Greek Fire and Black Powder

From earliest times, incendiary substances have been used in warfare, whether on the tips of flaming arrows, on the projectiles of catapults or ballistae, or the flaming oils, tar, or pitch poured down on attackers from the walls of besieged cities. The invention called *Greek Fire* appears to have consisted of the addition of saltpeter (potassium nitrate) to the combustible mixtures already in use, providing the fuel with its own oxygen supply (i.e., that provided by the pyrolytic decomposition of the oxidizer) so that it could burn in confinement, even under water, and produced flames that were virtually impossible to extinguish. According to the Byzantine historian, Theophanes the Confessor, Greek Fire was invented around A.D. 670 or 672 in the reign of Constantine IV (surnamed *Pogonatus*, “the Bearded”) by the Greek-speaking Syrian-born engineer, Callinicus (or *Kallinikos*, if your prefer the Hellenized to the Latinized spelling.) Although the details of how it was used are almost indecipherably vague, Greek Fire was a petroleum-based liquid mixture, and one method for its dispensation apparently involved pumping and shooting the flaming liquid from devices called “siphons”, much like a modern-day flame-thrower, and another method of delivery may later have consisted of hurling a glass vial of it along with a flaming wick, so that upon impact with the target the glass container would shatter, thus scattering and igniting the incendiary mixture, much like a cross between napalm and the fire-bomb known in later years as the “Molotov Cocktail.” Yet another method of ejecting the incendiary was through the use of what was then called a *strepta*, but again the details of how this device worked have been left hopelessly vague (perhaps this was a successfully-kept military secret.) One early Twentieth Century historian of Pyrotechnics (Brock) speculated that fire from these flame-throwing copper tubes may have operated in the manner of pyrotechnical fountains or Roman candles. Fortunately for us, a formula for Greek Fire has survived through a passage from the Eighth Century* book of Marcus Graecus, *Liber Ignium ad Comburendos Hostes* — a passage which has come down to us through a quotation by the Ninth Century Arabian physician, Mesue:

> “Greek Fire is made as follows: take sulfur, tartar, sarcocolla, pitch, melted saltpeter, petroleum oil, and oil of gum, boil all these together, impregnate tow [i.e., the coarse or broken part of flax or hemp, prepared for spinning] 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 ...
> *Flying fire* may be obtained in the following manner: take one part of colophony [rosin], the same of sulfur, and two parts of saltpeter. Dissolve the pulverized mixture in linseed oil, or better in oil of lamium. Finally, the mixture is placed in a reed or a piece of wood which has been hollowed out. When it is set on fire, it will fly in whatever direction one wishes, there to set everything on fire.”

The second paragraph of this passage is particularly intriguing, for the "flying fire" referred to is subject to various interpretations. This term has been taken by some to mean a *rocket*, although it seems more likely to refer to a Roman candle or a liquid-fuel version of a pyrotechnical fountain, for, as anyone who has worked with homemade rockets will tell you, unstabilized rockets do not reliably "fly in whatever direction one wishes," while a pyrotechnical fountain or Roman candle can more reliably be directed. The problem of stabilization — whether by stick or by fins — makes the rocket seem to be the less simple interpretation of the passage. One would at very least expect to find some mention of how to solve the problem of stabilization in any instructions on how to make a war rocket. Perhaps the writer meant that it is the *fire itself* that does the flying, and not the device from which it issues. Another mixture mentioned in the *Liber Ignium* of Marcus Graecus is of even greater interest:

> "Take one pound of sulfur, two pounds of grapevine or willow charcoal, and six pounds of saltpeter. Grind these three substances in a marble mortar in such a manner as to reduce them to a most subtle powder. After that, the powder in desired quantity is put into an envelope for flying or for making thunder. 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 an 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 above-described powder. The envelope intended to fly in the air has as many thicknesses [ply] as one pleases; that for making thunder, however, has a great many."

