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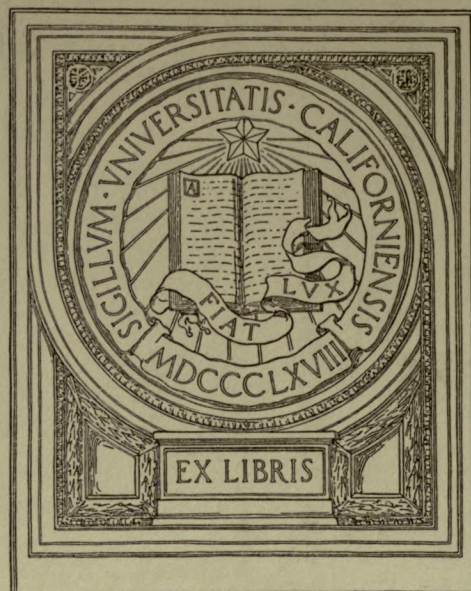


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# HIGH EXPLOSIVES

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BY

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UNIV. OF  
CALIFORNIA

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# HIGH EXPLOSIVES.\*

By W. R. QUINAN.

## CHAPTER I.

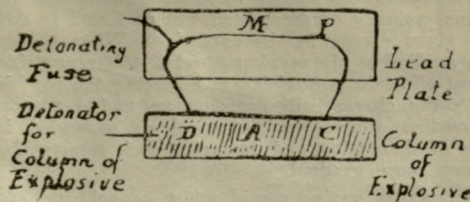
The following is the first of a series of important articles which will appear in this journal from week to week on the subject of high explosives. The articles in question appeared in the *Australian Mining Standard* from December, 1909, to February, 1910.

This is a detailed account of experimental determinations of the "Velocity of Detonation" in a variety of explosives, most of them peculiar to the American market and differing from the European makes. Some of the results are very interesting.

The determinations were made by two methods—first, by the well-known Bichel method, in which a welded string of cartridges at least 10 ft. long is detonated, and the time determined with an electrical chronoscope; second, by means of the new detonating fuse of M. d'Auriche. This fuse, as used by Dr. Comey, is filled with a composition having a fixed velocity of detonation of 6,000 metres per second. To make the experiment, a piece of fuse of suitable length is cut off, and the ends capped with detonators. The fuse is laid upon a heavy lead plate, and the middle point (M) of the fuse is marked upon the plate. If both caps are fired the detonating waves in the fuse meet at some point (P), and leave the plate indented in such a way that the point of meeting can be readily and sharply identified on the plate. If the caps are fired simultaneously the point of meeting of the waves is (M).

To determine the velocity of detonation in a column of explosive the terminal caps of the fuse are inserted in the column with a distance in metres (A) between them. The column is then detonated from one end. The meeting point of the waves in the detonating fuse is some point (P).

Let, MP = b, Let, X = velocity of detonation in the column of explosive.



T being the time it takes the waves to pass from D to P by the two paths DMP and DCP, we have :—

$$T = \frac{DMP}{6000} = \frac{A}{X} + \frac{CP}{6000}$$

DMP being equal to CP + 2b, we have :—

$$X = \frac{6000 A}{2b}$$

\* Summary of a paper by Dr. Arthur M. Comey, Director of the Laboratory of the Dupont Powder Company of America, entitled "Study of the Velocity of Detonation."

So delicate and accurate is the d'Auriche fuse in transmitting the detonating wave that the ends of fuses can be inserted into the column of explosive at intervals of a few inches, and the velocity measured for these short spaces, and also the average velocity measured for the whole distance covered, in one experiment, so that an increase or decrease of velocity during the passage of the wave can be noted.

