CHAPTER 1

In Pursuit of Energy and Energetic Materials

1.1 Introduction

In Hindu mythology, “energy” has been given a place of pride. Similar to Greeks who deified the qualities of love and valor, Hindus deify energy (*Shakti*) as Goddess *Kali*. The existence of life on the Earth is unthinkable in the absence of sources of energy and energy-giving materials. Since the evolution of human civilization, man has been in tireless pursuit of sources that provide him more energy for livelihood, comfort, and advancement. Evidently, the first “energetic” material that the prehistoric man used was firewood that burned (or underwent combustion in a more scientific parlance) to provide him the source of heat with which he could cook meat and vegetables for more palatable consumption. It is interesting to note that since the commencement of civilization, until a few centuries back, firewood was the main fuel for providing energy to man.

The discovery of coal helped him to make giant leaps in the process of industrial advancement. With the advent of oil hardly two centuries back, the very pattern of life all over the world has radically changed. Today, oil is the lifeline of modern living. Despite the possibility of using nuclear energy and other nonconventional sources of energy, such as solar energy, tidal energy etc., oil still rules the roost and one is justifiably worried about what would happen, say, after a century or so when the indiscriminate tapping of this fossil fuel from the mother earth will leave our posterity high and dry.

1.2 Gunpowder to Nitrocubanes

The so-called energetic or energy-giving materials mentioned in the preceding paragraph viz. firewood, coal, and oil are actually fuels. Unless oxygen from air is available to them, they do not burn and give the energy in the form of heat. However, man, who, with his inborn aggressive instinct has caused several wars, was not to be satisfied with fuels such as the above, which he thought could be reserved only for cooking, illumination, and other similar activities. To advance from the arrow-bow-spear-sword warfare, he wanted something that would propel a harmful projectile, preferably through a barrel, at his

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enemy. The first material that met such a need was gunpowder, which, as we all know today, is a physically intimate mixture of finely ground potassium nitrate (KNO_3; 75%), charcoal (carbon, 15%), and sulfur (10%). Here was something that did not depend on atmospheric oxygen because most of the needed oxygen for combustion came from oxidizer KNO_3. It was in the fourteenth century that the monk Berthold Schwarz invented a gun and used black powder for propelling stones from it. This discovery of the usefulness of black powder for accomplishing mechanical work may be considered as the real beginning of the history of explosives. It was only required to simply load the gunpowder in the cannon and ignite it so that the high-pressure gases produced would propel the cannon balls on to the enemy. The various decomposition reactions of gunpowder are as follows:

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

$$4KNO_3 + 7C + S \rightarrow 3CO_2 + 3CO + 2N_2 + K_2CO_3 + K_2S$$

More than 1000 years back, Chinese appeared to have invented gunpowder mainly for the purpose of fireworks. During the year 1250, Roger Bacon described the constituents of gunpowder, but its first use in guns was made by the British in the year 1346 at the Battle of Crecy. Many wars of the eighteenth and nineteenth centuries are reported to have been fought with gunpowder playing a key role. Rockets using gunpowder were used against Napoleon’s army between 1803 and 1815. Tippu Sultan, a king from South India, is reported to have inflicted heavy casualties on the British Army in several battles using gunpowder. We should note that in all of these cases, the gunpowder was used only as a propulsive material.

The explosive property of gunpowder was reported by Roger Bacon in the thirteenth century and was rediscovered by Shwarz in Germany in the fourteenth century. During the seventeenth century, the explosive property of gunpowder was used for quarrying purposes in Europe. It must be remembered that gunpowder is basically a “deflagrating” (i.e., fast, layer-by-layer burning) material and at certain conditions (e.g., confinement), the deflagration gets converted into violent “detonation” (i.e., explosion accompanied by destructive shock wave).

The use of gunpowder was a messy affair. It was dirty to handle; it fouled the gun barrels; it was unpredictable in performance; and, above all, it produced so much smoke and flash that the enemy had no problem in locating the position of the gun. Therefore, there was a search to make a “smokeless propellant.” One route was to prepare compounds in which a single molecule had the “oxidizer” element, “fuel” element, and the energy-giving moiety. There would not be any need for mixing oxidizers and fuels to achieve propulsion. In the middle of the nineteenth century, chemistry had considerably advanced in Europe, and the chemists concentrated their efforts to produce compounds

