or potassium chlorate compositions the beautiful colors which copper salts impart to the flame of alcohol, wood, and so forth. It seems, perhaps, that the temperature of these compositions is too high. We have not succeeded any better in producing a practical green light according to the directions which are found in many fireworks books for mixtures of finely divided copper with black powder or of saltpeter, sulfur, antimony sulfide, verdigris, and so forth.

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[48]*Ibid*., p. 32.

Brilliant fire. The addition of steel filings, powdered cast iron, ground zinc, and ground copper to black powder or to mixtures of *Saltpeterschwefel* and black powder give lights which throw out sparks. Ground zinc is obtained most readily by shaving down sticks of zinc and grinding the turnings in an iron mortar.[49]

The compositions which Meyer prefers for the most brilliant colors are as follows:[50]

1. Purple red:{ 100 *Chlorkalischwefel*, 30 strontium carbonate.
   100 *Chlorkalischwefel*, 40 calcium carbonate
2. Rose red: 100 *Chlorkalischwefel*, 30 gypsum.
3. Yellow: 100 *Chlorkalischwefel*, 40 anhydrous sodium carbonate.
4. Blue: 100 *Chlorkalischwefel*, 40 ammoniated basic copper sulfate, 20 potassium sulfate.
5. Light blue: 100 *Chlorkalischwefel*, 50 burned alum or potassium sulfate.

6: Orange: 100 *Chlorkalischwefel*, 20 calcium carbonate, 20 sodium carbonate.

7: Violet: 100 *Chlorkalischwefel*, 20 calcium carbonate, + 20 alum.

8: Green:{ 100 *Chlorkalischwefel*, 15 boric acid.
100 *Chlorkalischwefel*, 350 of a mixture of 1300 barium nitrate, and 320 sulfur.

Meyer discusses his observations on the colors which various salts give to the flame of alcohol, and describes the combinations which he considers to be the most useful.

The color producing substances are some of them soluble in alcohol, some of them not, but in either case they are effective only as solid substances, for they produce no effect as long as they are in solution, but act first only when they are dried out on the borders of the liquid.[51] A solution therefore always burns first as ordinary alcohol and begins first later to show the bright colors as single little flames until these gradually increase and

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[49]*Ibid.*, p. 33,34.

[50]*Ibid.*, pp. 33, 34.

[51] This is generally true, but does not apply to boric acid. Warm alcohol quickly estrifies boric acid, and the ester evaporates along with the alcohol, colors the flame, any yields a white smoke of boric acid again. The colored flame may be demonstrated strikingly by setting fire to the vapors which emerge from the top of an air condenser attached to a flask in which an alcoholic solution of boric acid is boiling vigorously.

finally color the whole flame. It is therefore preferable to heap the powdered color-producing substances into mounds, and to put on them only as much alcohol as is needed to make them moist. They commence then at once to burn with the colored flames. The alcohol which burns away must be replaced in small portions at a time. Also, a stirring of the colored mass and an external heating of the vessel during the burning are advantageous. These flames are never high except when external heat is applied, which is not always convenient, and it is better to bring cotton into the combination. This can be done by leaving wicks for some little time in the solutions, which ought not to be too concentrated, so as not to make the wicks burn with difficulty. Such a wick, as long as it holds out, burns with the color which has been given to it, a fact which shows how little of the coloring substance is consumed.

To produce larger flames, large flocks of cotton are soaked in such solutions, dried out, moistened with alcohol, and after they have again been pressed out, dusted with the finely pulverized coloring substance. These are now stuck on tubes which are bent out into points and have funnels attached to their upper ends. When the ball is now ignited, there results a superior, very beautiful colored sphere of fire which can be maintained as long as one wishes if a little alcohol is poured into the funnel at the right time.

For blue or green it is advantageous to use balls of asbestos, or to heap the substance in a mound as described above, since it cannot be prevented that a cotton wick would burn at the same time and that its red flame would injure the color by mixing with it. These burning balls are of great usefulness in the theatre, where fastened on wires they can be swept about gaily or made to appear like free-floating spheres of fire.

Crystallized salts which serve as coloring substances, if they contain water of crystallization, must be freed from it by gentle ignition

The same colors can be produced as fireworks compositions, but not in all cases with the same substances.

Strontium chloride here gives a very beautiful red, also lithium chloride.

Yellow, sodium carbonate, the nitrate particularly good.

Blue is obtained by means of well-burned alum, pale blue by potassium carbonate.

Calcium chloride gives orange the most beautiful coloring.

Most potassium salts yield violet, purified potassium nitrate the most beautiful of all which is much purer still than the color of fireworks compositions.

Boric acid gives green, and copper chloride a very beautiful green. A mixture of boric acid and verdigris gives a very pure green without the little red flames which always accompany the flames of copper salts. The flame of barium salts is a lighter green.

Ferrous sulfate gives a bright flame which throws out sparks.[52]

Meyer devotes the latter part of his dissertation to a discussion of the ways in which the primary compositions and the colored light mixtures may be utilized, and attaches two addenda, the first dealing with recreational fireworks, and the second with colored fires for theatrical lighting. Some of his remarks throw interesting sidelights on the state of the fireworks art in 1833.

He states that sporting powder is improved if it is made from saltpeter containing 5 to 10 percent of potassium chlorate,[53] and that blasting powder is improved if 85 or 90 parts of it are mixed with 10 or 15 of *Saltpeterschwefel* and the mixture grained in hard, round, large, polished grains.[54]

Chlorkalischiesspulver is the safest chlorate mixture which the author has found in his experiments, and is recommended for use, instead of fulminate, in copper caps for priming firearms. The caps constitute a portable and safe source of fire.[55]

> *Chlorkalipulver* may also be lighted very surely and easily by a few drops of sulfuric acid, and so is very well suited for firing charges for blasting rocks which stand in the sea. One can prepare the ignition, calmly row back to land, and from there fire at the desired time. *Chlorkalipulver* is placed on top of the charge and the acid is poured into a moveable beaker hasnging above it to which is fastened a cord which is pulled from ashore, or a glass bulb is filled with sulfuric acid and inserted into the *Chlorkalipulver*. When this is broken by some contrivance, then the acid fires. *Chlorkalipulver* can be ignited by friction if it is glued between papers roughened with pumice or powdered glass and then torn.
>
> Potassium chlorate mixtures have been used for a considerable time with sulfuric acid, and more recently with friction, as a source of fire. The mixtures commonly employed heretofore for this purpose were not the most readily kindled, and they evolved much chlorine and sulfurous acid which is disagreeable indoors. The poor ignitability of sulfur matches which light by dipping was the reason why the vials became useless if they were anywhere once left open, which was often very disagreeable, particularly at night. If, instead of the mixture ordinarily employed heretofore, a mixture of equal parts *Chlorkalischwefel* and *Chlorkalipulver* is used, and rubbed down with a dilute spiritous solution of rosin, then the vials, which had become useless with the former matches, all light very well again. The fire is surer; a match never

[52]*Ibid.*, pp. 35-37.

[53]*Ibid.*, p.38.

[54]*Ibid.*, p. 39.

[55]*Ibid.* p. 41.

misfires, even with really wretched glass. A mixture of colophony and turpentine can be applied instead of the undercoating of sulfur. By this shrewd arrangement the odor of chlorine is reduced, and the odor of sulfurous acid is replaced by that of rosin. However, the rosin does not take fire quite as certainly as the sulfur coating, and the igniter vials become somewhat smoked up from the above mixture.[56]

The saltpeter mixtures and, even better, the chlorate mixtures provide a ready source of high temperatures which can be used for such purposes as melting platinum.[57]

Rockets can be used for signalling at sea, by ships in distress, for showing the direction of the wind, and so forth.

> Equally important, the illuminating power of fireworks compositions in various colors can be used for telegraphing at night. The colors speak forth for themselves very brilliantly in short sentences. For this purpose 8 or 10 different variations of color are available, and these, singly and in combinations of 2,3,4, and so on, make shorter messages possible. The English for some little time have been using a similar telegraphy for the fleet.[58]

For colored fire the compositions can often be burned loose, but for many other purposes they require to be compacted. If they cohere fairly well without being strongly compressed, they can be mixed with a little rosin dissolved in alcohol and pressed together. This is not suitable for blue and green flames which the rosin colors red, but these ought to be moistened with a water solution of saltpeter.[59]

Colored fire compositions tend to leave a residue which sometimes clogs the orifice and interferes with the burning and with the color of the remaining composition. Where several colors in succession are wanted, ordinary cases of paper are not suitable. The several compositions are loaded one after another into a tube, 1/2 to 1 line wall thickness, cast from an alloy of 1 1/2 parts lead, 1 tin, and 2 bismuth -- first an inch of clay, then the compositions pressed down with a wooden tamper. The piece is burned in a dish and the metal recovered with very little loss.[60]

Rockets are given fiery tails of different kinds by the addition of appropriate substances to the driver composition, steel or crystallized cast iron for white, zinc for

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[56]*Ibid.*, p. 42.

[57]*Ibid.* p. 43.

[58]*Ibid.*, p. 44. Meyer has a footnote: "Remark. Ordinarily only the white, red, yellow, blue, violet, and green are used, but these are enough for 4,300 signals."

[59]*Ibid.*, p. 44.

[60]*Ibid.*, p. 37.

greenish, pyrolusite or coarsely powdered charcoal for red, and sodium carbonate for yellow.[61]

The last addition to the treatise deals with Colored Lights for Theatre Illumination.

> During the printing of this publication the author carried out still more experiments on this subject from which it appears that the following mixtures are best suited to the purpose:
>
> *White* from 85 *Saltpeterschwefel* (3 saltpeter and 1 sulfur) and 15 black powder.
>
> *Red* from 106 parts thoroughly dried strontium nitrate and 32 parts sulfur, to which non-burning mixture *Chlorkalischwefel* (4 parts potassium chlorate and 1 part sulfur) is added until the composition has the proper rate of burning for the particular purpose. Ordinarily, 30 to 35 parts of the latter must be added to 100 parts of the former mixture.
>
> *Green* from 130 parts barium nitrate and 32 sulfur. The procedure is the same as with the strontium salt, and here too 30 or 35 parts *Chlorkalischwefel* is the right proportion for ordinary stage illumination.
>
> *Rose*, 50 *Saltpeterschwefel* is mixed with 50 *Chlorkalischwefel*, and 8 parts black powder, and 25 parts chalk are incorporated therewith.
>
> *Blue*, 50 *Saltpeterschwefel* is mixed with 50 *Chlorkalischwefel*, and 20 parts potassium sulfate and 30 parts ammoniated basic copper sulfate are incorporated therewith.[62]

Meyer's colored flames demonstrate fully his theory that the colors result from the volatilization of color-producing substances in the hot flame of burning pyrotechnic compositions. He recognized and introduced many of the best color-producing substances now known. The mixture of potassium chlorate and sulfur which he used as his primary combustible is an extremely dangerous one. Mixtures which contain these two substances are sensitive to shock, to friction, to heat, and subject in the presence of moisture to a self-catalyzing *souring* which may result in spontaneous combustion. They have caused so many serious accidents that their use has been forbidden in England since 1894. In spite of their faults, they perform in a very satisfactory manner, and have continued to be used in this country, in Italy, and elsewhere. It is interesting to note that the first further developments in colored flame compositions after Meyer were by the substitution of other combustible materials, cane sugar, milk sugar, shellac, starch, dextrine, in place of the sulfur, in the direction precisely to furnish mixtures in conformity with the later ordonnance.

After Meyer the next important improvements in chlorate colored flame compositions were made by the Frenchman Chertier, who seems to have been the first to use calomel

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[61] *Ibid.*, p. 51.

[62] *Ibid.*, pp. 53, 54.

extensively for the production of more brilliant colors. It is possible that he may have been influenced little or not at all by the work of Meyer.

Knowledge of advances in pyrotechny diffuses sluggishly, partly because the few books which have been written on the subject have been issued in small editions, partly because fireworks formulas have been trade secrets and have been transmitted largely by word of mouth. Pyrotechny is a conservative art. Innovations are slow in finding general adoption, and methods and ideas once accepted are slow to be displaced.

The first edition of Audot's book on fireworks,[63] Paris, 1818, gives a fair picture of the state of the art at the time of its publication. It describes compositions based on saltpeter containing such substances as copper filings, zinc filings, antimony sulfide, powdered amber, lampblack, and verdigris, which yielded flames which were somewhat colored. The second and third editions repeat the same formulas, and it is not until the fourth edition,[64] 1853, that the author mentions chlorate mixtures, saying that chlorate had at that time "been used by pyrotechnists only about a dozen years but that it had made a revolution in their art by the great activity which it gives to the flaming combustion of coloring materials which saltpeter theretofore had not been able to bring to combustion."[65] He states that his own trials have been made according to the prescriptions of M. Chertier, author of an excellent book on pyrotechny and particularly on colored fires."[66] He gives formulas for eight chlorate color compositions,[67] three of which contain no sulfur; seven contained calomel, two stearin, two sugar, two lampblack, and six gum lac.

The eighth edition of Websky's "Lustfeuerwerkskunst,"[68] 1891, contains folding plates which show the proportions by weight of the several components of 166 colored flame compositions recommended variously by 13 pyrotechnists, namely Bau, Chertier, Dietrich, Eschenbacher, Frey, Leblanc, Loden, Meyer, Scharfenberg, Schnell, Steingassner, Uchatius,

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[63]"L'Art de Faire, á peu de frais, les Feux d' Artifice pour les fetes de famille, mariages, et autres circonstances semblables. Par un Amateur," Paris, chez Audot, 1818.

[64]"Quatreme Edition, Par M. L. E. Audot. Augmenteé des nouveaux feux de couleur, des fusées à parachutes, et des notions sur la lumière electrique," Paris, L'Auteur, 1853.

[65]*Ibid.*, p. 13.

[66]*Ibid.* p. 55. Brock, *op. cit.*, p. 184 cites M. Chertier's "Nouvelles recherches sur les feux d' artifices," Paris, 1854, a year later than Audot's fourth edition, but states, p. 147, that Chertier "published a pamphlet on the subject about twenty-five years previously."

[67]*Ibid.*, pp. 57, 58, 59, 65, 66.

[68]Marin Websky, "Lustfeuerwerkskunst. Leichtfassliche, bewährte Anleitung zur Anfertigung von Lustfeuerwerken inbesondere für Dilettanten und Freunde der Lustfeuerwerkerei. Achte Auflage. Mit theilweiser Aenderung nach hinterlassenen Papieren des Autors, vollständig umgearbeitet und erweitert von Tassilo Giesl v. Gieslingen," Wien, Pest, Liepzig, 1891, pp. 233-36.

and Weber. Ten of the compositions are ascribed to Meyer;[69] none of these are among those reported in the present paper while there is one which resembles Meyer's red flame composition but is not exactly like it. We conclude that Websky, or perhaps even von Gieslingen who revised his book, considered that Meyer's colored flame compositions still possessed interest for the practical pyrotechnist.

[69]Websky, *ibid.*, p. 31, states that *Saltpeterschwefel* is a mixture of three parts of saltpeter and one of sulfur, which agrees with Meyer, and *Chlorkalischwefel* four parts of potassium chlorate and one of sulfur, which is substantially the same as the 79/21 mixture which Meyer actually recommends. In Websky's book the name is misspelled, "Mayer."

EARLY PYROTECHNICS -- PART I

Fire for the Wars of China

Old Documents Throw New Light on Rocket Ordnance

by
Tenney L. Davis
Ordnance[13]
[1948]

Chinese military leaders of ancient dynasties understood the tactical use of rocket-propelled arrows.

The "Wu pei chih" ("Treatise on Military Equipment") by Mao Yuan-i, written about 1621, is a veritable treasure house of information about early Chinese military pyrotechnics and throws important new light on the history of rockets, guns, and chemical weapons. It shows that the Chinese long ago understood the tactical use of rocket-propelled arrows. It distinguishes clearly between incendiary-carrying fire arrows thrown by bow or by whip and fire arrows which were rocket-propelled.

It calls for a reconsideration of the evidence relative to the use of rockets by the Kin Tartars in defense of Loyang and K'ai-feng-fu in 1232, and indicates that the language of the historical record probably does not refer to rockets at all. Its evidence is especially significant because much of it is in the form of pictures which are without the ambiguity which often inheres in old technical terms.

Of the "Wu pei chih," chapters 129 to 135 inclusive are devoted to military pyrotechnics and comprise 310 double pages containing 222 single pages of pictures. An historical survey is included by which the pieces represented by some few of the pictures may be identified and dated. But most of the material is in a form similar to that of a rich and diversified collection of fossils presented for the study of a paleontologist.

The opinion that huo-yao (fire powder) came to China from the outer barbarians is expressed by Fang I-chih in the eighth book, Section Huo-pao (fire throwers). of his "Wu li shao shih" ("Short Notes on the Nature of Things"), written about 1630. He says: "it is recorded that in the second year of K'ai pao of the Sung dynasty (969 A.D.) Ya I-fang laid fire arrows (huo-chien) before his majesty; and Chang Ho-chung relates that Yu Yun-wen discharged thunderbolt projectiles from his vessels (ships) at the Battle of Ts'ai-shih. They were made of paper, filled with lime and sulphur, and on falling into the water they burst into flames which leapt upwards."

The latter do not concern our present inquiry, but the fire arrows are of great interest to us. It is important to determine whether they were rockets or not.

Pictures in the "Wu pei chih" show fire arrows which are unequivocally not rockets. One, shown with a bow, carries incendiary material in a paper or cloth sack bound to the shaft close behind the barbed head. Another is a tube of bamboos, having lateral vents and filled with incendiary mixture, fitted for throwing by a whip or by a throwing stick and hence clearly not a rocket.

Another, a slender bamboo shaft with a barbed head, has a tube of spattering fire attached near its forward end. The picture looks like the drawing of a rocket but is actually

Fig. 1. Incendiary rocket arrows were fired in clusters from round bamboo baskets.

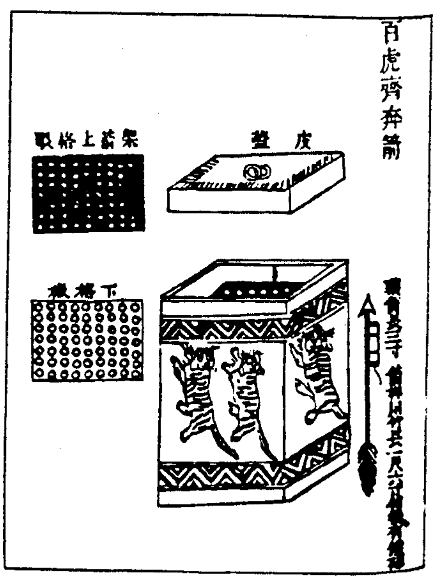


Fig. 2. This portable launcher fired a 100-rocket cluster, ranging over 300 paces.

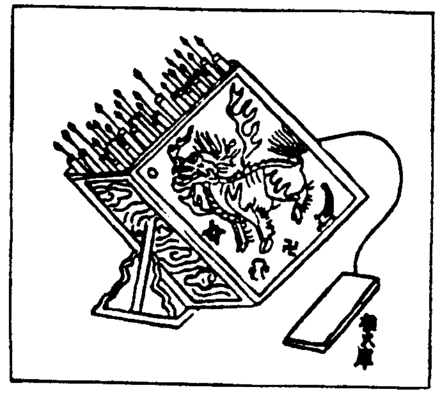


Fig. 3. This stationary, variable-range launcher fired 100 heavy rocket arrows.

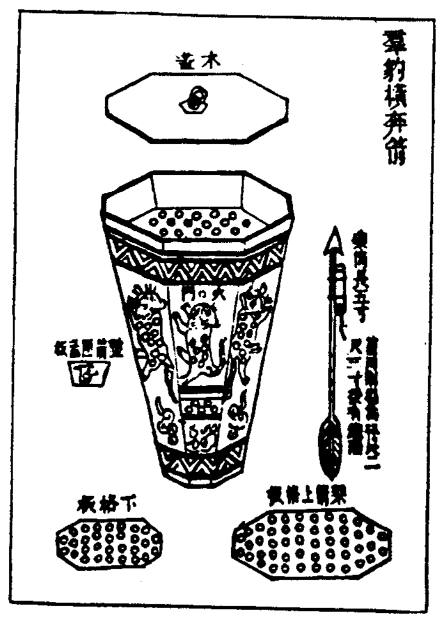


Fig. 4. The portable launcher above fired 40 rockets to a distance of 400 feet.

the picture of a whip arrow. Another incendiary arrow is equipped with two tubes of spattering fire.

The fire arrows equipped with tubes of pyrotechnic composition were probably a later development than those which carried merely stacks of the incendiary mixture. Perhaps they were contemporaneous with the flying fire spears which we shall mention later. The tube directed the fire forward against the target. If is were lighted too soon, the jet effect would interfere with the proper flying of the arrow, but the right result could be secured by a delay fuse or slow match to withhold the first until the arrow had reached its destination. A turning around of the tube, directing its fire backward, would have produced a jet-assisted arrow or one which was rocket-propelled.

The armies of Genghis Khan and his immediate successors during their invasions of northern China were not acquainted with fire powder and other devices of military pyrotechnics, but the Kin Tartars used them against the Mongols in defense of Lo-yang and K'ai-feng-fu in 1232. The facts are reported by the Sung historians and the siege of Lo-yang by Subutai, the lieutenant of the son of Genghis, is described with greater fullness in the "Wu pei Chih."

"The Kin (Tartars) at this time had huo-pao called chen-t'ien-lui [heaven-quaking thunderers]. They employed iron vessels filled with a drug which they lighted with fire and these, when launched forth and set blazing, gave forth a sound like that of thunder which could be heard beyond the distance of too li [about 35 miles]. Their effect was felt over an area of half a mow [about the twelfth on an acre].

"The Mongols constructed arched ways covered with bullock's hide which they pushed up to the foot of the walls in order to undermine them, the hollow being of sufficient size to allow men to pass underneath, and the garrison could do nothing about them until a man among the Kin brought forward an invention which consisted in suspending the heaven-quaking thunderers by iron chains and letting them down into the places excavated where the fire burst out from them, utterly destroying every fragment of the bullocks' hides and of the men they sheltered.

"They also had fei-huo-chiang [flying fire spears] to which the drug was applied and which, on being ignited, burnt forward with a sudden flame to a distance of ten paces and upwards, so that no one durst approach them. The Mongols feared nothing but these two devices."

The "flying fire spears" have been taken for rockets, and the date, 1232 has been quoted as that of an early, perhaps the earliest, use of rockets in warfare. But the flying fire spears, from the historical account and from the pictures in the "Wu pei chih," seem actually to have been spears equipped with fire tubes which threw fire forward for a distance of about thirty feet. One of the pictures particularly, which shows fire spouting forward from the tube in the same direction as the spear point, proves conclusively that the weapon was not a rocket of any kind. Indeed, the text suggests that it was intended to be used for thrust, like a bayonet, rather than as a thrown missile.

Moreover, thirty feet is an unreasonably short trajectory for a rocket but is a distance over which fire might easily be thrown by a Roman candle. Further, the "Wu pei chih" describes rockets which fly more than 400 paces.

We conclude that it has not been proved that rockets were used for military purposes in 1232.

Nevertheless, at the time of the printing of the "Wu pei chih" and probably long before it, the Chinese had already developed great skill in the tactical use of rockets and were far ahead of the Europeans in their military applications. Rocket-propelled arrows with poisoned, razor-sharp heads, when fired in clusters, provided a formidable weapon and one uniquely qualified for such special uses as attacks from ambush and the defense of defiles.

The Europeans of the same period had better rockets but had not yet found much use for them in military operations. Biringuccio in 1540 described rockets or serpents, and Hanzelet Lorrain (Jean Appier) in 1630 was acquainted with recreational rockets which threw out crackers (grasshoppers), stars, and serpents. He recommended the military use of 6 and 7-pound rockets with grenades in their heads. These, he believed, would frighten both men and horses and would break up a squadron of cavalry. This is the only warlike application of rockets mentioned in his book and is one to the earliest, actual or suggested, in Western Europe.

The rocket arrows which are pictured in the "Wu pei chih" have feathered tails and iron weights to counterbalance the driver tubes which are bound to the shaft at the forward end.

Other pictures show quivers for carrying rocket arrows, and many devices for launching them.

Baskets for shooting clusters of eighteen or twenty incendiary rocket arrows (Fig. 1) were made from bamboo splints four feet long and wider at the open end than at the bottom. They were equipped with straps for holding in front of the firer.

Among the devices for shooting clusters of rocket arrows was a tall shield decorated with the head of a demon or devil through whose wide-open mouth the rockets were fired. Another (Fig. 2) was a square box, "short and small, and particularly intended to be carried in infantry battles on land by one soldier," from which 100 arrows could be shot to a distance of more than 300 paces.

A stationary launcher (Fig. 3) for one hundred or more heavy rocket arrows was mounted on an iron axle between tow supports so that it could be tilted.

Another portable launcher (Fig. 4) fired to a distance of 400 paces 40 powerful rocket arrows having bamboo shafts 2.3 feet long with 0.5-food driver tubes. "Whenever meeting with the enemy in the open country, merely with ten or twenty boxes before the ranks, for a breadth of several thousand feet everything will be arrows."

(Mr. Davis will discuss other phases of early pyrotechnics in future issues.--The Editors)

EARLY PYROTECHNICS - PART II
Evolution of the Gun
Missing Links Found in Projectile Weapons' Ancestry

by Tenney L. Davis
Ordnance[14]
[1948]

Did our modern weapons originate in the fire-spouting devices of the ancient Chinese?

A Paleontologist confronted with a miscellaneous collection of fossils is able to sort them into groups or classes and within the classes to arrange them in the order of their complexity in such manner that a continuous and gradual development is apparent. The conclusion that this order represents the process of their evolution becomes well-nigh inescapable.

The "Wu pei chih" ("Treatise on Military Equipment") of Mao Yuan-i, written about 1621, presents for our study just such a varied collection of "fossil" fire weapons. Selected portions of it have been translated recently by Prof. James R. Ware and discussed by Davis and Ware in the Journal of Chemical Education, 24, 522-537 (1947). It is abundantly illustrated by pictures which are unequivocal and often more revealing than the text itself.

Among its many pyrotechnic devices certain ones furnish a seemingly complete picture of the steps in the evolution of the gun from spouting fire weapons-illustrating all the possibilities from Roman candles to match-fired guns with separate-loading ammunition. The fact that the various contrivances are not dated affects in no way the validity of the conclusion.

The question about Greek fire which has been most puzzling to historians has been not so much what it was composed of as how it worked. Some have thought that it was used in rockets; others that it was a liquid incendiary squirted by means of a pump. But the most probable conclusion from the evidence appears to be that it operated in the manner of a Roman candle, burning in a tube and ejecting masses of incendiary material from time to time to a considerable distance. The obvious continuity of the series from Roman candle to modern gun gives additional probability to the belief that Greek fire did indeed operate in this way.

And the discovery of heretofore unknown "missing links" between the automatically repeating, incendiary-throwing Roman candle and the single-shot gun which throws an inert projectile gives great plausibility to the belief that guns arose by an evolutionary process from the liquid or Romaic fire of the Byzantines.

Greek fire, introduced by the engineer Kallinikos of Heliopolis in Syria, supplied the principal basis of Bytantine naval and military strategy for more than seven centuries, from about 670 A.D. until the fall of Constantinople in 1453. Its composition was a closely guarded "divine secret," but its performance as reported by the annalists and chroniclers indicates that it contained saltpeter.

It was used in four ways; (1) in siphons, or large copper tubes fixed in the prows of the ships, from which masses of burning material were ejected; (2) in strepta, or smaller, permanently mounted, maneuverable tubes from which the fire could be aimed in various directions; (3) in cheirosiphons or portable hand tubes of spouting fire; and (4) in fire pots or incendiary grenades.

The name "liquid fire" perhaps refers to the composition being prepared and loaded while plastic from heat but, more likely, to the manner in which the fire could be poured out.

The first three of the above-mentioned devices were probably precursors of our modern Roman candles. There is also considerable likelihood that the cheirosiphons were used in tow ways: As jet-propulsion devices, forerunners of rockets, they could be pointed in the desired direction, fire end toward the operator, and then released from the hand; as fire-spouters they would require to be grasped firmly, fire end away from the operator. The "Wu pei chih" describes and illustrates fire-spouters which may perhaps be identical with the Byzantine cheirosiphons.

The historian, Anna Commena, daughter of Alexis (Emperor of Byzantium, 1081-1118) described how her father made good use of Greek fire against the Pisans.

> "Knowing that the Pisans were skilled in naval warfare and fearing the issue of battle, [the Emperor] placed in front, on the prows of each of the ships, snarling copper and iron heads of lions and of other wild animals and had them gilded to make their appearance still more fearful; then he ordered the fire to be prepared which, by means of strepta, should be launched against the enemy though their mouths so that it should appear that the lions and other wild animals vomited it . . . The barbarians were frightened by the shooting fire to which they were not accustomed and which, though its nature was to rise in the air, came down again, sometimes below, sometimes from the side, wherever the person wished who was directing it."

The same author also tells how the inhabitants of Durazzo, when their city was besieged by Boemond in 1106, used Greek fire against the Normans in a fight in a subterranean passage. Her description of the composition and of its use is clear enough if we understand that saltpeter (which she does not mention) was one of the ingredients.

> "To make the fire for certain ingenious contrivances, the dried gum (rosin) from firs and from other evergreen trees is collected and is ground up with sulphur, and the mixture is packed in the hollow stems of rushes into which it is introduced by a strong and continued puff of the breath like a flute-player's note. Then it is lighted by applying fire to one end, and, like a burning meteor, it falls on whatever objects are opposed to it. The inhabitants of Durazzo, by using this fire in hand-to-hand fighting, burned the beards and faces of the enemy."

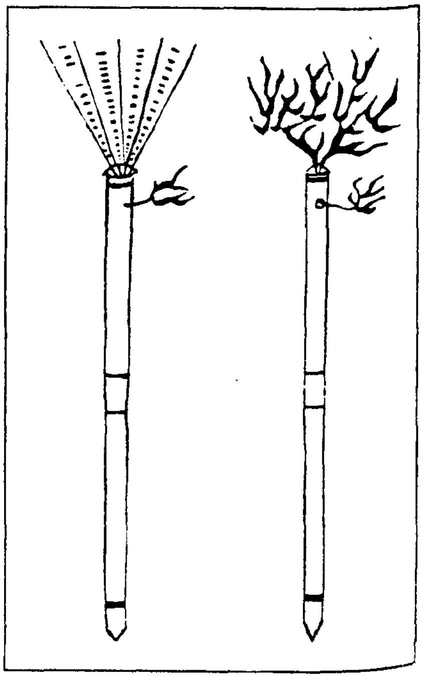


Fig. 1. The "upset-horse fire-serpent divine staff," of wrought iron, was loaded with spattering fire and lead bullets.

Fig. 3. A 3-shot matchlock shoulder gun with separate-loading ammunition.

Fig. 2. This prototype of the modern gun fired 20 shots without reloading.

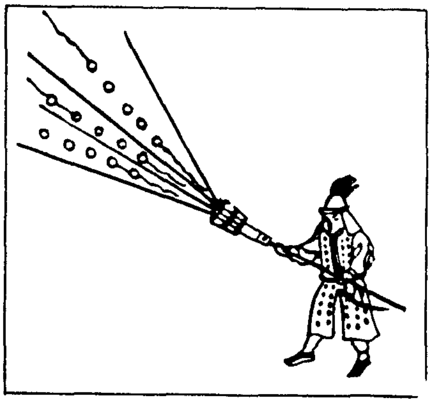


Fig. 4. A multiple-shot "gun" with one large iron barrel and ten smaller ones.

From these descriptions we are able to recognize the same or related devices when we find them described in the "Wu pei chih" and from the later descriptions to work backward toward a surer, clearer conception of Greek fire.

The first siphon was perhaps a tube into which a warm and plastic mixture of saltpeter with sulphur, rosin, bitumen, etc., had been stuffed. The charge burned unevenly, the flame darting behind the denser portions where it built up pressures, intermittently ejecting blazing masses with a coughing action. In the course of time improvements were made-one composition was found to be more suitable for the incendiary projectile, another for producing the gas which propelled it. Black powder was developed for the latter purpose, suitable for use in fireworks before guns were invented.

The "Wu pei chih" describes a fire weapon which was loaded like a Roman candle and threw incendiary pellets which burned with a bright light and a toxic smoke. The text tells how it was loaded: first a layer of slow powder containing relatively much charcoal and relatively little saltpeter, then a layer of "spurting powder," then one pellet, of a size adapted to the tube, containing saltpeter, camphor, pine perfume, realgar, and white arsenic, then the same sequence again until five such loadings had been made. It states that the pellets traveled several hundred feet.

The use of bullets in this device instead of incendiary pellets converted it into an automatic repeating gun. And the separating of the charges behind the several bullets, so that fire would not travel from one to the next, deprived the instrument of its automatic action and made it possible to shoot it repeatedly at will.

The "upset-horse fire-serpent divine staff," pictured in Figure 1, consisted of a tube of wrought iron, three feet long, loaded with spattering fire and lead bullets, supported by a wooden handle four feet in length.

Two repeating guns, each with several rounds loaded in the same barrel, are shown in Figures 2 and 3.

The first of these was made of wrought iron, weighed fifteen pounds, and was five feet long. The middle portion was solid for one foot, and the tow ends consisted of hollow bands each supplied with its own powder charge and match, paper wadding, and bullet weighing 0.15-ounce. Ten shots could be fired from each end.

The second device, a shoulder gun, was made of wrought iron 1.2 feet long and 0.22 of a foot in diameter. A wooden staff-handle was attached 0.3 of a foot behind the forward end. The barrel accommodated 3 cartridges, each 0.3 of a foot long and 0.17 of a foot in diameter, and was slotted along the top for the fuses. Each cartridge contained 0.8 of an ounce of powder.

It seems probable that these devices did not always operate smoothly but that accidents were caused by the fire of the first charge communicating itself to the other charges. Such mishaps could be avoided by loading each charge in a separate barrel, and it is likely that guns evolved in this way.

A particularly interesting specimen is shown in Figure 4, a multiple-shot gun with one large barrel of wrought iron and ten smaller ones, each 1.5 feet long and each loaded with "several tens" of shot.

The "Wu pei chih" contains pictures of guns and cannon of Asiatic origin such as the Chinese are known to have used in 1356 and probably as early as 1236. It also contains pictures and a description of the "fo-lang'chi," calivers or swivel guns with removable breech, which the Portuguese navigators had on shipboard when they visited Canton in 1517. It is indeed a rich museum of antiquities for the student of the history of fire weapons.

(Dr. Davis will continue his discussion of early pyrotechnics in subsequent issues. - The Editors.)

EARLY PYROTECHNICS -- PART III
Chemical Warfare in Ancient China:
Poison Fumes for Military Purposes

by: Tenney L. Davis

Ordnance[15]
[1949]

The "Wu pei chih" of Mao Yuan-i, written about 1621, contains clear, satisfyingly detailed descriptions of various devices of chemical warfare which the Chinese developed at an early time. These descriptions confirm and fill out the rumors and vague stories heretofore available to students of the methods and instruments of war. As do weapons of other categories described in the "Wu pei chih," these chemical weapons vary from the most simple and primitive to more sophisticated contrivances involving features which are used today and commonly considered to be among the latest improvements.