The first determinations were made with the Bichel apparatus. Some of the results were as follows :—

*American Dynamites.*—Various grades of American dynamites—that is, nitroglycerin mixed with an active dope (nitrates and cellulose absorbents)—were tried—from 75 per cent. N.G. down to 5 per cent. N.G. It was found that the velocity diminished quite regularly with the grade from 6,265 metres per second for 75 per cent., down to 1,294 metres for the 5 per cent. Forty per cent. gave 4,848 metres, 30 per cent. 4,172, and 10 per cent. 2,103 metres per second. The law of variation of the velocity in these "straight" dynamites (called "Lig-Dyns," as made by the Cape Explosives Works) is therefore very simple.

*Gelatins or Gelatin-Dynamites.*—These, as made in America, contain a small percentage of nitro-cotton dissolved in the nitro-glycerin, which gives them a gelatinous consistency and a resemblance to the gelignites in Europe, but as a rule the Americans depend more upon the absorbent power of the cellulose ingredients, and use less nitro-cotton. The results were rather odd :—

Percentage strength.	Velocity of Detonators— Metres per second.
75	2,165
60	2,104
55	2,355
50	2,279
45	2,230
40	2,278
35	2,484

In these tests gelatin-dynamite of the same grade was used as a primer, but caps of different strengths were employed without, however, causing any appreciable effect on the velocity. With the gelatins there is no increase in velocity, with increase in strength—in fact, a slight, but irregular, decrease is noted. But if a primer of 40 per cent. "straight dynamite" was used to start the detonation, very different results were obtained as follows :—

*Gelatins with 40 per cent. Dynamite Primers.*

Percentage strength.	Velocity of Detonators— Metres per second.
75	6,999
60	6,606
50	5,862
40	5,544
35	5,122

showing not only a regular law of increase of velocity with the grade, but much higher velocities.



*Ammonia Explosives.*—These are dynamites in which part of the nitro-glycerin is replaced with ammonium nitrate. The following results were obtained, and were independent of the size of the detonator or the use of a primer:—

Percentage strength.	Velocity of Detonators— Metres per second.
60	3,008
50	4,381
40	4,123
35	3,960
30	3,556
25	3,187

These results are low compared with the Lig.-Dyds, or "straight" dynamites, but high compared with the gelatins. The velocity for the 60-grade is anomalous. With this exception, there is an increase of velocity with the grade.

*Nitro-Glycerin.*—The plan of exploding this in glass tubes was first tried, but a tube with  $\frac{1}{4}$  in. bore would not transmit the wave. The column could only be detonated for a few inches from the cap;  $\frac{3}{4}$  in. glass tubes gave an average velocity of 654 metres per second. With  $\frac{1}{2}$  in. light sheet iron tubes, using a 24.5 grain cap (1.6 grams) five tests were made. These fell into two groups, one giving an average of 7,690 metres, the other only 1,451 metres. With  $\frac{1}{2}$  in. wrought-iron pipe, using a 24.5 grain cap, a velocity of 8,527 metres was obtained and with a cap containing 12.1 grains (0.8 grams) an average velocity of 2,019 metres. Using the d'Aurriche fuse an average velocity of 7,234 metres resulted. We thus have the peculiar phenomenon with liquid nitro-glycerin of two widely differing velocities of detonation with apparently no intermediate steps. The higher velocity evidently depends in a general way upon the size of the tube holding the liquid, the strength of the tube, and the use of heavy detonators. The results given so far were obtained by the method of Herr Bichel. They generally represent average velocities of detonation in welded columns of explosive  $\frac{1}{4}$  in. in diameter and 10ft. long, enclosed in thin wrought-iron tubes. The d'Aurriche detonating fuse was used specially to determine the law of increase or decrease in the velocity with the length of the column. The confinement was in a paper tube, and the average velocity obtained was therefore generally lower than by the Bichel method—strong confinement being favourable to higher velocities.