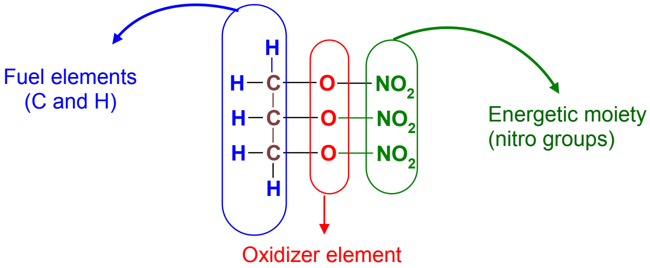
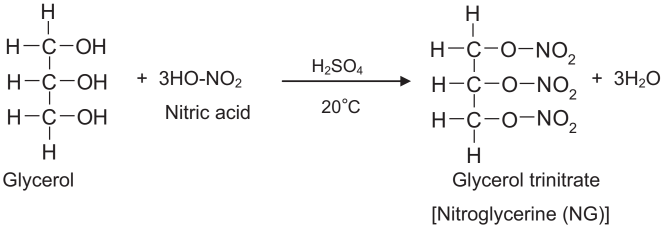


Figure 1.1
Molecule of Nitroglycerine (NG).

that would satisfy this three-in-one requirement. They nitrated several organic compounds to get their nitrato or nitro products. Nitrocellulose (NC), nitroglycerine (NG), and trinitrotoluene (TNT) were some of the products that could serve their purpose. For example, in a molecule of NG (obtained by the nitration of glycerine), we have the fuel elements, oxidizer element, and the energy-giving (or energetic) moiety viz. nitro groups as shown in Figure 1.1.

[The nomenclature "nitroglycerine" is a misnomer. Basically, NG contains three nitrate ($-O-NO_2$) groups and should be actually called "glyceryl trinitrate," produced by the esterification of glycerol by nitric acid (HNO_3). Likewise, NC is, in fact, cellulose nitrate].

NG is prepared by slowly adding glycerol to a mixture of HNO_3 and sulfuric acid (H_2SO_4) maintained at 20 °C.



The NG molecule does not depend on external oxygen. On the other hand, it has a slight excess of oxygen after oxidation of carbon and hydrogen to carbon dioxide (CO_2) and water (H_2O), respectively.

$$4C_3H_5(NO_3)_3 \longrightarrow 12CO_2 + 10H_2O + 6N_2 + O_2 + \text{heat}(1467\ \text{kcals})$$

Such a substance that has excess of oxygen after combustion is said to have a positive oxygen balance.

One of the earliest explosives synthesized was NC (see Figure 1.2). During the 1830s, NC was synthesized by the nitration (using a mixture of conc. HNO_3 and conc.

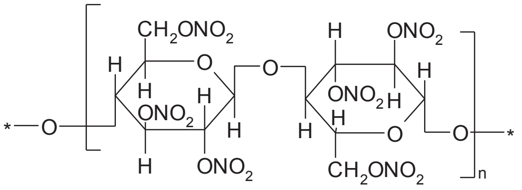


Figure 1.2
Structure of Nitrocellulose (NC).

H_2SO_4) of cellulose, a well-known natural polymer and a main constituent in plants. *NC is a fibrous high explosive and is dangerously sensitive in dry conditions.* NC needs to be stabilized after its preparation by proper chemical treatment. Otherwise, traces of acids and other byproducts accelerate its decomposition. In the middle of the nineteenth century, several disastrous explosions occurred in factories and storage houses because of the unstabilized NC. In 1866, Abel published his research work on the stabilization of NC. In 1884, the French scientist Vielle "gelatinized" NC by partly modifying its fibrous nature using a mixture of ether and alcohol so that it could be used as a reasonably insensitive "propellant powder" for manufacture and handling.

Synthesis:

$$\underset{\text{Cellulose}}{C_6H_7O_2(OH)_3} + \underset{\text{Nitric acid}}{3HNO_3} \xrightarrow{H_2SO_4} \underset{\text{NC}}{C_6H_7O_2(NO_3)_3} + 3H_2O$$

On explosion, NC gives carbon monoxide (CO), CO_2, H_2O, nitrogen, and heat as follows:

$$2C_6H_7O_2(NO_3)_3 \longrightarrow 9CO + 3CO_2 + 7H_2O + 3N_2 + \text{heat}$$

The modern era in the history of explosives began in 1838 with the preparation of NC by Pelouze by nitrating paper-based cellulose, but it was not until 1846 that its explosive properties were known. Similar to black powder, it was at first used for propellant and blasting purposes. In 1847, Ascanio Sobrero prepared NG, a powerful liquid explosive. NG was found to be extremely sensitive to shock, and Sobrero probably thought that the best thing was to put it under a lid and forget about it. However, after approximately 15 years, Alfred Nobel (1833–1896), the Swedish scientist, a prolific inventor and a philanthropist, opened that lid and started his struggle with NG. Despite its great hazard, he had the vision to realize its great potential and unshakeable confidence that one day he would tame it. (Alfred's tenacity was unbelievable. In an accident related to his work on detonators, his younger brother was killed and his father died heart-broken. However, Alfred never relented and carried on with his research and development in detonators). NG (nitroglycerine) is a dangerously sensitive material when it undergoes even mild impact. Kieselghur was found to be the first inert material, which when mixed with NG could desensitize NG, by taming its sensitivity. Dynamite was the first substance using NG that could be safely and conveniently handled. After a lapse of approximately 135 years, dynamite is still used for certain civil applications. A more startling discovery by Nobel followed when he mixed sensitive NG with sensitive NC and got an insensitive, gelatinized dough. This gelatinized material was found to be a powerful blaster and accordingly called "blasting gelatin." This discovery paved the way for the development of many blasting explosives (dry NC can absorb up to 11.5 times its weight of NG; accordingly, blasting gelatine has a composition of 92% NG and 8% NC). In 1888, Nobel developed the first "smokeless powder" (called ballistite) for military application in place of gun powder. It was a mixture of NC and NG (called "double-base") and substances such as camphor, which acted as plasticizers. Prolific inventions by Nobel resulted in many patents to the credit of this genius who revolutionized the explosives industry. He accumulated a huge fortune and it is common knowledge that the prestigious Nobel Prizes are given as a result of this fortune.

From the middle of nineteenth century, many explosives and energetic ingredients have been synthesized. Appendix A gives the important milestones in the history of development of explosives and propellants. During the last 150 years, with great strides made in the field of chemistry, physics, instrumentation, and computers, we have come a long way in the field of explosives and propellants. Scientists are constantly on the hunt for better and better candidate molecules with regard to energy content, rate of release of energy, density, and other parameters so that they can be used for futuristic explosive compositions or as propellant ingredients.

The pursuit that started with gunpowder some centuries back is still very much on. The targets are presently molecules that have a highly strained structure, have maximum density, and contain energetic groups. One such molecule that has been recently synthesized is octanitrocubane (Figure 1.3).

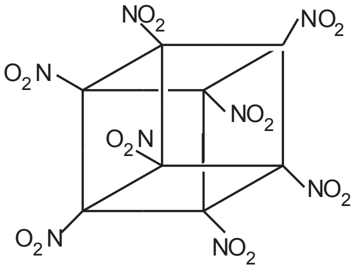


Figure 1.3
Octanitrocubane.

The advancing techniques of modern warfare lead to more and more specialized requirements for explosives and propellants. We will see in greater detail about such requirements in subsequent chapters.

1.3 Classification of Explosives

The term "explosives" has been defined in various ways and probably the most accepted definition is as follows: "An explosive is a chemical or mixture of chemicals which, when suitably initiated, can react so rapidly and with such liberation of energy that there can be damage to the surroundings." The explosives can be classified in two different ways:

1. High explosives or detonating explosives (subdivided into primary explosives and secondary explosives)
2. Low explosives or deflagrating explosives (propellants)

Propellants that propel a projectile from a pistol, mortar, or gun fall under the category of low explosives. They deflagrate layer by layer at a predetermined rate evolving a large amount of high-pressure hot gases that do the trick of propelling the projectile. Rocket propellants that cause the self-propulsion of a rocket are also referred to as low explosives.

Primary explosives are quite sensitive to initiation by mechanical impact, flame, or spark. Among high explosives, secondary explosives such as TNT and RDX (research and development explosive) detonate with violence, causing a high-velocity shock wave and blast effect. They are fairly insensitive and need to be initiated by primary explosives such as certain metallic azides. Although they are not as powerful as secondary explosives, primary explosives have enough power to detonate a secondary explosive on initiation.

The second type under which explosives can be classified is based on their end use viz. military explosives and civil explosives (sometimes referred to as commercial explosives). The requirements, properties, and cost are quite varied between these two categories of explosives. The important requirements of *military explosives* are presented in the following subsections.

1.3.1 Maximum Power per Unit Volume

This implies that a given volume of a high explosive (e.g., in a shell or warhead), on detonation, should produce high-pressure and high-temperature gases in such a way that they do maximum work (of expansion) per unit time.

1.3.2 High Velocity of Detonation

Velocity of detonation (VOD) is the rate at which the shock wave front travels in the medium of an explosive. This is a vital parameter for most of the military explosives because it is directly proportional to the shattering effect of the detonation (e.g., in a grenade) and the jet velocity in shaped charges. It is measured in units of kilometers per second or meters per second (e.g., VOD of RDX is 8.850 km/s).

1.3.3 Long-Term Storage Stability

Wars are not an everyday affair. In times of peace, all of the explosives-filled ammunitions are under storage over long periods of time—sometimes for a few decades. For this purpose, one cannot choose an explosive that deteriorates in stability within a few years. Therefore, military explosives should have long-term stability over a wide range of temperatures (e.g., from −40 °C to +60 °C).

1.3.4 Insensitivity to Shock and Impact

Explosives should go off when they are supposed to go off (reliability), but they should not go off when they are not supposed to go off (safety). Hence, this is an important safety-related requirement for any military explosive at various stages of handling and transport.