Chemical warfare appears to be the oldest of all modes of warfare - older than firearms, older than man, mammal, and reptile - as old as jellyfishes which are able to inflict a sting. The most primitive human use of chemical warfare is evidently in the poisoned darts and arrows, their points smeared with curare or with the juice of the ouabaio tree, employed by the savages of South America and Africa.

The Chinese made similar use of tiger-shooting poison on the tips of their rocket-propelled arrows. More interesting are the cases in which artificially prepared chemical substances are used. Most interesting of all, perhaps, are those in which the toxic material is delivered in a flame or converted to a mist by the action of fire.

The "Wu pei chih" describes incendiary arrows for shooting from a bow. These were prepared by binding to the shafts of the arrows, close behind the barbed heads, sacks of paper or cloth filled with mixtures made up in large part from the three basic ingredients of black powder (saltpeter, sulphur, and charcoal) and also containing varying amounts of white arsenic, yellow arsenic (orpiment), and red arsenic (realgar). The white arsenic was probably used to brighten the flame, the orpiment perhaps to color the smoke, but the realgar is definitely specified by the text as a poison.

Incendiary Devices

Improved incendiary devices, contrived to shoot the fire forward or more forcefully against the target, were made by loading pyrotechnic mixtures into small tubes which were attached, open end forward, to the shafts of arrows and of "flying fire spears." The mixtures contained mercury or cinnabar (mercury sulfide). The smoke from them was poisonous, and the burns which they produced must have been irritating and slow healing.

Perhaps an incendiary mixture like this was used in the ancient fire arrows recovered from the disused arsenal at Hami and actually employed in warfare in 1930 which produced infected, charred wounds suspected of being caused by phosphorus.

In order that the accomplishments of the early Chinese may be evaluated fairly, it ought also to be recorded here that the Italian Biringuccio, in his "Pirotechnia" (1540) described small paper tubes loaded with a mixture of coarse gunpowder. Grecian pitch, sulphur, grains of common salt, iron filings, crushed glass, crystalline arsenic, and so forth, that were tied to lances or pikes to give along tongue of flame useful in mild weather in battles at sea and on land. The same author mentions an opinion, held by certain ones in his day, that mercury added to gunpowder in the proportion of one ounce of mercury to every pound of sulphur makes the powder stronger and more powerful. The Frenchman Hanzelet Lorrain in his "Pyrotechnie" (1630) describes a mixture made from gunpowder, sulphur, saltpeter, camphor, and mercury for use in the cloth sacks of incendiary arrows.

The "Wu pei chih" lists the "ingredients of powder for fire and offense," naming as the chief ingredients saltpeter, sulphur, several varieties of charcoal, orpiment ("regulating fire"), and realgar ("poison fire"). Subsidiary ingredients, along with several which we cannot identify and others of doubtful potency, were a number of plant and animal poisons which may or may not yield toxic smokes. Others such as powdered ginger and blister fly would probably give pungent and perhaps poisonous vapors, and the smoke from burning poison ivy, as every New England farmer knows, is particularly vicious in its vesicant action.

The text describes stenches and offensive mixtures containing fish oil, roe, spiders, and so forth, along with saltpeter, white arsenic, litharge, and other ordinary materials, and states that sawdust fried in tung oil and packed in sacks produced lachrymatory smoke.

"Stench Warfare"

Stink pots were made up of "paper tubes containing all sorts of powders" -- fourteen small tubes arranged around a large tube in a single container, the several fuses wound together into a single fuse by which the pot was lighted. The use of a bursting charge in the central tube converted the device into a toxic incendiary stick bomb. The contrivance pictured in Figure 1 contained in its middle a powder charge which, on exploding, threw missiles about and scattered a burning mass which gave off poisonous fumes and lachrymatory smoke. The text states that it contained tung oil, "silver rust" (presumably "water-silver rust" or mercury oxide), sal ammoniac, "gold juice," garlic juice, roasted iron filings, porcelain dust, and cast-iron bullets.

The "string-of-100-bullets cannon" (see top of page 396) threw out poisonous smoke along with bullets which were fed gradually into the stream of outpouring gas and were carried along with it. It was cast of pure copper, about four feet long. A trough a little more than a foot long was cast on its side. "Store here about one hundred bullets. When [the gun is] raised on its side, the bullets will fall into the barrel. They will fire out in succession."

The weapon required a charge of one and one-half pints of fa powder. The text states that "it is very fierce, not a solitary thing can be seen, not a step taken, so that one will capture alive bandits and soldiers." The fa powder was made from realgar, orpiment, saltpeter, sulphur, bamboo charcoal, birch charcoal, willow charcoal, white arsenic, stone

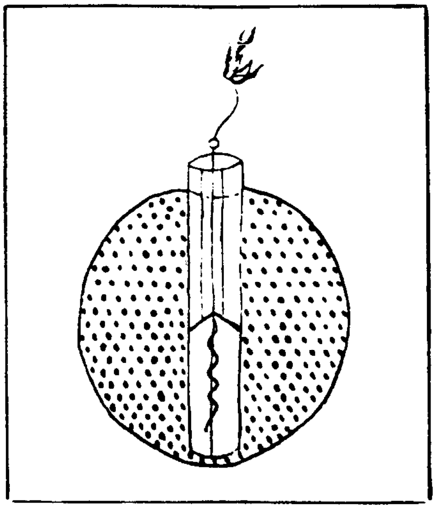


Fig. 1. This bomb threw out missiles, poisonous fumes and lachrymatory smoke.

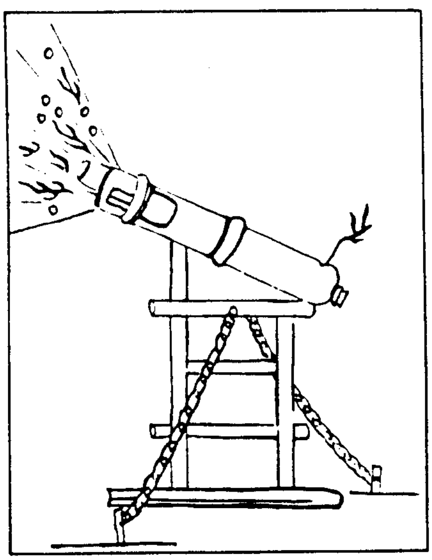


Fig. 2. This aerosol projector was loaded with poisonous and noxious materials.

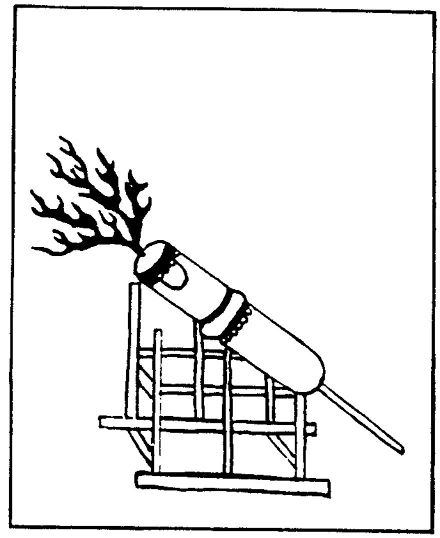


Fig. 3. Cast-iron chemical shells filled with powder were fired by this mortar.

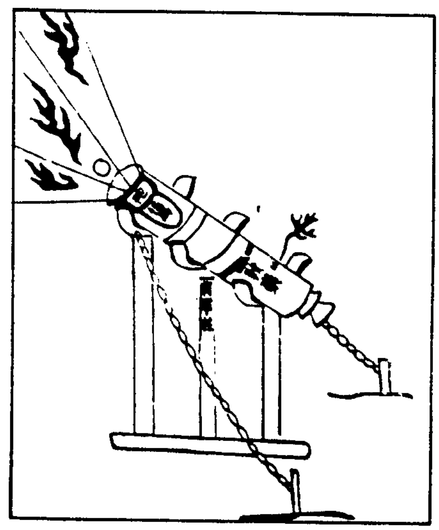


Fig. 4. This mortar fired shells filled with a half pound of "divine fire."

coal, human sperm, pine perfume, big grains, elm grains, red smartweed, black smartweed, foreign bitter, river bitter, and the four kinds of ginger.

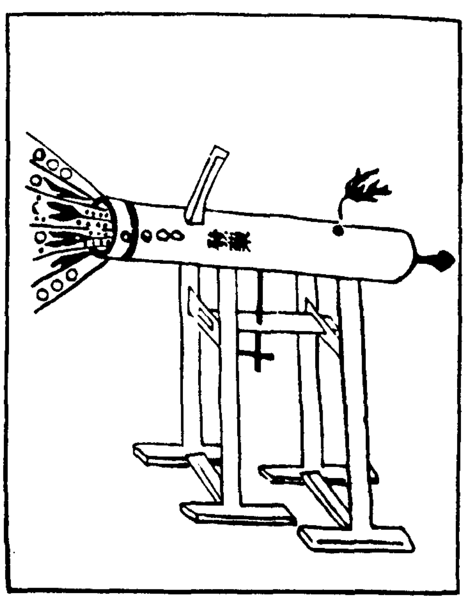
The "poison-mist-divine-smoke cannon," Figure 2, was an aerosol projector. It was loaded with white arsenic, realgar, orpiment, wolf dung, and other noxious materials. "When attackers mount the wall, these are lighted and burst forth with spreading smoke."

The "eight-direction-whirlwind-poison-mist-thunder shell" and the "flying-cloud-thunder shell" were cast-iron chemical shells fired from the mortars which are shown in Figures 3 and 4, respectively. The former was charged with "divine smoke" and fa powder. "There will be a loud thunderclap, and the pieces of iron will fly like bullets." The latter weapon was "as big as a bowl, as round as a bowl." and held half a pound of "divine fire." The directions say, "Shoot ten at a time."

Colored Smokes

It is interesting to find that early in the seventeenth century the Chinese had already developed colored smokes for military use. The "Wu pei chih" gives formulas for blue white, red, violet, and black smokes, none of which however seem to have been particularly good. If they were distinguishably different from one another, then they were useful. The coloring matter used for the blue smoke was woad, identical with indigo which is still the standard material for this purpose in modern practice, although at present it is beginning to be replaced by brighter, synthetic colors.

Editor's Note - This is the last of a series of three articles on early pyrotechnics by Mr. Davis. The first was "Fire for the Wars of China" which appeared the July-August 1948 issue and established as a source of historical fact the "Wu pei chih" (treatise on military equipment) written by Mao Yuan-i about 1621. This volume sheds considerable light on the hitherto vague subject of ancient oriental rockets and guns. The second article, entitled "Evolution of the Gun," was published in the November-December 1948 issue and treated the early attempts of the Chinese to project missiles with gunpowder; also their use of fire-producing agents employed in especially designed tubes.



Early Chinese Rockets

Probably as Early as the Thirteenth Century,
but Certainly by the Seventeenth, Chinese Ingenuity
Had Adopted Rockets to a Variety of Special Military Uses

by
Tenney L. Davis

Ordnance
[1949]

The date of the first use of rockets for military purposes is not known with certainty. The Kin Tartars, defending Lo-yang and Kai-feng-fu against the Mongols in 1232, are reported to have used "flying fire spears" which by some have been taken for rockets. The Sung historians state that these devices "burnt forward with a sudden flame to distance of 10 paces and upwards, so that no one durst approach them" This, the historical record practically proves that the devices were not rockets at all, for 10 paces is an unreasonably short trajectory for a rocket, more like the distance through which a Roman candle would throw its fire.

The Wu Pei Chih (Treatise on Military Equipment) by Mao Yuan-i, written about 1621, contains much information about early Chinese military pyrotechnics and many clear, unequivocal picture, among them pictures of spears equipped with tubes for spouting fire forward in the direction of the spear point, and rocket-propelled arrows capable of flying for 300 or 400 paces. We conclude that the use of rockets a Lo-yang and Kai-feng-fu is not proved by the texts which make reference to "flying fire spears".

There are, however, certain evidences which indicate that rockets were probably already known by the middle of the Thirteenth Century. Roger Bacon and Marcus Graecus, both of whom were writing at about this time, describe what appear to be firecrackers and toy rockets, and the title of the latter's Liber Ignium ad comburendos hostes (Book of Fires for Burning the Enemy) suggests that he considered his contrivances to be adaptable to warlike uses.

In any case, at the time when the Wu Pei Chih was printed, the Chinese had Already developed great skill in the tactical use of rockets and were far ahead of the Europeans in their military application. Rocket-propelled arrows (Fig. 1) with razor-sharp heads, sometimes poisoned, sometimes carrying incendiary charges, were uniquely qualified for special jobs of offense and defense, for setting fire to enemy installations, for attacks from ambush, for the defense of defiles and gateways.

The Wu Pei Chih contains many pictures of rockets for various military purposes, of devices for making them (Fig. 2), carrying them (Fig. 3), and for launching them singly (Fig. 4) and in clusters. Clusters were made up of bundles of tubes, each tube serving to launch one rocket (Fig. 5), or they were made by enclosing many rockets in a single container (Fig.6) where the sticks were held in position and separated from one another by

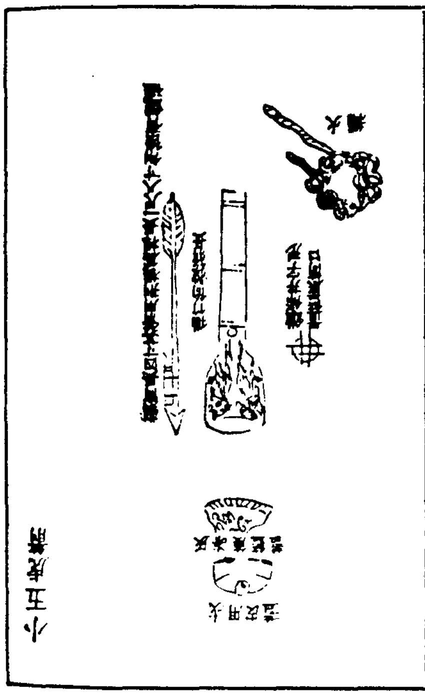


Fig. 1. Rocket driver tube, shown singly with its central cavity, and shown attached to arrow with the fuse running throughout its length.

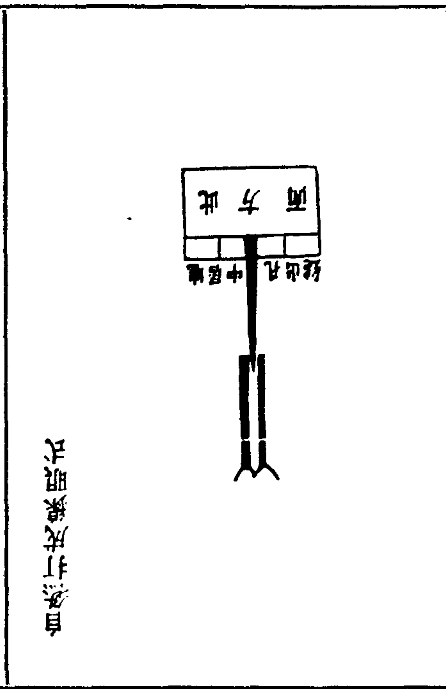


Fig. 2. Tool for making the central cavity in the rocket's propelling charge "does a better job than the drill preferred by the artisans. If the rocket-arrow is to fly straight, the hole must be straight, otherwise it will go off at a tangent."

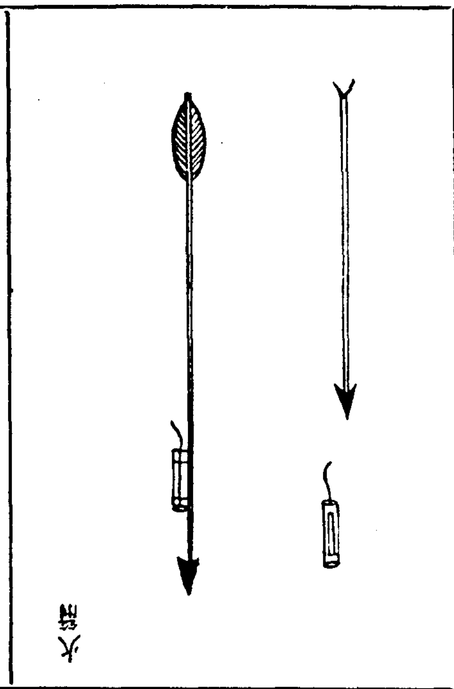


Fig. 3. (Above) Quiver for carrying several rocket-arrows.

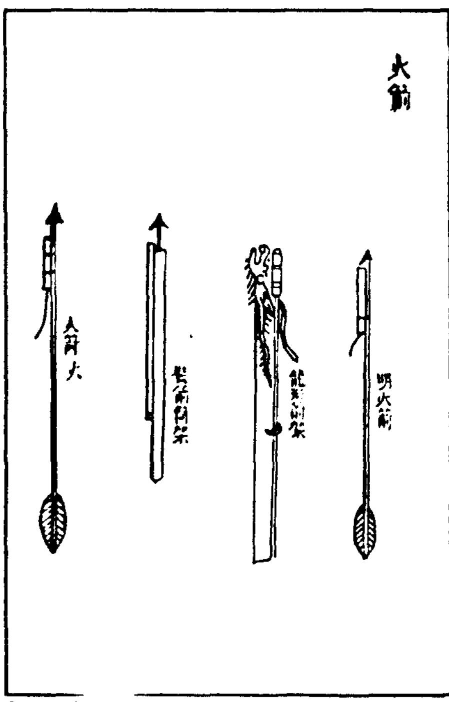


Fig. 4. Devices for launching single rocket-arrows. In one instance the rocket is launched from a tube; in the other, it is fired in the open while the stick is held in position by a loop or ring passed around it.

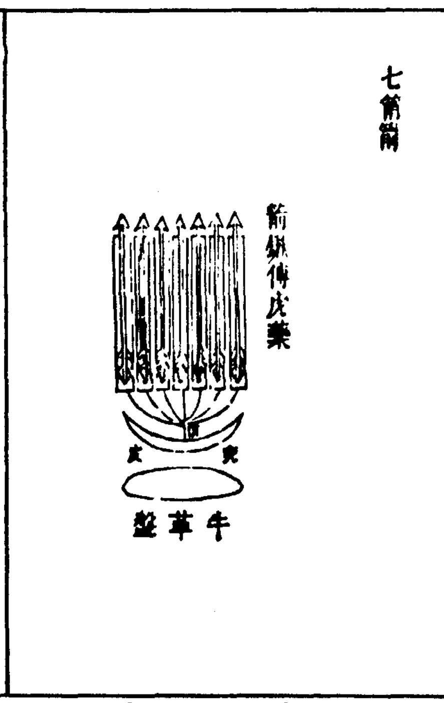


Fig. 5. Rocket-arrows in tubes, each connected by a fuse (match) to a single master match by which they may be fired simultaneously. The tubes are gathered together into a bundle for firing the cluster.

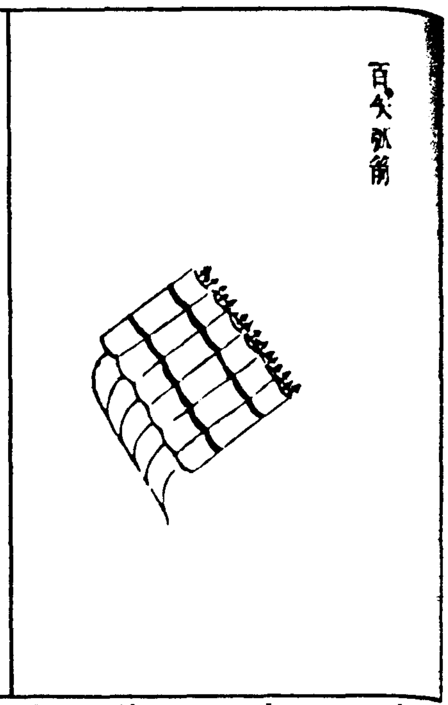


Fig. 6. Clusters of rocket-arrows which are fused for ripple or successive firing. When the master fuse or match is lighted, the arrows in each of the individual clusters fire one another in a successive array.

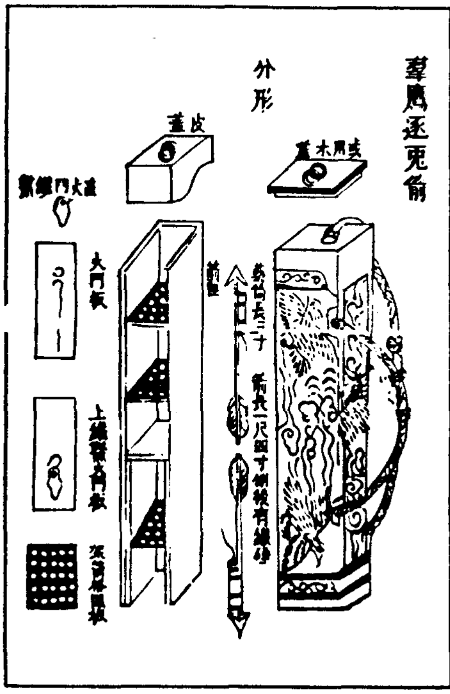


Fig. 7. Portable box of wood or leather containing two sets of 25 rocket-arrows. The sets are arranged to be fired separately, enabling a soldier to meet two emergencies for close fighting.

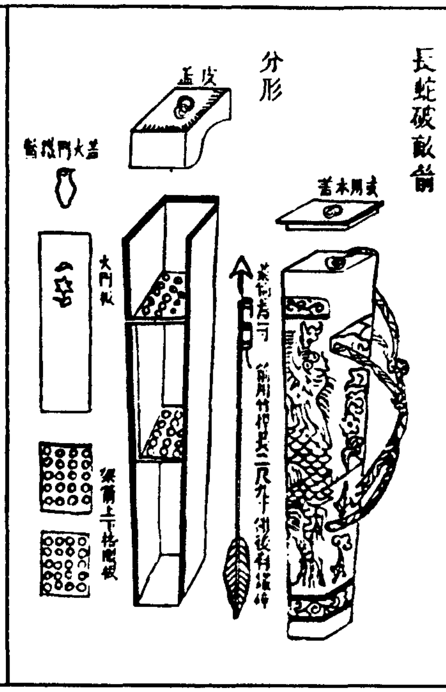


Fig. 8. Portable launcher for firing rocket-arrows against an enemy at 200 paces. Total weight, five or six pounds. The arrows are of bamboo, and points are smeared with poison.

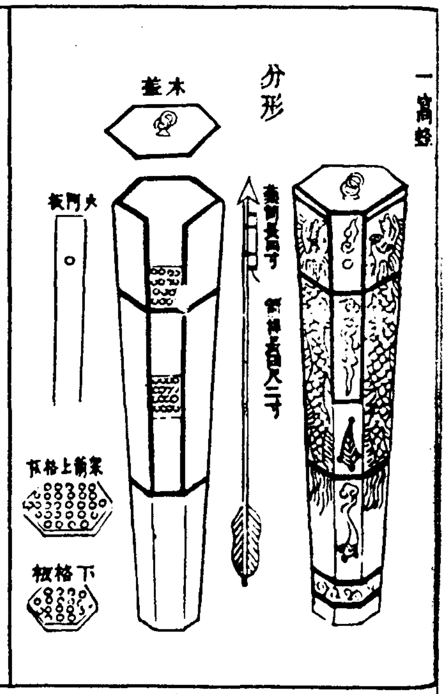


Fig. 9. Launcher for shooting a shower of rocket-arrows to a distance of 400 paces or more. The open end is enlarged so the rocket-arrows will spread out in flight to cover a large area.

splints or by passing them through holes in the frames. The driver tubes in back of the heads were counterbalanced by iron weights behind the feathers of the tails.

Incendiary rocket-arrows were fired from baskets made from split bamboo, four feet long, and wider at the open end than at the bottom. The baskets were covered with paper brushed with oil for protection against wind and rain, and were supplied with straps by which they could be held in front of the soldier in position for use. Each basket carried about 20 arrows connected to a master match which passed through an aperture in the side of the basket. The arrows had steel tips smeared with poison, and carried pellets of incendiary composition which took fire after the driver charge had burned out. "These are particularly efficient for the burning of fodder, wall-towers, and ships. On meeting the enemy it is possible to anticipate the attack."

One portable launcher consisted of a small wooden box with a leather cover, arranged to fire a cluster of 100 small rocket-arrows. The shaft of each arrow was of bamboo, one and six-tenths feet long, the driver tube three-tenths of a foot long, and a piece of iron was attached behind the feather so that the center of gravity was four fingers width below the mouth of the driver tube. The arrows flew for a distance of more than 300 paces. Other sizes were used against boats and carts, but the kind described here was short and small, and intended to be carried in infantry battle on land by one soldier. Other launchers contained tow sets of 25 rocket-arrow, the sets arranged to be fired separately from opposite ends of the carrying case (Fig. 7).

Another portable launcher (Fig. 8) fired 30 rocket-arrows having shafts two and nine-tenths feet long and driver tubes four-tenths of a foot long.. "Each box is to weigh not more than five or six pounds, so that one soldier may carry it. Wait until the enemy is within 200 paces, then fire suddenly all at one. The effect is fierce, so that one soldier is superior to thirty."

Another portable launcher (Fig. 9) fired 40 powerful rocket-arrow, sticks two and three-tenths feet long, driver tubes five-tenths of a foot long, carrying iron weights behind the feathers to bring the centers of gravity six fingers width below the mouths of the driver tubes. The arrows flew more than 400 paces. Before firing they were held in the launcher with their heads separated more widely than their tails, so that they spread out in flight and scattered transversally over a width of several hundred feet. "Whenever meeting with the enemy in the open country, merely with 10 or so boxes before the ranks, for a breadth of several thousand feet everything will be arrows."

A fixed launcher of a size to hold 100 or more rocket-arrows was made of wooden boards, and was set upon an iron axle between two supports so that it could be tilted to vary the range. "Whenever there are bandits to be suppressed, [this contrivance] being stationed on the strategic roads, aim it and fire. The arrows will go for several hundred paces. If these are made in several hundreds, it will indeed be a great help."

Before the early part of the Seventeenth Century Chinese ingenuity had already adapted rockets to a variety of special military uses, and had developed tactical techniques which are useful today with rockets carrying charges of high explosive. The Europeans of the same time had developed larger and fancier rockets for recreation and display. Biringuccio in 1540 described rockets which burst at the top of their flight sending forth six or eight other rockets or serpents, and Hanzelet Lorrain (Jean Appier) in 1630 described rockets which threw out crackers (grasshoppers), stars, and serpents. The latter recommended the military use of rockets of six or seven pounds weight with grenades in their heads, which, he believed, would frighten both men and horses, and would easily break up a squadron of cavalry. this is the only warlike application of rockets mentioned in his book, and represents, apparently, the most advanced thinking in Europe at that time on the tactical use of rockets in act of warfare.

Early Chinese Military Pyrotechnics

by Tenney L. Davis[70] and James R. Ware[71]

Journal of Chemical Education

[1947]

The antiquity of firearms in China -- that is, of guns and cannon -- has been the subject of numerous studies by Chinese and by Occidental scholars, the most recent and the most conclusive of which are two papers by Goodrich[72] and Goodrich and Fêng,[73] from which it appears that guns were in use in China nearly two centuries before the Portuguese navigators visited Canton in 1517, and probably as early as 1236. In the first of these papers Goodrich reports the existence and publishes photographs of ancient Chinese iron cannon bearing dates of 1356, 1357, and 1377, and mentions copper cannon, now or formerly in the Peiping Museum, some dating from the period of Hung-wo (1368-98) and others from the ensuing periods of Yung-lo through Chêng-t'ung (1403-49). In the second paper Goodrich and Fêng survey the literary evidences, citing earlier studies on the subject and quoting from Chinese sources, and conclude that there are good reasons to believe that the Chinese had real firearms in the 13th century. In 1132 long bamboo tubes were filled with pyrotechnic composition and used for throwing flame, in 1259 bullets were loaded into the tubes along with the composition and were thrown out when it burned, and in 1236 *p'ao* were cast from gold, silver, iron and bronze.

The history of firearms constitutes an approach to the longer, broader, and less familiar history of fireworks, and from fireworks firearms were undoubtedly derived. Indeed, our knowledge of Chinese fireworks has heretofore been largely a by-product of those who were invested primarily in the history of Chinese firearms.

Among early Chinese texts on military subjects two in particular,[74] which deal chiefly with the technical aspects of military[75] pyrotechnics, have attracted our interest -- namely,

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[70]Emeritus professor of organic chemistry, Massachusetts Institute of Technology; Director of Scientific Research and Development, National Fireworks, Inc.

[71]Associate professor of Chinese; formerly, co-editor of *The Harvard Journal of Asiatic Studies*.

[72]Goodrich, L. C., *Isis,* 35, 211 (1944).

[73]Goodrich, L. C., and Fêng Chia-shêng, *ibid.*, 36, 114-23 (1946).

[74]We are grateful to Dr. A. W. Hummel of the Library of Congress for calling our attention to these texts, for helping us to procure microfilms from the copies in the Library of Congress, and for kind permission to reproduce parts of them. We have also used a copy of the second of these texts which we found in the library of Harvard University.

[75] "Huo-hsi Lüeh," by Chao Hsüeh-min, written before 1753, treats of civil or recreational fireworks. *Cf.*, T.L. Davis and Chao Yün-ts'ung, *Proc. Amer. Acad. Arts Sci.,* 75, 95-107

"Têng T'an Pi Chiu," by Wang Ming-hao, written near the end of the 16th century, and "Wu Pei Chih," by Mao Yüan-i, written about 1621. Both contain many informative and interesting illustrations.

In "Têng T'an Pi Chiu," chapter 29 bears upon the use of "fire" and comprises 76 double pages with 23 illustrations, or, more exactly, 23 single pages which carry pictures, sometimes more than one.

The "Wu Pei Chih" is the much more interesting document. Its chapters 119 to 135 inclusive form 310 double pages and contain 222 single pages of pictures, among them nearly all of those which are included in the "Têng T'an Pi Chiu." It has been studied by W. F. Mayers who used a considerable portion of the historical materials which it contains along with such other information as he could glean from Chinese sources to support the conclusions of a paper on the history of gunpowder and firearms in China which he read before the Royal Asiatic Society at Shanghai on May 18, 1869, and published shortly afterward in the Society's journal.[76] He reproduced more than a dozen pictures from it, of guns and of pieces of fireworks, and described several of the latter, which, however, he did not seem to have understood very clearly himself. Mayers stated that the "Wu Pei Chih" contains pictures of nine kinds of matchlock guns besides 14 other weapons "more or less fantastic" for vomiting fire, of 14 kinds of explosive vessels in the shape of flasks, jugs, etc., of numerous devices using rocket-propelled arrows, some of which he judged to be "obviously no more than crude and impractical fancies," and of a dozen or more cannon of various kinds from the caliver (*fo-lang-chih*), which the Portuguese brought to Canton on shipboard in 1517 to unwieldy masses of metal on heavy trucks like the "great commander" (*ta-tsiang-kiün*). We note that certain of the pictures, showing cannon similar to the early dated examples to which Goodrich has called attention, represent firearms which the Chinese had before the advent of the seafarers from Europe, hence cannon indigenous to China or, at least, of overland provenance. The "Wu Pei Chih" contains much material on pyrotechnics which was beyond the interest of Mayers or outside the focus of his inquiry, and it is a portion of this treasure trove that we now wish to bring forward and to make more readily accessible to Occidental students.

The contents of the "Wu Pei Chih" presents itself for our study in a form similar to that in which a rich and diversified collection of fossils might present itself for the study of a paleontologist. Our method, which we can scarcely hope to pursue to its conclusions in the present paper, must be the method of the comparative morphologist. The specimens have been brought together by an early collector, who for the most part, has not fixed their dates nor described the strata and terrains in which he found them. Some of them represent forms which are still extant. Others are of such simple and primitive structures that they must have been near to their origins. And yet others are of forms which have not been described heretofore, intermediate in their complexity between the most primitive and the most recent.

(1943).

[76]Mayers, W. F., *J. North China Branch Roy. Asiatic Soc.*, N.S., 6, 73-103 (1871).

These represent missing links in the development of pyrotechnic devices and indicate the mode of their evolution.

Numerous dated events in the history of Chinese fireworks have been reported from Chinese sources by Mayers[7] and by Goodrich[3,4] and Fêng.[4] Set down succinctly in a chronological table they supply a background to our examination of the "Wu Pei Chih" and a framework upon which we may hang at least a portion of its contents.

6th century Bamboos, crackling in a fire, used in Hupeh and Hunan to drive away malignant spirits. Firecrackers not yet known.

603-617 Emperor Yang of Sui dynasty introduced fireworks, probably firecrackers.

618-906 T'sang dynasty. Fang I-chih (ca. 1630) believes that recreational fireworks were already known, *fire trees* and *silver flowers*. A certain "Yüan Shu Chi," whose history is very beclouded, mentions crackers, rockets, serpents or squibs, and exhibition pieces.

917 The sovereign of Wu had a furious fiery oil for use in warfare.

968 Yo I-fang prepared *fire arrows* for the Sung emperor.

1126 Fire balls, thrown from catapults, used against the Kin in defense of K'ai-fêng-fu.

1132 An invention of Ch'ên Kuei, long bamboo tubes filled with pyrotechnic composition, used to rout bandits at Tê-an.

before 1164 Wei Shêng used *fire stones* against the Kin, made from saltpeter, sulfur, and willow charcoal, thrown from catapults.

1221 Kin Tartars attacked a Chinese city with *t'ieh-huo-p'ao*, explosive bombs, gourd-shaped, of cast iron about two inches thick.

1232 Kin Tartars, defending Lo-yang and K'ai-fêng-fu against the Mongols, employed *heaven-quaking thunderers* (explosive bombs) and *flying fire-spears* (equipped with fire-tubes).

1259 Chinese at Shou-ch'un employed *t'u-huo-ch'iang*, long bamboo tubes which threw smoke and fire and one or more bullets.

1272 Chang Shun had *fire spears* and *fire ballistae* on board boats at Siang-yang fu.

1356, 1357, 1377 Cast iron cannon of these dates exist in Chinese museums.

1368-98 1403-49 Copper cannon of these periods in museum at Peiping.

1407 Emperor Yung-lo established a fire-weapons brigade. General Chang-fu, in his assault on Topang, used guns and bombs attached to animals.

THROWN INCENDIARIES

Arrows Carrying Incendiary Composition

Incendiary arrows for shooting from a bow, Figure 1, were prepared by binding to the shaft of the arrow, close behind the barbed head, sacks of cloth or paper filled with an incendiary powder made up in large part from the three basic ingredients of black powder.

The mixture was lighted by means of a fuse. Other incendiary arrows, for throwing by a whip or throwing stick, Figure 2, were made by filling long, thin bamboo tubes with the powder. "Wu Pei Chih" 119.10b, gives recipes for an arrow powder and for a bursting powder which is preferably used as an incendiary.[77]

Arrow powder	
Saltpeter	5 pounds
Sulfur	14.9 ounces
Willow charcoal	12.0 ounces
Eggplant charcoal	0.5 ounce
White arsenic	0.5 ounce
Camphor (?) (*chao-nao*)	0.1 ounce

Bursting powder	
Saltpeter	5 pounds
Sulfur	1 pound
Charcoal	15.5 ounces
White arsenic	0.5 ounce
Camphor (?)	0.1 ounce

Mix with good spirits and dry.

Fire Balls

Another treatise on military subjects, "Wu-ching Tsung Yao" compiled in 1044 by Tsêng Kung-liang, give I.12.58a, a recipe for *huo-yao* or incendiary powder for use with whip arrows or with barbed arrows, 5 ounces of it packed behind the barb, I.12.60b-61b. The same powder was also used for the preparation of incendiary missiles, fire stones or fire balls, which were thrown by catapults.