*Tests with d'Aurriche Detonating Fuse.*—In these tests from one to four cartridges,  $\frac{1}{4}$  in. x 8 in., were generally used. The detonating fuses were used to determine the velocity of detonation in each stick or cartridge, as well as the average velocity for the whole column. Some of the results were as follows:—

"Straight" Dynamites.—Sixty per cent. grade gave a nearly uniform velocity of 5,800 metres; 50 per cent. grade gave an increasing velocity from 5,066 in 1st stick to 5,507 in the 4th stick; 40 per cent. grade gave an increasing velocity from 3,901 in 1st stick to 4,890 in 4th stick. This tendency to increase reaches its maximum in the 40 per cent. The grades below 40 per cent. show the same tendency, but in diminishing degree. The very low grades become nearly uniform like the 60 per cent.

#### *Gelatin-Dynamites.*

	1st stick.	4th stick.
60 per cent. ... ..	2,437	2,452
40 per cent. ... ..	2,019	2,005

A single experiment using a 40 per cent. "straight" dynamite primer on 60 per cent. gelatin gave

1st stick.	3rd stick.
7,304	6,222

These results, though somewhat irregular, which was oftener the case with "gelatins" than with "straight" dynamites, show no particular tendency to increase of velocity with progression of the wave.

*Blasting Gelatin.*—A large number of tests were made with blasting gelatins, using 20 grain (1.3) caps. It was found that the velocity of detonation increased very rapidly from a low velocity at the point of detonation, and reached a maximum in about 4 inches. Results of tests with a sample of blasting gelatin gave an average velocity of 2,000 metres for the first 2 inches, 3,000 metres for the second 2 inches, and an average of 6,850 metres for the next 11 inches. (These results would be more valuable if we had a description of the blasting gelatin, the percentage of nitro-cotton and its content of nitrogen—also the physical characteristics of the explosive—its hardness, plasticity, etc.)

*Velocity of Detonation through Air.*—The d'Aurriche method was also used to determine the velocity of transmission of detonation through air. The cartridges were put in a strong paper tube with an air spacing. It was found that the 60 per cent. "straight" dynamite had a range of 48 inches, and the 40 per cent. a range of 40 inches, and so on down to 20 per cent., with a range of 32 inches. The velocity was measured for every 5 inches of the intervening space. It was proved that the velocity of the detonating wave decreased rapidly with the distance. For the first 5 inches it was generally a little below the normal for the explosive itself, but fell off rapidly with the increasing distance. The average for the 40 per cent. was 2,253 metres per second for the range of 40 inches.

The author's theory is that the normal velocity of the detonating waves through air is that of sound, or 340 metres per second, but this velocity conforming to the properties of the waves of sound and other waves of compression and rarefaction, is greatly increased at the high temperature and pressure, which exist in the immediate vicinity of the detonation—rapidly decreasing, however, as the temperature and pressure decrease with increasing distance from the explosive.

(This is equivalent to saying that the detonating waves are transmitted through air according to the laws of sound and degenerate into sound waves as the temperature and pressure fall with increasing distance. But when the velocity falls below a certain limit depending upon the strength and sensitiveness of the explosive, the waves are no longer capable of causing detonation.)

One interesting observation is, that the velocity of detonation in the second cartridge, if detonation is produced at all, is normal and independent of the degeneration of the wave in air. The most remarkable case of the detonating wave in one medium exciting a velocity greater than its own in another, is the action of the 40 per cent. "straight" dynamite on the high grade "gelatins."

*General Comments on the Paper.*—The introduction of the d'Aurriche detonating fuse is of record importance in the study of explosives, and ought to lead to a new development of economy and efficiency in practical blasting. It gives the mine manager a ready means of determining the velocity of detonation of an explosive, and the relation this bears to efficiency in rock-getting. The so-called high explosives vary greatly in their normal velocities of detonation, which are found ranging from 26,000ft. down to 6,000ft. a second. Every chemical composition may be considered as having a normal rate of detonation, but even this velocity must be defined as pertaining to a definite degree of confinement and the use of a detonator of adequate strength. The rate of detonation of some explosives is much more influenced than others by the degree of confinement and the strength of the detonator. In some the physical condition of the explosive has great influence (this is not touched upon in Dr. Comey's paper), and some can have their velocities greatly increased by the use of a primer of different composition.

