

# Energetic Materials, Part I: Black Powder, Nitroglycerin, and Dynamite

An explosive, according to the dictionary, is "any substance that can be made to produce a volume of rapidly expanding gas in an extremely brief period." This Historical Note and the next one will look at the development of energetic materials used as industrial and military explosives. This first part will focus on black powder, used thousands of years ago, through the creation of nitroglycerin, to the discovery of dynamite. Next month's Historical Note will describe the development of nitrocellulosic explosives such as gun-cotton, as well as TNT and other explosives used in World Wars I and II.

Dynamite, discovered by Alfred B. Nobel in 1866, was one of the first detonating, or "high" explosives, which are characterized by extremely rapid decomposition and the development of high-pressure shocks. Earlier materials used deflagrating or "low" explosives, which were simply fast-burning powders that produced relatively low pressures. The most familiar low explosive had been used for many centuries—black powder.

For perhaps 2000 years the Chinese used black powder in their fireworks and to send smoke signals. Called "Greek fire," black powder (or some similar low explosive) was also used for pyrotechnics in eastern Europe in the 700s A.D. By the late 13th century, the Arabs were using black powder in a "gun"—a bamboo tube reinforced with iron, which used an explosive charge to fire an arrow. About this same time, on another continent, English medieval scholar Roger Bacon at Oxford University included thorough instructions for preparing black powder in a published volume—but he encoded the details in a difficult Latin anagram to conceal the instructions.

Black powder, a mixture of 75% saltpeter (potassium nitrate), 10% sulfur, and 15% charcoal (carbon), is relatively insensitive to shock and friction, but is easily ig-

nited by flame or heat. In the early days, torches, hot iron rods or glowing tinder were used to set off black powder, usually by igniting a trail of powder leading to the main charge, giving people time to take cover before the explosion.

Since the deflagration of black powder is a surface phenomenon, coarse granulations burn more slowly than fine grains. Grain sizes are designated with a complicated system of letters and numerals.

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Italian chemist Ascania  
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—nitroglycerin—  
in 1846.

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The saltpeter for black powder was originally extracted from compost piles and animal dung; later, large deposits in India supplied manufacturing needs. During the 1850s, enormous quantities of sodium nitrate, which could be converted to saltpeter through reaction with readily available potassium chloride, were discovered in Chile.

Chilean sodium nitrate absorbed a great deal of moisture, though, and manufacturers did not initially consider it good enough for use in black powder. In 1858, American industrialist Lamot du Pont began to make sodium nitrate, from which he made his own blasting powder. Du Pont's sodium nitrate blasting powder produced an explosive inferior to black powder, but it remained good enough for many mining and construction applications—and it was a good deal cheaper. The potassium nitrate composition came to be called "blasting powder A" and was used mainly

for firearms and military devices; the sodium nitrate version used the letter B and was used for most other industrial applications.

Black powder may have been used for blasting mines in Germany as early as 1613, and almost certainly was used in Schemnitz, Hungary, by 1627. For the remainder of that century, the use of black powder in mining spread slowly because of its high cost, the miners' fear of roof collapse, and the lack of efficient tools for drilling boreholes. In 1679, black powder was used for blasting the Malpas Tunnel of the Canal du Midi in France.

But because it is a deflagrating explosive material, black powder has a severe drawback in mining—it tends to ignite coal gas and coal dust, which led to many mine explosions. By 1800, several European governments had set up testing stations to search for safer substitute materials.

Around the turn of the 18th century, the first "high" explosive—mercury fulminate—was discovered. Mercury fulminate is very sensitive, easily ignited, and has a rapid deflagration-to-detonation transition.

The beginnings of modern energetic materials research, however, did not begin until a century later, when Italian chemist Ascanio Sobrero discovered nitroglycerin in 1846. At first Sobrero called his concoction pyroglycerin, or blasting oil.

Nitroglycerin was extremely dangerous, with great risks inherent in its manufacture and application. No dependable means could be found to detonate it other than the chancey ignition systems known at the time. Pure nitroglycerin is relatively insensitive when frozen, and since it freezes at 52°F (11°C), merely packing it in ice will keep it safe.

By the 1850s some nitroglycerin was being used instead of black powder for certain applications, but the "blasting oil" was seen as merely a laboratory curiosity. However, about a decade later, Swedish researchers Immanuel Nobel and his son Alfred began working (independently) on the commercial potentials of large-scale production and application of nitroglycerin.

The elder Nobel had been working on developing munitions, especially submarine mines, charged with black powder for the Russian Tsar. At the same time, young Alfred Nobel had been studying in the United States for four years; he saw a wild country being opened up for civilization, and he envisioned roads and canals blasted out of the rock through the controlled use of explosive materials. Alfred returned to his father, who had just dem-

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onstrated a comparatively simple way of producing nitroglycerin, similar to Sobrero's original method.