Here we have the first historical description of how to make not only a black powder, but rockets and firecrackers as well! Note that this formulation differs from that of Greek Fire: whether it be pumped by hand or driven through nozzles by the force of oxidized combustion, Greek Fire was an incendiary liquid which could be accurately directed at enemies, while this last-mentioned composition was a dry black powder which could be used to make pyrotechnical self-propelling devices (i.e., rockets) and explosives (more specifically, firecrackers). Even today, willow charcoal is considered by pyrotechnists to be the best form of carbon to use in making gunpowder! Because Greek Fire was the first incendiary substance to make use of an oxidizer (saltpeter), and because further experimentation along these lines unquestionably led to the development of black powder, it may be said that Greek Fire was the direct ancestor of black powder, and in turn, of all pyrotechnical and explosive compositions. Although the Chinese are generally credited with its invention, we see in the work of Marcus Graecus that a form of black powder which could be used in rockets and firecrackers was already known to the Eighth Century* Byzantine Greeks. The first mention of a primitive form of black powder in China was in the mid-Ninth Century work, *Classified Essentials of the Mysterious Tao of the True Origin of Things*, attributed to Cheng Yin, in which he warns against mixing this powder because of the danger of burning both the experimenter and the house in which the experiment is taking place. The next historical mention of black powder occurs around 1040 in China, when Tseng Kung-Liang published three different recipes for black powder; around 1150 the Chinese were perfecting the rocket; by 1221 the Chinese were using bombs that produced shrapnel and caused considerable damage (previous uses of black powder merely exploited the frightening sound of the loud explosions); and the first known gun (a small cannon) was made in China in 1288. Thus it can be seen that the Chinese unquestionably advanced the state of the art of fireworks, and invented guns and fragmentation bombs to fully exploit the power of black powder — and because they invented guns it may even be said that the Chinese invented *gunpowder* (i.e., black powder manufactured for the purpose of propelling bullets) but, unless Marcus Graecus' book turns out to be a fake, or is mis-dated*, the priority for the discovery of *Black Powder* must in all fairness go to the Greeks.

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* There seems to be considerable disagreement on the World Wide Web about the time period in which Marcus Graecus lived. Nearly every Web-site which gives him mention places him in a different century. He has been dated anywhere from the Eighth Century to the Thirteenth Century, and none of the web-pages cite any historical references to lend credence to their estimates, but these mutually-contradictory estimates are always stated as if they were beyond question. In the authoritative, and highly recommended book, *The Chemistry of Powder and Explosives* by Tenney L. Davis, Ph.D., it is stated that Marcus Graecus' book was quoted by the Ninth Century Arabian Physician, Mesue, and that the original was "... probably written during the Eighth [Century]." In his footnote on *Liber Ignium ad Comburendos Hostes*, (literally, "Book of Fires for Burning the Enemy") Dr. Davis cites Hoefer's *Histoire de la Chimie*, second edition, Paris, 1866, Volume 1, pages 517-524 (and a further discussion in the same source, Volume 1, page 309.) Until I see any compelling historical evidence to the contrary, the Eighth Century is the time-frame into which I will continue to place Marcus Graecus — and hence, the invention of Black Powder.

The Historical Importance of Black Powder:
The discovery that a mixture of potassium nitrate, sulfur, and charcoal is capable of doing useful mechanical work is quite simply one of the most important discoveries of all time, and it was an invention which profoundly changed all of history. Three great discoveries in effect ended that stagnant millennium known as the Middle Ages: 1) the discovery of the New World, which made available new foods, new drugs, new natural resources, and new lands in which people might prosper, multiply, develop new cultures, and escape religious oppression; 2) the re-introduction of Greek thinking through books preserved by the Moslems, along with the all-important invention of printing, which made possible the rapid, cheap, and widespread diffusion of ideas and knowledge, so that the Theocrats no longer had complete control over what ideas the people may or may not be exposed to, and, 3) the discovery of the controllable force of gunpowder, which made possible huge

engineering feats, and enabled the accomplishment of these feats much more rapidly and much more cheaply than could be done by huge numbers of slaves, which was the only way to do such things before the advent of explosives — this eventually put slaves out of a job! Of course it goes without saying that gunpowder changed the face of war, for now the stronger, the faster, the fiercer, or the more skilled swordsman or archer would not automatically prevail in combat, but rather the wilier, the more ruthless, and the better shot. Gunpowder also ushered in the Industrial Revolution for, as a blasting powder, it gave man unprecedented access to coal and minerals in the earth, which in turn brought on directly the age of iron and steel, and with it the era of machines, and of rapid transportation and communication.

It is often said that the Chinese invented gunpowder during Europe's Dark Ages, and if we mean by "gunpowder" *black powder manufactured for the purpose of propelling bullets from guns*, then this statement is indeed technically correct, for the Chinese do appear to have invented the gun (although there is a German tradition, perpetuated by a monument in Freiburg, which claims that the priority for the invention of both the gun and gunpowder belongs to a Thirteenth or Fourteenth Century Franciscan monk named Berthold Schwarz, a dabbler in black magic. No contemporary accounts of the friar's alleged discovery remain, however.) Obviously, a substance called "gunpowder" could not exist before the invention of a device which relies on that substance, a device called "the gun," and so we must concede that those that invented the gun (probably the Chinese) were also the ones to first use "gunpowder," if "gunpowder" is taken to mean *black powder which is intended for the purpose of propelling bullets from guns*. But what about black powder? Weren't black powder and gunpowder originally one and the same substance? And if so, doesn't this mean that the Chinese also invented that? Yes, black powder and gunpowder were originally one and the same substance, but this does not necessarily mean that black powder did not exist before the Chinese invented the gun. In point of fact, there is historical evidence (such as that provided by Marcus Graecus' work) that black powder and similar mixtures were used in incendiary compositions and in pyrotechnic devices for amusement and for war long before the invention of the gun. Apart from its early use as an incendiary (in the form of a pyrotechnical fountain) it is also possible that black powder was used in *petards* [bombs used for blowing down gateways], long before it was used for its ballistic effect. Thus we must conclude that the mixture known as "black powder" existed long before that same mixture came to be called "gunpowder" in deference to the new and important application for which this mixture was increasingly being used.