It is generally assumed that the higher the velocity of detonation of an explosive, the greater its efficiency in rock-getting. There is this justification for the belief—a maximum rate of detonation implies a perfect detonation, whereas an abnormally low rate denotes insensitiveness and probably an incomplete metamorphosis. It does not follow—provided this condition of perfect detonation be fulfilled—that the maximum rate is the most favourable for rock-getting. For certain special purposes, such as "plastering" or surface blasting of boulders, the highest possible rate under the circumstances is undoubtedly desirable, for in this case the confinement is slight, and the rate of application of the energy must be of lightning quickness to effect the purpose. In blast holes, where the explosive is well confined and expends its energy to greater advantage, it is probable that a medium velocity of detonation will be found to do more useful work for a given energy in the explosive. When the energy of an explosive is applied at the maximum rate, it is reasonable to suppose that the local effect in pulverising and heating the rock in immediate contact with the charge will consume an undue proportion of the energy—a portion which would have been expended in the more useful work of disrupting and removing rock masses if the application had been more gradual.

Blasting gelatin varies considerably in velocity of detonation, depending upon its composition and physical condition. It is believed that a blasting gelatin of normal rate is more efficient in rock-getting than one which, by composition, instability, or other cause, is of maximum quickness.

Gelignite seems to have normally a low rate of detonation. It is believed that if this can be somewhat quickened by use of a primer its efficiency as a rock-getting explosive will be generally improved. In the special case of insensitiveness there is no doubt that the use of a suitable primer is called for both to correct this trouble and to develop the full energy of the explosive.

[These comments are general and off-hand. In future papers I propose to treat the "Detonation of Explosives" in more detail, and to show the bearing of our latest knowledge, or lack of knowledge, of the subject upon practical blasting.]



## CHAPTER II.

## Historical—Alfred Nobel—Detonation—The Vagaries of Nitro-glycerine.

*Historical.*—From this year, A.D., 1909, the introduction of high explosives into the engineering industries dates back about half a century. The world owes this great boon mainly to the genius, or to be more critical, to the iron courage and perseverance of one man—Alfred Nobel, the Swedish engineer. It was he who tamed nitro-glycerine and subdued it to the hand of the miner. Nitro-glycerine had been discovered 10 or 12 years before Nobel began the work of studying it, learning its nature and properties, and turning these to practical account. Little was known about it, except that it had wrecked a number of laboratories in different parts of Europe, where chemists had attempted to follow up Sobrero's discovery. The story runs that his father Emmanuel Nobel, who had moved to St. Petersburg and was a dabbler in explosives, was employed with a Professor Jacobi in devising a system of submarine torpedoes for the Russian Government during the Crimean War to keep the allied fleet out of the Neva. It is probable that the elder Nobel thus learned how to make nitro-glycerine on the small scale practised by chemists. Sometime after the war he returned to Stockholm and put up a tiny factory for its manufacture. This was in the later fifties—probably in 1859. Alfred Nobel, who had returned a year or two before from an apprenticeship in America, became interested in the enterprise, and put his shoulder to the wheel. An explosion at the little factory killed his youngest brother Johannes, and broke the father's heart, but even this could not daunt Alfred Nobel. He had grasped the significance to the industrial world of this new agent—nitro-glycerine—and nothing could turn him back. He found funds to build a new factory and devised apparatus for manufacturing it on a large scale—apparatus that has been copied with slight modification by all manufacturers of modern date. He sent out nitro-glycerine packed in bottles or tin cans to various parts of the world under the trade name of "glonion oil." In nearly every instance he received news sooner or later from each consignment of a disastrous explosion. To mention some of these:—There was one on a steamer lying at Aspinwall on the Isthmus of Panama; a ship going to Chili was blown up; there was an explosion at Quenast, in Wales; another in a New York hotel, and still another in Wells, Fargo's Express office in San Francisco. This latter explosion was caused by part of a lot consigned to Julius Bandmann, to whom Nobel afterwards assigned the United States patent for dynamite taken out in 1867. What iron nerves the man must have had! The terrible news arriving in instalments distressed him, but he never wavered from his purpose. He went on patiently with his experiments. He had solved the problem of making nitro-glycerine on a commercial scale, but two other problems pressed. One was to prevent it from exploding when an explosion was not wanted—the other was to explode it when an explosion was wanted. Nobel was not by training a chemist, and did not at first realise the necessity of thorough purification of the nitro-glycerine. The disasters referred to were generally the result of slow decomposition of the nitro-glycerine under confinement. During a certain stage the decomposing liquid is very sensitive to jar or shock, while it generally explodes spontaneously some time or other if kept bottled up. The pioneer in clearing up this matter, though his work came some years later, was Geo. M. Mowbray, who manufactured liquid nitro-glycerine for boring the great Hoosac Tunnel at North Adams, Massachusetts. Mowbray, who was a chemist, saw at once that it was necessary to thoroughly purify the nitro-glycerine by washing out all traces of the acids to prevent decomposition. He set a standard in this regard which all later manufacturers have been glad to follow. It remained, however, for Nobel to strike the keynote of safety. It was he who first clearly realised that the liquid form of nitro-glycerine was in itself a danger. Liquids being incompressible, are ill suited to withstand the shocks and jars of transportation and use when they are explosive. Hence came the invention of dynamite. By absorbing nitro-glycerine in a porous earth called Kieselguhr, he obtained an explosive paste with some resilience and capacity for absorbing shocks. This was "dynamite," or Nobel's safety powder—the greatest practical step in high explosives.