That year, 1862, Immanuel and Alfred Nobel built a nitroglycerin plant, Nitroglycerin, Ltd., at Heleneborg, Sweden. American chemist George Mowbray began his work with nitroglycerin by founding a manufacturing plant in Massachusetts in 1867. Much of Mowbray's product was used in blasting the Hoosac Tunnel in nearby North Adams, Massachusetts. Before he was forced to shut down his plant several years later, Mowbray safely shipped about a million pounds of frozen nitroglycerin throughout the eastern United States and Canada.

In 1863 Alfred Nobel patented his invention of the blasting cap, which allowed safe, reliable detonation of nitroglycerin from a distance. The blasting cap used a tiny charge of mercury fulminate in a metal cap, which could then be detonated when desired. Instead of applying heat, the strong shock from the mercury fulminate detonated the nitroglycerin. This proved to be a tremendously important breakthrough for the safe use of explosive materials.

On September 3, 1864, Nobel's Heleneborg plant exploded, killing several workers including Alfred Nobel's youngest brother, Emil Oskar. Other explosions continued to claim lives in applications and in production plants for liquid nitroglycerin. Many of the accidents were caused by careless handling and by workers who did not appreciate the danger of the material they were dealing with. For a time, in order to be away from potential victims, Alfred Nobel even lived on a barge moored in the middle of a lake while conducting his experiments to find a safer energetic material.

In 1866, at a newly established explosives factory in Krummel, Germany, Nobel came across a cask of nitroglycerin that had leaked into its diatomaceous-earth packing material, called "kieselguhr." The kieselguhr, impregnated with nitroglycerin, had dried into granules.

Nobel experimented with the powder, finding that the material could be roughly handled without danger, but that a blasting cap would cause it to explode with nearly as much force as pure liquid nitroglycerin. Being so insensitive to shocks, the granular substance seemed ideal for handling and shipping. Nobel named this diatomaceous-earth/nitroglycerin mixture "dynamite"—from the Greek dynamis, for "power." Nobel patented dynamite in Sweden, England, and the United States. Sticks of the dynamite powder in waxed-paper tubes rapidly replaced liquid nitro-

glycerin and black powder for most blasting purposes.

Dynamite is a ductile and easily handled energetic material. The heat liberated in a dynamite explosion ranges from about 900 to 1200 calories per gram, depending on its nitroglycerin content. High-nitroglycerin dynamites can produce a shock pressure of almost a million pounds per square inch, traveling between 2000 and 4000 meters per second. The shattering effect of this shock is useful for breaking hard rock. Other dynamite recipes create lower shock pressures, down to about 60,000 pounds per square inch, which are useful for mining soft coal in large chunks.

Dynamite's ability to detonate also depends on its porous and granular structure. Coarse-grained dynamites have a less shattering action. When dynamites are highly compressed, detonation is likely to fail. By appropriate compounding and granulation, explosives can be prepared to break soft minerals (i.e., coal) or shatter hard rock.

Nobel's "Dynamite No. 1" was 75% nitroglycerin and 25% of the diatomaceous-earth kieselguhr. Nobel soon realized,

though, that the inert substance of the kieselguhr added nothing to the explosive power (and actually detracted, since it absorbed some of the heat). He began to use active materials such as wood pulp, rye flour, starch, and sugarcane pith for the nitroglycerin absorbents, and sodium nitrate for an oxidizing agent; he also added calcium carbonate as an anti-acid. By varying these "doping" materials, Nobel could manufacture dynamites of differing strengths. These became classed as "straight dynamites," according to their percentage of nitroglycerin. For example, 40% straight dynamite (a standard used by the U.S. Bureau of Mines) contains 40% nitroglycerin, 44% sodium nitrate, 15% wood pulp, and 1% calcium carbonate.

In later years, Nobel continued his string of inventions, developing blasting gelatin and smokeless powder, as well as working on some non-explosive materials, such as synthetic rubber and artificial silk. Through his many patented inventions, and also through successful exploitation of the Baku oil fields in Russia, Nobel became one of the world's richest men. He died on December 10, 1896, in San Remo, Italy.


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Editor: **Professor Arthur Willoughby**, Professor of Electronic Materials,  
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Editors: **Professor William Bonfield**, Professor of Materials, Queen Mary College,  
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It has become apparent that progress in the field of biomedical materials, particularly in the development of second generation implants and prostheses with an enhanced lifetime in the body, depends on a multi-disciplinary approach in which the materials contribution is set in the context of the relevant science, engineering and medicine. **Materials in Medicine**, a new refereed quarterly companion to the **Journal of Materials Science** will publish a range of topics from the basic underpinning science to clinical applications, around a central theme of materials in medicine and dentistry.

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