1.3.5 Ability to Withstand Large Accelerations

The high explosives filled in ammunition have to encounter huge accelerations (e.g., in the bore of a gun accelerations up to 40,000 g may be experienced) or negative accelerations (e.g., in the penetration by an armor-piercing shell through an armor plate). It should be ensured that the HE (high explosive) filling should not be initiated by such acceleration or deceleration.

In sharp contrast to military explosives, civil explosives do not generally require high VOD or too high of a blast effect. In fact, a high-VOD explosive may prove to be disastrous in certain civil applications such as coal mining in which the high-velocity shock waves might result in adiabatic compression and the initiation of the marsh gas (methane) present in the coal mines. The "power" of the explosives or explosive compositions can be tailored by adjusting the composition to suit the needs.

Cost is a dominant factor in civil explosives. One cannot afford to produce a costly civil explosive simply because it will not sell. A coal-mining magnate may simply ask you "What is the cost of your explosive needed to mine 1 ton of coal in the required range of lump size?"

Unlike military explosives, the shelf life of civil explosives is not very critical. After all, they are fast-moving items, and one might talk of shelf life of 6 months or 1 year versus 20 or 25 years for a military explosive.

1.4 Explosives and Molecular Structure

Why are only some compounds explosives whereas many others are not? Only in some compounds, the molecules are

1. having a huge potential energy packed in them (which is related to their heats of formation, a topic that will be discussed in the Chapter 2);
2. in a *meta*-stable state, implying that they need only a small amount of trigger or activation energy to initiate them for the release of the dormant potential energy in a very short time.

Because this is basically a molecular phenomenon, a relationship does exist between the molecular structure and the explosive property.

It was proposed that an explosive molecule has in its structure certain groups that are responsible for their explosive property (e.g., $-ONO_2$, $-NO_2$, $N\text{-}NO_2$, $-ClO_4$, $-N_3$, etc.). These were called "explosophores" (similar to "chromophore" groups such as an azo group that imparts color to a dye). Paul W. Cooper in his book *Explosives Engineering* talks about four different substituent groups found in explosives viz.

1. Oxidizer contributor (e.g., $-ONO_2$, $-NO_2$, $-NF_2$)
2. Fuel contributor (e.g., alkyl, $-NH_2$, $-NH$)
3. Combined fuel-oxidizer contributor ($-ONC$: fulminate, $-NH\text{-}NO_2$: nitramines)
4. Bond-energy contributor (e.g., $-N_3$: azides), which contributes energy to the detonation process when their high-energy bonds are broken.

If we take the above combinations, there must theoretically be thousands of explosives (particularly organic) available to us. However, the actual number of explosives being used or pursued is severely restricted by several factors, such as thermal stability, sensitivity, chemical compatibility, toxicity, and explosive output of the finally synthesized explosive apart from the cost and feasibility of the synthesis.

In terms of molecular structure, the explosives can be classified as shown in Figure 1.4.

1.5 Classification of Propellants

Propellants are defined as low explosives or deflagrating explosives. Such a definition is rather loose because the roles of a deflagrating explosive and detonating explosive can be reversed depending on the conditions. A propellant detonates under very high confinement and a high explosive such as RDX can be made to silently burn as a propellant ingredient. However, in this book, the term "propellant" will refer to those materials that burn (without the help of external oxygen) layer by layer at a predetermined or predictable rate evolving high pressure and hot gases.