Basic Theory Behind Chemical Explosives:

The inactive element nitrogen does not unite easily with other elements. If it should do so, the unions so produced are very unstable. In fact, the nitrogen compounds are so unstable that on the slightest provocation the nitrogen breaks away with a bang! Most explosives, except nuclear explosives, depend upon this fact (a notable exception being that class of explosive mixtures which is based upon the oxidizing power of chlorates or perchlorates). The vast majority of non-nuclear explosives contain either *nitrate* (NO_3)

or *nitro* (NO_2) radicals. In addition, some explosives contain ammonium (NH_4) radicals. When compounds that contain nitrate or nitro radicals are mixed with other compounds that can easily use the oxygen of these unstable radicals, an explosive is the result. In certain cases, the compound containing the nitrate or nitro radicals actually supplies the means of its own destruction by furnishing the elements that can use the oxygen readily. When something, such as a shock or flame, starts the reaction, the unstable nitrate or nitro radicals release their oxygen for combination with other elements and liberate free nitrogen gas. Nearly always, most of the other products of the reaction are gases also, and because of the high attendant temperatures produced, terrific pressures result.

BLACK POWDER FORMULA:

Potassium Nitrate (a.k.a. saltpeter) [KNO_3] .... 15 parts (75%) by weight
Powdered Charcoal (carbon) [C] .... 3 parts (15%) by weight
Sulfur (a.k.a. brimstone) [S] .... 2 parts (10%) by weight

THEORETICAL CHEMICAL REACTION OF BLACK POWDER EXPLOSION:

$$2KNO_3 + 3C + S \rightarrow K_2S + N_2\uparrow + 3CO_2\uparrow$$

202.21 g. +	36.03 g. +	32.06 g. →	110.26 g. +	28.01 g. +	132.03 g.
Potassium Nitrate	Carbon	Sulfur	Potassium Sulfide	Nitrogen	Carbon Dioxide

The combustion of each gram of Black Powder evolves 725.7 calories of heat and 0.2742 liters of remaining gases (measured at STP: 0° Celsius, 760 mm of mercury). These (measured) results indicate by calculation that the explosion of Black Powder produces a momentary temperature of about 3880° Celsius.

Note that the theoretical chemical reaction of a Black Powder explosion does not precisely describe what really happens in practical situations. This is largely because powdered Charcoal is not pure carbon, but in addition to the carbon which predominates, it also contains hydrogen, oxygen, and ash. In practice, the gaseous products of Black Powder combustion include not only carbon dioxide and nitrogen, but also carbon monoxide, hydrogen sulfide, methane and hydrogen. Similarly, in practice potassium sulfide is not the only solid product of Black Powder combustion, but also produced are potassium carbonate, potassium sulfate, potassium thiocyanate, and ammonium carbonate. In addition, in many cases, not all of the potassium nitrate, sulfur, and carbon are consumed in the explosion, so that traces of these (especially the sulfur) remain with the other solid products of the reaction.

The optimum proportions of the ingredients of black powder lie in the range 75:12.5:12.5 to 75:15:10 (of Potassium Nitrate:Charcoal:Sulfur by weight) and any considerable deviation from this range produces a powder which burns more slowly or produces less vigorous effects. Sometimes a slower burning powder is desirable though, as in the case of rockets. If charged with a too-vigorous formula of black powder, rockets tend to explode instead of traveling. This problem in rocketry is sufficiently common to have received an arcane techno-speak acronym: CATO (for Catastrophic failure At Take-Off). Rockets of different take-off weights require different fuel formulas. In making Black Powder rockets, experiment, consistency, and careful record-keeping are the key, but the rule of thumb is that if rockets burst before or while ascending, one should add more (or coarser) charcoal dust to the formula, and if they ascend too slowly one should add more saltpeter.