Grind together with a pestle and sift-	
Chin-chou sulfur	14 ounces
K'o sulfur	7 ounces
Saltpeter	2.5 pounds

Grind together-	
Realgar	1 ounce
Ting powder	1 ounce
Massicot	1 ounce

[77]One *catty* (pound) equals 16 *liang* (ounces); 1 *liang* = 10 *ch'ien*; and 1 *ch'ien* = 10 *fên*. At present 1 *catty* = 500 grams.

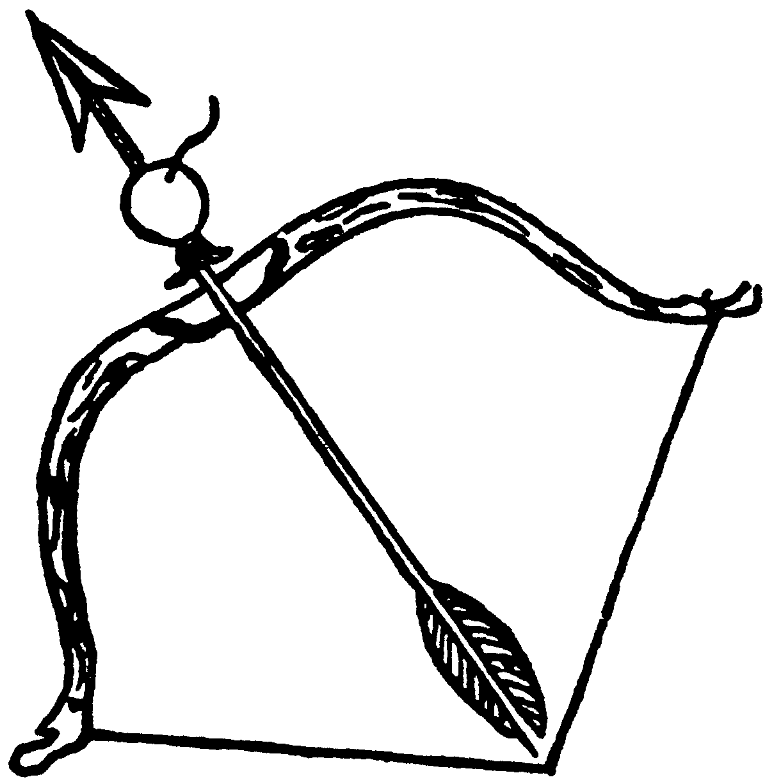

Figure 1. Incendiary Arrow for Shooting from a Bow. "Wu Pei Chih" 126.10b.

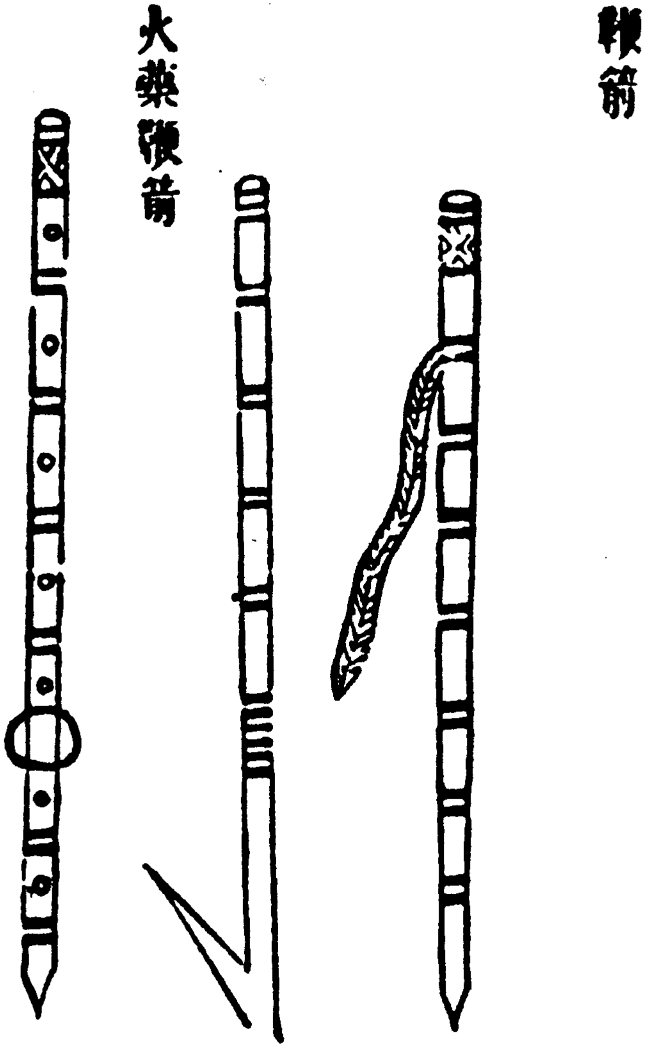

Figure 2. Incendiary Arrow for Throwing by a Whip or by a Throwing Stick. "Wu Pei Chih" 126.13b.

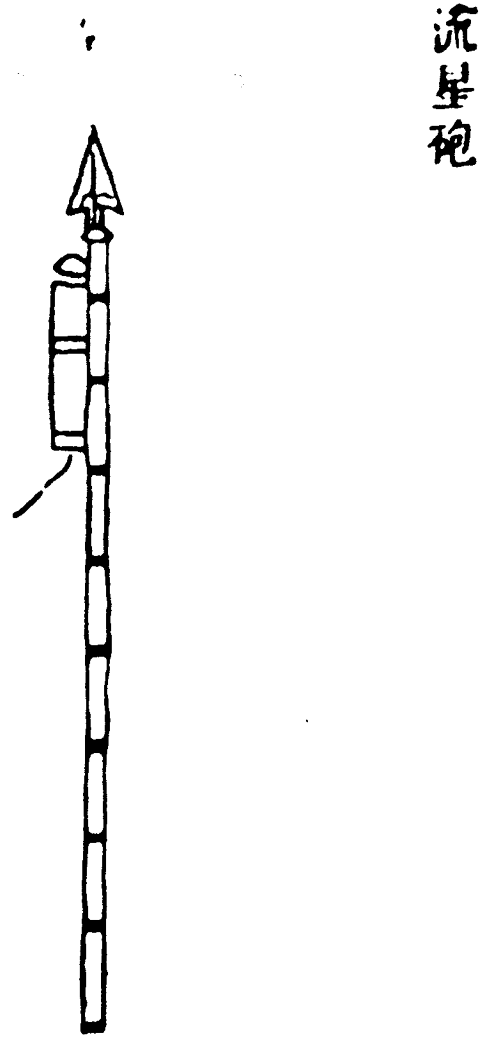

Figure 3. Incendiary Whip Arrow with Tube of Spattering Fire. "Wu Pei Chih" 128.16b.

Powder-	
Dry lacquer	1 ounce
Roast to bits or powder-	
Hemp roots (?)	1 ounce
Bamboo roots (?)	1 ounce
Boil to a paste-	
Bee's wax	0.5 ounce
Clear oil	0.1 ounce
T'ung oil	0.5 ounce
Pine pitch	14.0 ounces
Heavy oil	0.1 ounce

Mix all these together evenly, wrap in five thicknesses of paper, bind with hemp, smear with pine pitch, and throw by catapult.

The same work, I.12.65a, describes an improved fire ball which makes a roaring noise when it burns.

Pestle to a powder-	
Sulfur	1.25 pounds
Saltpeter	2.5 pounds
Charcoal	5 ounces
Rosin	2.5 ounces
Dry lacquer	2.5 ounces
Cut into small pieces-	
Bamboo roots	1.1 ounces
Hemp roots	1.1 ounces
Melt and mix-	
T'ung oil	2.5 ounces
Small oil	2.5 ounces
Bee's wax	2.5 ounces
Melt and mix	
Paper	12.5 ounces
Hemp	10 ounces
Massicot	1.1 ounces
Charcoal powder	8 ounces
Rosin	2.5 ounces
Yellow bee's wax	2.5 ounces

Combine all these and smear all over the ball. Make the ball by wrapping around a piece of bamboo [a mixture of] 30 pieces of thin porcelain [the size of] iron cash and 3 or 4 pounds of incendiary powder. The two ends of the bamboo will protrude about an inch. Smear powder on the outside. If the enemy attacks by tunneling, we then dig holes to intercept him. When the ball is lighted with a hot poker, it will make a noise like a rumbling. When it is lighted, fan its smoke and flames so as to smoke and burn the enemy.

The open tube through the center of the mass would cause the missile, when thrown through the air, to produce a thunderous sound beyond the roar of its burning. Perhaps the *feu grégeois* which the Saracens used in the sixth crusade (1248-54) was of this sort, of which Joinville gave an eyewitness account, that it made such a noise as it drew near that it seemed to be a thunderbolt from heaven, that it seemed like a dragon flying through the air, as large as a keg of verjuice, with a fiery tail as long as a great sword.[78]

Spattering Fire for Arrows and Spears

"Wu Pei Chih" 128.18a, gives a recipe[79] for a composition to be charged into small tubes attached to arrows and spears for producing a spattering fire, Figures 3,4,5, and 6.

Spattering fire

Saltpeter	1 pound
Sulfur	4.5 ounces
Pine charcoal	3.8 ounces
Cinnabar	1.6 ounces

The performance of this composition would depend on the manner in which it was mixed and loaded. A well-mixed and tightly packed mass would give a fountain or jet of fire, a slightly non-homogeneous mixture would sputter, and one containing an admixture of less porous and slower burning fragments would behave like a Roman candle.

The *flying fire spears* which the Kin used in 1232 while defending Lo-yang and K'ai-feng-fu against the Mongols-"which, on being ignited, burnt forward with a sudden flame to a distance of ten paces and upwards, so that no one durst approach them"[80]-were evidently

[78]JOINVILLE, "Histoire du Roy Saint-Loys," quoted by LALANNE, "recherches sur le Feu Grégeois, et sur l'introduction de la poudre à canon en Europe," 2nd ed., Paris, 1845, pp. 55-6.

[79]This is the recipe which MAYERS, *loc. cit.*, pp. 102-3, judged erroneously to be "the nearest approach to a description of gunpowder as at present fabricated" contained in the "Wu Pei Chih," the only one, out of the many in the treatise, which he reported. We correct his typographical error in the amount of pine charcoal. The word, *spattering*, used by Mayers and not in the Chinese, evidently describes clearly the performance of the composition.

[80]MAYERS, *ibid.*, p. 91; LALANNE, *loc.cit.*, p. 74, thought that the *flying fire spears* were rockets, probably armed rockets similar to those which the Hindus used against the British at

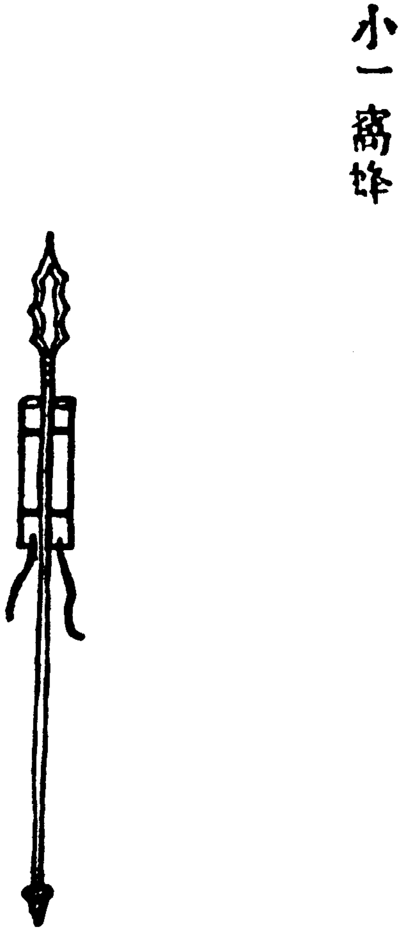

Figure 4. Incendiary Arrow with Two Tubes of Spattering Fire. "Wu Pei Chih" 128.17b.

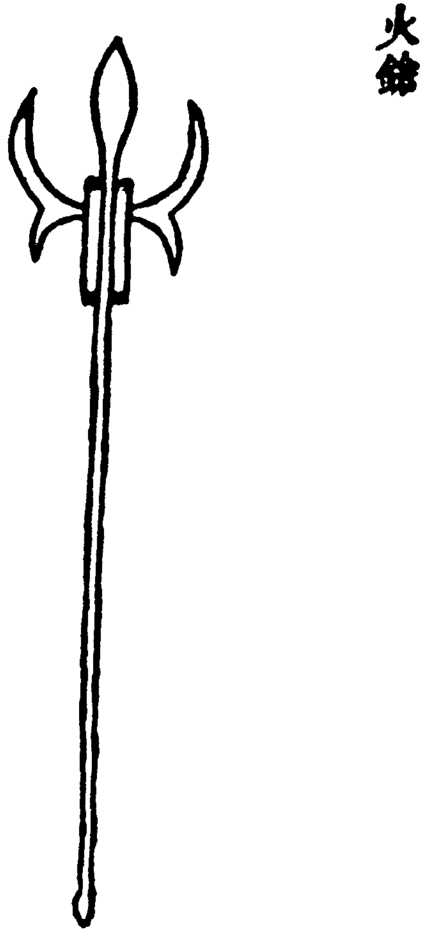

Figure 5. Fire Spear with Two Tubes of Spattering Fire. "Wu Pei Chih" 128.2b.

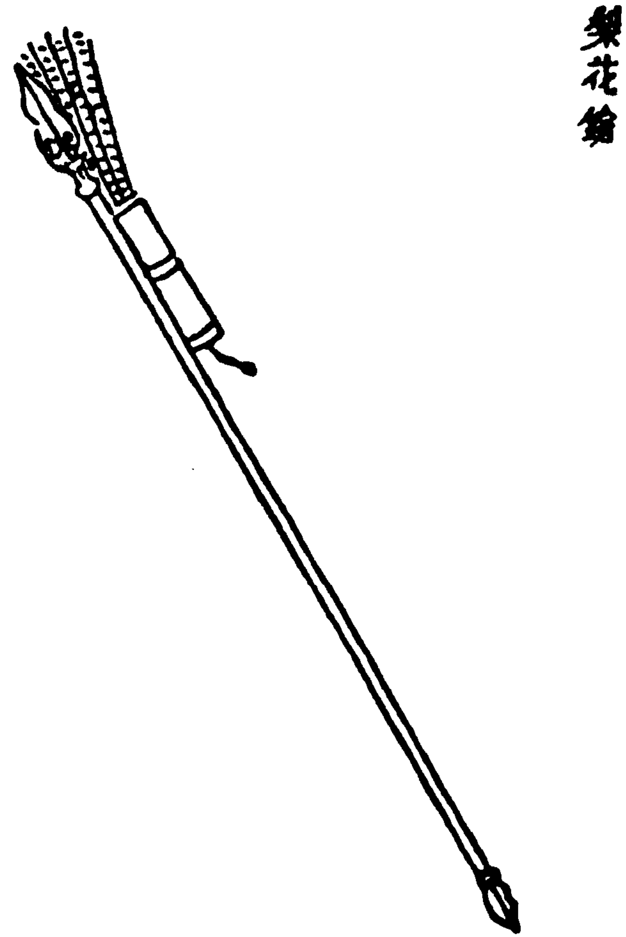

Figure 6. Fire Spear, Showing How Fire is Thrown Forward. "Wu Pei Chih" 128.3b.

used for thrust, like a bayonet, not as thrown missiles, and were contrived in such manner that they spurted fire in the same direction as the spear point was aimed.

The spattering fire, because of the mercury in its composition, would produce extremely unpleasant burns. The smoke would be poisonous and the flame would cause a chemical burn as well as the ordinary effects of heat.[81] Jean Appier (Hanzelet Lorrain), in a book on fireworks which was printed in France in 1630, only a few years later than the "Wu Pei Chih," describes and illustrates, Figures 7 and 8, incendiary darts and arrows carrying a similar mercurial composition contained in cloth sacks of double thickness, tied to the shaft, bound with string, and arranged to throw fire towards the target.[82]

In addition to the pyrotechnic compositions listed in the next section of this paper, the "Wu Pei Chih" 119.17b describes an incendiary mixture which appears to be suitable for use in the sacks of incendiary arrows and in fire balls, fire stones, and so forth.

Bright incendiary powder

Gingko biloba	1 pound
Rosin	1 pound
Sulfur	2 pounds
Orpiment	3 ounces
Male arsenic (realgar)	3 ounces
Saltpeter	7 pounds

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the siege of Seringapatnam in 1799, but he had not seen the "Wu Pei Chih" and its illustrations.

[81]CABLE, MI, WITH F. FRENCH in "The Gobi Desert," The Macmillan Company, New York, 1944, p. 241, tell of the infected wounds, charred as if they had been caused by a chemical, which they treated in 1930, wounds produced by ancient fire arrows recovered from the disused arsenal at Hami. It is entirely unlikely that the incendiary contained phosphorus as they suggest, but the facts are consonant with the belief that it was a mercurial such as is described in the "wu Pei Chih."

[82]LORRAIN, H., "la Pyrotechnie," Pont à Mousson, 1630, p. 263, gives the recipe, as follows. "Take a *quarteron* of powder (gunpowder) ground up and sieved, a *quarteron* of powdered sulfur, three *quarterons* of saltpeter fine and well-dried, a *treseau* and a half of camphor, and two *treseaux* of mercury, the whole powdered and mixed by hand and moistened with a little petroleum. Note that it is necessary to grind the camphor with the sulfur, and also the mercury. Then fill your cloth bag as hard as you can. Then sew up the hole through which you have filled it, and fasten it strongly with heavy wire or string. Afterwards make a little hole or two at the end which is near the barb of the said iron, and insert one or two little skewers of wood. Then cover with brimstone made as is described in the chapter on the said brimstone. And when you wish to shoot, pull the skewers, prime with good powder pure and well ground up, set the shaft on the bow or arbalest, setting fire to the said primer and letting it take hold well before shooting."

Charcoal of bamboo, birch, or willow, to each pound [of the proceeding mixture]	4 ounces

It also describes 119.20a, a "powder combining the three fires" (flying, poison, and superior) which is evidently intended for use in tubes to produce a spattering fire.

Triplex fire powder

Saltpeter	1 pound
Sulfur	6 ounces
Charcoal of bamboo, calabash, willow, or pine	4 ounces
Cinnabar	0.3 ounce
Mercury	0.3 ounce

Grind until the stars (*i.e.*, droplets of mercury) disappear.

PYROTECHNIC COMPOSITIONS

Materials

Chief ingredients of powder for fire and for offense, "Wu Pei Chih" 119.11a

Saltpeter, a principal
Sulfur, a principal
Calabash charcoal, a burning charcoal
Bamboo charcoal, the exploding charcoal is from the leaf
Willow charcoal, a principal charcoal
Pine charcoal, a principal charcoal
Birch bark charcoal, torpedo charcoal
Hemp grass, soundless
Orpiment, regulating fire
Realgar, poison fire

Subsidiary ingredients of powder for fire and for offense, "Wu Pei Chih" 119.11b

Peach flower, arsenic, red
Agate arsenic, variegated
Camphor (?) (*chao-nao*), dark fire
Ch'en-chou cinnabar, explosive
Mercury, explosive
Silver (?), brilliance
T'ieh-chiao arsenic, blackens
Chiang-tzu oil, poison
Dried lacquer, fire
Croton bean, sputter
Croton oil, brilliance
Hemp oil, boiling

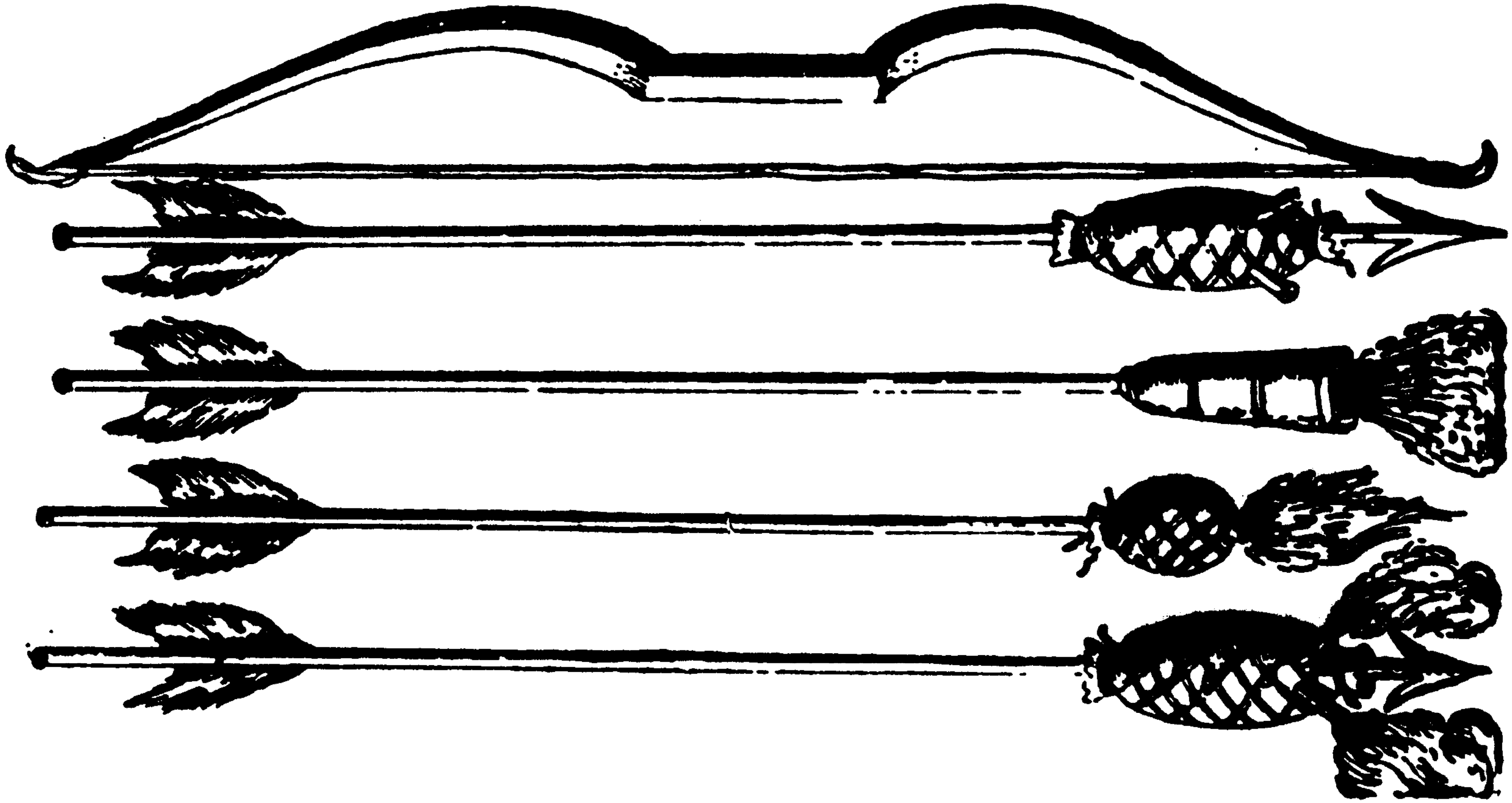

Figure 7. French Incendiary Arrows Designed to Throw Fire Forward Against the Target. Hanzelet Lorrain, 1630.

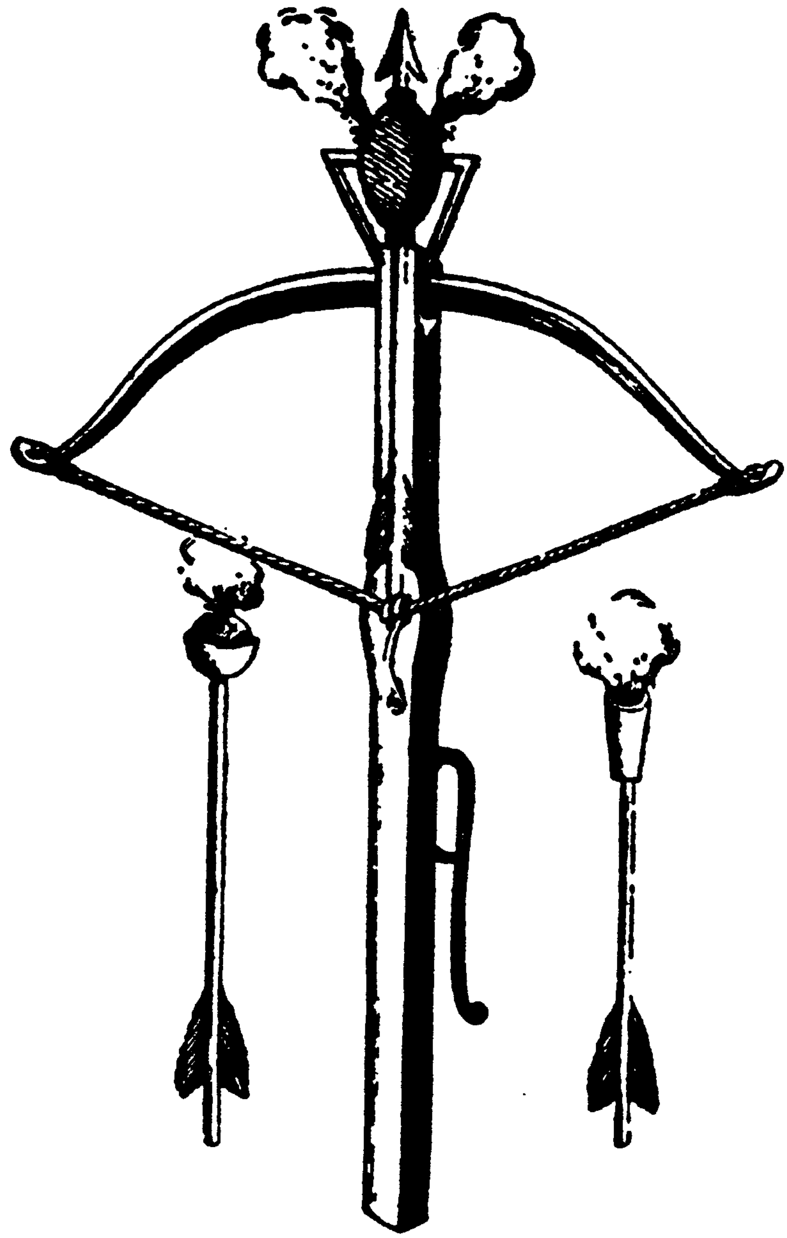

Figure 8. French Incendiary Darts for Shooting from a Hand Arbalest. Hanzelet Lorrain, 1630.

Hemp-seed oil, explosive
Azalea flowers, bewildering
T'ung oil, burning
Gold juice, brilliance
Garlic juice, poison
Aconite lycocton, hot
Gingko biloba leaves, fire
River porpoise, the slipperiness counteracts the wind
Aconite, hot
Fischer aconite, hot
Siebold's spurge, counteractive
Szechuan varnish, emetic
T'ieh-chiao lotus, poison
Polygonum blumei or orientale and *Hsiao-liao*, poison
River yellow, sharp
Powdered ginger, bewildering
Prosopis flexuosa, crackling
Pinellia tuberifera, silence
Day flower (?), if dampened with it, the skin or flesh becomes burnt
Aconitum Napellus, L., poison
Wild aconite, poison
Poison ivy (or *gelsemium elegans*), intestine-severing
Sulfur ash, poison
Blood-meat-grass, when wetted with it, the pores spout blood
Herpestis Monniera, poison
Pa-frost, poison
Human sperm, poison
Wolf dung, wind
Seal-throat-grass, on rinsing the throat with it one becomes mute
Blister fly, arsenic
Scolopendrid, poison
Cobra (?), poison
Kei (?)-snake, poison
Gelsemium elegans (or poison ivy), on entering the intestines it cuts them to bits
Toad, poison
Tabasheer, poison
Rush flower grass, fire
Reed-flower, fire
Polygonum Blumei, poison and brilliance

These are used in the compounding of superior fire, poison fire regulating fire, flying fire, and brilliant fire.

Black Powder

Fire Powder (for fireworks), "Wu Pei Chih" 119.10a

Saltpeter	5 pounds
Sulfur	1 pound
Charcoal of eggplant or willow or pine branch	1 pound

Grind together in three batches: 5800 strokes. Mix with spirits in ratio of 1 (spirits) to 3 (powder). Then shape into pellets the size of panicled millet or green peas. The batch is all right if a lighted pellet will not burn the palm of the hand. Use in small quantities, for it is very fast.

Fire powder (for incendiary match). "Wu Pei Chih" 119.10b

Pure saltpeter	1 pound
Sulfur	3.6 ounces
Willow charcoal	4.3 ounces
Eggplant charcoal	0.5 ounces
White eggplant charcoal	0.5 ounces
Camphor (?)	0.3 ounces

Mix as described in the preceeding recipe, but do not form into pellets. To be used with powder from preceeding recipe in rolled or flat match.

Fire arsenic (priming powder or first fire). "Wu Pei Chih" 119.20b

Saltpeter (made with alcohol)	1 ounce
Calabash charcoal	0.3 ounce
Blister fly	0.3 ounce
Sulfur	0.03 ounce

Explosive powder (for priming). "Wu Pei Chih" 119.21a

Saltpeter	4 ounces
Sulfur	0.3 ounce
Charcoal	0.08 ounce

Ordinary powder for guns. "Wu Pei Chih" 119.20b

Saltpeter	4 ounces
Sulfur	0.1 ounce
Charcoal	0.17 ounce
Blister fly	0.1 ounce

Cannon powder. "Wu Pei Chih" 119.21b

Saltpeter	10 ounces
Sulfur	6 ounces
Calabash or bamboo charcoal	3 ounces
Orpiment	1 ounce
Realgar	0.5 ounce

Lead (bullet) gun powder. "Wu Pei Chih" 119.21b

Purified saltpeter	40 ounces
Sulfur	6 ounces
Charcoal of willow or calabash or eggplant stalks	6.8 ounces

Grind each separately until very fine. Mix together with a bit of water, dry, pestle it 1000 times, take up and dry in the sun. Do this three times so as to make a fine powder. Each gun will use 0.25 ounce of powder, or, to shoot far, 0.3 ounce. The size of the bullet will vary with the weight of the powder. It is useful to add a spider skin.

Flat match. "Wu Pei Chih" 119.11a

Cut a strip of thin cloth. Brush it with thin flour paste, and, while it is wet, spread it with the fire powder. Fold double, and the match is made. Stick it on the wall so that it may dry in the shade. After oiling with t'ung oil, it may be used. This will keep the rain out of it.

Slow Fire

The *fire seed* described in "Wu Pei Chih" 119.20b, appears to be a mixture designed to burn slowly and inconspicuously for a long time -- a desirable composition for use when percussion primers, friction matches, etc., were not yet know -- but the burning time which is claimed for it seems greatly exaggerated.

Asbestos	1 pound
Iron rust	3 ounces
Charcoal powder	3 ounces
Bran	3 ounces
Pulp of the red jujube fruit	6 ounces

Mix roughly with rice water and form into cakes. Each ounce will last a month.

Fountain Powder

To a modern American or European fireworks-maker, the term "Chinese Fire" means a pyrotechnic composition containing ground cast iron, along with saltpeter, charcoal, and sulfur, and, if a particularly energetic jet of fire is desired in a gerb or in the driver of a Catherine wheel, with meal powder as well.[83] The ground cast iron gives scintillating sparks

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[83]Jones, R. in "Artificial Fire-Works," etc., 2nd ed., London, 1766, p. 44, gives recipes for "Chinese Fire. Saltpeter twelve ounces, meal powder 2 pound, brimstone one pound two ounces, and beat iron twelve ounces," and "For Gerbes. Meal powder six pound, and beat iron two pound one ounce and a half." He discusses, pp. 83, 84, the necessity for protecting the iron particles from moisture and suggests that they be coated with sulfur by stirring them with melted

which are characteristic of Chinese fire. Since the term has been in use in Europe for two centuries or so, it is especially interesting now to find an authentic Chinese recipe for fountain fire in "Wu Pei Chih" 119.21b.

Saltpeter	2 ounces
Sulfur	0.25 ounce
Finely ground [iron] roasted in t'ung or croton oil	0.15 ounce
Charcoal	0.35 ounce

Rocket Powder

Rising fire. "Wu Pei Chih" 119.10b

Saltpeter	5 pounds
Sulfur	14.8 ounces
Charcoal	15.5 ounces
White arsenic	0.5 ounce
Camphor	0.1 ounce
Blister fly	0.2 ounce

Mix in one batch with spirits, and dry. Then re-grind, mix again with spirits, dry, and grind.

Rising powder. "Wu Pei Chih" 119.21a

Saltpeter	1 ounce	1 ounce
Sulfur	0.3 ounce	0.3 ounce
Litharge	0.04 ounce	
Charcoal	0.3 ounce	0.35 ounce

Day Rising Powder. "Wu Pei Chih" 119.21a

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brimstone. James Cutbush, in "A System of Pyrotechny," etc., Philadelphia, 1825, p. 371, says, "The Chinese have long been in possession of a method of rendering fire brilliant and variegated in its colours. Cast iron reduced to a powder more or less fine, is called iron-sand, because it answers to the name given to it by the Chinese. They use old iron pots, which they pulverize, till the grains are not larger than radish seed; and these they separate into sizes and numbers for particular purposes." He mentions that "rockets, into the combustion of which, iron filings and iron sand enter, cannot long be preserved, owing to the change which the iron undergoes in consequence of moisture," and seems to have been unacquainted with the use of linseed oil for protecting the iron, as is done at present, or of tung oil which is even better. He gives several formulas for Chinese fire, of which we note here only the one for gerbs, p. 376 -- namely saltpeter 1, sulfur 1, meal powder 8, charcoal 1, and pulverized cast iron 8.

Saltpeter	1 ounce
Charcoal	0.09 ounce

Night rising powder. "Wu Pei Chih" 119.21b

Saltpeter	4 ounces
Sulfur	0.25 ounce
Charcoal	1 ounce

COLORED SMOKES

Blue smoke. "Wu Pei Chih" 120.5b

Saltpeter	2 ounces
Birch bark	1 ounce
Sulfur	0.05 ounce
Charcoal	0.1 ounce
Blue dye (from woad)	0.3 ounce

White smoke. "Wu Pei Chih" 120.6a

Saltpeter	1 ounce
Sulfur	0.5 ounce
Charcoal	0.1 ounce
Lead powder	0.04 ounce

Red Smoke. "Wu Pei Chih" 120.6a

Saltpeter	1 ounce
Rosin	2 ounces
Massicot [PbO]	1 ounce
Pitch	0.08 ounce

Violet Smoke. "Wu Pei Chih" 120.6a

Saltpeter	1 ounce
Sulfur	0.3 ounce
Charcoal	0.1 ounce
Violet powder (cinnabar)	0.5 ounce
Hemp Oil	a trifle

Black Smoke. "Wu Pei Chih" 120.6b

Saltpeter	1 ounce
Sulfur	0.2 ounce
Charcoal	0.3 ounce
Lignite	0.3 ounce
Fresh shoots of the soap bean tree	0.3 ounce

STENCHES

Many of the subsidiary ingredients of pyrotechnic mixtures produce poisonous, suffocatipng, and malodorous smokes. "Wu Pei Chih," 119.22a-25b, describes stenches and other offensive mixtures containing fish oil, roe, spiders, and so forth, along with saltpeter, with saltpeter, white arsenic, litharge, and other ordinary materials, and states, 120.2a, that sawdust fried in *t'ung* oil and packed in sacks supplies a means of producing lachrymatory smoke.