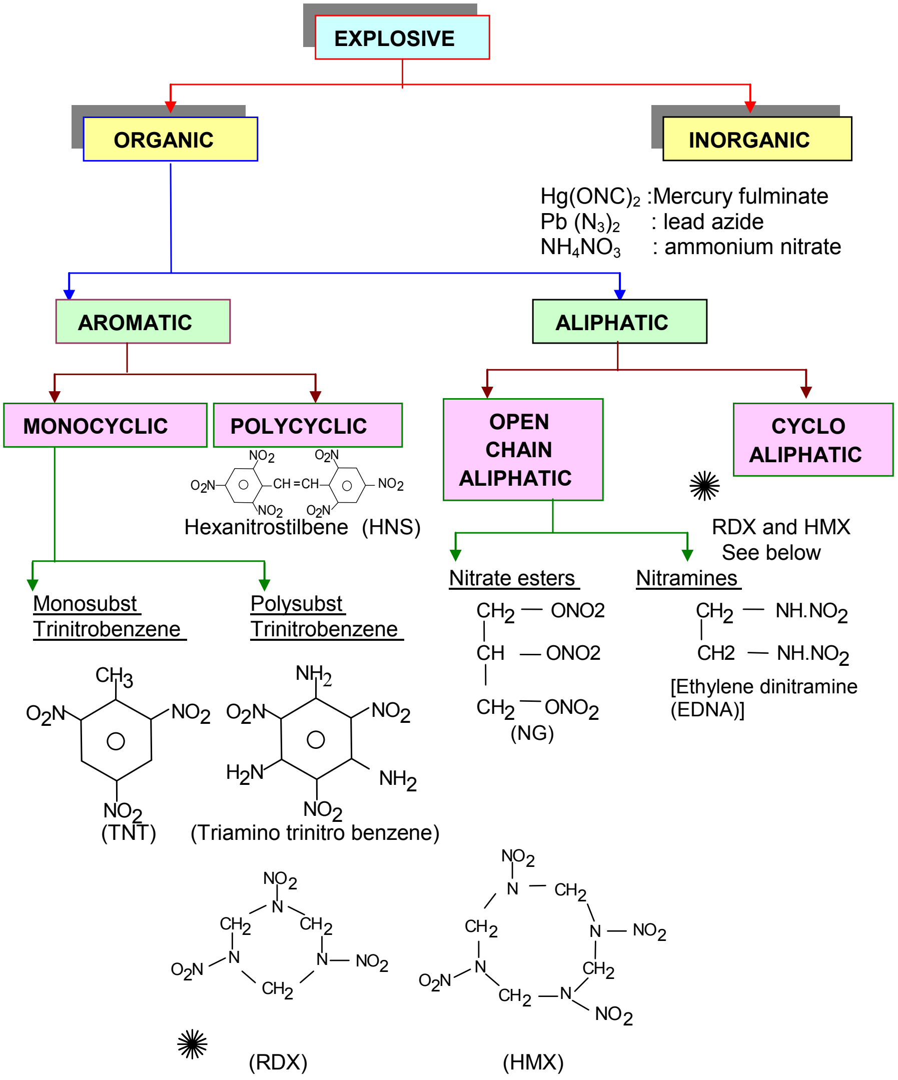


Figure 1.4

Classification of Explosives on the Basis of Their Molecular Structure.

Over the years, the field of propellants has grown vastly in terms of variety, application, and technology. The propellants can be classified based on either where they are going to be used (rockets or guns or small arms) or the chemical composition (i.e., single-base propellants containing mainly NC; double-base propellants containing NC and NG; and triple-base propellants containing NC, NG, and nitroguanidine; composite propellants containing a solid inorganic oxidizer such as ammonium perchlorate (NH_4ClO_4; AP) dispersed in a polymeric fuel-binder matrix; etc.). The chemistry and technology of these

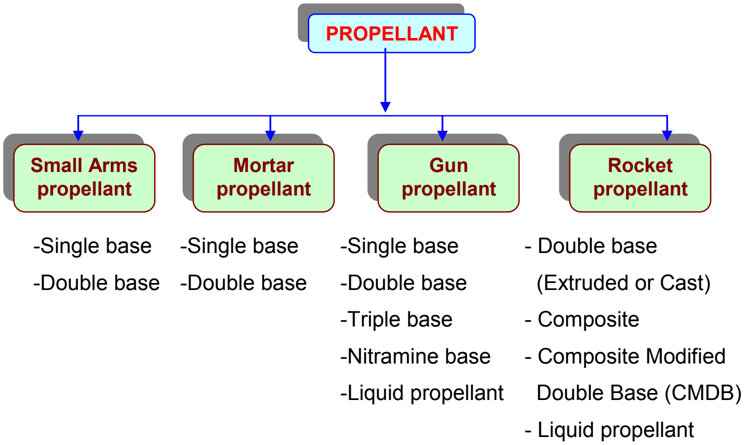


Figure 1.5
Classification of Propellants Based on Their End Use.

propellants will be discussed in subsequent chapters. A broad classification of propellants based on their end use is given in Figure 1.5.

1.5.1 Small-Arms Propellant

They are normally fine grains of propellants, mostly based on either single-base propellants (NC) or double-base propellants (NC + NG) including the so-called "ball powder." They are loaded in the cartridge cases meant for propelling bullets from rifles and pistols.

1.5.2 Mortar Propellant

Mortars are weapons used in warfare for propelling shells that are muzzle-loaded. Normally, there are two types of charges of propellant: primary and secondary. The most common composition is based on NC and NG, and the propellant is in the form of fine flakes of specified dimensions.