Black Powder is no longer used in modern firearms (except in the "muzzle-loaders" used by nostalgic history buffs) owing to the vast quantities of acrid smoke produced by its combustion, and the considerable amount of residue left in the barrel of the gun (necessitating frequent cleaning.) Most modern guns now use a nitrocellulose "smokeless powder" which burns much cleaner than black powder. Smokeless powder not only produces less smoke and residue than does Black Powder, but what little smoke is produced also stinks less, for the by-products of nitrocellulose combustion do not contain sulfides as do the by-products of Black Powder combustion (the latter of which include hydrogen sulfide, a gas which helps to give rotten eggs and intestinal gaseous emissions their smell. Indeed, the etymology of *Petard* — the medieval black powder bomb used for blasting down castle gates — reflects this olfactory, if not quite auditory similarity, for *petarade* is a French word for "farting".) Although no longer used in firearms, Black Powder is still much-used in pyrotechnics, though — the fireworks industry uses black powder extensively for making fuses and priming, and a coarse grade of black powder (called "lift powder") is still used as the propellant of every mortar-fired aerial shell, and an ultra-fine grade of black powder (called "meal powder") is used as the burst charge in many aerial star shells, whether by itself or coated on rice hulls. Black Powder is really a *deflagrating* explosive, not a *detonating* explosive. This means that in small quantities Black Powder burns vigorously and rapidly with a puff of smoke and a flash of light but does not really explode unless it is confined, whereas the detonating explosives do not require confinement in order to produce an explosion. Mind you, a sufficiently large quantity of Black Powder *can* explode, even unconfined, but it takes on the order of 500 pounds of Black Powder in order to achieve such unconfined detonation. Contrast this with Flash Powder, which will detonate with concussion in open air (with no container) if the amount of flash powder exceeds about 50 grams (less than 2 ounces), and the primary detonating contact-explosive nitrogen tri-iodide will detonate sharply in *any* quantity — even in a quantity smaller than a speck of dust!

Manufacture of Black Powder:
If you were to combine potassium nitrate, powdered charcoal, and sulfur — even in exactly the correct proportions — you would likely be in for a disappointment, for the resulting Black Powder, although it would burn quite well, would also burn quite slowly for an explosive. It turns out that the physical state of the ingredients plays a very important rôle in the performance of the Black Powder. The ingredients must be pulverized almost to molecular fineness, either by arduous grinding via mortar and pestle, or by tumbling in a ball mill with grinding balls for many hours. Even then, the performance of home-made Black Powder cannot compare with that of its commercially-manufactured counterpart. Home-made Black Powder can successfully be used to propel skyrockets, and can be induced to explode if strongly confined — say, within a pipe-bomb, where the unrelieved heat and pressure accelerate the powder's combustion reaction until the pipe ruptures explosively, throwing dangerous shrapnel — but if the goal is to loft or burst a pyrotechnical shell, or to produce a Black-Powder-dispersed-fuel-air fireball, it would be best to stick to commercially-manufactured Black Powder. Commercially-manufactured Black Powder is subjected to considerable processing in order to make it burn as swiftly as it does. The ingredients are either mixed in the dampened state, or the sulfur and charcoal are stirred into a hot saturated solution of potassium nitrate and then allowed to cool. The resulting mixture is then milled for 3 hours under wheels which weigh 8 to 10 tons each and then hydraulically pressed at 1200 pounds per square inch. Finally, in the most dangerous phase of the operation, the pressed Black Powder "cakes" are cracked or crushed between several sets of crusher rolls, and shaken on sieves until the particles are just the right size for use, and as a final step the granulated powder is rounded or polished by tumbling in a revolving wooden barrel, sometimes being dried at the same time by forcing a stream of warm air through the barrel. If a glazed powder is desired, the glaze (graphite) is usually applied before the final drying and the Black Powder, still warm from the tumbling, is tumbled a while longer together with the graphite. A test which has been used since ancient times to determine the quality of black powder is carried out by dumping a small sample onto a cold flat surface and setting fire to it. A good powder ought to burn in a flash and leave no "pearls" of residue, or globules of fused salts. A solid residue indicates that either the ingredients have not been incorporated intimately enough to begin with, or that the powder has at some time in its history been wet, causing the saltpeter to crystallize out of the mixture, forming large crystals which undo the effects of all that processing meant to intimately incorporate the three ingredients. [On a related note, gunpowder was also used in a crude test of the alcohol content of "spirits." As defined by the U.S. Government, "proof spirit" (i.e., 100 proof alcohol) is a spirit containing 50 percent by *volume* of ethyl alcohol and 50 percent water — and 200 proof alcohol is 100 percent ethyl alcohol. The term "proof-spirit" is a relic of the days when there was no ready method of

determining the alcohol content of liquors, and so those wishing to determine this poured a little of the liquor under question onto a small heap of Black Powder and attempted to light it. A spirit was considered "under proof" if it contained so much water that gunpowder moistened with it refused to burn, and was called "over-proof" if it did not prevent the ignition of gunpowder. Thus, "proof-spirit" was a spirit of such a strength that it barely allowed gunpowder dampened with it to burn, the addition of a very small amount of water rendering the spirit "under-proof."]