STINK POTS

The toxic smoke pot shown in Figure 9 is loaded with "paper tubes containing all sorts of powders." The text states that "it burns eyes, beards, and hair, and that it frightens." Figure 10 pictures another offensive incendiary containing 14 small tubes of composition and one large one in a single container, the several fuses wound together into a single fuse by which the pot is lighted. The contrivance represented in Figure 11 contains in its middle a powder charge which on exploding throws missiles about and scatters a burning mass which gives off poisonous fumes and lachrymatory smoke. The text states that it contains *t'ung* oil, *silver rust* (presumably *water-silver rust*, which is mercury oxide), sal ammoniac, *gold juice*, garlic juice, roasted iron filings, poercelain dust, and cast iron bullets.

SPOUTING FIRE WEAPONS

The same spattering fire composition which was used in small tubes attached to arrows and spears was also used as the principal charge in larger weapons. The *upset horse fire-serpent divine staff*, shown in Figure 12, consists of a tube of wrought iron, three feet long, loaded with spattring fire and lead bullets, supported by a wooden handle four feet in length. It was evidently intended for use against horses and horsemen. Figure 13 represents another device operating on the same principle, made from bamboo, wound with wire, and filled with noxious substances. The fire weapon pictured in Figure 14 is loaded like a Roman candle and throws incendiary pellets which burn with a bright light and a toxic smoke. The text describes how it is loaded, first a layer of slow powder containing relatively much charcoal and relatively little saltpeter, then a layer of spurting powder, then one pellet the size of the tube containing saltpeter, camphor, pine perfume, realgar, and white arsenic, then the same sequence again until five such loadings have been made. It states that the pellets travel several hundred feet.

The *string-of-100-bullets cannon*, Figure 15, throws out poisonous smoke and vapors, along with bullets which are fed gradually into the stream of outpouring gases and are carried along with them. It is cast of pure copper about four feet long. A trough a little more than a foot long is cast on its side. "Store here about one hundred bullets. When [the gun is]

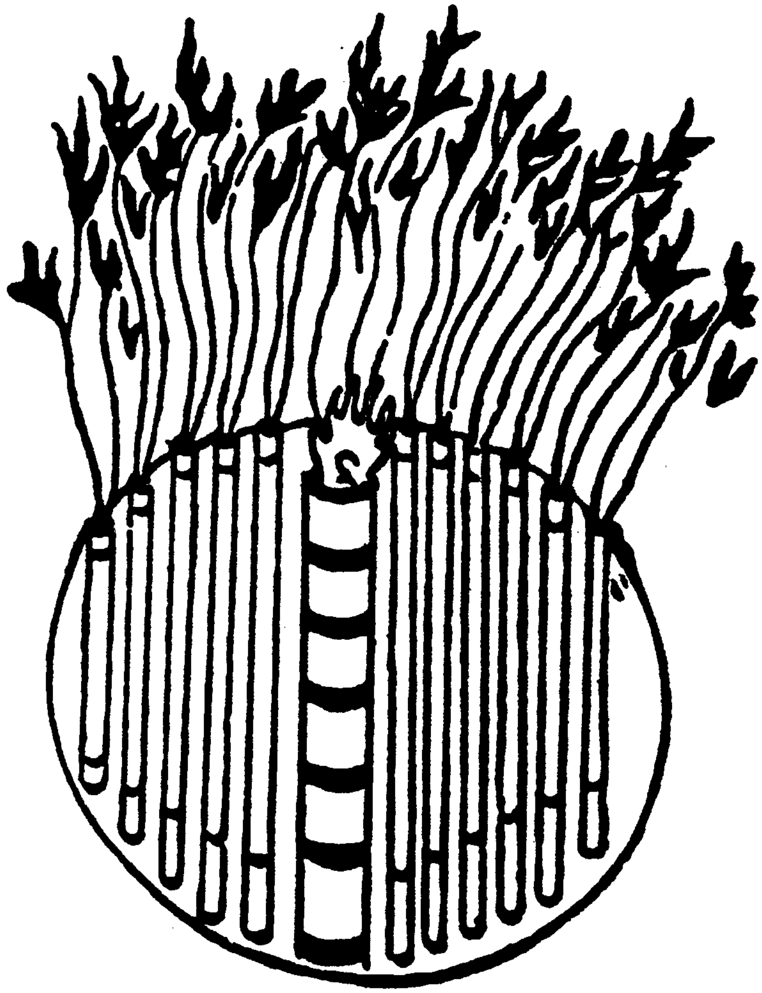


Figure 9. Toxic Incendiary Stink Bomb. "Wu Pei Chih" 122.17b.

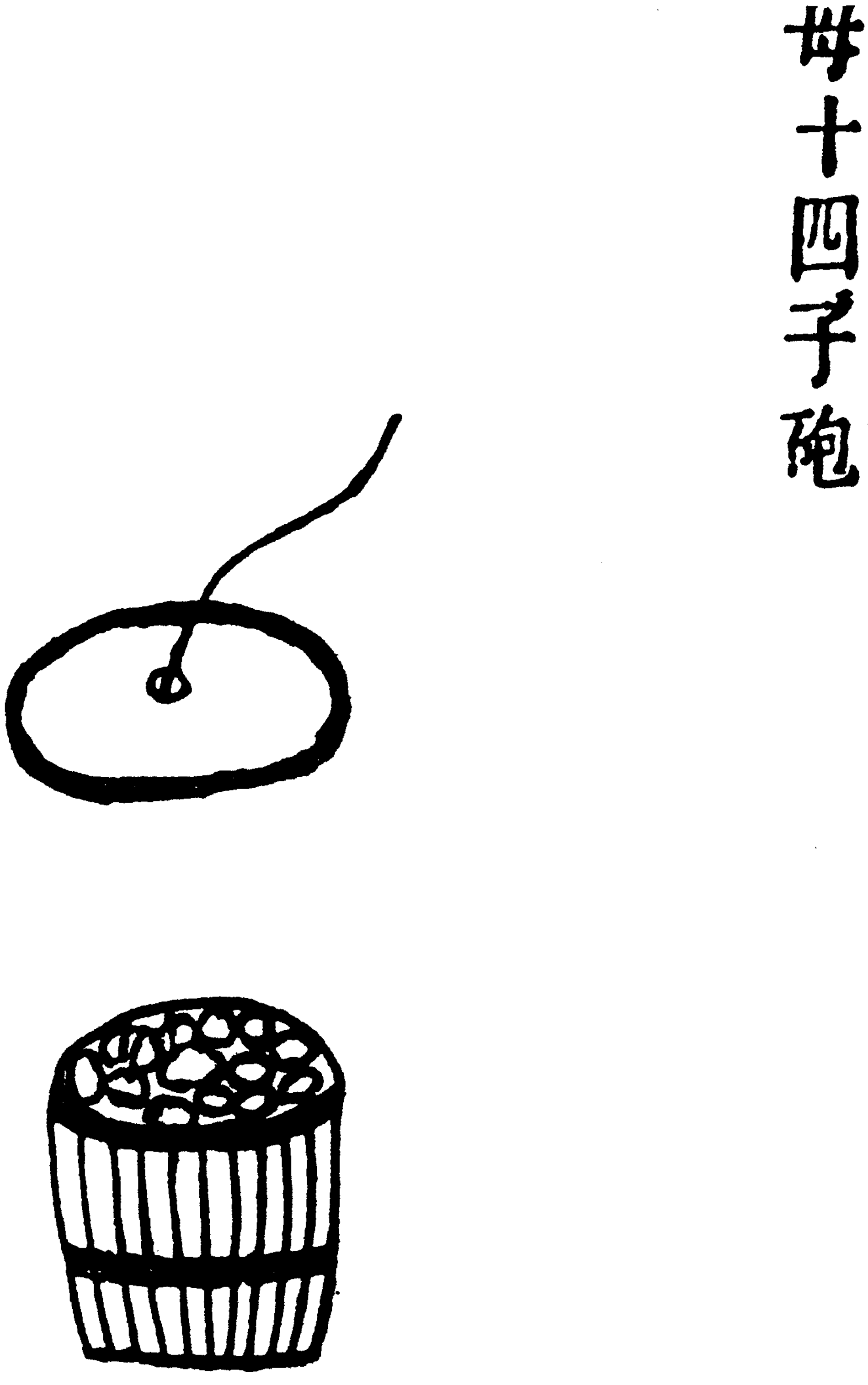


Figure 10. Offensive Incendiary Stink Pot. "Wu Pei Chih" 12319a.

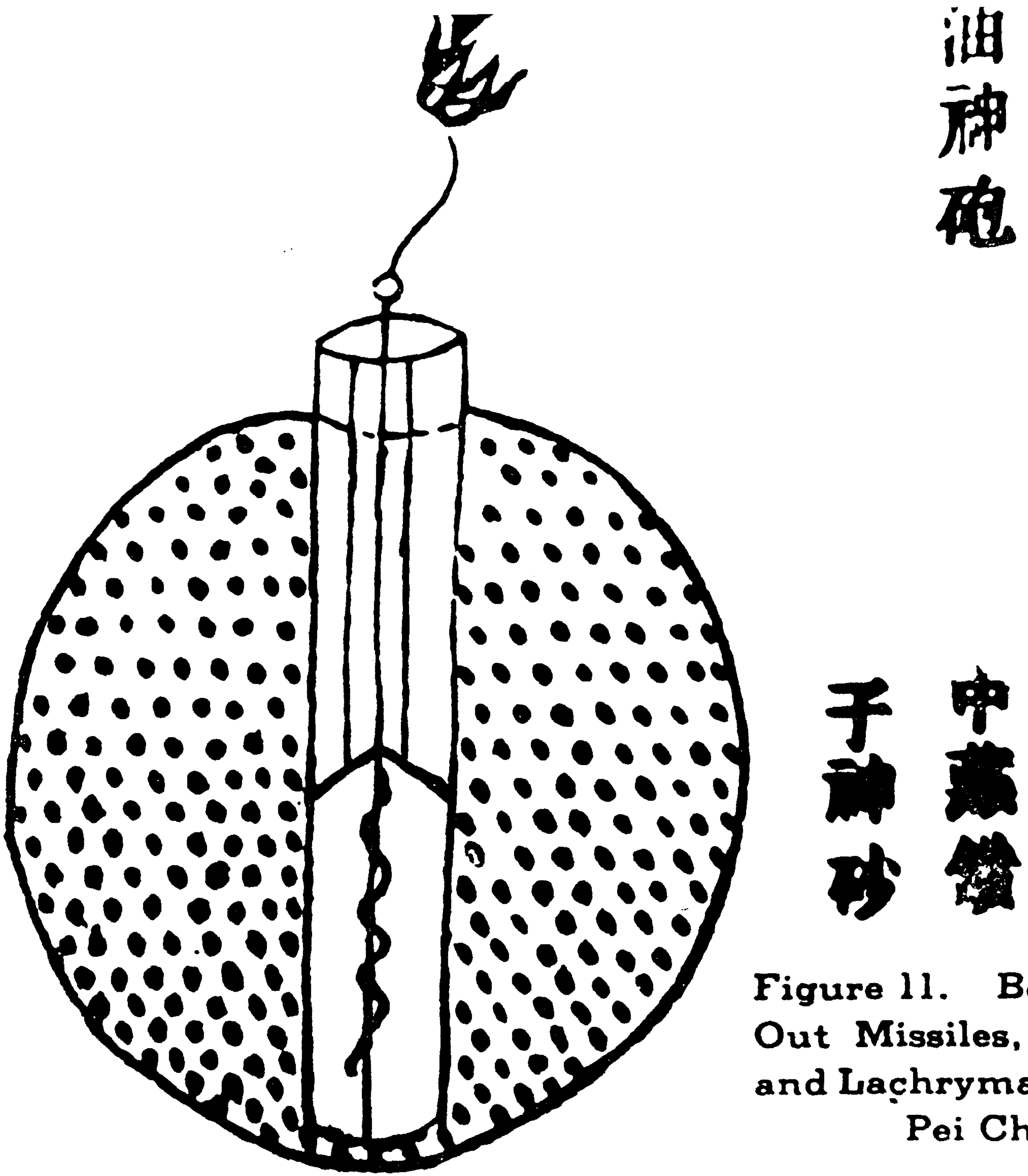
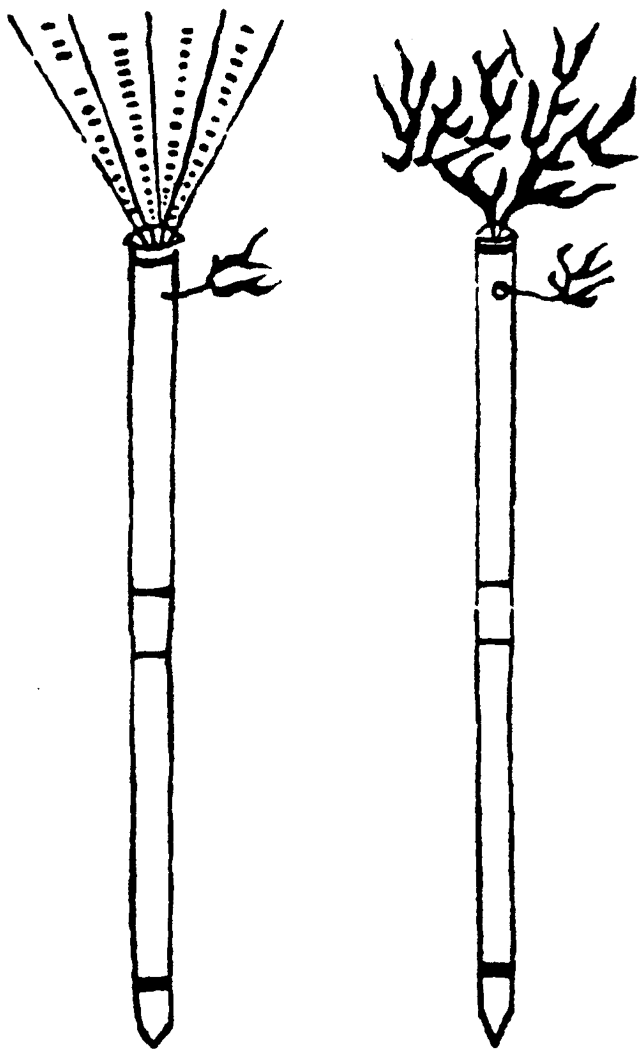


Figure 11. Bomb Which Throws Out Missiles, Poisonous Fumes, and Lachrymatory Smoke. "Wu Pei Chih" 122.19b.



倒馬火蛇神棍

Figure 12. Upset-Horse Fire-Serpent Divine Staff, Seven Feet in Overall Length, Spouts Toxic Fire and Bullets. "Wu Pei Chih" 128.10b.

Figure 13. Wire-Wound Bamboo Portable Toxic Fire Spouter, Throwing Flame and Bullets. "Wu Pei Chih" 124.18b.

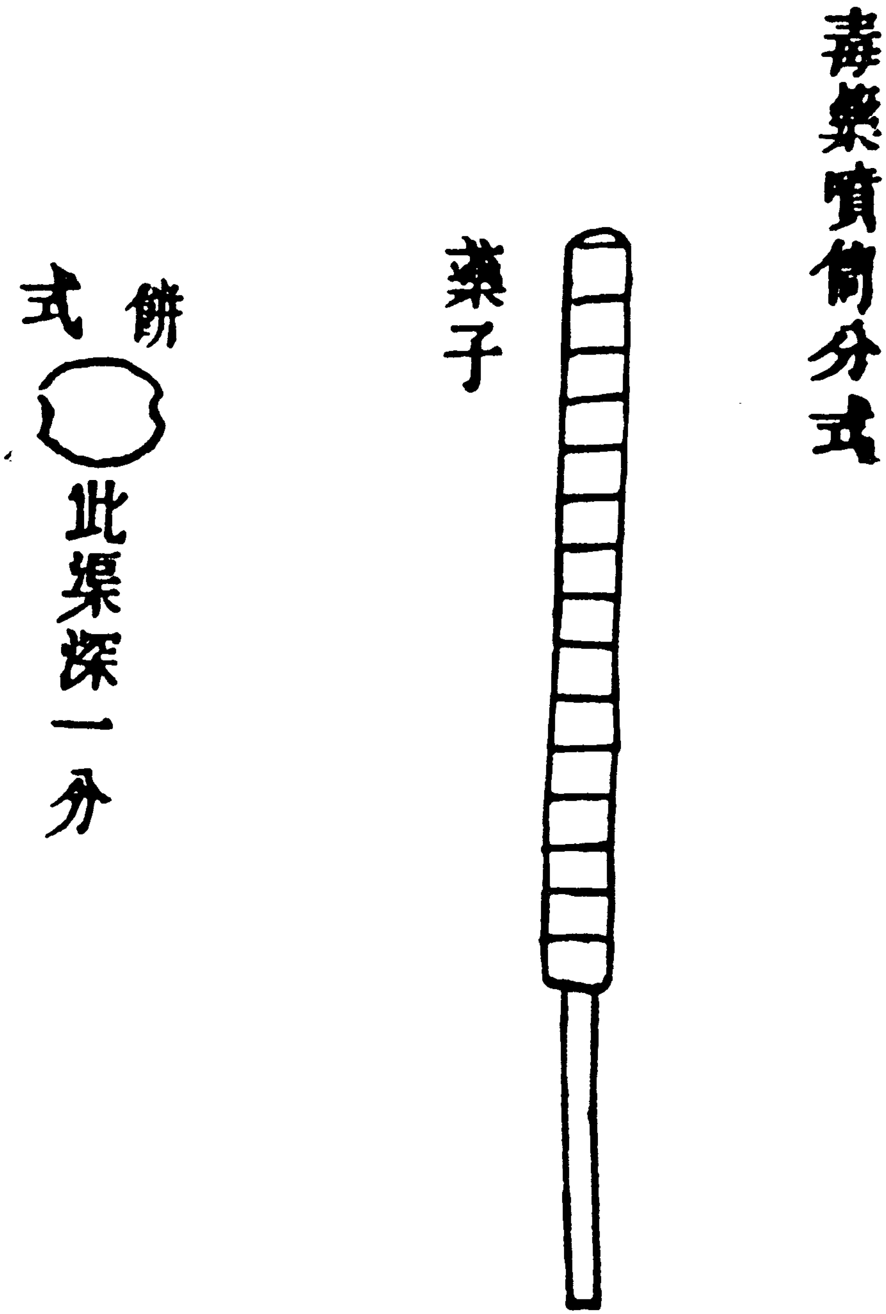


Figure 14. Thrower of Toxic Incendiary Pellets, a Form of Roman Candle. "Wu Pei Chih" 129.2a.

白子連珠砲

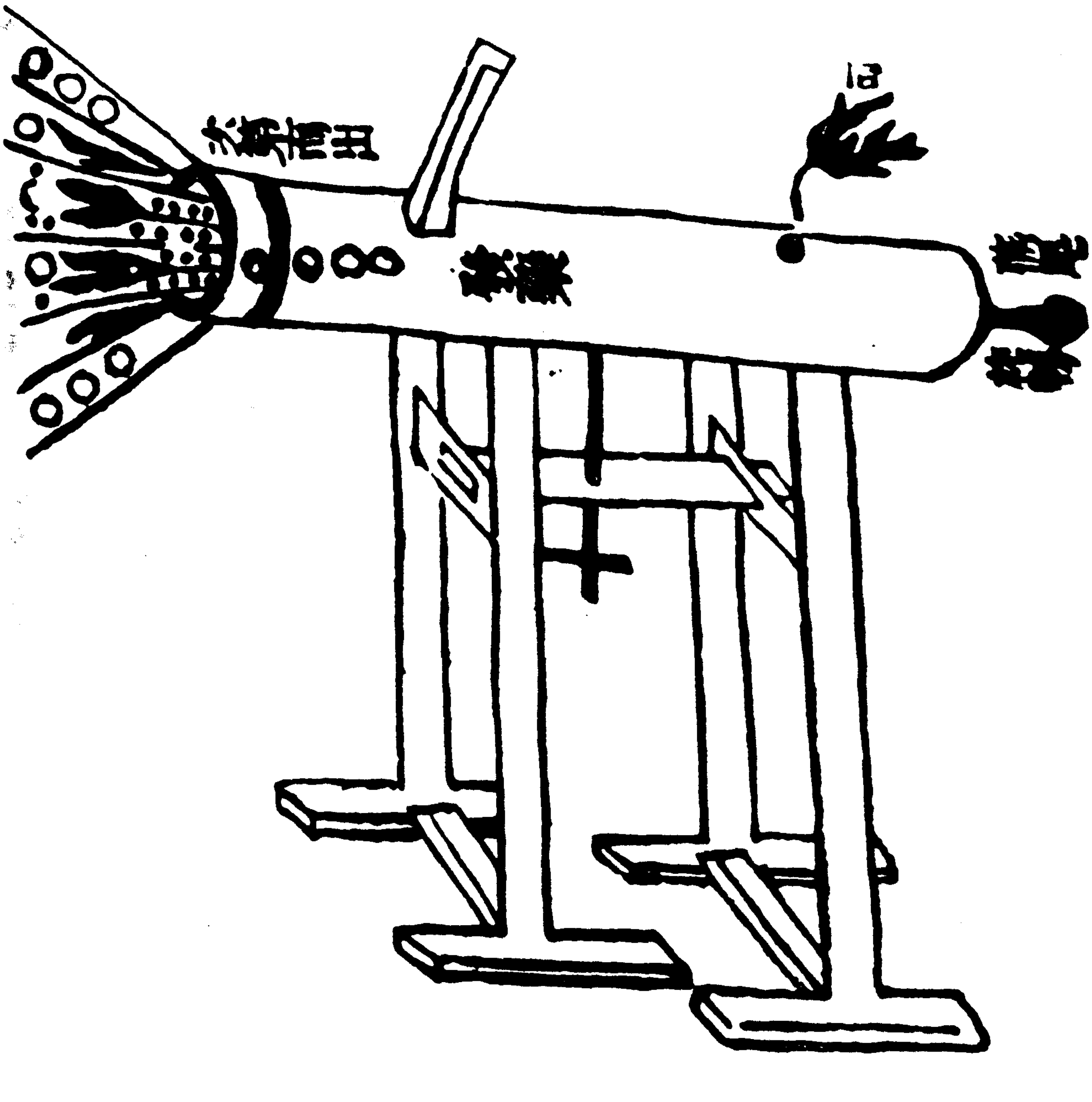


Figure 15. String-of-100-Bullets Cannon. A Toxic Aerosol Projector Which Also Throws Bullets. "Wu Pei Chih" 122.13a.

raised upright, the bullets will fall into the barrel. They will fire out in succession." The weapon takes a charge of one and one-half pints of *fa* powder. "Wu Pei Chih" 119.1Sb, says of *fa* powder: "it is very fierce, not a solitary thing can be seen, not a step taken, so that one will capture alive bandits and soldiers." The text, 119.19a, mentions its components - realgar, orpiment, saltpeter, sulfur, bamboo charcoal, birch charcoal, willow charcoal, white arsenic, stone coal, human sperm, pine perfume, big grains, elm grains, red smartweed, black smartweed, foreign bitter, river bitter, and the four kinds of ginger.

The *poison-mist-divine-smoke cannon*, Figure 16, is loaded with white arsenic, realgar, orpiment, wolf dung, and other noxious materials. "When attackers mount the wall, these are lighted and burst forth with spreading smoke."

Concerning the device shown in Figure 17, called a *lotus*, the text says: "Mix up evenly all sorts of powders and place in the bottom of this container. Arrows a foot long, with iron heads and iron feathers, are added." The weapon apparently spews forth all sorts of fire, smoke, and poison, along with shrapnel intended to produce wounds.

EXPLODING WEAPONS, GRENADES, BOMBS, SHELLS

"Wu Pei Chih" describes and illustrates many weapons which function by exploding, by producing a frightful noise, and by throwing fragments about for creating wounds, starting fires, or producing toxic and suffocating smokes. Some are to be carried by animals, some to be thrown by hand or by catapult, and some to be shot from cannons and mortars.

The *hornets-warm bomb*, Figure 18, is made from a round basket of splints. Forty or fifty layers of paper are pasted on it and allowed to dry. Then 15 layers of oiled paper are pasted on. Through a hole three pounds of gunpowder is introduced, a half pound of *iron thorns*, and several dozen each of *flying-swallow poison* and paper fire-crackers. This makes a fairly sizable package which is carried and thrown by means of a flexible rope handle.

The *eight-directions-whirlwind-poison-mist-thunder shell*, Figure 20, is fired from a gun. It is made of cast iron and is charged with *divine smoke* and *fa* powder to produce a toxic and suffocating smoke. "There will be a loud thunder clap, and the pieces of iron will fly like bullets."

The flying-cloud-thunder shell, Figure 21, is made of cast iron, "as big as a bowl, as a round as a bowl." It holds half a pound of *divine fire*. It it to be shot from a cannon. The directions say: "Shoot ten at a time."

The next accompanying the picture of soldier firing three mortars, Figure 22, reads as follows.

A large (wide) iron cannon is packed with powder. Make a small hollow shell of cast iron, and pestle it full of fire powder. Insert a small bamboo tube and place a rather long fuse. Place over the mouth of the large cannon. First light the fuse of the shell, then that of the large cannon. The large cannon will despatch [sic] the shell which will burst over yonder.

ROCKETS

We have very little satisfactory information concerning the antiquity of rockets. The Kin Tartars defending Lo-yang and K'ai-fêng-fu against the Mongols in 1232 used *flying fire spears (fei huo chiang)* which have by some been taken for rockets, and the date, 1232, has been quoted as that of an early, perhaps the earliest, use of rockets in warfare. But the flying fire spears, from the historical account and from the pictures in the "Wu Pei Chih," seem actually to have been spears equipped with fire tubes which threw fire forward for a distance of about thirty feet. This is a reasonable distance for fire to be thrown from a small tube, but it is an unreasonably short trajectory for a rocket and one which would yield but little military advantage.

At the time when "Wu Pei Chih" was printed, the Chinese had already developed great skill in the tactical use of rockets and were far ahead of the europeans in their military application. Rocket-propelled arrows with razor-sharp heads, when fired in clusters, provided a formidable weapon, and one uniquely qualified for special jobs of offense and defense, for attacks from ambush, for the defense of defiles and gateways. There are many hints in the "Wu Pei Chih" which might have been, and perhaps were, of assistance to the engineers and strategistswho were concerned with the design, development, and use of special weapons during World War II.

While the Chinese turned their genius toward improving the military uses of rocket propelled arrows, they do not appear to have tried greatly to improve the rockets themselves, but seem, if we may judge from the pictures in the "Wu Pei Chih," to have remained contented with small rockets of inferior workmanship and performance. The Europeans of the same time had better rockets, although they had not yet found much use for them in military operations. Biringuccio in 1540 was acquainted with rockets which burst at the top of their flight, sending forth six or eight other rockets or serpents,[84] and Hanzellet Lorrain in 1630 with recreational rockets which threw out crackers (grass-hoppers), stars, and serpents. The latter was familiar with the use of an awl or augur for boring the charge, and also with the use of a spindle and graduated drifts for pounding it in place. He recommended the military use of rockets of six or seven pounds weight with grenades in their heads. These, he believed, would frighten both men and horses and would easily break up a squadron of cavalry; but this is the only warlike application of rockets mentioned in his book.[85]

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[84]"The Pirotechnica of Vannochio Biringuccio, translated from the Italian with an Introduction and Notes by Cyril Stanley Smith & Martha Teach Gnudi," The American Institute of Mining and Metallurgical Engineers, New York, 1942, p. 443.

[85]Lorrain, *op. cit.*, pp. 224-5, 234-9.

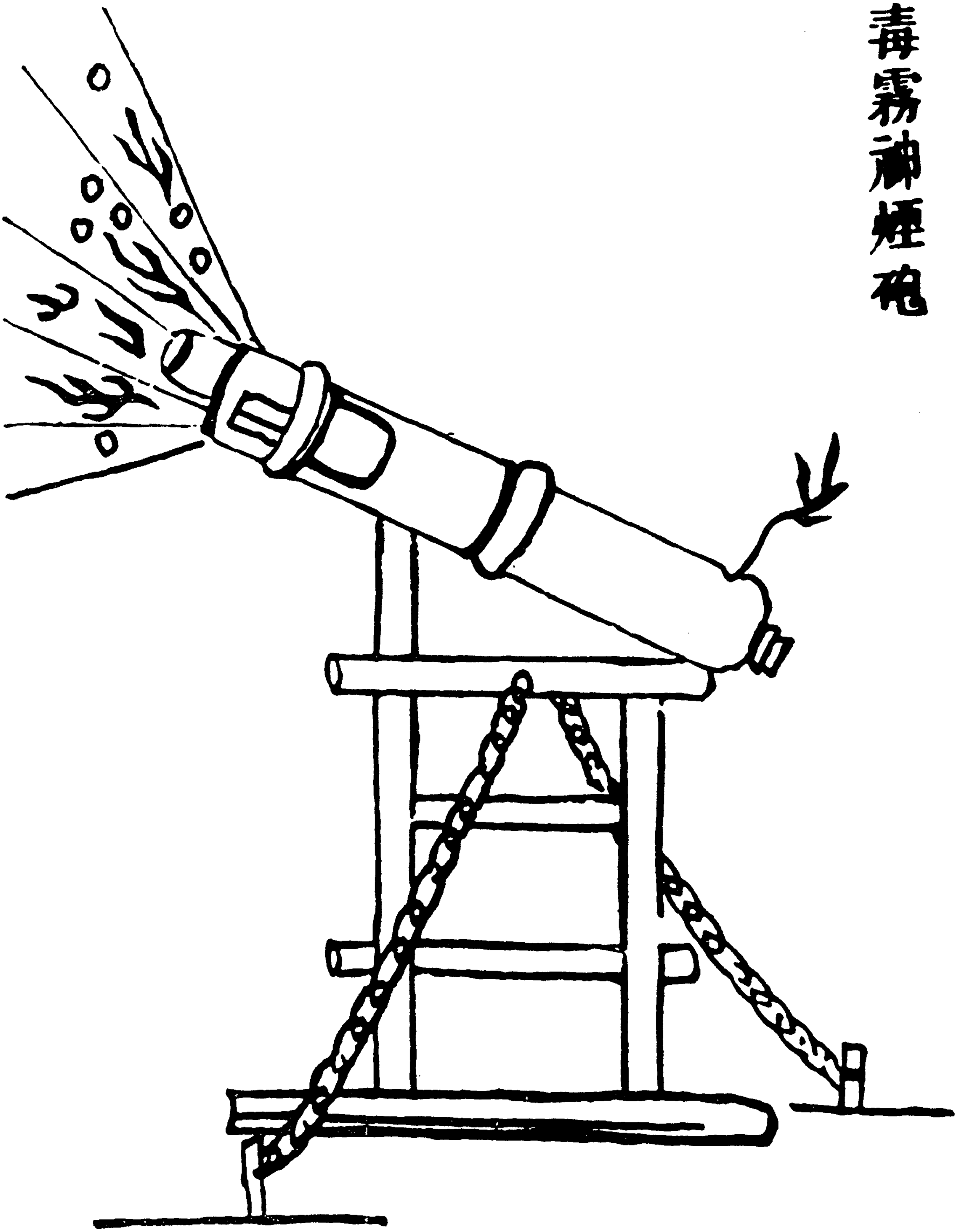

Figure 16. Poison-Mist-Divine-Smoke Cannon. "Wu Pei Chih" 122.22b.

一把蓮

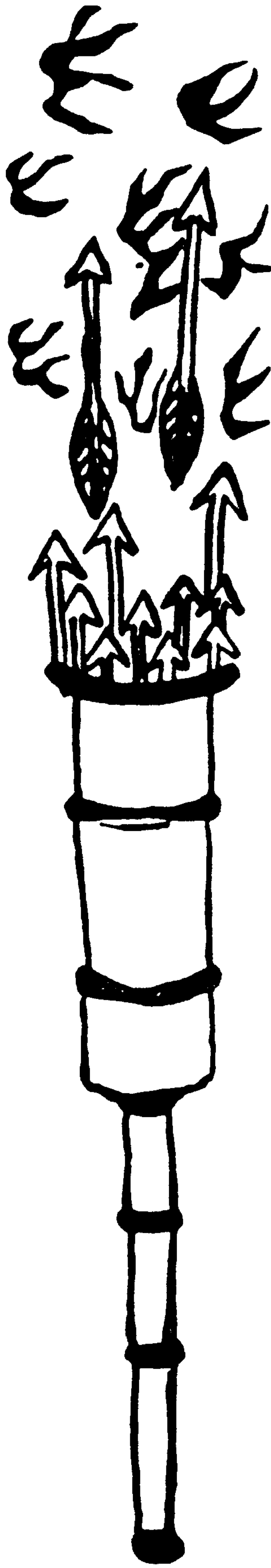

Figure 17. The Lotus, a fire, smoke, poison, and shrapnel ejector. "Wu Pei Chih" 129.6a.

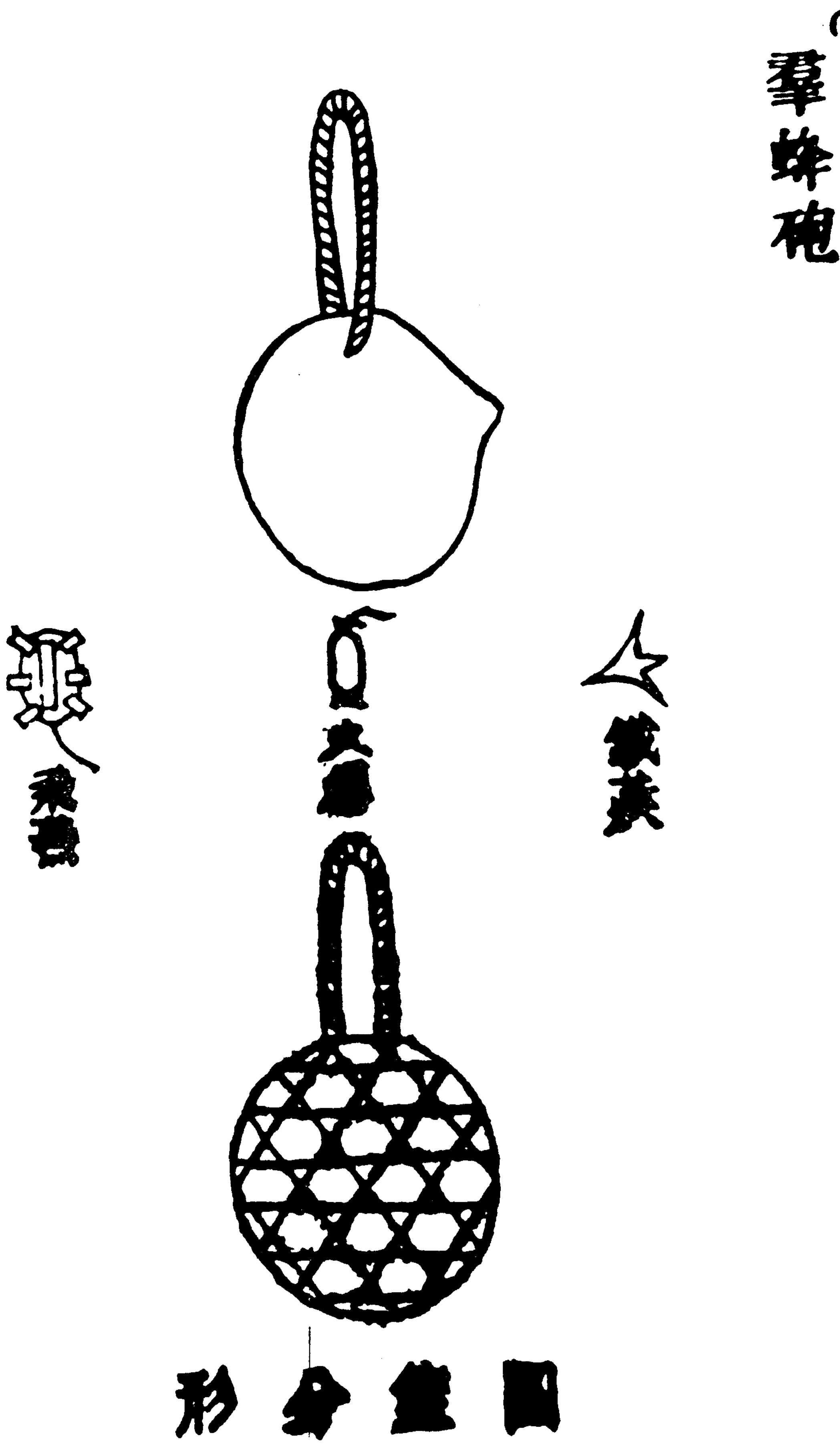

Figure 18. Hornet-Swarm Bomb. "Wu Pei Chih" 123.4b.