Going back to the other problem—getting the nitro-glycerine to explode when the bore hole was charged and everything was ready for the blast—Nobel must have been surprised when he found his servant capricious and baulky in the extreme. His earliest patents show that he expected to overcome the difficulty with gunpowder. By exploding this in the bore hole he anticipated setting free the great energy of the nitro-glycerine, but it was no go. Sometimes he got an explosion of a low order and sometimes a total failure. He even mixed the two together, but this worked even worse. The mixture burnt without developing even the useful energy of gunpowder. Finally, he hit upon the idea of using gun caps charged with mercury fulminate. He was on the right track at last, and when he lengthened the copper tubes and used comparatively heavy charges of fulminate composition the problem was solved. Detonation of a high explosive at will made its appearance

for the first time; success was reached in 1864. This, perhaps the most important and far-reaching of his inventions, was not patented.

By 1867 Nobel had overcome all the tremendous difficulties in his path and given the world a working high explosive—dynamite which served its purpose well for nearly twenty years.

Before saying good-bye to this wonderful man I wish to recapitulate that he was the first to solve the problem of making nitro-glycerine on the large scale, to devise a means for detonating it, and to invent a safe form for its use. In subsequent years he patented blasting gelatine and ballistite, both record-making inventions. The first remains the most powerful and the ideal explosive for the miner where great energy is required, while the second was the forerunner of smokeless powder, containing nitro-glycerine as an ingredient. Cordite is an offshoot, so to speak, of this invention.

Alfred Nobel may be called the Father of High Explosives. Simple in character and practical in his work, his fame should be cherished among those who are engaged in the making and hauling of modern industrial explosives. In the dark days, when little was known of the nature of the terrible agent, nitro-glycerine, it was he who had the courage to drag the monster into the light and chain him to be the obedient servant of man. He had to grope his way and learn by bitter experience, but when once started upon his task, like Christian in Bunyan's "Pilgrim's Progress," he set his teeth and moved always forward. As a humble follower in his footsteps, I take great pleasure in making this simple tribute to his memory.