From the foregoing discussion, it should be clear that it is far better to purchase commercially-manufactured Black Powder than to try to make it oneself. If the goal is to make an explosive on the spur of the moment, **Flash Powder** [of which the formula appears later on] is a far better choice than Black Powder. It is easy to make successfully, and pound-for-pound, it is not only far more powerful than Black Powder, but is even more powerful than dynamite — although it is useless as a projectile propellant for it would blow apart the barrel of any gun or mortar it was set off in. Nevertheless, there are applications for which there is no substitute for Black Powder — notably, as a pyrotechnical shell propellant, and in fuses and pyrotechnical priming — and so it may at times be necessary to make Black Powder at home or in the field. For this reason, I am including here the Field-Expedient procedure for making Black Powder which appears in the (CIA's?) *Improvised Munitions Black Book, Volume 1*. [When Black Powder is needed, I am afforded the convenience of purchasing commercial grade Black Powder from muzzle-loader shops or pyrotechnicians' conventions, so I have never put this procedure to the test]:

How to Make Black Powder (Field-Expedient Method):

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1. Place 5 pints (or else 2.5 liters) of any kind of alcohol (whiskey, rubbing alcohol, etc.) into a 2 gallon (or else 7.5 liters) capacity bucket.

2. Into another 2 gallon (or else 7.5 liters) capacity bucket — this one must be *heat-proof*, such as a metal bucket — put 3 cups (or else 0.75 liter) of granulated potassium nitrate, 2 cups (or else 0.5 liter) of powdered wood charcoal, and ½ cup (or else 0.125 liter) of powdered sulfur. Now add 1 cup (or else 0.25 liter) of water and mix thoroughly with a wooden stick until all ingredients are dissolved.

3. Add 2 more cups (or else 0.5 liter) of water to the mixture produced in step 2. Place the bucket on a heat source and stir until small bubbles begin to form.

[CAUTION: Do not Boil the mixture. Make sure *all* the mixture stays wet. If any is dry, as on the sides of the bucket, it may ignite.]

4. Remove bucket from heat and pour the mixture into the other bucket — the one containing the alcohol — while stirring vigorously.

5. Let alcohol mixture stand about 5 minutes. Secure a cloth measuring at least 2 feet square (or else 0.6 meters square) over the lip of the empty bucket so that the cloth acts as a filter. Strain the mixture obtained in step 4 through the cloth to obtain black powder. Discard the liquid. Unfasten and wrap the cloth around the black powder and squeeze to remove all excess liquid.

6. Dry one of the buckets and place a flat window screen measuring at least 1 foot square over it. Place a workable amount of the damp black powder on the screen and granulate it by rubbing the solid through the screen and catching the granules in the bucket. [NOTE: If granulated particles appear to stick together and change shape, recombine the entire batch of powder and repeat steps 5 and 6.]

7. Spread granulated Black Powder on flat dry surface so that a layer about ½ inch (1.25 cm) thick is formed. Allow the powder to dry. Use radiator or direct sunlight. This should be dried as soon as possible, preferably in one hour. Owing to the growth of potassium nitrate crystals during drying, the longer the drying period, the less effective the black powder. [CAUTION: Remove from heat *as soon as granules are dry*. The Black Powder is now ready for use.]

How to Make Meal Powder and Pyrotechnical Priming:
Pyrotechnical Priming is a Black Powder slurry, which, if coated onto a cotton string and allowed to dry, produces a fuse known to pyrotechnicians as *Raw Match* or *Black Match*. Pyrotechnical priming can also be coated onto anything that one wishes to burst reliably into flame as soon as it is subjected to the merest spark. For example, the ends of pyrotechnical time fuses are often dipped into this priming (in lieu of cross-matching), to ensure reliable ignition from the momentary flash of the lift charge, and the "stars" of pyrotechnical shells are often coated with priming if their composition is difficult to light, or if an intended "hard break" threatens to "blow the stars blind." In order to make pyrotechnical priming, start by grinding commercially-manufactured Black Powder (*not* nitrocellulose gunpowder) in a mortar and pestle (or simply tumble the Black Powder for a day or so in a lapidary tumbler loaded with lead — or other non-sparking — balls). The result will be an ultra-fine grade of Black Powder known to pyrotechnicians as *Meal Powder*. (NOTE: If using the ball-mill or lapidary tumbler method of trituration, keep all life-forms, including yourself, far away from the tumbler while it is in operation, for any

spark which might for any reason occur within the barrel of the tumbler would turn it into a shrapnel-hurling bomb. This could ruin one's whole day!)
Now, to make pyrotechnical priming, take 11 parts (by weight) of this Meal Powder, add 1 part (by weight) of yellow Dextrin, stir well to blend these, and then add water, a little at a time, with continuous stirring, until a thick black slurry results. The consistency is important. The black goo should be liquid enough to smoothly coat anything that is dipped into it, but solid enough so that it doesn't drip off whatever it is coated onto. Save priming in a closed air-tight container to prevent it from drying out. This slurry can be used to make fuses in the manner described in the next two paragraphs.