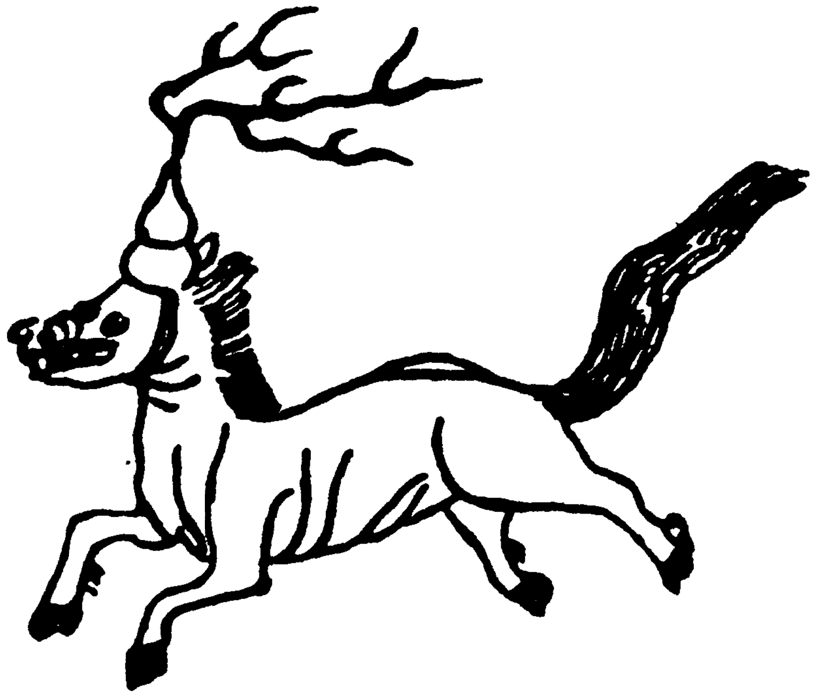

Figure 19. A Bomb on an Expendable Carrier Going Forward Toward the Enemy's Position. "Wu Pei Chih" 131.13b.

Figure 20. Eight-Directions - Whirlwind - Poison - Mist - Thunder-Shell. "Wu Pei Chih" 123.5 b.

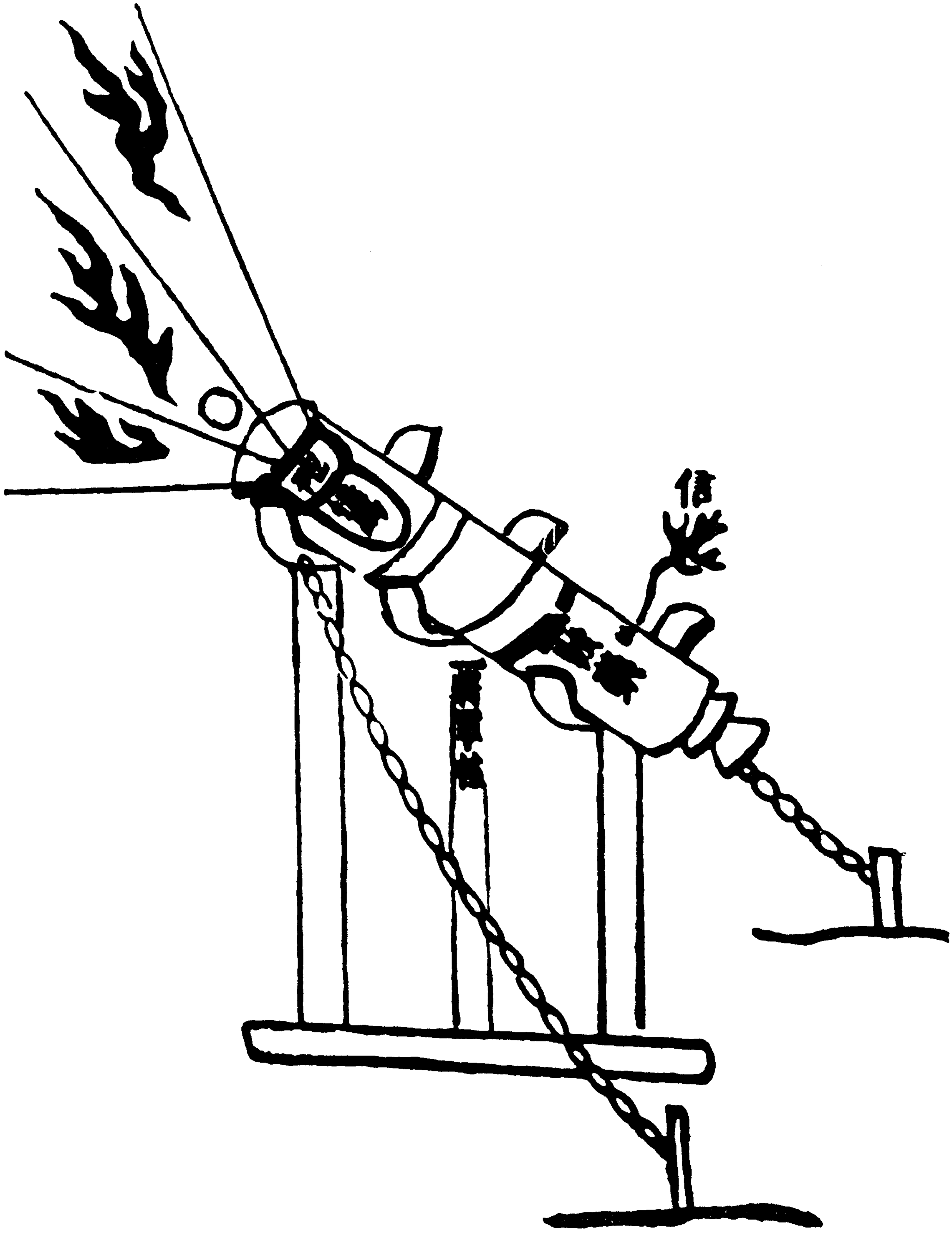

Figure 21. Flying-Cloud - Thunder-Shell Shot from a Cannon. "Wu Pei Chih" 122.18b.

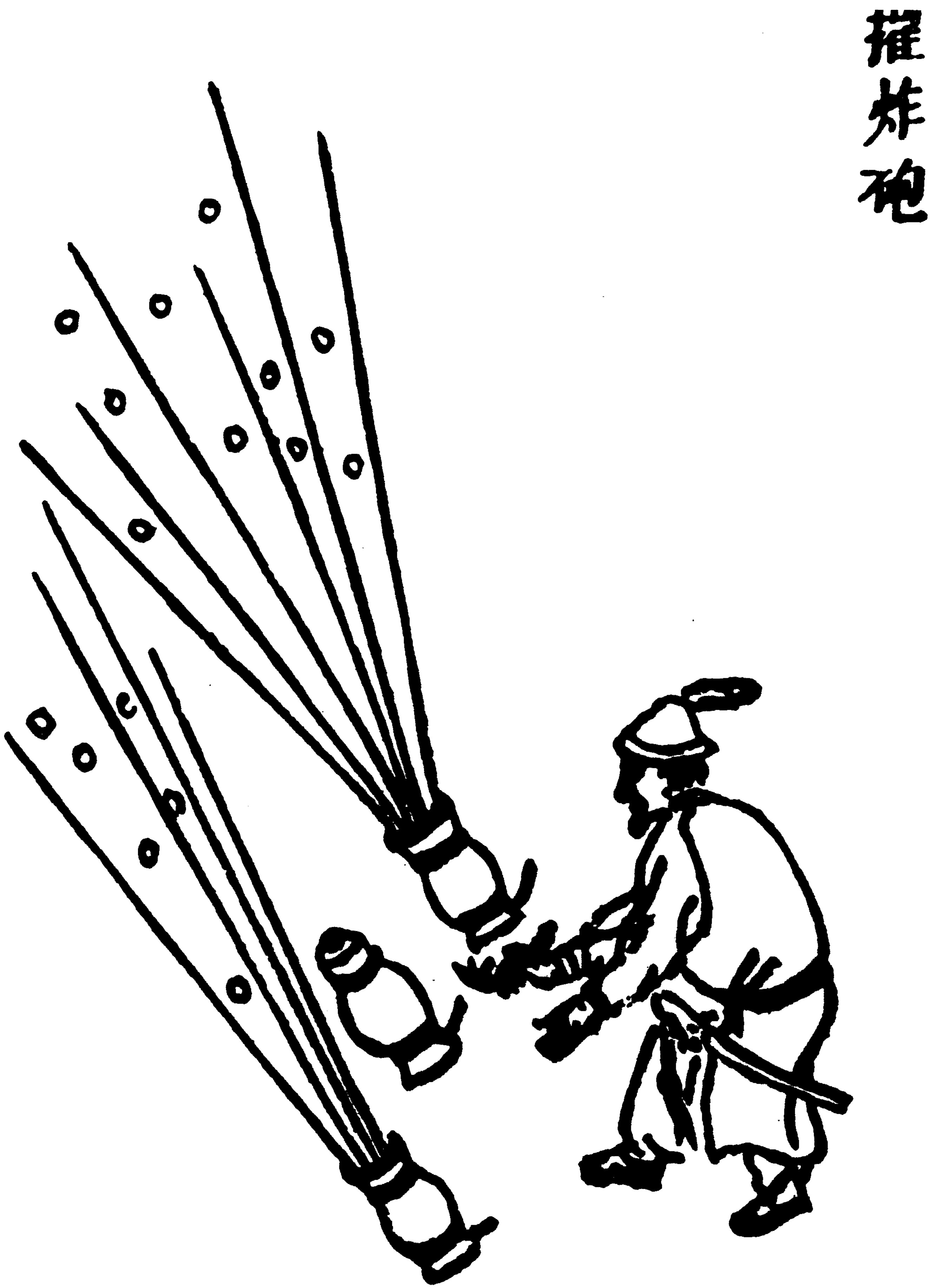

Figure 22. Explosive Shells Thrown from Mortars.

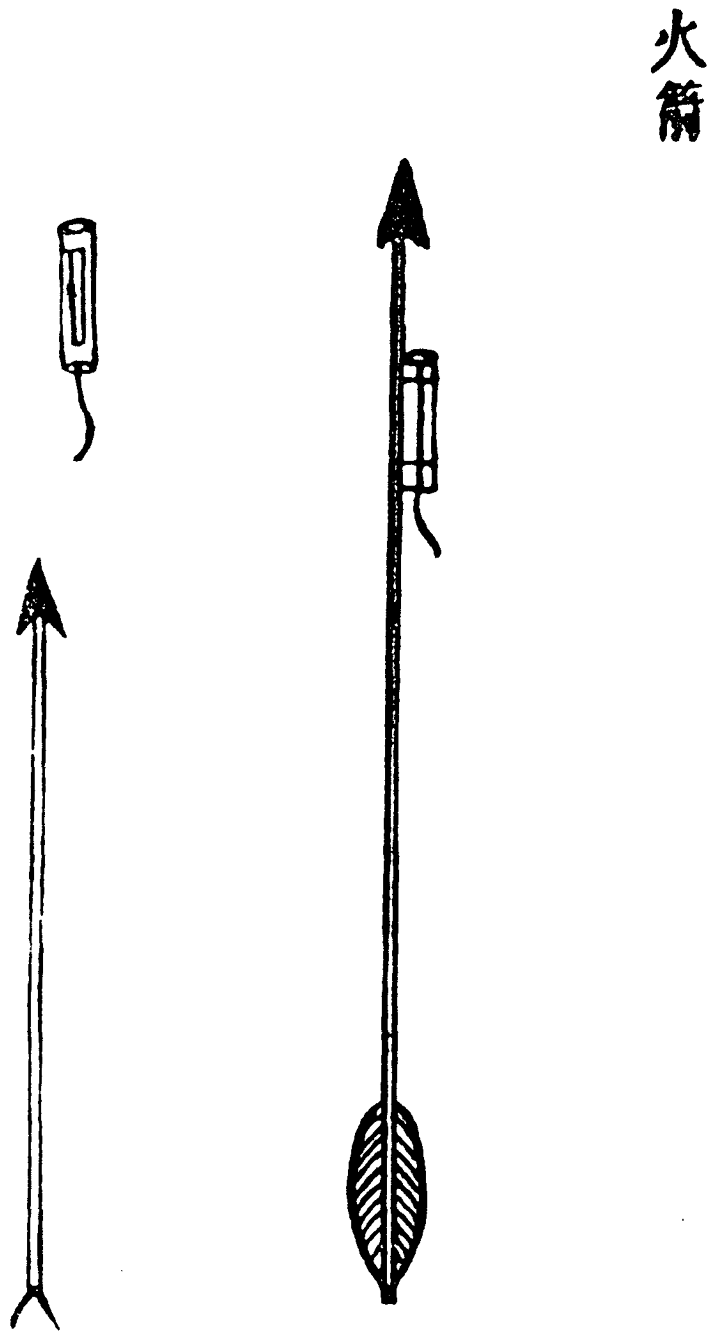

Figure 23. Rocket Showing Central Cavity. Rocket Attached to Shaft of Arrow. "Wu Pei Chih" 126.2b.

The "Wu Pei Chih" has a picture, reproduced in figure 24, of a tool for forcing an awl straight into the middle of the rocket charge. "It does a better job than the drill preferred by the artisans. If the rocket-arrow is to fly straight, the hole must be straight otherwise it will go off on a tangent." There are also pictures of devices for carrying the rockets and for launching them singly and in clusters. The text describes some of them as follows.

Rocket-basket-arrows. "Wu Pei Chih" 126.16b-17a (Figure 26): Make a cylinder of bamboo splints, length four feet, wider at the opening than at bottom. Cover with paper, and brush with oil as a protection against wind and rain. On the inside arrange cross pieces for compartmentalizing the arrows. Let the bamboos have three internodes. On the outside arrange a strap (for holding the cylinder) in front of the person. In the side leave a holefor passing the fuse. Connecting together (the fuses) fasten *rising powder* to the arrows. Each cylinder will contain 17 or 18 arrows or 20. On the steel tips smear poison. In front of the *rising powder* attach a pellet of *bright powder*. These are particularly efficient for the burning of fodder, wall-towers, and ships. On meeting the enemy it is possible to anticipate the attack.

Arrows which will rush out on a solid front (like) 100 tigers. "Wu Pei Chih" 127.11b-12a (Figure 27): The powder capsule (driver tube) is 0.3 foot long. For the arrow shaft employ bamboo 1.6 feet long. Behinf the feathers there is an iron weight. The leather cover. The holes in the upper frame for holding the arrows. The lower frame plate. Within the box employ *fierce* arrows, powder capsules, shafts of *Fei-tuan* bamboo. Let there be 100 arrows. Behind the feather place an iron weight so that the center of gravity will be four fingers [width] fron the mouth of the capsule. It will be possible to shoot over 300 paces, 100 arrows at a time. If smeared with tiger-shooting poison, the might [of the arrows] will be very fierce, whence the name [fierce of the arrows]. If they are to be used against boats or carts, one may vary the size at wish, but the *divine-contrivance* type would be best. The type shown here is short and small, and particularly intended merely to be carried in infantry battles on land by one soldier.

Leopard-herd-rush-transversally arrows. "Wu Pei Chih" 127.12b-13a (Figure 28): Wooden cover. Powder-capsule (driver tube) 0.5 foot long. The arrow shaft, 2.3 feet long, is to be made of *Ching* [bamboo] sticks. At the end there is an iron weight. Fuse aperature. Plate for adjusting the cover of the arrow box. Upper frame-plate for holding arrows. Lower frame-plate. The box holds *divine-contrivance* arrows. The capsules are 0.5 feet long. The shafts are made of Fei-tuan or Ching [bamboo] sticks 2.3 feet long. Let there be 40 arrows. Behind the feather add an iron weight so that the center of gravity is six fingers [width] from the mouth of the capsule. They will be able to travel over 400 paces, 40 at one time. By arranging the arrows so that at the mouth of the box, laterally, they are separated somewhat, whereas at the bottom they are closer together, at one firing they will scatter transversally over several hundred feet. Whenever meeting with the enemy in open country, merely with 10 or so boxes before the ranks, for a breadth of several thousand feet everything will be arrows. Since [with this] one can attack the enemy to both left and right, the name is *Leopard-herd-rush-transversally arrows.*

Long-snake crush-enemy arrows. "Wu Pei Chih" 127.13b - 14a (Figure 29): Sketches of the parts. Leather cover. Sometimes a wooden cover is used. Iron turtle for covering the fuse aperture. Powder capsule 0.4 foot long. Shaft of arrow is made of bamboo 2.9 feet long. Behind the feathers there is an iron weight. Fuse aperture plate. Upper and lower frame holes and plate for holding the arrows. In the wooden box one stores 30 rocket-arrows. The powder capsules are 0.4 feet long. The shafts are 2.9 feet long. In all cases the points are to be smeared with tiger-shooting poison. Each box is to weigh not more than five or six pounds, so that one soldier may carry it. Wait until the enemy is within 200 paces, then fire suddenly all at once. The effect is fierce, so that one soldier is superior to 30, whence the name.

A *screen of divine rocket-arrows.* "Wu Pei Chih" 129.16a-16b (Figure 30): Plant fire treasury (?). Make this box of wooden boards, of a size to hold 100 or so rocket-arrows. Place it between two supports so that it can be tilted on an iron axle. Whenever there are bandits to be suppressed, [this contrivance] being stationed on the strategic roads, aim it and fire. The arrows will go for several hundred paces. If these are made in several hundreds, it will indeed be a great help.

GUNS

The discovery that black powder could be used for the propulsion of projectiles did not at once result in the discontinuance of the old weapons. Arrows continued to be fired from bows and arbalests, and efforts were made to shoot them from tubes by the propulsive action of powder. The "Wu Pei Chih" contains a picture, Figure 31, of a gun for shooting an arrow as a projectile. It consists of a tube of pure copper, three feet long. It shoots one arrow at a time, requires a charge of 0.3 ounce of *fa* powder, and throws the arrow for a distance of 200 or 300 paces. A drawing, Figure 32, in a European manuscript of about 1430-40 shows one soldier carrying a tubular gun loaded to shoot an incendiary arrow in company with another soldier who is carrying an arbalest loaded with a missile which is similar.[86]

The *peerless bamboo General*, Figure 33, is a gun or portable mortar. Mayers[87] erroneously considered it to be an "approach to the modern form of rocket . . . in every essential particular a weapon corresponding to that introduced into the British army by Sir William Congreve . . . . A stout section of bamboo was to be taken, and all the joints except the last one were to be drilled through. A tube was thus prepared, within which gunpowder was to be closely rammed down, the base having first been strengthened with a

[86]ESSENWEIN < A., "*Quellen zur Geschichte der Feuerwaffen,*" Leipzig, 1877, Plate B.I.

[87]MAYERS, *loc. cit.*, pp. 101, 102. He also thought the arrow-shooting gun, Figure 31, to be a form of rocket "containing its own means of propulsion."

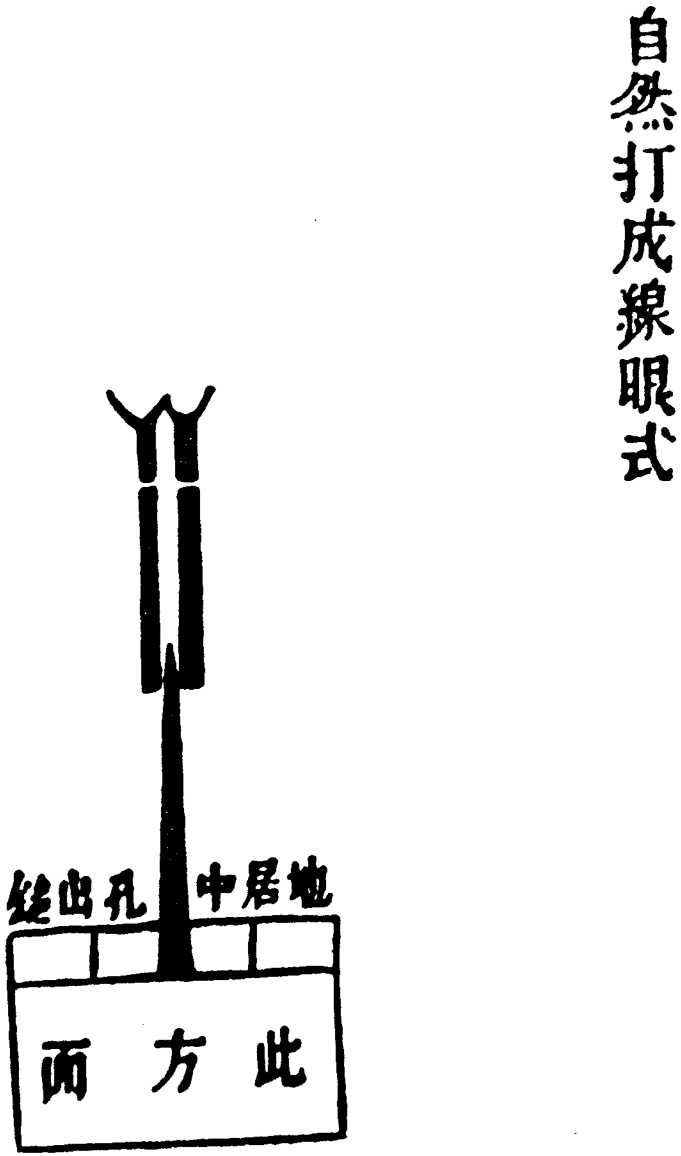

Figure 24. Tool for Making the Central Cavity in the Rocket's Propelling Charge. "Wu Pei Chih" 126.3a.

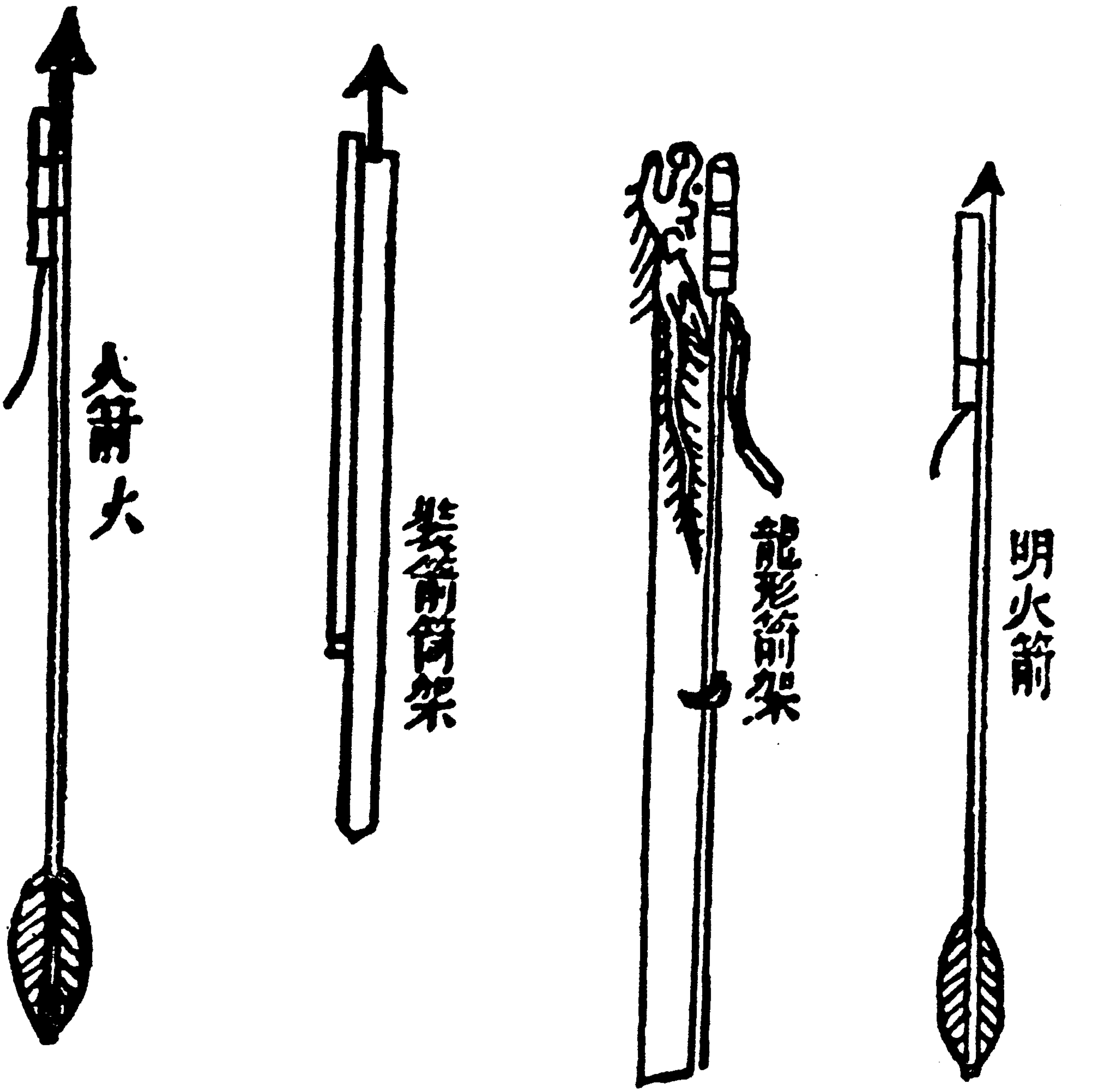

Figure 25. Rocket-Propelled Arrow with Tube for Launching. "Wu Pei Chih" 126.4b.

Figure 26. Clusters of Rocket-Arrows Fired from Baskets. "Wu Pei Chih" 126.16b.

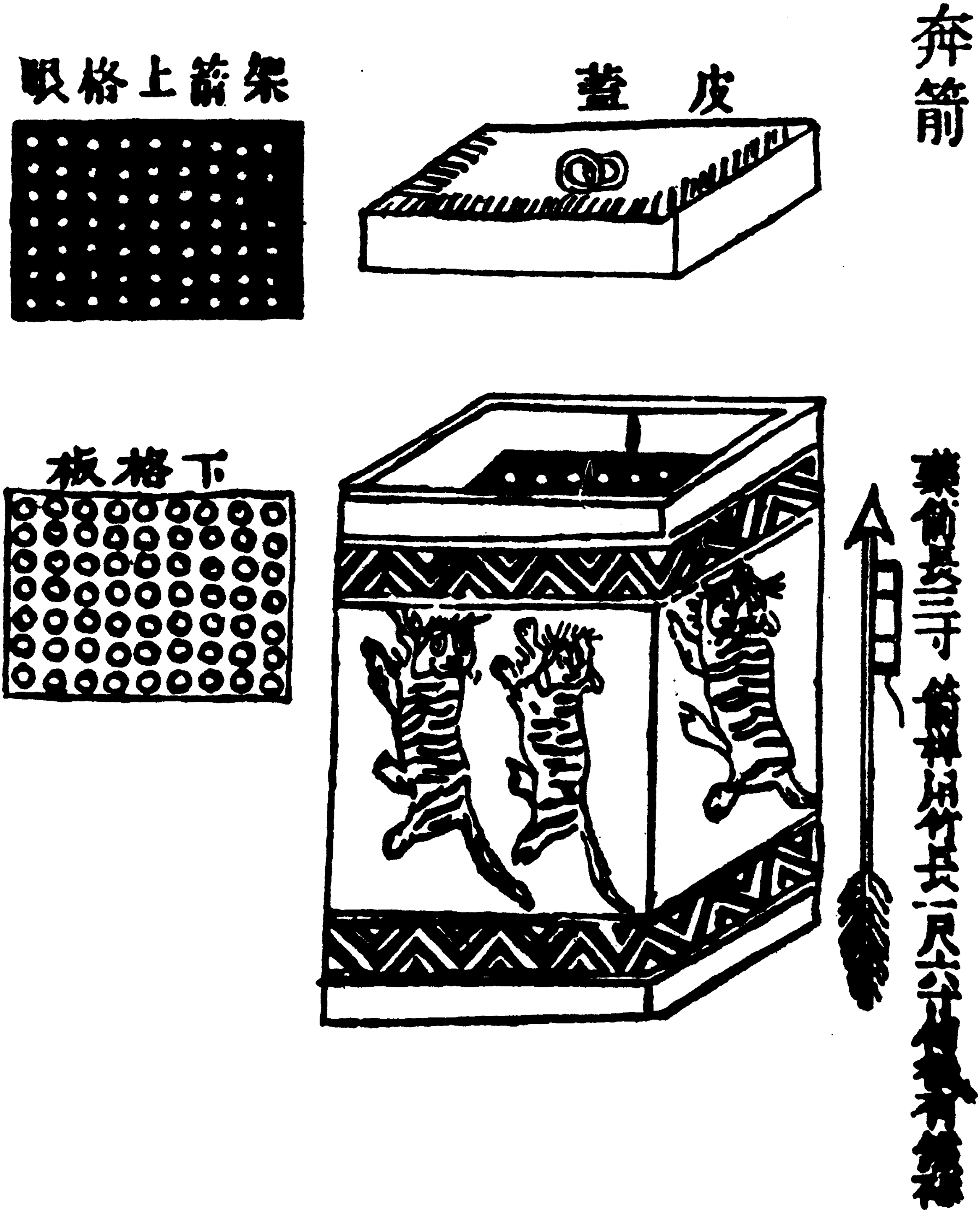

Figure 27. Arrows Which Will Rush Out on a Solid Front Like a Hundred Tigers" "Wu Pei Chih" 127.11b.

Figure 28. Leopard-Herd-Rush-Transversally Arrows. "Wu Pei Chih" 127.12b.

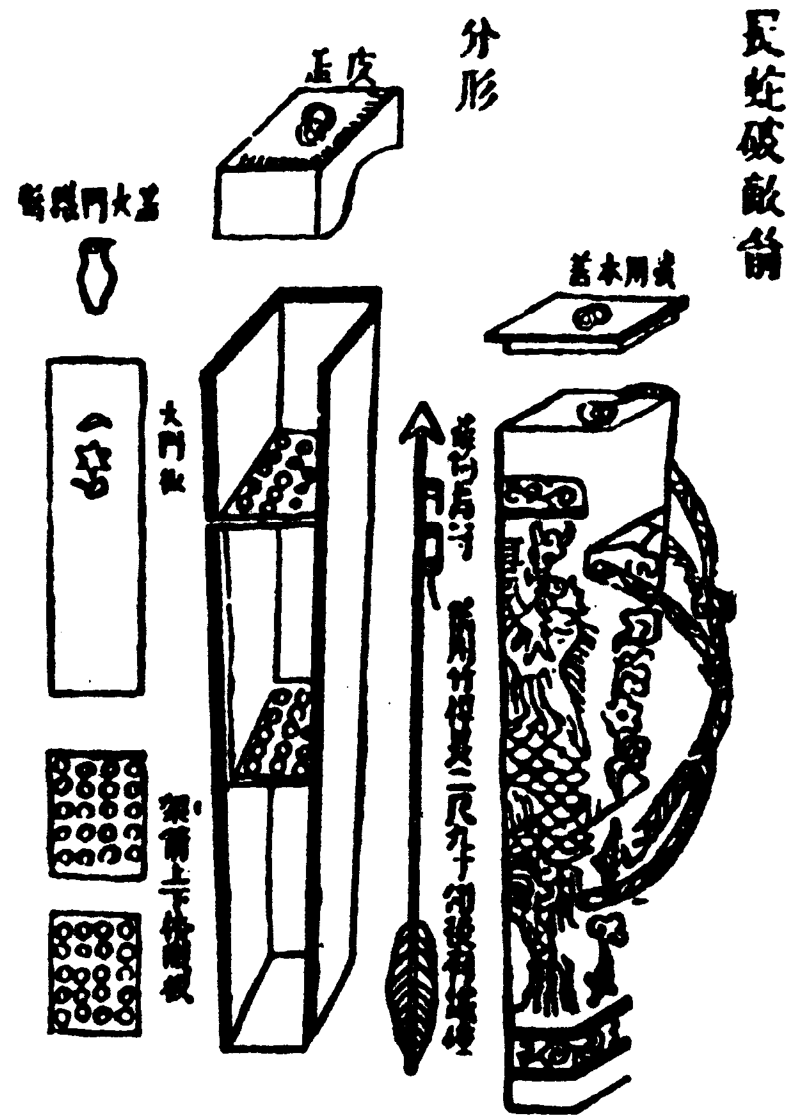

Figure 29. Long-Snake-Crush-Enemy Arrows. "Wu Pei Chih" 127.13b.

Figure 30. "A Screen for Divine Rocket-Arrows." "Wu Pei Chih" 129.16a.

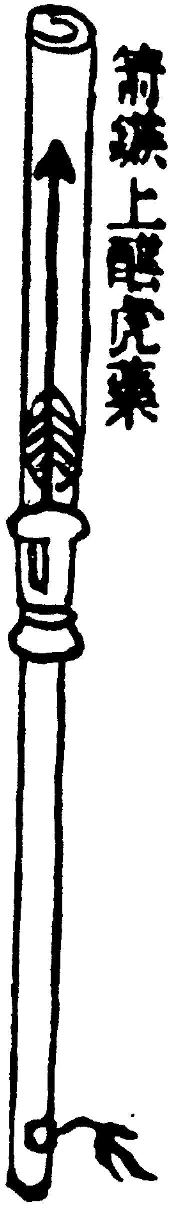

Figure 31. Gun Shooting an Arrow as a Projectile.
"Wu Pei Chih" 126.15b.

wad of clay, surmounted by a round plate of metal, above which a perforation was to be made, to serve as a vent. Through this hole four or five inches of slowmatch was to be introduced. The powder with which the tube was filled was to be protected by a wooden plug and an iron disk, the latter having circular holes drilled through it. At the base of the tube a handle was to be inserted, and the whole was to be tightly bound round with twine. The range . . . is stated to have been 700 to 800 *pu* (or about 1500 yards); and its effect are alleged as most terrific and destructive."