*Detonation.*—Everyone knows that there are two forms of explosion—combustion and detonation—and the average man's idea of the two phenomena is fairly definite; but few know that there are intermediate forms or lower orders of detonation—explosions which it is impossible to accurately classify. Various theories have been proposed for detonation. The one generally accepted is the wave theory. According to this, the detonator sets up a wave of short but intense vibrations, which, radiating from it, cause the successive layers of the explosive to undergo a sudden chemical transformation. The wave is reinforced by the successive explosions and carried onward to the bounding surfaces of the stuff with a high but definite velocity, which is determined by the nature of the explosive and the special conditions of the experiment. One might think that whatever the initial order of the explosion, the great energy set free in the successive layers would determine the final velocity of detonation; that is, if the column of explosive were long enough, the velocity would attain a certain normal figure, no matter how the wave was started, whether by a weak or strong detonator, but under the conditions of use this is certainly not so. A weak wave remains weak and retains a low velocity. This fact alone, notwithstanding the complication of the phenomena involved, tends to show that a true wave is concerned, the velocity of which, in a given explosive medium, is mainly dependent upon the intensity of its vibrations.

Mercury fulminate, so far as is known, is the detonating agent par excellence. Berthelot, the great French authority, holds that of all known explosives, it is capable of producing the greatest pressure on the unit of confining surface. He ascribes this to two of its properties—first, to the simplicity of its chemical metamorphosis, which gives non-dissociable products, one mercury vapour being monatomic and the others diatomic; second, to its great density, which enables one to concentrate its action and apply it to a small area. It is also known to have a very high velocity of detonation—probably the highest of any known explosive, except, perhaps, some of the other fulminates. It is readily exploded by friction, shock, spark or flame. Whether it undergoes combustion or detonation by simple ignition depends upon the confinement. Small quantities unconfined burn up with less violence than fine gunpowder under the same conditions. It must be noted that the energy of mercury fulminate is very small, and its effects local. Theoretically, energy is independent of quickness. It is a question of heat and gas volume.

When Nobel found that he could produce the detonation of nitro-glycerine by using a copper capsule charged with fulminate, the idea spread rapidly to all parts of the world where nitro-glycerine or its preparations were used, and in a few years dynamite caps were articles of commerce. The Germans were prompt to take up the manufacture as well as the factories in New England which had been engaged in making cartridge cases and caps for guns. These early dynamite caps were woefully inadequate. They were short copper tubes, scarcely half an inch long, containing only a few grains—rarely more than three—not of fulminate, but of fulminate composition. Parenthetically, it may be said that the handling of pure fulminate is so dangerous that the cap manufacturers usually mix a diluent with it to lessen the risk of accident to the workmen. This diluent is generally potassium chlorate, and a composition in vogue in England and on the Continent is 80 per



cent. fulminate to 20 per cent. chlorate. Some makers use the proportions 95 to 5. A small percentage of gun-cotton has also been used; also of other explosives, nitro-saccharose and nitro-inannite. It is a point well worth determining whether any of these additions are really helpful to the detonation. They increase the energy, but it is not known how they affect the efficiency of the detonator in setting up the right sort of vibration. The right sort of vibration may also vary with the nature of the explosive. It is to be hoped that before long some skilled experimentalist will take up this study and make the subject clear. The cap factories could perhaps tell us something, but they keep their knowledge to themselves. The ordinary tests for caps, except for comparing the strength of those of like composition, being energy tests, are fallacious.

It is well to note here that the detonation of dynamite caps is obtained by simple ignition under confinement. In the ones made to fit safety fuse, the fuse supplies the ignition as well as the confinement. In the electric detonators there is a sensitive priming composition set on fire by the current, either by a spark in high tension fuses or by the tiny red-hot platinum wire forming the "bridge" in low-tension fuses. Good confinement is necessary in both cases to develop the detonating power of the fulminate. Especial care should be taken in preparing detonators, for firing with safety fuse, otherwise the detonation of the "charge" may be crippled at the fountain head.