How to Make Raw Match (also known as Black Match) Fuse:
Raw Match (a.k.a. Black Match) is a type of fuse which burns at the rate of around 1 inch per second (or around 2.5 centimeters per second). Because this type of fuse is not water-resistant, and the Black Powder priming crumbles off easily when the fuse is flexed or handled, Raw Match is used as such mostly for cross-matching pyrotechnical time-delay fuses to ensure reliable ignition of the delay fuse from the flash of the lift charge (this is done by making a hole through the thick waterproof time delay fuse on either end of its length, and inserting a piece of Raw Match through each of these holes.) After it is made, most Raw Match is used for making *Quick Match*, which is the fuse most used in the display fireworks industry [the method for making Quick Match appears under the next heading.] Raw Match is made by coating thick (about 1/8 inch) cotton string with Black Powder pyrotechnical priming, or by coating many small strands of cotton string and then braiding or twisting them together. This latter "multi-strand" method is the better of the two, for it gives a fuse which burns more fiercely because the priming is coated on both the outside *and* the inside. To make Raw Match fuse, begin by boiling the desired length of cotton string for about five minutes (in water) in order to remove any of the moisture-resistant coating that some varieties of string have. Then, while it is still wet, tie one end of the string to a nail that is placed about waist-high and run the string to another similarly placed nail about 30 feet away. Do this with as many lengths of string as needed. Put on some rubber gloves and take a good handful of Black Powder priming which has had enough water added to it to make it about the consistency of thin mud. The consistency is important. It should not be so thin that it runs easily out of the hand, nor should it be so thick that it goes on unevenly or too heavily on the string. With your other hand (the clean one) hold the bucket or pan of priming slurry under the string as it is being coated, so as to catch any drippings, and then walk backward from one end of the string to other as you coat it by letting the string run through the priming in your hand. Water may have to be added from time to time to the priming to keep the consistency thin enough, as the string soaks much of the water from the priming (and this is the reason for having the string as wet as possible before the priming is applied.) If the weather is dry, in a day or so the Raw Match will be dry enough to be cut into sticks (and wrapped in stiff paper to guard against flexure), or made into Quick Match fuse.

How to Make Quick Match Fuse:
Quick Match is the most-used type of fuse in the display fireworks industry. It burns with explosive rapidity — at a rate of more than 20 feet per second — and it is used as the fuse leader of every pyrotechnical shell that is hand-fired (as opposed to electrically-fired), and is extensively used for *finale-chaining*, that is, for fusing together that sequence of shells (mostly salutes) which is rapidly fired in machine-gun fashion at the close of every traditional fireworks display. Quick Match is made by simply enclosing Raw Match in a paper tube called a "pipe." Match piping serves the dual purpose of protecting the friable, moisture-sensitive Raw Match as well as making it burn much faster. The last 3 inches of a Quick Match fuse are left bare (but kept covered with a "safety cap" until just before use) so that when it is lit these first three inches of Raw Match take three seconds to burn to the piping. Once the flame reaches the piping, each burning cinder of Black Powder priming gets shot ahead, in rocket fashion, along the inside of the paper pipe, lighting the Black Powder there, which in turn gets rocketed ahead to light Black Powder further down the pipe, and so on. The end result is that, when the slowly-advancing flame of the uncovered Raw Match reaches the piping of a length of Quick Match, the piped length of the fuse seemingly disappears all at once in a puff of smoke and a spray of glowing embers. To make Quick Match, begin by making match pipe by dry-rolling 3 or 4 turns of paper (Kraft, Manila or even newspaper) around a dowel ¼ inch (circa 6 millimeters) in diameter and securing it with a little paste (so that it doesn't unroll). The longer the paper pipe is made, the harder it is to roll, but the less of them need to be joined together later on. Three-foot lengths offer a reasonable compromise. These may be easier to roll if they are rolled at a slight spiral. Finally, slip these paper match pipes over the 30-foot lengths of Raw Match, still strung between two nails, joining these three-foot paper pipes together into a continuous paper envelope which encloses the entire length of the Raw Match. Whenever two pipes must be joined, crease or gather the end of one pipe so that the next pipe may be slipped over it with about an inch of overlap, before pasting the pipes together. The best commercially-made Quick Match has a braided multi-strand core of Raw Match, and the match piping is a double-layer, with wax paper on the inside (to offer moisture-resistance) and Kraft paper (the kind that paper grocery bags are made out of) on the outside.

How to Make Flash Powder:
Flash Powder is the explosive powder used to make cherry bombs, M-80 salutes, and the aerial salutes used in professional fireworks displays — those shells in which a blinding flash of white light is followed by a tremendous concussion that can be felt in the pit of the stomach. Pound for pound, Flash Powder is more powerful than dynamite, and the truth of this assertion was demonstrated at a past Pyrotechnicians' Guild International Convention: Two identically-constructed plywood shacks resembling out-houses were erected in an open field. In one was placed a pound of dynamite, and in the other was placed a zip-lock plastic bag containing a pound of loose Flash Powder. The shack containing the dynamite was leveled rather dramatically when it was set off remotely, but