Mayers understood how the powder charge is loaded, but failed to note that the gun discharges a collection of missiles, a lead bullet, fragments of cast iron, and a stone bullet or iron coin. The description, "Wu Pei Chih" 123.9a-b, which accompanies a sketch of the separate parts (not reproduced here) makes this last point clear.

Pack powder and bullet sketch: wood cover, stone bullet, iron lotus seed-case coin, bamboo fire doorway, powder, smooth iron coin, yellow mud.

Sketch of parts: iron lotus seed-case, 0.1 inch thick, placed over the powder to accompany the lead bullet and the [crushed] cast iron. When a stone bullet alone is used, it is no longer necessary to employ the coin.

Smooth iron coin, size of hole, placed over mud.

Two ordinary stakes [about 3 feet in length, tied to form a crotch on which on occasion the contrivance may lean. To attain longer flight for the bullet the head of teh contrivance is raised. A large stone is used to hold the handle in place and prevent it from moving back].

Wood cover is sealed with oiled paper or persimmon varnish.

Bamboo body, wood handle, hemp plait or three-strand rope.

ARTILLERY AND FIELD PIECES

The *siege gun*, Figure 34, "Wu Pei Chih" 122.4b-5a, is made of copper, weighs 500 pounds, and discharges at a single shot 100 lead bullets each weighing 4 pounds.

Useful against large concentrations of troops. Destroys everything it hits. Requires a screen to protect the operators from the flare-back. Requires also a strong protective force. Small-scale ones are usable at sea, but great precautions must be exercised and the guns ought to be mounted on rafts of their own. Not to be used for defense from a wall. It is good for shooting up, not down.

Tiger-crouching gun. "Wu Pei Chih" 122.14a-16a (Figure 36): Two feet long, weighs 36 pounds, holds 100 shot of 0.5 ounce each. Insert in front of the shot one large stone or one lead ball weighing about 30 ounces. But with the lead ball cut the number of shot by 50 per cent.

Swab the barrel. Insert fuse. Add powder. Add covering. paper. Lower ramrod lightly. Lower wooden piece. Lower ramrod and ram forcefully until the powder reaches in front of the first hoop. Lower one layer of shot, earth, [then] ram. Repeat this operation four times. Lower the large [piece of] shot and ram. Force it in level with the muzzle. When the gun is filled, fire.

Creation-revolve gun. "Wu Pei Chih" 123.2b-4a (Figure 37): Weighs 20 pounds, has barrel 2 feet 2 inches long and stock 2 feet 9 inches long. Rear end of barrel has piece fitting into groove in stock. Barrel is bound to stock, and there are upper and lower iron bands. There are front and rear sights.

With 2 ounces of powder, one large bullet weighing 4 ounces goes 500 to 600 paces. Or 30 small bullets each weighing 0.6 ounce go 300 to 400 paces. Gun rest has iron point at end and wooden cross-piece at top. In middle there is an iron ring through which muzzle is inserted for firing. The shot will scatter over a target 20 or 30 paces wide. The men fire in succession; four men to a gun, hence the term "revolving [like creation]."

A *hornets' nest of lead shot.* "Wu Pei Chih" 123.21a-22a (Figure 38): Like the barrel of a cock-musket but shorter; muzzle is also larger. Holds 100 shot. On lighting the powder, the shot will travel 4 or 5 *li.* Its power may be compared to the *fo-lang-chi,* but the latter is heavy and hard to carry. It is lighter than the cock-musket, and the cock-musket shoots only one pellet. By means of a thong one man may carry it at his belt. In battle it is supported on teh ground by an iron *foot.* Its muzzle is raised 3 or 4 inches. Its rear end is blocked by a wooden stake driven into the ground. It may also be mounted on a carriage for defense of camp gates.

REPEATING GUNS WITH SEVERAL BARRELS

Cartwheel cannon. "Wu Pei Chih" 123.23b-24a (Figure 40): Each wheel has 18 spokes 1.4 feet long. To the left and right of each spoke there are placed two barrels. A barrel is forged ciruclar of pure iron, weighs one a half pounds , and is one foot long. Notches are made on the sides of the wheel, so that 36 barrels are place done ach wheel and are fastened inf ront by an iron catch and in the rear are hooked to the hub. In the barrels one packs powder and shot. Each mule carries two wheels. In the stand [used to suppor the wheel for firing] there is inserted an iron pivot. The mouths of the barrels are protected with leather to preserve the powder and shot. Along with the stand, teh weight [of the load per mule] is something over 200 pounds.

Multiple-shot gun with main and subsidiary barrels. "Wu Pei Chih" 124.13b-14a (Figure 41): Make it of refined wrought iron, each barrel being 1.5 feet long. Belt to the exterior 10 small barrels, each 0.5 foot long. At the bottom use a handle of *Cudrania triloba* wood. In each tube pack several tens of shot. Employ a man of great strength to carry it and to shoot it in the presence of the enemy.

REPEATING GUNS WITH A SINGLE BARREL

Twenty shots without reloading. "Wu Pei Chih" 125.13a-b (Figure 43): Make it of wrought iron to weigh 15 pounds, 5 feet long. The middle portion is solid for one foot, the two ends consist of hollow bands. In each [hollow] four-inch section drill a hole. Each end will then have ten holes. Pack powder into one section, and tamp it lightly. Drop in one

Figure 32. Early European Hand Guns, from a Manuscript of about 1430–1440. Note That Both an Arbalest and a Gun Are Ready to Shoot

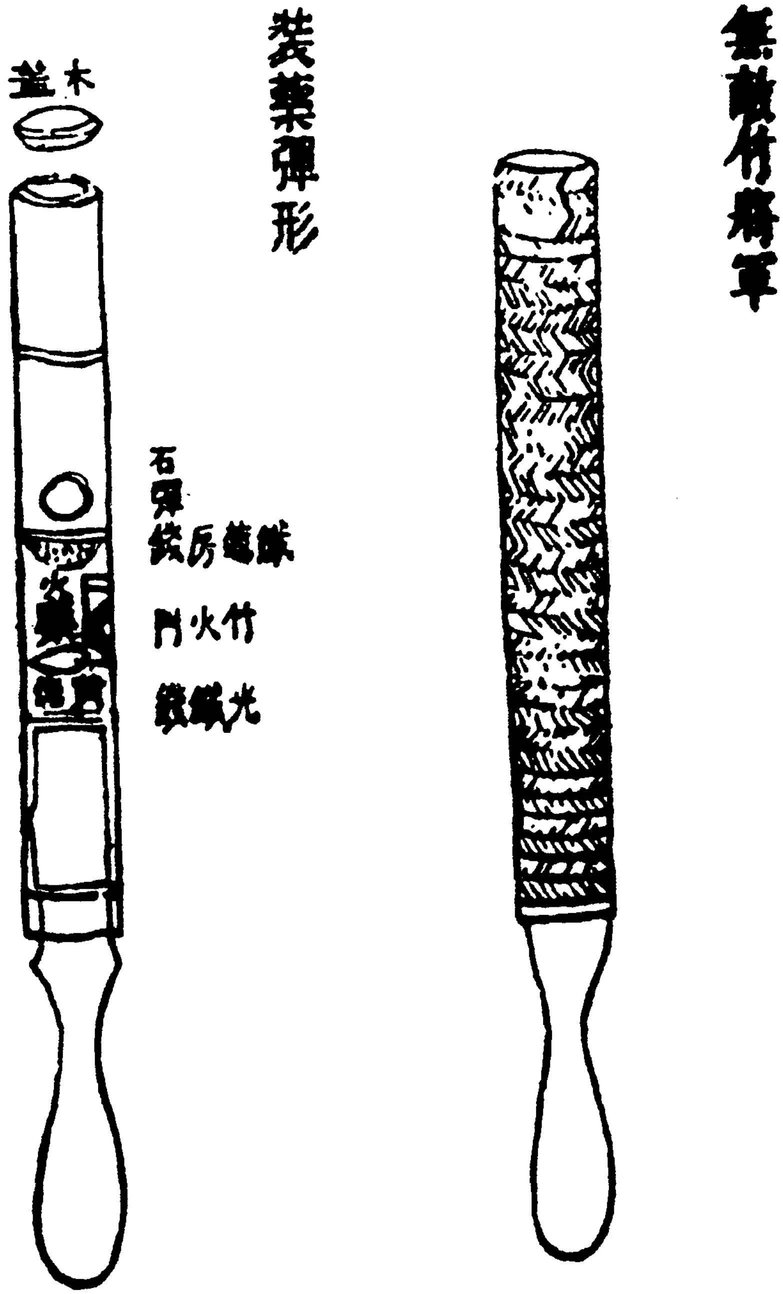

Figure 33. "Peerless Bamboo General." A Portable Bamboo Gun or Mortar. "Wu Pei Chih" 123.9a.

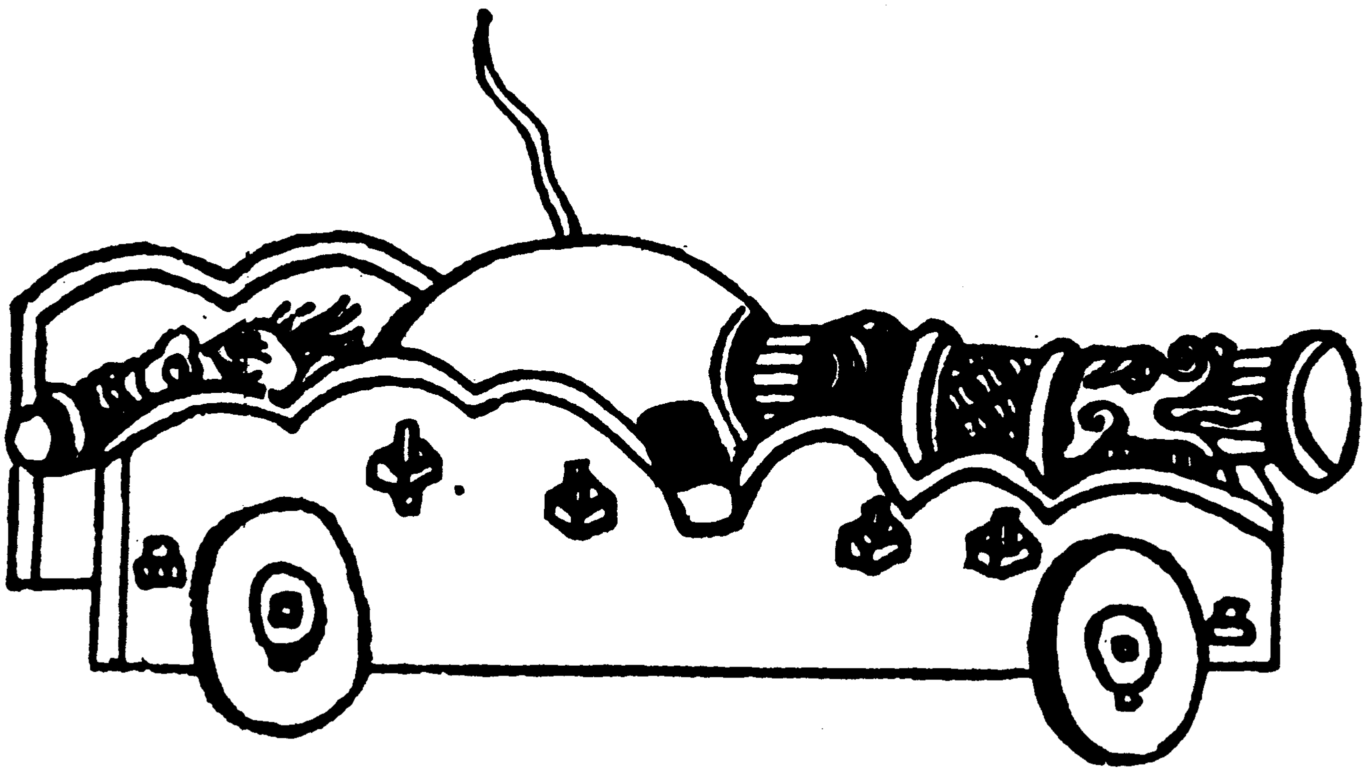

Figure 34. Siege Gun, Made of Copper, Weighs 500 Pounds. "Wu Pei Chih" 122.4b.

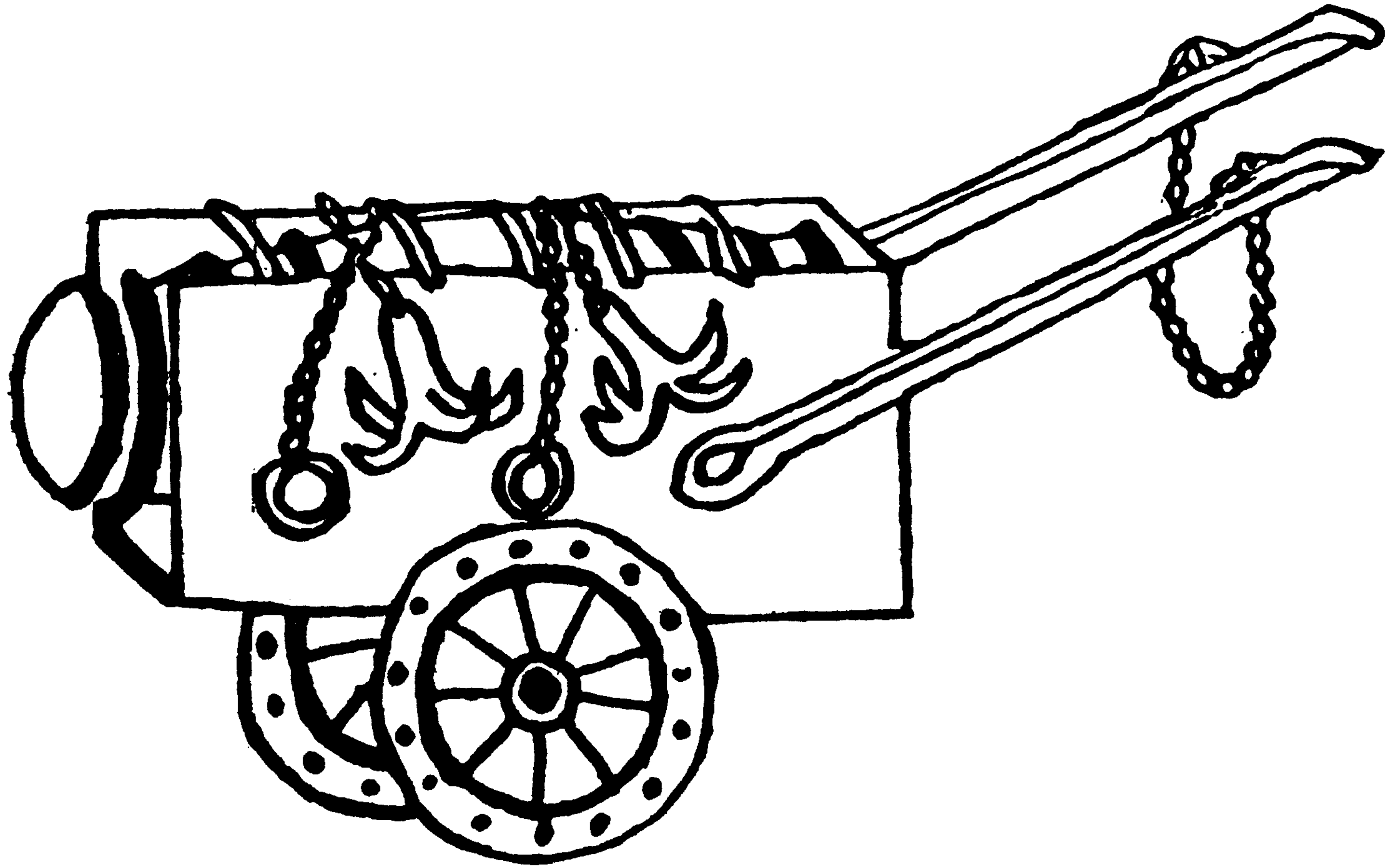

Figure 35. Attack Gun. Three Sizes, 280, 200, and 150–160 Pounds, Respectively. Grapnels to Anchor the Gun Against Recoil. "Wu Pei Chih" 123.24b.

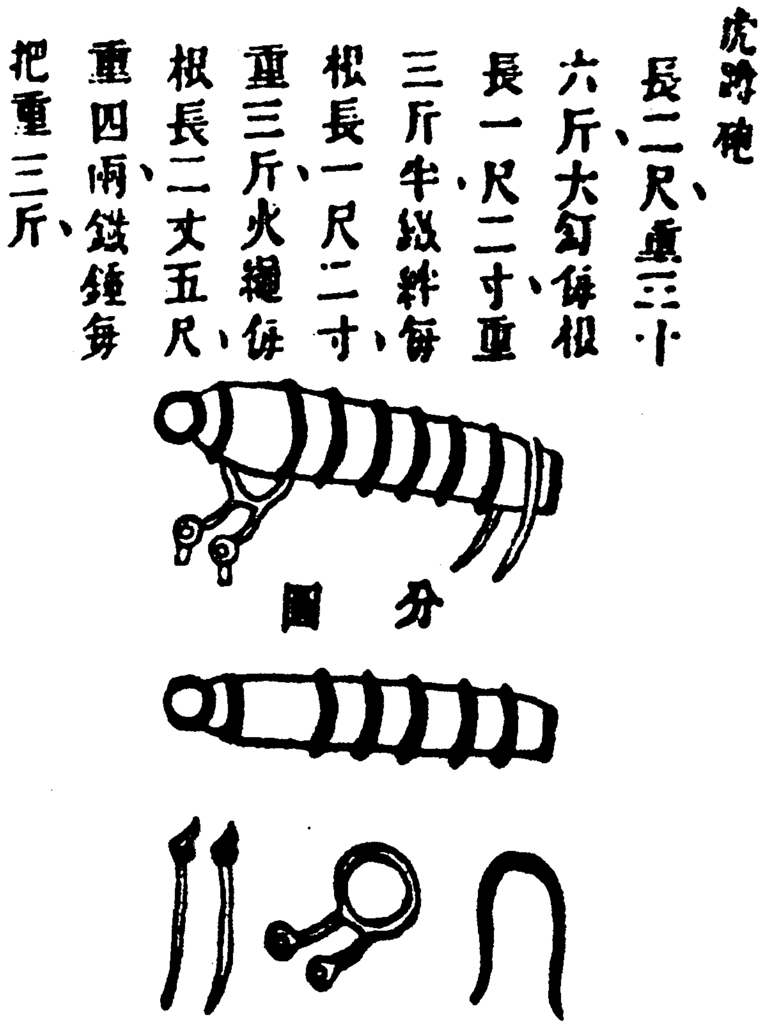

Figure 36. Tiger-Crouching Gun, Weighs 36 Pounds. "Wu Pei Chih" 122.14a.

Figure 37. Creation-Revolve Gun, Weighs 20 Pounds, Employs a Gun Crew of Four Men. "Wu Pei Chih" 123.2b.

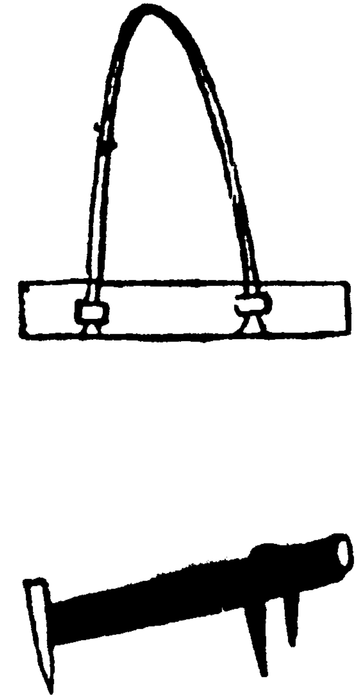

Figure 38. A Mobile Mortar Which a Soldier Can Carry at His Belt, A Hornets' Nest of Lead Shot. "Wu Pei Chih" 123.21a.

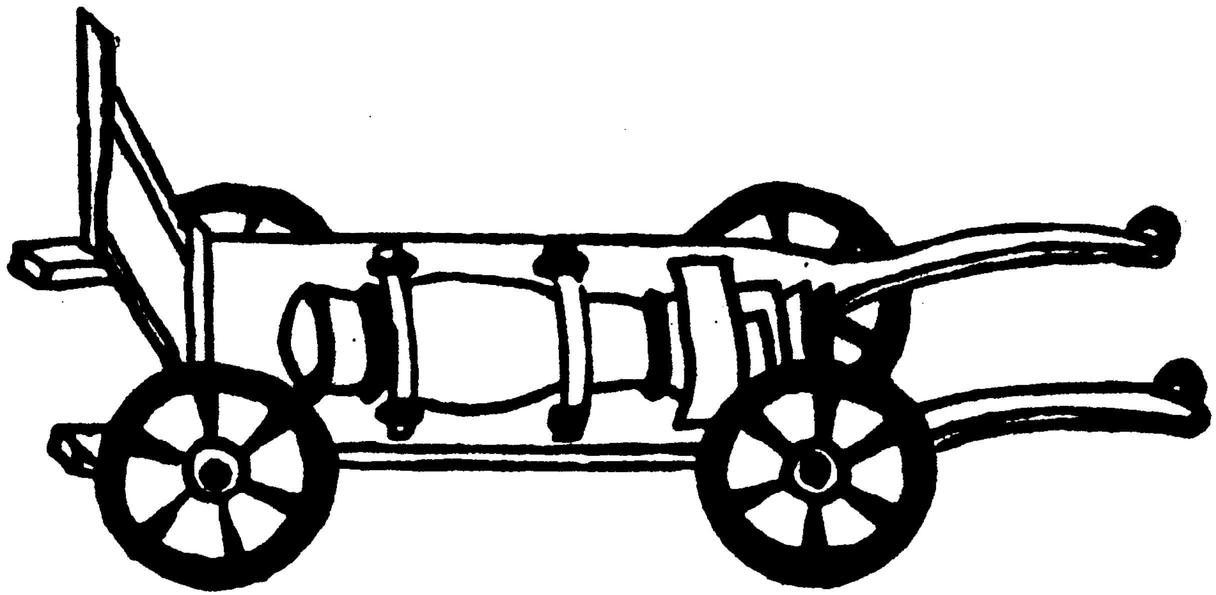

Figure 39. Thunder Gun, Shoots 1000 Shot at Once, Made of Cast Copper, 20 Inches Long, 5 Inches Bore. "Wu Pei Chih" 123.27a.

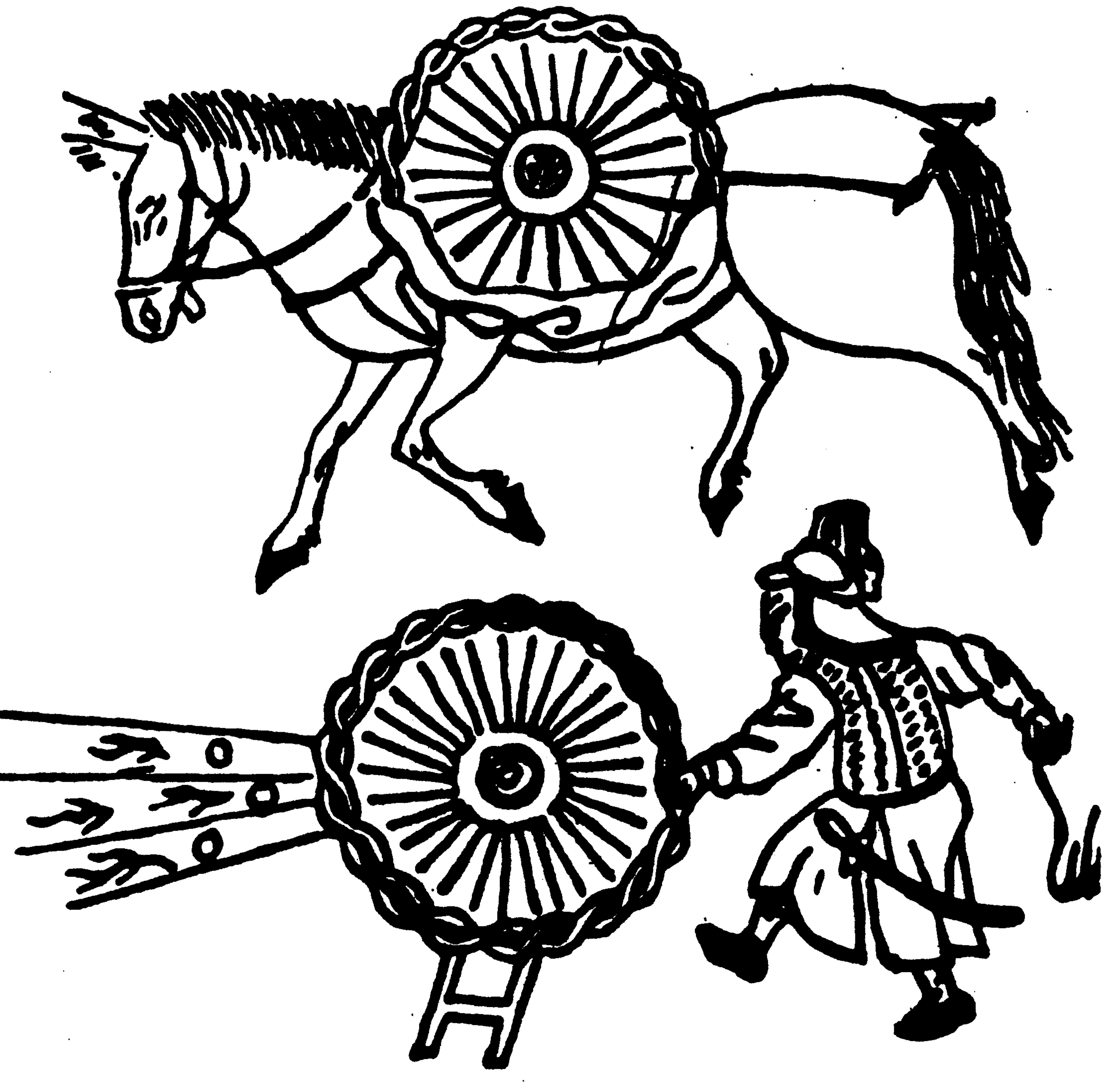

Figure 40. Cartwheel Cannon, Fires 36 Shots in Rapid Succession. "Wu Pei Chih" 123.23b.

Figure 41. Multiple-Shot Gun with One Large and 10 Small Barrels. 'Wu Pei Chih" 124.13b.

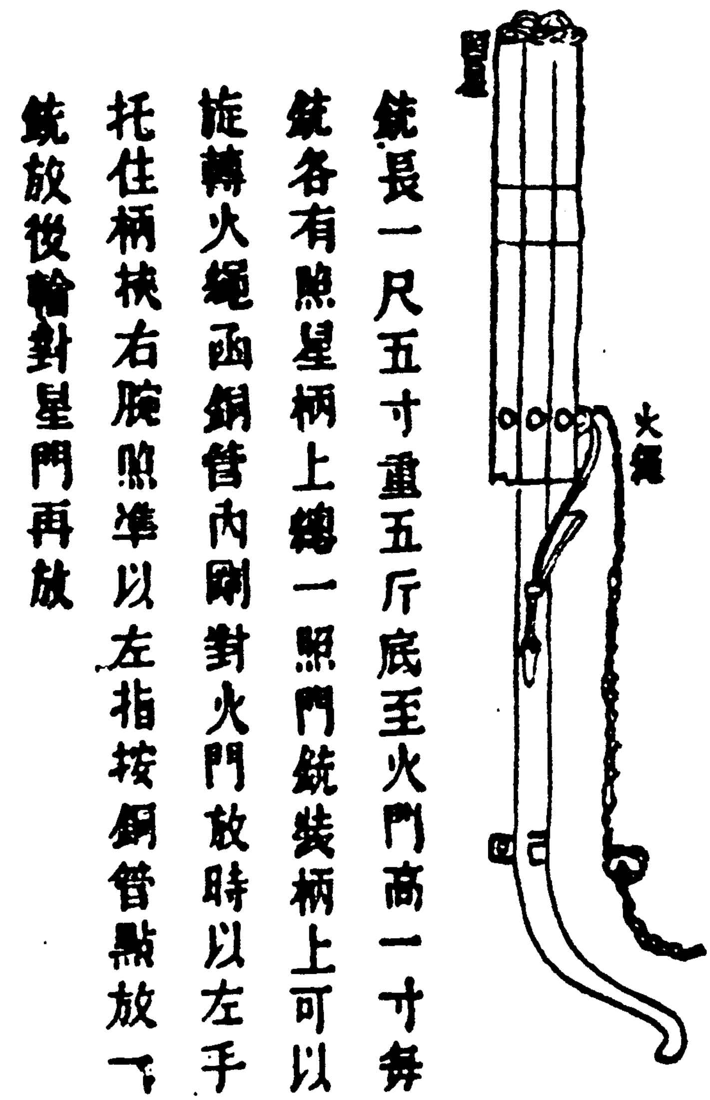

Figure 42. Match-Lock for Multiple-Shot Gun, a Device for Applying the Tinder Rope to the Firing Holes One after Another. "Wu Pei Chih" 125.14a.

Figure 43. Twenty Shots Without Reloading. "Wu Pei Chih" 125.13a.

Figure 44. Three-Shot Match-Lock Shoulder-Gun, with Separate-Loading Ammunition. "Wu Pei Chih" 1241.4b.

pellet weighing 0.15 ounce. Insert a paper protector. The rest [of the sections are prepared] on this model until the ten openings have been packed. Set them off in succession by way of the openings.

Gun with a stock, three-shooter. "Wu Pei Chih" 124.14b-15a (Figure 44): Make it circular of wrought iron so as to be 1.2 feet long and 0.22 foot in diameter. Three-tenths of a foot behind the barrel place a wooden staff-handle. Make a slot along the upper side of the barrel. Have ready three cartridges, each 0.3 foot long and 0.17 foot in diameter. After attaching the stock, insert [the cartridges] in the slot without disturbing the fuses. The cartridges contain 0.8 ounce of powder and two 0.2 ounce pellets each. On meeting th enemy, put it to the shoulder and fire.

GUNS OF FOREIGN ORIGIN

Portuguese calivers (Figure 45). When the Portuguese mariners visited Canton in 1517, the cannon which they had on board their ships attracted the interest of more than one contemporary writer whose comments upon them have been bequeathed to us. Through some confusion o fterms, the guns received teh name of *fo-lang-chi* meaning Franks or Frankish, which was probably the name give to the Portuguese themselves by their Arab or Malay interpreters. Ku Ying-hsiang, whose report upon the guns is abstracted in the "Wu Pei Chih," observes[88] that "*Fo-lang-chi* is [in reality] the name of a country, and not of cannon . . . . The guns *(ch'ung)* of the Portuguese were of iron, five of six *chih* (six or seven feet) in length, broad in the girth and with elongated necks. They were perforated longitudinally, and five small barrels were used, which were loaded with powder in succession and placed inside the body of the piece, from which they were shot off. They (the guns) were hooped in addition with timber in order to gurad against bursting. The foreigners' vessels had four or five of these guns on either side of their lower decks."

Ch'i Chi-kuang, who is said to have died in 1585, pictures and describes the guns in his "Chi Hsiao Hsin Shu" (*Hsüeh ching t'ao yüan* edition) 15.18a-19b, and states that the bullets are slightly larger than the chamber opening and are rammed in for one inch. The same author's "Lien Ping Shih Chi Tsa Chi" (*P'ing-hua-shu-wuts'ung-shu* edition) 5.18b-20a describes and illustrates the *fo-lang-chi* and its nine chambers or separate-loading cmplete rounds of ammunition.[89]

The latter have handles, and are inserted one at at time into the breech of the gun. This eliminates tamping of the shot and powder [into the barrel, since they are already

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[88]MAYERS, *loc. cit., p. 96.*

[89]It is interesting to find among the illustrations of the recent article by Robert Cardwell on "Pirate-Fighters of the South China Sea," *National Geographic Magazine*, 89, 787-96, June, 1946, two which show *fo-lang-chi* (with percussion primers) and one which shows giant Roman candles for use against present-day pirates.

assembled in the complete round]. The rear of the chamber is bolted [to the gun] so that there is no crack at its front or rear. In loading the chamber, the amount of powder is proportionate to the size of the chamber. Of old we used a wooden piece (literally, wooden *horse*) and also used lead shot; and whenever a heavy shot was confined by a light [wooden] piece, the gun was damaged and frequently [the shot] was of low velocity. Today we insert the powder without the need of tamping, and we do not use a wooden piece. It is only necessary that teh lead bullet equal the size of the opening. Of old the lead bullet was rammed in and flattened with a flat-ended ram, so that it was not sharp when it emerged. Today we make a concave-ended ram of iron, and ram the bullet into the barrel to a depth of 0.8 in. Thus the bullet remains round and is sure to be sharp on emerging and will travel more than one *li* and will pierce men and horses.

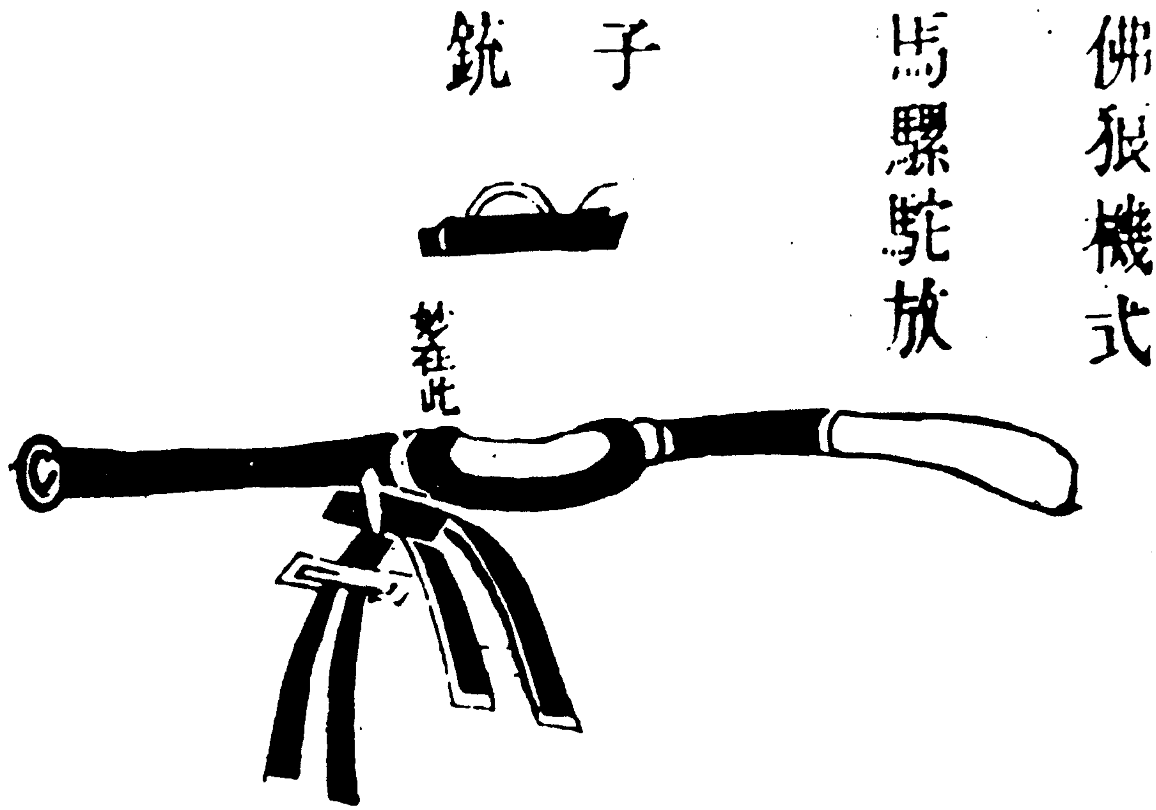
Bird beak guns. For improved small firearms, the Chinese appear to have been indebted to the Japanese who perhaps derived their knowledge of them from the Portuguese seafarers. Lang Ying, a writer of the latter part of the 16th centrury, who is cited by Mayers,[90] in his valuable Miscellanies entitled "Ch'i-hsiu-lei-kao," says: "As regards the bird-mouth (bird-beak) wood guns, the Japanese invaded Chekiang (in 1522) during the reign of Kia Tsing, and on some of their number being taken prisoner, possession was obtained of their weapons, and they were made to give instruction in the method of manufacturing them." Mayers suggests that the term bird-mouth, *niao tsui*, probably refers to the bell-shaped muzzles of the early blunderbusses, but may perhaps be the origin of the term, *niao ch'iang* or bird gun which now applies to muskets of all sorts. It seems more likely to us that the term, bird-beak, refers to the shape of the lock, possibly a flint-lock.