1.5.3 Gun Propellant

Gun propellants are also called "smokeless powders," a term that originated in the nineteenth century to distinguish the newly developed NC propellants from the traditional gunpowder. They are indeed largely smokeless on firing. Solid gun propellants mostly contain NC. In addition, conventional gun propellants consist of mixtures of one or more explosives with various additives, formulated and carefully processed to burn smoothly without detonating, under the conditions in which they are normally used. The essential required properties of gun propellants are as follows:

1. Minimal smoke or flash
2. Less toxic fumes
3. Long shelf life under all environmental conditions
4. Easy and rapid ignition
5. Low sensitivities to all other possible cause of initiation
6. Low flame temperature

1.5.4 Rocket Propellant

Rocket propellants provide a simple and effective way of creating propulsion for flight. The first true military use was by British troops in the eighteenth century against Indians. By 1805, Sir William Congreve had devised a system for the British, and these propellants provided an important military advantage in the following decade. By the start of World War I, such rockets, all powered by gunpowder, had become obsolete. Since then, the vital importance of rocket-powered weapons to attack on land, sea, and in the air has tremendously increased.

Basic information about the nature of composition and the application of various types of propellants is given in Table 1.1. The significance of the ingredients with respect to their chemistry and energetics vis-à-vis the final application will be discussed in the chapters on gun and rocket propellants.

1.6 Pyrotechnics

("Pyro" in Greek means "fire.")

The display of fireworks on festive occasions has been recorded in history, and the Chinese appear to have been the first to master the art of making and using pyrotechnics of this type several centuries back. The civilian use of fireworks for festivals and celebrations is on the increase all over the world (Figure 1.6) In India alone, several thousands of tons of fireworks and crackers are consumed on the day of Diwali (the light festival of India), submerging the entire country under a thick layer of pollutant gases of sulfur dioxide (SO_2), CO, CO_2, unburnt particulate suspension, etc., apart from the added effects of noise pollution.

Pyrotechnics have a multifarious and often a very vital role to play in military applications. Pyrotechnics are used to produce effects other than those produced by high explosives, initiating mixtures, and propellants. They produce light for illuminating or signaling purposes, heat required for an incendiary effect, smoke for signaling and

Table 1.1: General composition of propellants.

Sl. No	Type of Propellant	Composition		Method of Preparation	Main Application
		Major Ingredients	Minor Ingredients		
1.	Single base	NC	Plasticizers, stabilizers, flash reducers	Extrusion	Small-arms and gun ammunition
2.	Double base	NC, NG	Plasticizers, stabilizers (for rocket propellants, ballistic modifiers are also used)	Extrusion (casting for certain rocket propellants)	Gun ammunition, rockets, and missiles
3.	Triple base	NC, NG, nitroguanidine	Plasticizers, stabilizers, flash reducers	Extrusion	Large-caliber naval guns, artillery guns
4.	Nitramine base	NC, NG, RDX	Plasticizers, stabilizers (for rocket propellants, ballistic modifiers are also used)	Extrusion	Gun ammunition, rockets, and missiles
5.	Composite propellants	AP, aluminum, polymeric binder cum fuel	Plasticizers, burn rate catalysts, etc.	Casting	Rockets and missiles
6.	Composite modified double-base propellants	NC, NG, AP, aluminum	Plasticizers, burn rate catalysts, etc.	Casting	Rockets and missiles
7.	Liquid propellants for rockets	Liquid oxidizers (e.g., red fuming HNO_3, hydrogen peroxide), liquid fuels (e.g., aniline, hydrocarbons)	—	Prepared oxidizer and fuels kept in separate tanks	Rockets and missiles

screening, and intervals of time between explosive events ("delay"). Chemically, they are an intimate and finely powdered mixture of an oxidizer, a fuel (metallic or organic), and other ingredients needed for specific use such as binder, color-giving metals, etc. They are made into pellets or granules of different shapes and sizes to achieve certain parameters such as burning rate, and the making of pyrotechnics is as much an art as it is a science.

The main feature of most of the pyrotechnic reactions are (1) they are basically solid–solid reactions (in which the particle size of the reacting chemicals plays a vital role), (2) they evolve a large amount of heat in many cases, and (3) most of them hardly evolve any gas. Some of the applications of pyrotechnics for military use are as follows:

1. Producing color signals (e.g., by use of the salts of Ba, Sr, and Na for producing green, red, and yellow colors, respectively).

Figure 1.6
New Year Eve fireworks display at London Eye. *(With permission from Martin Coffin, Phoenix Fireworks Inc., Kent, UK.)*

2. Introducing a controlled or predetermined time delay in certain operations (e.g., a few milliseconds or even a few seconds delay in the operation of a fuse or explosive mixture of gases). Delay compositions are mixtures of materials that, when pressed into "delay tubes," react without evolution of gases to ensure minimum variation in the delay period (The evolution of the gases is undesirable because the pressure developed by them inside of the tube will change the reaction/burning rate and in some cases the system is not designed to withstand the pressure). Some examples of such a mixture are ($BaCrO_4 + B$) and ($KMnO_4 + Sb$)
3. Producing flares attached to an antiaircraft missile. The flares help the missile to home on to the target (e.g., $Mg + NaNO_3 +$ laminac).
4. Creating smoke for the purpose of obscuration, (e.g., $Zn + KClO_4 +$ hexachlorobenzene).