the shack containing the Flash Powder charge was blown to smithereens in a much louder blast, accompanied by a huge cloud of white smoke. Despite being superior in power not only to Black Powder, but even to dynamite, Flash Powder is quite simple to make, but it must always be treated with extreme caution, for it is far more dangerous to handle than dynamite. This is not only because of Flash Powder's superior brisance, but also because dynamite is a *high explosive*, which means that it requires the triggering explosion of a detonator to set it off, while Flash Powder is a *primary explosive*, which means that the slightest spark, even static electricity, can set it off. Flash Powder can be made from two simple ingredients (although two other ingredients are optional.) Before they are combined, each of these ingredients is safe, but once they are combined, watch out! As with Black Powder, (which, incidentally, is classified as a *low explosive*, or *propellant*,) the physical state of the chemical components of Flash Powder is absolutely crucial. Each must be an ultra-fine powder, and each ingredient may require days of tumbling in a ball-mill or lapidary tumbler with non-sparking grinding balls (but *separately*! Mixed Flash Powder must *NEVER* be ground or milled, or a horrendous explosion may be the result). Always keep in mind that in pyrotechnics, as in skydiving, rock-climbing, and high-voltage experimentation, *you aren't allowed to make even a single mistake*. Before attempting to make Flash Powder, one would be well advised to become thoroughly educated in the chemistry of explosives, and in the many things that can lethally go wrong when dealing with them [a good way to start is by reading Bill Ofca's *Fireworks Safety Manual*, as well as *Bill Ofca's Technique in Fire, Volume 1, Concussion Sound: All About Aluminum, Flash Powder, and Aerial Salutes,* (B&C Products, Inc., 66 Holt Road, Hyde Park, NY 12538)] Besides being inherently dangerous, the manufacture of an explosive such as Flash Powder — except in licensed bunkers in remote locations — is also punishable by law. It would seem that people take a dim view of the prospect that their entire neighborhood might be taken out by some private experimenter's slip-up, or by the malicious act of a madman. This seems understandable — after all, one may have the right to risk one's own life, but one does not have the right to risk the lives of others. In view of all these facts, I cannot recommend that anyone reading these words should attempt to make flash powder. I would feel terrible if the knowledge that I imparted were to be used in a way which resulted in the loss of anyone's life, limbs, or liberty. But knowledge is power, and many violent unscrupulous people already have this knowledge, so I feel it is my duty to balance the scales by empowering with the same knowledge the gentle intellectuals that would gravitate to this web-site. Here, then, is the procedure for making Flash Powder:

1) Purchase about 500 grams of ultra-fine Aluminium [Al] powder. The state of division of this component of the Flash Powder is absolutely critical. If an aluminium powder looks silver or even light in color, it simply will not produce a gut-thumping Flash Powder. The aluminium should be of a kind designated by the vendor as *German Black*, or *German Made Blackhead*, or *Dark Pyro* aluminium having a particle size of 400-800 mesh (or about 2 microns). The darker the aluminium

powder, the finer it is, and the finer the aluminium powder you use, the bigger the bang.

2) After purchasing 1 kilogram of Potassium Perchlorate [$KClO_4$], prepare it for use in Flash Powder by adding to it 1 gram of Cab-O-Sil (fumed silica anti-caking agent), and then ball-milling these together for about 30 hours in the *clean* barrel of a ball mill or rock tumbler with 100 or so 1-inch-diameter milling balls made of a non-sparking substance, such as lead, lead/antimony alloy, or ceramic. This will reduce the Potassium Perchlorate to an ultra-fine powder. [NOTE: if this step is omitted, the performance of the Flash Powder made from the un-milled oxidizer will be pathetic.]

3) If you choose to use sulfur [S] in the Flash Powder, make sure that you purchase *sulfur flour* **not** *flowers of sulfur*, for the later is much more acidic than the former, and makes the Flash Powder even more unstable, and hence, even more dangerous. Add 1 gram of Cab-O-Sil (fumed silica anti-caking agent) per 1000 grams of sulfur, and ball-mill these together for at least 10 hours in a lapidary tumbler, with milling balls made from a non-sparking substance, such as lead, lead/antimony alloy, or ceramic. [NOTE: it is claimed by some that the addition of sulfur makes Flash Powder more explosive, but it can also theoretically make it more *unstable* — possibly detonating from friction or rough handling. The use of sulfur in Flash Powder is entirely optional, though — I have made Flash Powder both with sulfur and without it, and tested equal quantities of the two formulas in aerial salutes fired in rapid succession, and I was not able to detect any difference in the concussion. Therefore, my conclusion was that if sulfur makes the Flash Powder more dangerous to handle, but does not add noticeably to its performance, why bother using it?]

4) Choose a location that is far removed from people and things that you wouldn't want to take with you, if you should blow yourself up. Set up a table there, and, unless it is quite humid, spray both the table and yourself with an anti-static spray (such as Static Guard.) Spread a large (1 meter square) sheet of heavyweight Kraft paper on the table, taping the corners down if necessary.