The "Wu Pei Chih" contains a number of pictures of small guns and of their parts, which pictures are obviously of more interest for the history of firearms than they are for the history of fireworks. We reproduce only two of them, Figures 46 and 47. The text which accompanies these pictures is not particularly enlightening or clear, and leaves the impression that the author, or his original, is describing a contrivance which he has not clearly understood. The text, 124.2b, says merely: "Sketch of the parts of the bird-beak gun. The fire door. This is the fire door cover. This is the fire door. The muzzle." In 124.4a, the lower left corner seems to be a sketch of the complete assembly of a *self opening fire door*. The other sketches seem to be of its parts, a *copper fish tail*, a *dragon's head*, but no information is given and one can only guess at the purpose of the various parts.

Although the "Wu Pei CHih" contains much material which we have not discussed, we have attempted to take in the foregoing to report upon that portion of its contents, pictures and text, which has the greatest interest for the history of fireworks.

Excepting certain remarks about incendiary arrows, fire balls, fountain fire, and rockets, we have not attempted to integrate the new material with the general history of fireworks., partly because of the lack of space and partly because the general history of European fireworks is not yet established.

[90]MAYERS, *loc. cit.*, pp. 97-8.



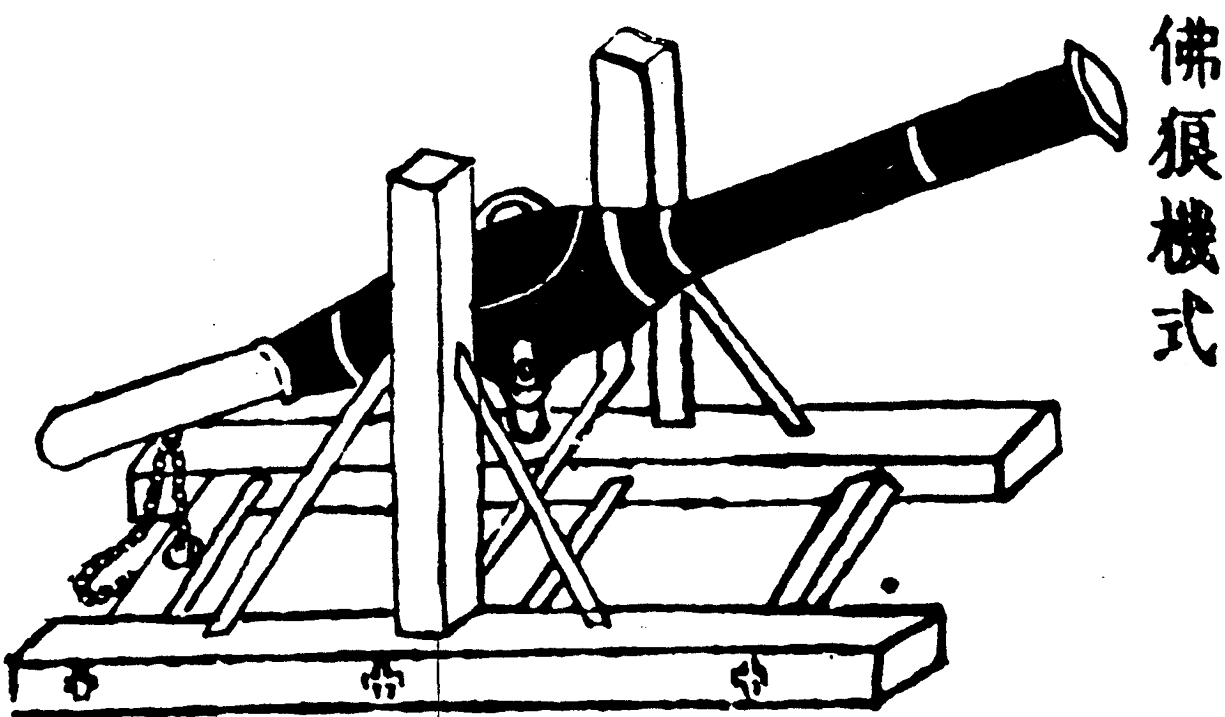


Figure 45. "Fo-lang-chi," Portuguese Calivers as Seen on Board the Foreign Ships Which Visited Canton in 1517. "Teng T'an Pi Chiu" 29.53b. The Same Pictures are Printed in "Wu Pei Chih" 122.6a, 7a.

Figure 46: "Sketch of the Parts of the Bird-Beak Gun." "Wu Pei Chih" 124.2b.

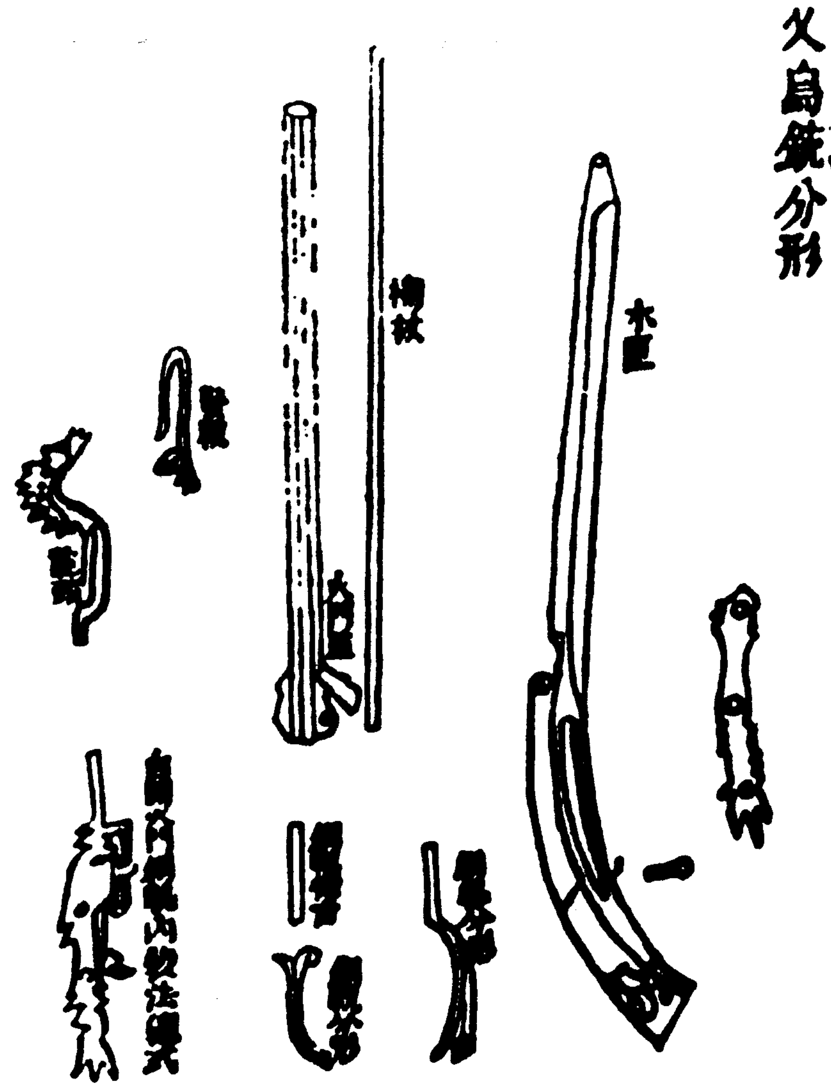


Figure 47. Parts of a Bird-Beak Gun. Possibly the Saw-Toothed Piece Is Part of a Flint-Lock for Producing Sparks. "Wu Pei Chih" 124.4a.

The pictures and text of the "Wu Pei Chih" supply a seemingly complete picture of the various steps in the evolution of guns from spouting fire weapons. Particularly interesting are the "missing links," the repeating guns which have several complete rounds loaded in the same barrel from which they are fired by lighting in succession. In one sense these are degenerate forms of the Roman candle. Roman candles are automatic repeating guns which throw incendiary projectiles. The fire weapons in question are not automatically repeating, and they threw, not incendiary, but merely inert projectiles -- and the later cannons were more degenerate still, not repeating, not automatic, and not incendiary throwers. In the history of firearms, as in the history of living organisms, the evolutionary process appears to tend toward complication of form in the whole and simplification of function in the part.

The *string-of-100-bullets cannon* operates on a principle not greatly unlike, or at least suggestive of, that of the fire-throwing guns which were carried by tanks in World War II. Toxic incendiaries, poison smokes, colored smokes, and clouds of rockets are all ancient Chinese tactical devices which have been called into play again in recent times.

Tenney Lombard Davis and the History of Chemistry

by Henry M. Leicester* and Herbert S. Klickstein**

Chymia 3[16]
[1950]

Chemists who are attracted to study the history of chemistry usually begin their work with genuine interest, but they seldom bring to their investigations any real background for serious and scholarly research. The course of study for the chemist of today is long and exacting, and leaves little time for philosophy, general history, or psychology, although these subjects are fundamental to an understanding of the thinking of the scientists of past times or to an understanding of the development of scientific ideas over the centuries. As a result of these deficiencies, much of the work that has been done in the historical field is of a trivial nature, and this fact leads many to the belief that studies in the history of science are only pastimes for retired professors during their declining years.

Occasionally, a man appears who demonstrates by his work the essential falsity of this concept. Such a man was Tenney Lombard Davis. He brought to the history of chemistry a breadth of view, a philosophical background, and a truly scholarly approach which enabled him to break new ground and give a new comprehension of the basic unity of human thought as revealed in the development of science and the ideas which underlie it.

Tenney L. Davis was an outstanding organic chemist and an authority on the chemistry of explosives. The rigid standards of research which are required in the technical branches of chemistry were applied by him equally to his historical studies. Throughout his entire career he considered the philosophical and historical background of every field and every idea with which he was concerned. His textbook, "The Chemistry of Powder and Explosives"[1] reveals almost as much of the history of this subject as would a historical monograph, yet it is a practical text in every sense of the word. In his purely historical studies, he enriched our knowledge of many important figures in the history of chemistry, and he opened a new field, Chinese alchemy, which emphasized as had never before been done in chemistry the fundamental unity of man's thinking. He brushed aside the provincial limitations of most historians and revealed the relationships between Greek, Arabic, Chinese, and European chemistry and alchemy.

A broad background and unusual training fitted Tenney L. Davis for his work. From his mother, he acquired a knowledge of the Bible, of poetry, and of literature which he carried with him through his life. An interest in philosophy developed early, and during his college years studies in logic and philosophy competed for his time with courses in pure chemistry. It was through his interest in philosophy that he was led into historical studies,

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*College of Physicians and Surgeons, San Francisco.

**Edgar Fahs Smith Collection, University of Pennsylvania, Philadelphia.

[1]New York, London, 1941-43, 2 Vols.; *ibid.*, 1943, complete in one volume.

and though it was only during the early part of his life that he published papers of a purely philosophical nature,[2] the philosophical approach underlay all of his work in the history of chemistry. A fluent knowledge of Latin, French, and German further aided him in his work.

The chronological bibliographies at the end of this paper, from which only his scientific papers have been omitted, supply a base for forming a clear idea of the evolution of the historical thought of Tenney L. Davis. His earliest studies, on Roger Bacon and gunpowder, followed logically from his interest in philosophy on the one hand, and in explosives on the other. A study of Bacon's ideas led easily to alchemy, and in the decade from 1920 to 1930 most of his historical work concerned European alchemy and related topics. The philosophical concepts of alchemy could not fail to fascinate him, and the understanding of the mentality of the alchemist which he thus gained stood him in good stead when he later widened his studies to include Chinese alchemy and the whole field of primitive science.

Although this interest in the philosophy and psychology of the alchemists supplied a connecting thread through all his work, his individual studies were varied in character. They revealed to the full the exactness of his thinking and the scholarly care with which he prepared his papers.

A consideration of the developments in the period when the emphasis shifted from alchemy to the phlogiston theory, and of the work of the great chemists of the time followed logically from his interest in alchemy. Boyle and Boerhaave attracted his attention, and his bibliographical studies of the "Sceptical Chymist" and the Elementa chemiae" cast much light on these famous books.

In the later years of the decade, Davis published several papers on notable New England chemists. This was probably the result of his association with Edgar Fahs Smith and Charles Albert Browne, who were then the leading figures in the field of the history of American chemistry. At this time, T. L. Davis was working actively with them to stimulate a more general interest in the history of chemistry. It was also quite natural that he should wish to know more of the development of chemistry in his native region, but these studies were only incidental to the chief body of his work. His major concern was always with the wider developments of chemistry as an intellectual activity of mankind, without regard to racial or national boundaries.

In 1930 appeared the first paper in the field in which Tenney L. Davis was to establish his greatest reputation. In collaboration with one of his students, Lu-Ch'iang Wu, he published an article on Chinese alchemy. In quick succession during the following years, thirty-five papers in this field appeared from his pen. Working first with Wu, and after the latter's early death, with a succession of his Chinese students and with collaborators in China with whom his investigations brought him into contact, he published his first translations into a western language of many of the chief Chinese alchemical texts. Interpretations and comparisons with the corresponding developments of western alchemy made clear the essential similarity of the concepts developed in these geographically widely separated areas. The work led him to the view that practical western alchemy actually developed from

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[2]See part 2 of the Bibliography.

Chinese ideas transmitted across Asia to the intellectual centers of Arab life. On the other hand, one of the basic ideas of both western and oriental alchemy, the doctrine of the contraries, the Ying-Yang theory, was a Babylonian of Egyptian concept which reached China in a fully developed state. Underlying the acceptance of all these ideas was the basic psychological pattern of the human mind, which gave rise to the idea of the mystical meaning of numbers, the philosophical acceptance of the doctrine of the contraries, , and almost all of primitive science. The papers in which T. L. Davis developed these ideas (I-44 and I-50) in the bibliography) are not only of the greatest importance for a comprehension of human thought, but they are striking examples of the clear thinking, the deep understanding, and the great learning of the author.

The task of Tenney L. Davis in obtaining and translating the Chinese texts was enormous. Chinese alchemy grew out of the purely philosophical system of Taoism. This was originally an attempt to find by philosophical means the Way of Nature (*Tao* means way or path), but it quickly became more practical, and in the minds of many Taoists became an attempt to explain the workings of the world around them, and particularly to apply these workings for their own benefit. Thus, they sought to obtain alchemical gold, not so much for its own sake, as to use it in preparing the pill of immortality by which they might themselves become immortal beings, or *Hsien*. For a time these alchemists worked with chemical apparatus and substances, and during this period (140-325 A. D.) the truly alchemical texts of Ko Hung and Wei Po-Yang appeared. Then Chinese alchemy split into two branches. One, the popular, degenerated into mere superstition among ignorant peasants. The other became once more philosophical, although it continued to use the ideas and expressions which had been developed by the genuine alchemists. The alchemical connotations were lost in the philosophical ones. Over the centuries, a vast compilation of literature, the Taoist Canon, was thus accumulated. In this the truly alchemical works and those which were philosophical were assembled side by side, and no index showed the contents of either. In one of his early papers, Davis noted that the standard bibliography of Taoism listed 1,464 titles, of which 132 seemed from the titles to be of an alchemical nature. Of these, 21 seemed to treat only of the spiritual, moral, metaphysical, physiological, or mystical side of alchemy. It was from this great storehouse that he set himself to separate the material which actually related to alchemy.

All of these works were written in classical Chinese, a language so difficult that even scholars who spend a lifetime in its study are often confused as to the exact meaning of a passage.[3] The few capable scholars in this field are seldom interested in science. The task is the more difficult, since Chinese scholars consider the Canon to be completely philosophical in character. In a letter from one of the Chinese collaborators of Tenney L. Davis is an account of how, in search of alchemical material in this great body of books, this writer approached both a Chinese classical scholar and a Chinese chemist to seek their aid. Both laughed at him, and assured him that he would find nothing of interest scientifically in the

[3] An excellent idea of the difficulties involved in translating classical Chinese is given by Bernhard Kalgren, "The Chinese Language. An Essay on Its Nature and History," New York, 1949, pp. 102-120.

Taoist Canon. Yet, by patient work, Davis was able to find many alchemical texts in the Canon.

The great difficulties of the task were overcome by the efforts of a group of Chinese and western chemists and sinologists, but the directing spirit was always Tenney L. Davis. He wrote many letters, he encouraged students, he collected texts, he guided translations and retranslations of manuscripts and books, but above all, from his background of philosophy, history, and alchemy, he coordinated, interpreted, and explained the results in a manner which no one else was qualified to attempt. The field he opened remains in large measure still untouched. No one knows what further treasures may be buried in the Chinese classics. Scholars for generations will build on the foundations laid by him, but there will be few who will bring to the work the skill, knowledge, and enthusiasm which were his.

The last phase of his historical work was carried out when he was forced into retirement by illness, and when he knew that any moment might bring an end to his life. Based on much of his earlier work, a study was begun of the early history of pyrotechnics. This almost untouched field involved a study of the Chinese sources and of early European manuscripts and books. He was unable to do more than indicate the contributions of various individuals in this field, but there is little doubt that if he had lived, he would have combined these preliminary studies to produce a unified picture of the whole.

In his later years, Tenney Lombard Davis was active in editorial work on the editorial boards of *Isis*, *Archeion*, and the *Journal of Chemical Education*. This work reached its culmination when he succeeded to the editorship of Chymia upon the death of Dr. C. A. Browne, who had been the first Editor-in-Chief. The first two volumes, which Tenney L. Davis edited, show the mark of his exacting scholarship on every page. An example of this scholarship is the care he devoted to the choice of a name for the new annual (see cut). Only those who were associated with him during the period before the publication of these volumes know how much of himself he put into them. Whatever may be the future of Chymia, it will always be the stronger because of his guiding hand during the critical days of its founding.

The authors wish to express their deep gratitude to Mrs. Tenney L. Davis for her kindness in supplying much of the information which made this paper possible.

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Sugars in Fireworks and Explosives

by

Tenney L. Davis, Ph.D.

Emeritus Professor, Organic Chemistry, Massachusetts Institute of Technology;
Director of Research and Development, National Fireworks, Inc.

THE SUGAR RESEARCH FOUNDATION, INC.

December, 1948

FOR MEMBERS ONLY

FOREWORD

The food uses of sugar naturally tend to dwarf all its applications in other fields, yet even as an industrial chemical sugar is entitled to a place of importance.

In connection with its use as a food, the energy content of sugar is frequently emphasized and it is reasonable to expect that this energy might find outlets other than the familiar physiological ones. Hence it is not surprising to note that since early times, this product has been used as an ingredient in many combustible and explosive mixtures.

Not only did the earliest matches contain sugar, but innumerable varieties of flares, colored light mixtures, smokes and signal light compositions and incendiary devices through the decades have been compounded with the use of this familiar household substance.

Currently, large quantities of sugar enter into the composition of low-freezing dynamite on a scale which alone justifies the classification of sugar as a chemical intermediate of consequence.

A number of uses of sugar and its close chemical relatives in pyrotechny and in explosives are described in the present report by an authority with long experience in this field both during two world wars and in the interval of peace between.

Robert C. Hockett
Scientific Director
Sugar Research Foundation, Inc.

LIST OF TABLES

WARNING

Never grind together any mixture of chlorate and a combustible substance. If any reader wishes to experiment with a mixture such as described in the text, it should be mixed in a porcelain vessel with a long wooden stick, made and used in small quantities, and kept in a cool dry place preferably for short periods only.

INTRODUCTION

Studies on the nitration of the carbohydrates and of other polyhydric alcohols were the first steps in a direction away from black powder toward the development of smokeless powder and modern high explosives. The nitric esters of glycerin, of cellulose, and of cane sugar were discovered about the same time, during the year 1846 or early in 1847. Schönbein described the nitration of cane sugar and the properties of the product before he first disclosed his method for the preparation of nitrocellulose – and nitrated sugar thus stands at the very beginning of the period of modern high explosives. Nitroglycerin and nitrocellulose soon assumed the leading roles, but the nitric esters of the various sugars were studied by chemists and several of them, particularly those derived from sucrose, glucose, and possible lactose are serving important purposes in the explosives industry at the present time.

SUGAR IN PYROTECHNY

Before modern explosives, sugar, as it happens, stood at the beginning of the development of matches and of modern fireworks.

1. *The Earliest Matches*

The first matches appear to have been the "dip splints" which were made and sold in Vienna in 1812. These were wooden splints tipped with sulfur, the sulfur coated with a match- head made from potassium chlorate and sugar and colored with vermilion. They were lighted by dipping into a glass or leaden vial containing shredded asbestos impregnated with concentrated sulfuric acid.

2. *Incendiaries of Sugar and Chlorate**

The chlorine dioxide which sulfuric acid liberates from potassium chlorate attacks many combustible substances and sets them on fire. The mixing of powdered chlorate with red phosphorus is an extremely dangerous operation and can be accomplished without an explosion only when the materials are thoroughly wet with water. Mixtures of sulfur and chlorate explode from percussion or when ground in a mortar. Sugar has the advantage that its mixture with chlorate can be made up and handled fairly safely, and the mixture burns without offensive fumes. The ignition of such a mixture by a drop of concentrated sulfuric acid is an interesting lecture experiment. A quantity of sugar-chlorate mixture wrapped up, with a glass bulb containing concentrated sulfuric acid in the middle of it, makes an incendiary device which will take fire when crushed by the heel or by the wheel of a vehicle. Time bombs employing this principle, the bulb being broken by the hammer of an alarm clock's bell, were reportedly used by enemy agents during World War I.

3. *Cane Sugar in Colored Flame Compositions.*

Red fire from strontium nitrate and a mixture of potassium chlorate** and sulfur was prepared during the early years of the nineteenth century, but colored flames in great variety were not known until 1833 when Moritz Meyer[1] first prepared them by incorporating various coloring salts with

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*See warning before start of text.

**See warning before start of text

mixtures of chlorate and sulfur. His compositions were dangerous to make and to store, sensitive to friction and percussion, and subject to deterioration and even spontaneous combustion, because of the acidity present in the sulfur. The first important improvements were made by substituting for the sulfur other non-acidic combustible materials, such as shellac, stearin, and cane sugar, which yielded , with chlorate, mixtures which were markedly less sensitive to shock and friction than those which contain sulfur. The first publication of the new formulas appears to have been about 1853 by Chertier* who appears also to have been the first , or one of the first, to make extensive use of calomel for brightening the colors, particularly of the green and blue flames. Two of his compositions which contain both cane sugar and chlorate are reported in Table 1. Audot, in the fourth edition of his book, 1853[2] , includes his first discussion of chlorate compositions, stating that his "trials have been made according to the prescriptions of M. Chertier," and reports eight chlorate compositions, two of which contain cane sugar. Of these two, one (the green) is identical** with Chertier's while the other (the blue) is different from his. Leblanc[3] in 1863 recommended two green compositions containing can sugar, one of them identical to Chertier's.

Table 1. *Early Colored Flame Compositions Containing Cane Sugar*

Color	Green	Blue	Blue	Green
Formula of:	Chertier	Chertier	Audot	Leblanc
Cane sugar	30	9	12	32
Potassium chlorate***	60	40	63	63
Barium nitrate	41	-	-	50
Copper potassium chlorate	-	-	69	-
Copper sulfide	-	22	36	-
Calomel	49	32	36	50
Stearin	-	-	9	--
Talc	-	2	-	-
Shellac	1	1	-	1

*We have not been able to examine a copy of Chertier's "Novelles Recherches sur les feux d'artifice," but have found the information concerning his compositions in the folding table of Martin Websky's "Lustfeuerwerkskunst," 8th ed., Wien, Pest, Leipzig, 1891.

**Audot recommends the proportions, 90/180/123/147/3, which of course yields the same mixture as the proportions, 30/60/41/49/1.

*** See warning before start of text.

4. Milk Sugar in Colored Flame Compositions

Leblanc apparently is to be credited with the next important improvement, with the use of milk sugar in these compositions. The tendency of cane sugar to attract moisture from the air makes mixtures which contain it sticky, not free-flowing, likely to cake, and to burn unevenly. Milk sugar stays dry and granular, almost gritty in texture. The milk sugar compositions which Leblanc recommends for Bengal flames for use in the theater, Table 2, are probably as safe, as stable, and as little sensitive to shock and friction as any chlorate compositions can be. They have the further advantage for indoor use that they produce no sulfurous smoke.

Table 2. *Leblanc's Theater Lights Containing Milk Sugar*

	White	Green	Red
Milk sugar	4	1	4
Potassium chlorate	12	2	12
Potassium nitrate	4	–	4
Barium nitrate	–	1	--
Barium carbonate	1	–	–
Strontium oxalate	–	–	1
Stearin	1	–	–
Lycopodium	–	–	1

5. *Milk sugar in colored smoke compositions*

Colored smokes are produced by the burning in appropriate containers of pyrotechnic mixtures which contain colored substances capable of being volatilized without an undue amount of decomposition. According to Faber[4], the compositions which were used in U.S. Airplane smoke grenades during World War I were as follows. For use in signals which burn, as they were intended to do, while falling through the air, the freedom from sulfurous smoke is not an important advantage. The use of milk sugar increases the cost, but also reduces greatly the danger in manufacture - and the dyestuff yields a smoke which is offensive to taste and smell, and probably poisonous anyway.

For the use of ventilating engineers who are interested in drafts and the circulation of air, a non-poisonous and inoffensive white smoke is produced by burning a mixture of potassium chlorate 3 parts , milk sugar 1, and finely powdered ammonium chloride 1.

Table 3. *Colored Smoke Compositions Containing Milk Sugar*

	Red	Yellow	Green	Blue
Milk sugar	1	24	26	5
Potassium chlorate*				
Paranitriline Red	3	-	-	-
Auramine	-	34	15	-
Chrysoidine	-	9	-	-
Indigo	-	-	26	8

6. *Sugar Charcoal in Fuse Powder*

Rinkenbach[5] and Allison have patented a fuse powder made from non-cellular charcoal prepared from cane sugar, and claim for it that it burns more slowly than ordinary fuse powder. A preferred powder made from potassium nitrate 74%, sulfur 10.4%, and sugar charcoal 15.6% burns in 96 instead of 29 seconds per unit of length.

NITRIC ESTERS OF THE SUGARS - THEIR USE IN EXPLOSIVES

Of all the nitric esters which are used in explosives, pentaerythrite tetranitrate (PETN) appears to be the most stable. This crystalline solid undergoes no visible decomposition at ordinary temperatures during long intervals of time. It is dissolved and decomposed by concentrated sulfuric acid, but it is difficult to hydrolyse by alkali and to denitrify by means of alkaline reducing agents. Its exceptional stability is perhaps associated in some way with its symmetrical molecule. Nitromannite (mannitol hexanitrate) a crystalline sold, m. p. 112° - 113°, and nitroglycerine (glyceryl trinitrate), which is an oily liquid at ordinary temperatures, although less stable than PETN, are both sufficiently stable to be used in commercial explosives. Of the two, the nitromannite, which has the larger molecule is distinctly less stable at slightly elevated temperatures. Nitroglycerin in a covered glass vessel may be heated to 75° for several days before it begins to give off acid fumes; nitroglycol (ethylene glycol dinitrate) is more stable yet, but nitromannite decomposes after a few hours and gives off red fumes. When a small quantity is heated, it decomposes at once at about 150° with abundant evolution of nitrous fumes, but ordinarily it does not deflagrate. When a larger sample is heated, deflagration occurs at 160° - 170°. The most stable of the nitrated sugars are about as stable as nitromannite.

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*See warning before start of text.

The physical properties of the nitrated carbohydrates follow more or less closely the physical properties of the parent substances from which they are derived. Thus, nitrocellulose is a horn-like material which deposits from a solvent as a tough film, nitroglycerin is a syrupy liquid more viscous and less volatile than nitroglycol, and the nitrosugars, like the sugars themselves tend to be sticky syrups or semi-solids and to crystallize with difficulty. The crystalline nitrates of mannose, maltose, lactose, and sucrose have found limited use in compound detonators and in general for the same purposes as nitromannite, where a small quantity of a very powerful explosive is needed. Sticky semi-solids are difficult to free from the last traces of residual nitrating acid, but they may be washed satisfactorily and stabilized if they are dissolved in a solvent. Nitroglucose and nitrosucrose dissolved in nitroglycerine are widely used in the United States in low-freezing dynamite.

The explosive nitric esters of the sugars are prepared by methods similar to those which are used for the preparation of nitrocellulose and nitroglycerin, by adding the sugar little by little to strong mixed nitric-sulfuric acid while the reaction mixture is chilled and stirred continuously, by dissolving the sugar in cold concentrated nitric acid and adding concentrated sulfuric acid drop by drop while the cooling is continued, by nitrating in glacial acetic acid solution or sometimes in other solvents.

The earliest experiments on the nitration of cane sugar are interesting because they illustrate the behavior which is characteristic of the nitrated sugars in general and the difficulties in the way of procuring these substances in a stable and crystalline condition.

1. *Early History of Nitrated Sugar*

At a meeting of the French Academy on January 25, 1847, Pelouse reported information received from MM. Florès Domonte and Ménard that mannite and sugars and gums of various sorts yielded by the action of nitric acid substances similar to pyroxyline. At a later meeting[6] he presented a letter from Sobrero in which Sobrero asserted that he had long before realized the production of fulminating substances from sugar and dextrine, and that he had communicated a note on fulminating sugar to the Academy of Torino on the last day of the preceding January. He analysed the substance and, although he was not able to prevent the formation of oxides of nitrogen during the combustion, he concluded that it contained four nitrate groups. Sobrero described nitromannite and nitrolactose for the first time in a paper which he presented to the Academy of Torino in February 1847[7] . He had already described nitroglycerine in a letter to Pelouze which Pelouze caused to be published in *L'Institut* of February 15, 1847[8].

When Schönbein[9] first announced his discovery of guncotton at a meeting of the Society of Scientific Research at Basel on May 27, 1846, he described his efforts to put it to practical use, and discussed the controversial question of priority of discovery, but he refrained from telling how he had made it. At the same time he described in much detail experiments on the nitration of cane sugar which he had been led to perform in consequence of certain theoretical speculations relative to ozone which he had discovered a few years before. One ounce of finely powdered sugar was stirred at 0° with three ounces of a mixture of two parts concentrated sulfuric acid with one part pure anhydrous nitric acid. After a few minutes a viscous mass separated from the acid liquid, without the disengagement of gas, and gradually assumed a pasty and plastic character. The product was washed with boiling water, under which it became semi-fluid, until it was free from acid, and was dried at a low temperature. It consisted of an amorphous mass, brittle at low temperatures and capable of being molded like jalap resin at slightly elevated ones. When heated more strongly, it deflagrated suddenly and with violence. It had an intensely bitter taste, ad imparted a bitter taste to the water with which it was boiled. It was decomposed by concentrated sulfuric acid, but dissolved in strong nitric acid and was reprecipitated, apparently unchanged, when the solution was diluted with water.

In the Jahresbericht of 1848 Berzelius tells that Svanberg[10] nitrated sugar by dissolving it in a mixture of equal volumes of fuming nitric acid and concentrated sulfuric acid, and precipitating the product by dropping the mixture into a large volume of water. The jelly-like product, after thorough washing, dried out to yield glassy masses which smelled of nitrous acid at first, but lost their odor on firther drying. When the material was heated, it did not burn instantaneously but the fire jumped from piece to piece with a sort of puffing. Many other chemists [11,12,13,14,15] studied the nitration of cane sugar. It became generally established that the nitrate of sucrose was a colorless, transparent, resinous mass which was solid and friable when chilled, which melted at about 30°, and was explosive and not very stable. Fifty years elapsed after its discovery before Will and Lenze[16] prepared sucrose octonitrate in a crystalline state and made a systematic study of its properties and of the properties of the nitric esters of other carbohydrates.

2. *Stability of Sugar Nitrates*

Will and Lenze heated pure samples of various sugar nitrates for long periods of time at 50° , and measured their decompositions by determining the losses of weight. Their results are summarized in Table 4.

Table 4. Relative Stability of Sugar Nitrates at 50°

Rhamnose tetranitrate	lost	1.2%	in	30	days	1
Arabinose tetranitrate	"	1.5%	"	24	hours	7
	"	40%	"	4	days	
Glucose pentanitrate	"	38%	"	24	hours	8
Galactose pentanitrate	"	42%	"	10	days	6
Galactose pentanitrate	"	41.7%	"	24	hours	9
Mannose pentanitrate	"	46%	"	24	hours	10
Sucrose octonitrate	"	11%	"	3	days	5
Lactose octonitrate	"	0.7%	"	3	days	3
	"	40.0%	"	40	days	
Maltose octonitrate	"	1.3%	"	11	days	2
	"	23.0%	"	43	days	
Raffinose hendecanitrate	"	9.0%	"	3	days	4

The numbers in the last column indicate relative position in the stability series.
[There is an apparent discrepancy given in the figures for Galactose pentanitrate. - ed.]

Of the substances which were tested, rhamnose tetranitrate was the most stable, mannose pentanitrate the least, and sucrose octonitrate about midway between the two. At a temperature considerably different from 50°, say at 0°, or at 100°, the relative positions of these substances in a stability series would not necessarily be the same.

3. Nitroarabinose (L-Arabinose tetranitrate), $C_5H_6O(ONO_2)_4$

Arabinose teranitrate[16], prepared by adding concentrated sulfuric acid drop by drop to a solution of arabinose in concentrated nitric acid at 0°, consists of colorless monoclinic crystals which melt at 85° and decompose in the melting point tube at 120°. It is readily soluble in alcohol, acetone, and acetic acid, and insoluble in water and ligroin. It reduces Fleming' solution on warming. It is exploded easily by percussion. It is left-rotating in alcohol solution, more strongly in a freshly-prepared solution than in one which has been allowed to stand. In 4.4% solution in alcohol [α]20°/D at start = -101.3°, after 20 hours = -90°.

4. Nitroglucose (D-Glucose pentanitrate), $C_6H_7O(ONO_2)_5$

Glucose pentanitrate[16] exists as a colorless viscous syrup, insoluble in water and ligroin, readily soluble in alcohol. It hardens at low temperatures and may be obtained in the form of a powder which melts below 10°. In a melting point tube it decomposes rapidly at 135°. It reduces Fehling's solution on warming. In 6% solution in alcohol [α]20°/D = 98.7°.