On the basis of the special effects produced by pyrotechnics, they can be categorized into four groups (Figure 1.7) as presented in the following subsections.

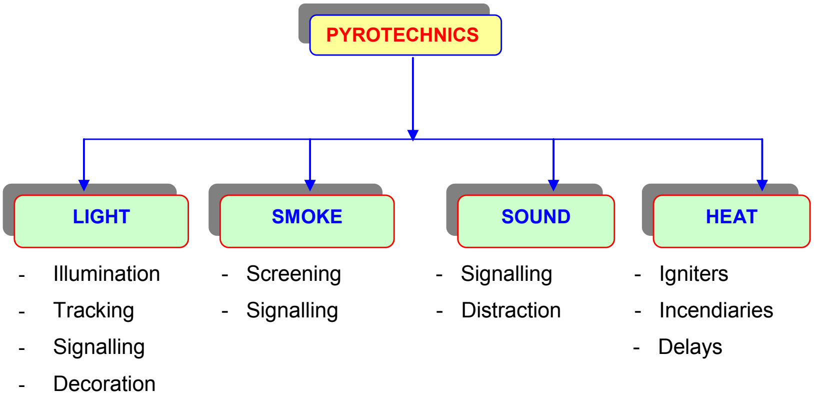


Figure 1.7
Classification of Pyrotechnics Based on Special Effects.

1.6.1 Light

Emission of bright light is the primary function of many pyrotechnic compositions. Aluminum or magnesium fuels are found in most white-light pyrotechnic compositions. These metals evolve substantial heat during oxidation and the magnesium oxide (MgO) and aluminum oxide (Al_2O_3) reaction products are good light emitters at the high reaction temperatures.

1.6.2 Smoke

Smokes are used for military signaling and screening. These are usually prepared by mixing certain dye stuffs with the fireworks. Military smokes were evolved from the mixtures of metal powders with halogenated organic compounds patented in 1920 by Captain Henri Berger of the French army. In modern warfare, special chemicals are being developed to produce smokes that stop the penetration of infrared radiation used by the enemy for detection purposes.

1.6.3 Sound

The acoustic sound wave produced by pyrotechnics is by a sudden release of high-pressure gas. Such pyrotechnics are used in various simulation devices.

1.6.4 Heat

Heat is often considered as one of the byproducts of pyrotechnics, and in some pyrotechnic applications heat or flame is the desired product. This effect can be used for either constructive or destructive purposes. Military pyrotechnic compositions as heat producers are mainly used in igniters, incendiaries, and delays.

Pyrotechnics are not conventionally classified under explosives. Each ingredient taken separately from a pyrotechnic composition may be inert. However, once they are mixed as an "oxidizer-fuel" mixture, which is also in the form of fine powder, the composition becomes an energetic material. Many of them are sensitive to impact, friction, and static electricity. Accidental initiation of pyrotechnics during a large-scale manufacture may result in the evolution of enormous heat/fire followed by disastrous detonations (some sensitive pyrotechnic dust can be initiated by as little energy as 10 μJ). Elaborate safety measures are called for while processing such compositions, such as the use of static discharge systems and nonsparking tools, maintaining at least 60% relative humidity in process buildings, mixing in liquid media in some cases, etc. The fundamental concepts of pyrotechnics are discussed in Chapter 7 of this book.

Names of international journals with their corporate office addresses, which are publishing recent research works, review papers, and new books related to energetic materials, are given in Appendix B. International societies, organizations, laboratories working in the field of explosives, propellants, and pyrotechnics are listed in Appendix C.

Appendix A

Important milestones in the development of explosives and propellants

Milestone	Year
Chinese invented black powder	~220 BC
English monk Roger Bacon experimented with black powder	1249
German monk Berthold Schwartz studied black powder	1320
Edward Howard of England rediscovered mercury fulminate	1800
Italian professor Ascanio Sobrero invented NG	1846
Schonbein at Base1 and Bottger at Frankfurt-am-Main invented NC	1845–47
Swedish scientist Immanuel Alfred Nobel set up manufacturing plant for NG	1863
Nobel's factory was destroyed	1864
Patent for Ghur dynamite	1867
Ballistite (smokeless powder)	1888
Cordite	1889
PETN (pentaerythritol tetranitrate)	1894
RDX	1899
HMX (high melting explosive)	1930
First PBX (plastic bonded explosive) composition	1952
Octol	1952
CL-20 (China Lake-20)	1987
ONC (octanitrocubane)	1999
N_5^+	2001