5) Weigh out 7 parts (by weight) of ultra-fine (ball-milled) Potassium Perchlorate [$KClO_4$] and dump this into a strainer, sifting the white powder evenly over the entire surface of the Kraft paper.

6) Now weigh out 3 parts (by weight) of ultra-fine German Black Aluminium powder [Al] and dump this into the same strainer, sifting the dark grey or black powder evenly over the white Potassium Perchlorate powder which covers the entire sheet of Kraft paper.

7) If you wish to omit the Sulfur from the Flash Powder, [it really isn't needed] skip to step 8. On the other hand, if you'd like to make sulfur-bearing Flash Powder, weigh out 1 part (by weight) of ultra-fine (ball-milled) Sulfur [S] and dump this also into the strainer, sifting the yellow powder evenly over the perchlorate-and-aluminum-covered sheet of Kraft paper.

8) If you wish to make *basic* Flash Powder (which produces a short-lived brilliant flash of white light followed by a gut-thumping concussion, but no sparks,) skip to step 9. On the other hand, if you'd like to make *Titanium-Enhanced* Flash Powder (the kind used in making *Titanium Salutes*, in which a slightly-longer-lasting burst of bright sparks is thrown from the short-lived Flash Powder blast), weigh out 0.5 parts (by weight) of Titanium [Ti] particles and sprinkle these evenly over the entire surface of the Kraft paper, which by now is laden with powders. The Titanium used should be in the form of particles designated by the vendor as *Titanium Sponge*, usually available to pyrotechnicians in 8-16 mesh, and in 20-40 mesh particle-size ranges. The 8-16 mesh particles should burn longer. Adding Titanium of such large particle-size to the Flash Powder will produce a burst of bright sparks that burn long enough to be seen after the initial blinding flash of the Flash Powder explosion. However, owing to the Titanium's potential for sparking if handled too roughly (say, by scraping against metal) the Titanium theoretically makes the Flash Powder more sensitive to impact and friction, and hence more dangerous to handle. The use of Titanium is entirely optional — it may be omitted from the Flash Powder without loss of explosive power. There just won't be any sparks. The most prudent course of action also allows for the most flexibility: simply make the Flash Powder *without* the Titanium, and if a Titanium Salute is required in the future, at the last moment spoon a teaspoon of sponge Titanium into the (3-inch) shell just before sealing it.

9) The powders covering the entire Kraft paper sheet on the table are now ready to be mixed by the approved method used throughout the explosives industry — for it is the safest known way to thoroughly mix sensitive explosives — it is a method called the *diaper method* (perhaps because the Kraft paper is manipulated like the folding of a diaper, or perhaps because the person doing the mixing may feel he may be needing a diaper if he continues to think of what would happen if somehow a spark found its way to the table!) The diaper method of mixing explosives proceeds as follows: Grab one corner of the Kraft paper sheet covered with powder, and pull it diagonally across the center of the sheet causing the powder to gently roll and shear in a line well past the center of the sheet. Now grab another corner of the Kraft paper sheet and repeat this rolling and shearing of the powder across the center of the sheet in another direction. Do this repeatedly in all directions until the powder seems homogeneously mixed. If any white lumps of Potassium Perchlorate remain, try to crush them gently with pressure from your finger. If they are not easily crushed in this manner, remove them from the sheet. If streaks of white persist, increase the shearing action by

pressing down gently on the back of the Kraft paper with your hand as you roll the powder under it. Continue the rolling and shearing until you are left with a homogeneous grey powder. Congratulations, you have just made Flash Powder — handle it gently and keep it from sparks, for you are now in grave peril!

10) Roll the Kraft paper sheet into the form of a funnel and — while being careful not to inhale the rising cloud of dust (it's not poisonous, but powdered metal in your lungs or eyes is never to be recommended) — carefully pour the Flash Powder into a paper container such as that in which "Quaker Rolled Oats" are sold. Such a container is regarded as the least likely to generate sparks, whether through scraping or through static electricity, and if worse comes to worst, an explosion will not produce shrapnel. Put the "Quaker Oats" Paper cylinder filled with Flash Powder inside a large seal-able plastic bag (possibly with the desiccant canister from a vitamin bottle) in order to protect the powder from moisture, and finally place this into a seal-able plastic pail to prevent any sparks from reaching the powder. Any time you handle Flash Powder, be sure to spray the work surface — and yourself — with anti-static spray, and be ever-mindful of any possible sources of sparks (keep asking yourself questions like: "What if that halogen lamp over the table were to shatter, as they sometimes do, and the hot tungsten filament were to fall onto this pile of Flash Powder?") If you must work with Flash Powder (as professional pyrotechnicians and special effects developers sometimes must) do so away from people and property, keep Murphy's Law firmly in mind at all times, be ever thoughtful and vigilant, and be ready at all times to sacrifice your life in order to save others.