Glucosan trinitrate, $C_6H_7O_2(ONO_2)_3$, is produced by the nitration of α-glucosan and by the action for several days of mixed acid on D-glucose. It is insoluble in water, and readily soluble in alcohol. It has been obtained in the form of crusts or crystalline aggregates which melted, not sharply, at about 80° and which probably still contained some glucose pentanitrate.

Nitrosorbite (D-sorbitol hexanitrate), $C_6H_8(ONO_2)_6$, isomeric with nitromannite, although we have not been able to learn that it is actually in use at the present time in this country, represents a possible outlet for glucose in the explosives industry. D-sorbitol occurs in the berries of the mountain ash, but is more readily procured by the electrolytic reduction of D-glucose. It crystallizes with one molecule of water in small crystals which lose their when heated and melt at about 110°. The nitration of D-sorbitol yields a liquid product from which the hexanitrate may be obtained[17] by dissolving in alcohol (47 g. in 400 cc. 95% ethanol) and precipitating by the addition of water (400 cc.). The precipitate, recrystallized from alcohol, yields nitrosorbite, m. p. 54-55°.

5. Nitromannose (D-Mannose pentanitrate), $C_6H_7O(ONO_2)_5$

Mannose pentanitrate[16] crystallizes from alcohol in transparent rhombic needles which melt at 81-82° and decompose at about 124°. It reduces Fehling's solution slowly on warming. In 5% solution in alcohol [α]20°/D = 93.3°.

6. Nitromaltose (Maltose octonitrate), $C_{12}H_{14}O_3(ONO_2)_8$

Maltose octonitrate [16, 18] crystallizes from methyl alcohol in glistening needles which melt with ecomposition at 164-165°. When heated quickly, it puffs off at 170-180°. If fused and allowed to solidify, it has a specific gravity of 1.62. It is readily soluble in methyl alcohol, acetone, difficulty [sic] soluble in ethyl alcohol, and insoluble in water. It reduces warm Fehling's solution more rapidly than nitrosucrose. In 3.5% solution in glacial acetic acid [α]20°/D = 128.6°.

7. Nitrolactose (Lactose octonitrate), $C_{12}H_{14}O_3(ONO_2)_8$

Lactose octonitrate[19] crystallizes from methyl or ethyl alcohol in monoclinic needles which melt with decomposition at 145-146°. Its specific gravity is 1.684, It is readily soluble in methyl alcohol, hot ethyl alcohol, acetone, and acetic acid, sparingly soluble in in cold ethyl alcohol, and insoluble in water. It reduces Fehling's solution on warming. In 2.8% solution in methyl alcohol [α]20°/D = 74.2°.

Nitrolactose has been recommended for use in detonators and blasting explosives. Large[20] describes primary charges for compound detonators consisting of mixtures produced by the concurrent precipitation of nitromannite or nitrodulcite with PETN or nitrocellulose and/or with tetryl or other nitro-compound. In particular he recommends a concurrently precipitated mixture of nitromannite 50 parts, nitrolactose 35, and tetryl 15. These mixtures when lighted by a flame burn in the open with a flash, but when confined in a blasting cap shell, they detonate and are capable of initiating the high explosive secondary or main charge of the detonator. Lange finds that nitrocellulose alone is satisfactory for this purpose, and reports that 0.2 g. detonates nitromannite and that 0.5 g. causes the satisfactory detonation of tetryl.

Crater[21] describes explosives containing nitrolactose, one consisting, for example, of nitrolactose 25%, ammonium nitrate 65%, sodium nitrate 6%, and vegetable absorbent material 4%, another containing nitrolactose about 78%, dinitrotoluene about 9%, and wood pulp about 13% made by dissolving the first two ingredients in acetone and impregnating the wood pulp with the solution. When used in explosives, nitrocellulose requires to be stabilized, in the same way that nitroglycerine does, usually by the adition of a small amount of diphenylamine. This substance reacts with the nitrous and nitric acids from the spontaneous decomposition of the nitric ester, removes them, and prevents them from attacking it further.

Lactose hexanitrate, $C_{12}H_{16}O_5(ONO_2)_6$, is a white, amorphous material which melts, not sharply, at about 70°. It has been isolated from the alcoholic mother liquors from the crystallization of the octonitrate.

8. Nitrosucrose (Sucrose octonitrate), $C_{12}H_{14}O_3(ONO_2)_8$

Sucrose octonitrate[16, 22,23,24] crystallizes in clear colorless needles or prisms which melt at 85.5°. The fused and solidified material has a specific gravity of 1.67. It is readily soluble in methyl alcohol, ether, and nitrobenzene, sparingly soluble in ethyl alcohol and benzene, and insoluble in water and in petroleum ether. It reduces Fehlong's solution on warming. In 3.4% solution in alcohol [α]20°/D = 52.2°.

Wyler has studied various methods for the preparation and purification of sucrose octonitrate, nitrating the cane sugar in the presence of various solvents which dissolve the nitrated product, of hydroxy esters such as dibutyl tartarate, dibutyl lactate, and ethyl lactate, ethyl glycollate, alone or mixed with alkyl nitrates such as ethyl or amyl nitrate, or with chloro compounds such as carbon tetrachloride or tetrachloroethane. The product crystallizes out while the nitration is being carried on, or is precipitated afterwards in the crystalline state by the addition of alcohol or of a hydrocarbon such as pentane. He purified sucrose octonitrate by dissolving it, not completely, in hot solvents and crystallizing on cooling, in either ethyl alcohol or propylene dichloride alone, or in mixtures of alcohols and chloro compounds. He found that when sucrose octonitrate is fused with a small amount of an alcohol, say with 15% of its weight of amyl alcohol, the purified material separates as a water-white lower layer which solidifies and contains no significant amount of alcohol.

Wyler found that sucrose octonitrate explodes at 153-161° when heated from 100° at a rate of 3° per minute. Monasterksi reported that it puffs feebly under a 20 cm drop of a 2 kg weight, more strongly under one of 25 cm., and that it detonates under one of 30 cm. He found that 10 gram samples in the Trauzl test gave average net expansions of 296 cc., a result which indicates that it has about the same explosive strength as picric acid.

9. *Other Nitrosugars*

The nitration of xylose[16] yields D-xylose tetranitrate, $C_5H_6O(ONO_2)_4$, an oily substance insoluble in water, which is evidently the trinitrate, $C_5H_7O_2(ONO_2)_3$. Xylosan dinitrate, $C_5H_6O_2(ONO_2)_2$, has been produced by the action of mixed acid on D-xylose. It exists in little spherical crystal aggregates, soluble in alcohol and melting at 75-80°.

L-Rhamnose tetranitrate[16], $C_6H_8O(ONO_2)_4$, crystallizes in compact masses of stout rhombic crystals which melt with decomposition at 135°. It dissolves readily in methyl and ethyl alcohol, acetone, and acetic acid, and is relatively stable. It reduces Fehling's solution on warming. In 2.3% solution in methyl alcohol [α]20°/D = -68.4°. L-Rhamnoe trinitrate , $C_6H_9O_2(ONO_2)_3$, is produced by the action of mixed acid on L-Rhamnose. It is a white amorphous material which melts below 100°, readily soluble in alcohol, insoluble in water. It explodes feebly under the blow of a hammer.

α-Methylglucoside tetranitrate[16] , $C_7H_{10}O_2(ONO_2)_4$,crystallizes from alcohol in quadrangular plates which melt at 49-50° and decompose at 135°. It is more stable than the nitrate of glucose. It reduces Fehling's solution slowly on warming. In 6.2% solution in alcohol [α]20°/D = 140°.

α-Methylmannoside tetranitrate[16], $C_7H_{10}O_2(ONO_2)_4$, from the nitration of D-α-methylmannoside, crystallizes in fine asbestos-like needles which melt at 36°. It is relatively stable at 50°. In 2.5% solution in alcohol [α]20°/D = 77°.

D- Galactose pentanitrate α , $C_6H_7O(ONO_2)_5$, from the nitration of D-galactose, crystallizes which melt at 115-116° and decompose at 126°. It reduces Fehling's solution slowly on warming.It is sparingly soluble in alcohol: in 4% solution [α]20°/D = 124.7°. D-Galactose pentanitrateβ is found in the alcoholic mother liquors from the α form, transparent monoclinic needles which melt at 72-73° and decompose at 125°. It reduces hot Fehling's solution.

Fructosan trinitrate α, $C_6H_7O_2(ONO_2)_3$, results from the action of cold mixed acid on D-fructose or on levulosan[26] , colorless, quickly efflorescing needles from alcohol, which melt at 139-140° and decompose at 145°. It is readily soluble in methyl and ethyl alcohol, acetic acid, and acetone, and is insoluble in water. It reduces hot Fehling's solution. In 1% solution in methyl alcohol [α]20°/D =62°. Fructosan trinitrate β is procured from the alcoholic mother liquors from the α form, crusts of white crystals which melt at 48-52° and decompose at about 135°. It reduces Fehling's solution rapidly on warming. In 5% solution in alcohol [α]20°/D = 20°.

Sorbosan trinitrate, $C_6H_7O_2(ONO_2)_3$, results from the action of mixed acid on D-sorbose at 15°. It consists of crystals which melt not sharply at 40-45°.

D-α-Glucoheptose hexanitrate[16], $C_7H_8O(ONO_2)_6$, from the nitration of D-α-glucoheptose, crystallizes from alcohol in transparent needles which melt at 100°. It reduces Fehling's solution on warming. In 3.4% solution in alcohol [α]20°/D = 104.8°.

Trehalose octonitrate[16], $C_{12}H_{14}O_3(ONO_2)_8$, from the nitration od trehalose, crystallizes from alcohol on doubly refracting pearly leaflets which melt at 124° and decompose at 136°. It reduces Fehling's solution on warming.

Raffinose hendecanitrate[16] , $C_{18}H_{21}O_5(ONO_2)_{11}$, from the nitration of raffinose, is an amorphous material which melts at 55-65° and decomposes at 136°. It reduces Fehling's solution on warming. In 3.6% solution in alcohol [α]20°/D = 94.9°.

α-Tetraamylose octonitrate[27] $[C_6H_8O_3(ONO_2)_2]_4$, from α-Tetraamylose crystallizes from acetic acid in fine glistening needles which decompose at 204°. It is readily soluble in pyridine, nitrobenzene, and ethyl and amyl acetate, and sparingly soluble or insoluble in alcohol, ether, benzene, and water. α-Diamylose hexanitrate , $[C_6H_7O_2(ONO_2)_2]_4$, prepared from α-diamylose or as the final product of the nitration of tetraamylose, crystallizes from acetone in plates which puff off at 206-207°. It is sparingly soluble in acetic acid, and is reported to be but slightly stable. The alcohol extract of the crude hexanitrate yields a certain amount of tetranitrate. β-Triamylose hexanitrate[27], $[C_6H_8O_3(ONO_2)_2]_3$, is prepared by dissolving either β-Triamylose or β-Hexamylose in strong nitric acid at 0° and adding concentrated sulfuric acid drop by drop, and extracting the crude product with alcohol. It crystallizes from the alcoholic extract in masses of microscopic cubes, m. p. 203°. The residue insoluble in hot alcohol is recrystallized from acetic acid and yields crystalline crusts of β-Triamylose enneanitrate[27], $[C_6H_7O_2(ONO_2)_3]_3$, M. P. 198°.

10. *Nitrated Sugars in Dynamite*

Practically all of the dynamite manufactured in the United States is of the so-called "l. f." or low freezing variety, made from mixtures of nitroglycerin with other explosives which lower its freezing point, with aromatic nitro compounds, with the nitric esters of ethylene glycol, of trimethylene glycol, of polyglycerin, of glycerin monochlorohydrin, of sugar, and so forth.

"Straight" dynamite consists of a mixture of nitroglycerin or l. f. nitroglycerin with an "active base" or "dope", that is, with a mixture of oxidizing salt and carbonaceous combustible material, say of sodium nitrate or ammonium nitrate with flour, wood meal, bran, or powdered coal. Straight dymamite is the best preferred and most widely used blasting explosive in the United States. Gelatine dynamite is second in importance. The latter has about the composition as straight dynamite except that it is made from nitroglycerin or l. f. nitroglycerin which has been gelatinized by the addition of 2-5% of collodion nitrocotton. It has less tendency to exude than straight dynamite, and water does not cause the immediate separation of liquid nitroglycerine from it as it does from straight dynamite. Gelatine dynamite is more sensitive to shock when frozen than when in the soft unfrozen state. But nitroglycerin itself and nitroglycerin straight dynamite are insensitive when frozen and cannot be exploded by means of a blasting cap. Moreover, when straight dynamite freezes, the nitroglycerin tends to form fairly large crystals, and these, when they thaw out, yield large drops or considerable masses of very sensitive liquid nitroglycerin which make the once frozen dynamite dangerous to handle.

The low-freezing nitroglycerin mixtures are made, not by mixing the explosive substances, but by preparing them together in the same batch, by the nitration of mixtures. The character of the material which is mixed with the glycerin affects the properties of the nitrated product, vapor pressure and toxicity, ability to form gels with the collodion nitrocotton, intrinsic stability, viscosity, and the ease with which the liquid product may be washed and stabilized., and hence to some extent the process of manufacture and the manner of use. Mixtures of one-third ethylene glycol and two-thirds glycerin are nitrated for use both in straight and gelatine dynamite. Twenty percent cane sugar added to the glycerin before it is nitrated, or frequently a mixture of 2% dextrose and 18% cane sugar, yields a low freezing nitroglycerin which is used extensively in the manufacture of straight dynamite but is not considered suitable for use in gelatin dynamite - and this is the principle way in which sugar is consumed by the explosives industry in the United States. It represents a considerable tonnage of sugar concerning the precise amount of which, however, it has not been possible to secure an estimate.

We have noted a few patents which are of interest because they indicate the problems and difficulties which appear important to those who are employed in the industry, what solutions and inventions are thought to be desirable, and suggest ways in which future developments may possibly occur - but we are not able to assert that any of these patents are being exploited at present.

Norton[28] recommends the use of L-xylose dissolved in the glycerin before nitration. He states that 25 parts of cane sugar dissolved in 75 parts of glycerin is the largest proportion of cane sugar which can be used practically, that it gives a very viscous liquid before it is nitrated, and after nitration a liquid which is too viscous to wash conveniently. A solution of 35 to 40 parts of xylose in 60 to 65 parts of glycerin is much less viscous than a solution containing the same proportions of cane sugar and is also cheaper.

> "Four parts of xylose are dissolved in six parts of glycerin. Twenty parts of the solution is nitrated with about 100 parts of a standard mixture of acids: nitric 45%; sulfuric 55%. The mixture of trinitroglycerin, nitrated xylose, and spent acid after settling from the acids is washed with water, and then with a two percent solution of sodium carbonate, in water, at a temperature of about 80°F. The alkali solution is then drawn off and discarded."

Moran[29] points out that the nitrated sugar with the nitroglycerin gives a material which is cheaper than nitroglycerin and is suitable for use in low-freezing explosives, but that objection may be made to it because of its instability. Nitrated polymerized glycerin gives stable, low-freezing explosives but it more expensive than nitroglycerin. Moran claims that nitrated glucosides (methylglucoside and others) mixed with nitroglycerin give low-freezing explosives which are stable and cheap. Thirty parts of the glucoside is dissolved in 70 parts of glycerin, and one part of the mixture is nitrated with 5 parts of mixed acid containing approximately 50% sulfuric acid and 44% nitric acid.

Moran states that a mixture of nitroglycerin with a nitrated glucoside gelatinizes with nitrocotton more readily than nitroglycerin alone, and hence is more preferable for making gelatin dynamite. He suggests the following formulas.

Table 5. Moran's Nitroglucoside Explosives

	Dynamite	Gelatin Dynamite	Ammonia Dynamite
Explosive base	40	33	10
Nitrocotton	--	0.75	--
Sodium nitrate	45	51	--
Ammonium nitrate	-	-	80
Chalk	1	1	-
Carbonaceous absorbent	14	14.25	10

Boyd[30] states that a 20% solution of cane sugar in glycerin is about the strongest which can be prepared and nitrated practically, but that nitrated sugar dissolves more readily in nitroglycerin and that solutions containing as much as 70% of it may be prepared. He claims a process of nitration in which part of the glycerin, for example, is nitrated, the sugar is then shaken directly into the nitrator, care being taken that it does not strike against the paddles or the sides of the nitrator before entering the acid, then the rest of the glycerin is added, and the nitration is completed.

Wrightsman[31] prefers to use as large a proportion of sucrose as possible. He says,

"While efforts have been made to introduce other carbohydrates in place of sucrose, this carbohydrate in the form of cane or beet sugar is by far the most satisfactory, considering price, purity, supply, stability, yield, explosive properties, etc."

He claims that the largest practical proportion of sucrose (20-25%) may be retained if 10-30% of a glucoside, such as dextrose methylglucoside, is substituted in the mixture to be nitrated in place of the same amount of glycerin or of glycol or of a mixture of the two. He recommends particularly a mixture of 25% sucrose, 15% dextrose methylglucoside, and 60% ethylene glycol or 60% of various mixtures of ethylene glycol and glycerine. He also claims similar advantages from the use of glucose in mixtures which contain glycerin monochlorohydrin, and recommends 10 to 30% glucose along with 20 to 25% sucrose in glycerin monochlorohydrin or in a mixture of that substance with ethylene glycol.

11. Nitrosucrose in Nitrostarch Explosives

Nitrostarch explosives are similar to dynamite except that they contain the solid nitrostarch instead of the liquid nitroglycerin. They are not subject to exudation and are not injured by low temperatures. They supply a possible outlet for a certain amount of cane sugar in the explosives industry, for nitrosucrose in admixture with nitrostarch can be stabilized more cheaply and more conveniently than it can be by itself. Wyler[32] has discovered that a mixture of cane sugar (glucose or cerelose) with 10% or more of its weight of powdered corn starch or cassava starch can be nitrated to yield a fluffy pulverulent mass which can be stabilized satisfactorily and can be handled as a powder at ordinary temperatures or higher.

> "100 lbs. Of finely ground cane sugar is thoroughly mixed with 25 lbs. of dried corn starch and the mixture fed to 360 lbs of 95% HNO_3, keeping the nitration mixture at a low temperature, say, below 20° C. at the end of this operation, all of the starch and all of the sugar will have gone into solution. Next 510 lbs. of oleum of about 105% H_2SO_4 strength is added slowly with continued cooling and stirring. When all of this oleum has been added, the nitrated sugar will have separed into a doughy plastic mass. This is separated from the acid and transferred to a kneading tank supplied with a current of tap water, where, in a short time the doughy mass is converted into a fine, pulverulent precipitate which is filtered, washed with tap water, and transferred to a stirring tank containing dilute alkali solution in which it is stirred for one hour or more to stabilize the nitrated product, which consists of a mutual solid solution of nitrated sugar and nitrated starch. The alkaline mixture is then filtered, washed with tap water, and dried at about 40°C."

Wyler also describes another method of nitration, with mixed acid instead of with strong nitric acid and oleum. The same amount of material is nitrated with mixed acid containing 64% sulfuric acid, 34% nitric acid, and 2% water. The temperature of the nitration is kept, preferably, below 20°C,. And the gummy crude product is removed and handled as has been described.

> The "dried co-nitrated product is a slightly yellow, dusty, low density powder, readily detonable and soluble in the usual solvents used for gelatin explosives and for lacquers. When made in the manner just described the product will contain about 14.50% N present as nitrate, and its packing density will be about one-third that of ordinary nitrostarch." It is "normally of a finely divided or pulverulent nature, even when not subjected to any cominuting operation," and is "a particularly valuable component for use in explosive compositions where a low density or 'high stick count' is desired."

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Cultural Relationships of Explosives.
Their Usefulness Begins and Ends – in Peace.
[1944]

By
Tenney L. Davis

Explosives are to be listed among the chemical substances which have been of great service to man. They have been potent factors in promoting the growth of civilization and the spread of culture. Although enormous quantities are being used at present for the destructive purposes of war, yet it is probably true in the long run that military explosives represent not more than 5% of all the explosives which are produced. Ninety five percent is used for beneficial and creative civil purposes of peace – to dig canals, to gain access to minerals under the earth, to open the way for engineering accomplishments of all kinds. Truly, explosives are substances of good repute and of good associations.

It is interesting to note that the discovery of America, the discovery of printing, and the discovery of gunpowder occurred at about the same time in history. And very difficult indeed it is to assess the comparative values of these discoveries and to decide in one's own mind which of them has been the most important or has done the greatest good. By the "discovery of gunpowder," we mean the discovery that useful mechanical work can be done by the combination of chemicals, saltpeter, sulfur, and charcoal, out of which black powder is made. This mechanical work, to cite one example, has given us coal and iron ore, and has ben directly responsible for bringing on the present age of steel, and with it such things as great ocean steamships, rapid communication, the automobile, the airplane, and the radio. It has made possible the rapid and wide diffusion of knowledge consequent upon the discovery of printing, and it has made possible the use and development of new wealth, hte new foods, the new drugs, and the new lands of the Americas.

Roger Bacon, about 1250, was probably the first in Latin Europe to set down a description of black gunpowder and to foresee the possibilities of its use. He considered the material so important that he concealed its exact composition in an anagram and in a little problem in algebra by which the solution of the anagram could be checked. Thus, he disclosed to composition only to the most studious and most intelligent of his readers. The treatise, "On the Marvellous Power of Art and Nature and on the Nullity of Magic," which is ascribed to Roger Bacon and which contains the famous black powder anagram, closes with the words– "Whoever rewrites this will have a key which opens and no man shuts, and when he will shut, no man opens." Although guns did not come into use until about 1350, it is evident that Roger Bacon foresaw that useful – and irreversible – mechanical work could be accomplished by means of his powder. And since his time explosives have shut the door upon much that is evil and opened the door permanently to much that is good.

Antiquity of Fireworks

Fireworks are older than explosives, and fireworks – pyrotechnics or the arts of fire – were used for pleasure and entertainment, and for magic, as in the exorcising of demons, long before they were used for purposes of war.

Some unknown scientist of an early time discovered that combustible material burned much more brightly and vigorously of saltpeter was added to it. Saltpeter (potassium nitrate) was found as an efflorescence in various arid places on the surface of the earth. It was the final product from the putrefaction of nitrogenous animal and vegetable materials. It had interesting properties. It was readily soluble in water and crystallized in handsome geometrical forms. It was a good preservative for meat. It had a pleasant and cooling taste, and actually lowered the temperature of water in which it was dissolved. The emperor Nero is reported to have used it for cooling his wine. It was an article of commerce at an early date.

By using saltpeter with different combustible materials different visual effects were produced. Sound and motion also resulted accordingly to the method by which the combustible material was utilized or packaged. An intimate mixture of finely powdered saltpeter, sulfur, and charcoal burned with a single quick flash, and it is this mixture which later found use as gunpowder. Other compositions burned for a longer time with a bright light, with smoke, or with the throwing about of glowing or scintillating sparks; and still others were designed which would burn when thrown through the air and could not be extinguished by water or by sand. Crackers, rockets, gerbs, and wheels were all known at an early date, and all were charged with compositions which contained saltpeter and were in fact black powder or modified black powder. The earliest printed books on fireworks describe the same devices as those which are used today. For three centuries at least no important improvements have been made in the mechanical construction of the pieces; the improvements have been in the use of new chemicals. Potassium chlorate is a more vigorous oxidizing agent than potassium nitrate. Its use, beginning early in the nineteenth century, gives brighter flames and sharper explosions. Certain safe high explosives have been made from this material, but it has never been slowed down sufficiently to make a satisfactory propellant powder. Barium salts for green, and strontium salts for red, soon came into use for the production of more interesting colors. Toward the end of the century magnesium was used for intensely brilliant lights andsoon after, the cheaper and more stable aluminum for "electric" effects.

The early history of fireworks is obscure. Pyrotechnic devices were apparently invented in China where they were developed to a fairly high state, and from China a knowledge of them evidently found its way to Byzantium over the trade routes. There is evidence which indicates that Chinese and European fireworks later developed independently but along parallel lines. The Chinese had breech-loading cannon at the beginning of the seventeenth century, perhaps earlier. As early as the Sung Dynasty they used rocket-propelled arrows for purposes of war.

Greek Fire – Early Incendiaries – Firecrackers

The earliest known document on the subject of fireworks and explosives is probably the "Book of Fires for Burning the Enemy" which was written by Marcus Graecus in the eighth century. This describes various mixtures containing saltpeter for use in crackers and rockets and in the Greek fire which made the Byzantines so successful for several centuries in their warfare against the Moslems. The latter fire was ejected from tubes attached to the prows of ships or from small hand siphons, or the combustible material was fastened to heavy stones and thrown with the projectiles from ballistic machines. It was of course enormously effective against wooden ships and against personnel.

"Greek fire," wrote Marcus Graecus, "is made as follows: Take sulphur, tartar, sarocolla, pitch, melted saltpeter, petroleum oil, and oil of gum, boil all these together, impregnate tow with the mixture, and the material is ready to be set on fire. This fire cannot be extinguished by urine, or by vinegar, or by sand."

The same writer describes another mixture which resembles black powder more closely, and tells how it is used in firecrackers and rockets. He even specifies grapevine and willow charcoal which, with alder charcoal, are still the preferred charcoals for making fuze powders and other grades for special purposes. –

"Take one pound of pure sulphur, two pounds of grapevine or willow charcoal, and six pounds of saltpeter. Grind these materials three substances in a marble mortar in such manner as to reduce them to a most subtle powder. After that, the powder in desired quantity is put into an envelope for flying (a rocket) or for making thunder (a cracker). Note that the envelope for flying ought to be thin and long and well-filled with the above described powder tightly packed, while the envelope for making thunder ought to be short and thick, only half-filled with powder, and tightly tied up at both ends with iron wire. Note that a small hole ought to be made in each envelope for the introduction of the match. The match ought to be thin at both ends and thick in the middle, and filled with the above-described powder. The envelope intended to fly through the air has as many thicknesses (ply) as one pleases; that for making thunder, however, has a great many."

Firecrackers appear to have been used as toys by European youngsters before the composition with which they were filled was yet known to European scholars. Roger Bacon judged that they would be useful in war because of their frightfulness. He wrote:

"Certain inventions disturb the hearing to such a degree that, if they are set off suddenly at night with sufficient skill, neither city not army can endure them. No clap of thunder could compare with such noises. Certain of these strike such terror to the sight that the coruscations of clouds disturb it incomparably less...We have an example of this in that toy which is made in many parts of the world, namely an instrument as large as the human thumb. From the forces of the salt called saltpeter so horrible a sound is produced at the bursting of so small a thing, namely a small piece of parchment, that we perceive it exceeds the roar of sharp thunder, and the flash exceeds the greatest brilliancy of the lightening accompanying the thunder."

Composition of Black Powder

Roger Bacon's gunpowder formula called for six parts of saltpeter, five of young willow charcoal, and five of sulphur, and did not correspond by any means to the most powerful combination of the three ingredients. After the invention of guns, numerous studies were made to determine the most advantageous proportions of the components. Since the time of Queen Elizabeth it has been accepted that the best ballistic effects are secured from black powder made according to the 6:1:1 formula, that is, saltpeter 75%, charcoal 12.5%, and sulphur 12.5%, or according to the formula, saltpeter 75%, charcoal 15%, and sulphur 10% or between the two or thereabouts. For four or five centuries no significant improvements have been made in black powder except in the methods of its manufacture, in hte shape of the grains, etc. For ballistic use it has been largely superceded by smokeless powder, the results of advances in chemistry, but it still remains the best material there is for communicating fire or for producing a quick hot flame for the ignition of smokeless powder.

Importance of Nitrogen

The property of saltpeter which qualifies it so well for use in gunpowder is its property of supporting combustion, its property of giving up its oxygen readily to substances which have a great tendency to react with that element. Other nitrates possess this same property as does nitric acid itself, a happy balance of readiness to give over the oxygen with a tendency toward retention of the oxygen sufficient to make them stable. There are other substances, such as potassium chlorate and permanganate, which contain oxygen enough, but give it up so readily that their usefulness is limited. The oxides of nitrogen, and their compounds and derivatives, appear to be uniquely suited to the needs of the explosives worker.

When black powder burns, the nitrogen of the nitrate forms nitrogen gas, the oxygen combines with the charcoal and the sulphur to form compounds of which some are gaseous and some, into the composition of which the potassium enters, are solid. The hot gases, largely nitrogen and carbon monoxide and dioxide, produce the expansive effect of the explosion; the solids, largely potassium carbonate, sulfate, and sulfide, produce the smoke and contribute nothing to the force of the explosion. When black powder burns, about 56% of its weight is converted into useless smoke. Compounds such as ammonium nitrate, cellulose nitrate (nitrocellulose), and glyceryl nitrate (nitroglycerin) contain only elements which yield gaseous oxides; they produce no smoke, and are more powerful explosives in consequence.

Combined nitrogen, then, is absolutely essential for the production of explosives. The development of new explosive substances, the production of ammonia and nitric acid for their manufacture, and the actual making of them from combined nitrogen and other materials – all these are problems for chemistry.

Chemistry in Warfare

There appear to be three principal varieties of warfare,

1. Physical
2. Chemical, and
3. Psychological.

In the first, we attack the enemy with physical instruments, tooth and claw, tomahawk, mace and pike, dagger and bayonet, bullet and fragments of metal from a shell or bomb. This is the commonest method of waging war. And it is an ancient one, appearing early in the evolutionary process. Cats and tigers are beautifully equipped by nature with instruments of physical warfare. In the second we attack the enemy with chemical agent, smoke which gets in his eyes, tear gas, sneeze gas, mustard, and phosgene. This method of warfare is very much more ancient in the evolutionary process than any of the others. The feeble and slow-moving skunk is equipped to practice it, and the primitive and unsubstantial jellyfish which yet is able to sting. In the third method we work our will upon the enemy through the use of propaganda and other psychological devices which cause him by his own acts to do the things we wish. This is the most recent, the most subtle, and the most powerful of the several methods.

Explosives in warfare are devices which apply matter physically in a manner to do physical injury to the person or property of the enemy. Chemical warfare is outside the interest of the present discussion. When we speak in this article of the importance of chemistry in warfare, we wish to be understood as referring to the physical warfare in which explosives are effective.

Herman Boorhave, Professor of Chemistry at Leiden, was acquainted more than two centuries ago with certain combinations of chemicals, such as nitric acid and oil of cloves, which were capable of reacting with explosive violence. Black powder was the only explosive known to him which was suitable for use in war. Yet he was so fully convinced of the importance of chemistry for war that he wrote the following extraordinary and thoroughly modern observation upon it.

"It were indeed to be wish'd that our art has been less ingenious, in contriving means destructive to mankind; we mean those instruments of war, which were unknown to the ancients, and have made such havoc among the moderns. But as men have always been bent on seeking each other's destruction by continual wars; and as force, when brought against us, can only be repelled by force; the chief support of war, must, after money, be now sought in chemistry."

If this were true in Boorhave's time, how much truer it is today when we are able by chemical processes to convert the inert but endlessly accessible nitrogen of the atmosphere into the combined or fixed nitrogen of ammonia and nitric acid. The substances are necessary for the production of explosives, and they are utterly necessary, too, for fertilizers and the growth of lpants. Man's newly acquired ability to synthesize them from the air has given him a new status in the universe. He is now no longer dependent upon the unsolicited bounty of nature for his food. He can demand his food and can cause the unfertile soil to yield it to him. And we note, in passing, that chemistry which is the most fundamental for war is also truly fundamental for peace, for the very sustenance of life itself.

Definition and Classification of Explosives

An explosive is defined as a material, either a single substance or a mixture of substances, which is capable of producing an explosion by its own energy.

The various materials which conform to this definition may be classified according to their modes of behavior, according to the manner in which they release their energy, according to the stimuli which induce them to produce explosions. There are thus three classes of explosives:

1. Propellants or low explosives function by burning rapidly; they produce hot gas and the expansion of the gas produces an explosion. Examples are black powder and smokeless powder.

2. Primary explosives or initiators explode or detonate when they are heated or subjected to shock. They do not burn. They explode whether they are confined or not. Their substances themselves, when they explode, tear themselves apart, and produce a considerable local shock, which is capable of initiating the explosion of the so-called high explosives. The most important primary explosives are mercury fulminate and lead azide.

3. High explosives differ widely among themselves in their combustibility, sensitivity to

shock, friction, etc., but are characterized by their ability to be exploded by the shock of the explosion of a suitable initiator. Examples are dynamite, trinitotoluene, tetryl, picric acid, nitrocellulose, nitroglycerine, ammonium nitrate, ammonium picrate, and nitroguanidine. Nitroglycerine burns easily and is exploded easily by shock. Nitroguanidine does not burn well at all. Ammonium picrate, properly loaded in a shell will withstand impact against heavy armor without exploding.

Behavior of Typical Explosives

Primary explosives occur in two places in the complete round of H. E. ammunition, in the primer cap at the base of the cartridge case, and in the fuze at the nose of the shell. The purpose of the primer cap is to produce fire when the trigger strikes it. The cap contains a mixture of mercury fulminate, potassium chlorate, and antimony sulfide. The fulminate in the first instance produces a fire which ignites the antimony sulfide, and this burns at the expense of the oxygen of the chlorate to produce a flame which sets fire to the black powder in the primer or igniter. The large flame from the black powder sets fire to the smokeless powder which constitutes the propelling charge.

If the fuze is a combination fuze designed to explode the shell either upon impact with the target or at a certain pre-determined time after it has left the muzzle of the gun, then it contains a primer cap which is fired by means of an inertia-operated device at the moment that the projectile starts its flight. The fire from this lights a train of black powder, the length of which has been adjusted by turning the time train rings, and from the end of this passes to the detonator, loaded with fulminate or azide, which explodes the shell. If the time train rings have been set to burn to a dead end without bringing the fire to the detonator, then the shell explodes only after it strikes the target. In this case an inertia-operated device fires a primer cap from which the fire passes directly to the detonator.

The high explosive with which the shell is loaded is one, obviously, which is insensitive enough to tolerate the shock of being fired from the gun. Trinitrotoluene (TNT) is generally preferred for this purpose. It is manufactured by treating toluene (a coal tar hydrocarbon) with mixed nitric and sulfuric acids. It melts at 81.5° C, below the boiling point of water, and is cast in the shell or loaded by pouring. After the TNT has cooled in the shell, a cavity for the booster is bored out in the middle of the front end of the charge, next to the detonator. This is then filled with the booster explosive, usually tetryl, more sensitive and more brissant than TNT, which serves the double purpose of securing a better detonation of the principle charge and of making it possible to build satisfactory ammunition which contains smaller, and hence safer quantities of fulminate or azide.

To one who is not familiar with explosives, the smokeless powder of the propelling charge is perhaps the most mysterious and impressive component of the ammunition. It is a dense colloided powder, having the appearance and the toughness of horn. In the open it burns slowly. In the confined space of the chamber of the gun, where the heat of its burning serve to accelerate the rate, it burns rapidly, but none the less progressively, and in such a manner that it pushes the projectile, and continues to push it, harder and harder, until the moment that the projectile leaves the muzzle of the gun.

U. S. military powder is a nitrocellulose powder in the form of short cylindrical grains having seven longitudinal perforations. The short grains make it possible to blend many small lots of powder into a large lot which is ballistically uniform. British cordite contains both nitrocellulose and nitroglycerine, and exists in the form of single-perforated anber-colored, flexible sticks or cords. It is hotter and more erosive in the gun than straight nitrocellulose powder, but it is also more powerful. When pushed by either of these powders, a 75mm anti-aircraft shell starts on its flight with a velocity considerably greater than half a mile per second.

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