Appendix B

International journals in the field of HEMs

Name of the Journal	Address
Propellants, Explosives, Pyrotechnics	Journal Customer Services, Wiley, 350 Main Street, Malden, MA 02148, USA Phone: 1-781-388-8598 or +1-800-835-6770; E-mail: cs-journals@wiley.com
Journal of Energetic Materials	subscriptions@tandf.co.uk
Journal of Pyrotechnics	Bonnie Kosanke, 1775 Blair Road, Whitewater, CO 81527, USA. Phone: 1-970-245-0692; Fax: 1-970-245-0692; E-mail: bonnie@jpyro.com
Combustion and Flame	Dan O'Connell, Publicity Manager, Science & Technology Books Phone: 1-781-313-4726
Defense Science Journal	Director, DESIDOC, DRDO Metcalfe House, Delhi- 110 054 India. E-mail: dsj@desidoc.drdo.in
Science and Technology of Energetic Materials	Japan Explosives Society, Kaseihin Kaikan Building. 5-18-17, Roppongi, Minato-ku, Tokyo 106-0032, Japan. Phone: +81-3-5575-6605; Fax: +81-3-5575-6607; E-mail: web-master@jes.or.jp

Appendix C

International societies working in the field of explosives, propellants, and pyrotechnics

Name of the Society	Address
Institute of Chemical Technology, Germany	Dr. Stefan Tröster, Fraunhofer-Institut für Chemische Technologie ICT, Joseph-von-Fraunhofer-Straße 7, 76327 Pfinztal, Germany. Phone: +49-721-4640-392
Institute of Detonation	Christopher Boswell, IHDIV, NSWC. Phone: 1-301-744-4619; E-mail: intdetsymp@navy.mil

International societies working in the field of explosives, propellants, and pyrotechnics—cont'd

Name of the Society	Address
American Institute of Aeronautics and Astronautics (AIAA)	AIAA Headquarters, 1801 Alexander Bell Drive, Suite 500, Reston, VA 20191-4344 USA. Phone: 1-703-264-7500 or 1-800-639-AIAA; Fax: 1-703-264-7551
Japan Society of Energetic Materials	Japan Explosives Society, Ichijoji Building, 3F, 2-3-22, Azabudai, Minato-ku, Tokyo 106-0041, Japan. Phone: +81-3-5575-6605; Fax: +81-3-5575-6607; E-mail: webmaster@jes.or.jp
High Energy Materials Society of India	High Energy Materials Research Laboratory (HEMRL), Sutarwadi, Pune-411021. Fax: 020-25869697; Website: www.hemsichd.org; E-mail: hemce2011@gmail.com

Suggested Reading

[1] S.M. Kaye (Ed.), Encyclopedia of Explosives and Related Items, vol. 1–10, U. S. Army Armament R&D Command, N.J, 1983.
(NOTE: This is the most exhaustive compilation carried out on explosives and related items. To be used for "reference" and not "reading.")
[2] R. Meyer, J. Kohler, Explosives, VCH Publishers, Germany, 1993 (Encyclopedia – handy for referencing).
[3] T. Urbanski, Chemistry and Technology of Explosives, vol. 1–4, Pergamon Press, Oxford, New York, 1983.
(Considered to be the Bible of explosives chemists and technologists – a 'must' reference book in any lab/institution/factory dealing with high energy materials.)
[4] Service Text Book of Explosives, Min. of Defence, Publication, UK, 1972.
[5] B. Morgan, Explosions and Explosives, Macmillan (Quantum Books), London, New York, 1967.
[6] A. Bailey, S.G. Murray, Explosives, Propellants and Pyrotechnics, Pergamon Press, Oxford, New York, 1988.
[7] T.L. Davis, The Chemistry of Powder and Explosives, Wiley, New York, 1956.

Questions

1. Who were the first to invent gunpowder? And, who was the first scientist to describe its chemical constituents?
2. What are the roles played by sulfur, KNO_3, and charcoal in gunpowder?
3. Write the chemical equation for the explosive reaction of gunpowder?

4. Write the molecular structure of TNT and indicate the fuel, oxidizer, and energetic moieties in it.
5. How could Alfred Nobel tame the dangerous NG? What do you think is the mechanism behind it?
6. Define explosives.
7. Classify the following explosives as primary, secondary, or low explosives: (a) Lead azide, (b) β-HMX, (c) TNT, (d) a rocket propellant, (e) tetrazene, (f) PETN, (g) RDX, (h) a gun propellant, (I) tetryl, (j) mercury fulminate.
8. Why is a molecular explosive preferred to a mixture that acts as an explosive?
9. What important characteristics should a military explosive satisfy?
10. Why can you not use a military explosive for civilian application (and vice versa)?
11. What are explosophores?
12. How would you classify propellants with respect to (a) application and (b) composition.
13. What are the different applications of pyrotechnics?
14. How do the following differ from each other? (a) a fuel, (b) a propellant, (c) a high explosive, and (d) a pyrotechnic.
15. What are the major and minor ingredients of common double- and triple-base propellants?
16. Name some applications of pyrotechnics in the military.