The history of the introduction of detonators and detonating explosions on the mining fields repeats itself all over the world. It took years to root out the notion that "any little old thing" in the way of a detonator was good enough to explode dynamite. My experience in the Pacific States of America, where I began the manufacture of mining explosives thirty years ago, will be found typical. The market was flooded with the tiny detonators mentioned above called "single force" caps. There were better ones—double and triple force—but they were scarce and hard to obtain. Some years later the two lower grades had disappeared. A local factory was established, and a quadruple and quintuple cap were made. The latter, if my memory serves me, contained about 12 grains of composition. This was a great improvement, but it took something like ten years of constant agitation by a few progressive spirits to reach even this stage. Truly, the miner underground has been long-suffering. In the early days he must have accepted the rapid pulse and violent headache of his calling as a necessary accompaniment to the use of dynamite, whereas these distressing symptoms were chiefly due to the vapour of unexploded nitro-glycerine thrown into the air of the drive after every blast. Mowbray, at the Hoosac tunnel, had noticed this effect when weak caps were used with his liquid nitro-glycerine, and a similar state of things prevailed for many years afterwards in the use of the various forms of dynamite. Kieselguhr dynamite, as is well known, when properly detonated produces no bad gases, but in practice this was only on a par with badly proportioned dynamites having active bases. In fact, this was the period of bad dynamites. Some were worse than others, but all were bad, because with the weak caps in vogue they could not be properly detonated. It was not until strong caps were introduced that it became worth while for the dynamite maker to study compositions.

*Vagaries of Nitro-glycerine.*—The experiments of Dr. Comey, of the Dupont works in America, are the latest observations on the detonation of high explosives. A summary of his paper was published in last week's issue of the "Mining Standard." This is well worth study, because, reading between the lines, one can learn a good deal about the laws governing detonation. Take nitro-glycerine, for instance, which is rightly regarded as the most dangerously sensitive explosive that the dynamite maker uses as a component. Yet even this explosive needs strong confinement and heavily charged caps to develop the highest rate of detonation. In glass tubes it virtually failed. Tubes of  $\frac{1}{4}$  in. bore would not transmit the detonation;  $\frac{3}{8}$  in. tubes gave a detonation, but evidently a crippled one, since the velocity was only 654 metres a second. One-inch tubes of light sheet iron seemed to be on the border-line of requisite confinement, because two widely different velocities of detonation were obtained with 24.5 grain caps. Strong  $1\frac{1}{2}$  in. iron pipes, however, were required, with 24.5 grain caps, to give the maximum velocity of detonation, but even with this size of column of explosive and strong confinement, weak detonators (12.1 grains) gave low velocities. The most curious feature of this investigation is that nitro-glycerine appears to have two widely different velocities of detonation, with no intermediate steps. The low rate covers a range up to about 2,000 metres, while the high rate beginning at  $\frac{3}{2}$  times this extends to 8,000 or 9,000 metres.

The early experimenters, Professor Abel among them, trying to detonate a stream of nitro-glycerine in an open trough, got a low rate, about 3,000 feet a second. Liquid nitro-glycerine, in fact, has been more or less of a puzzle to practical men. Under certain conditions it gave indications of a very high velocity of detonation. For instance, Mowbray, who used it in boreholes confined in tin cans, regarded it as the quickest of all high-explosives; but as he was an enthusiast and believed he was the only maker of tri-nitro-glycerine, while Nobel and others were making an inferior grade, his opinion does not now inspire much respect. On the other hand, General Abbott, of the United States Engineers, in his great work at the Engineer Torpedo School, Willett's Point, in devising a system of submarine mines, found a curious anomaly in its action.

He tried various explosives to ascertain their suitability for torpedoes, and determined their intensity by firing charges in the centre of a steel ring suspended at different depths under water. The steel ring was equipped with pistons and lead plugs arranged symmetrically around the charge to record its action. Nitro-glycerine was fired in tin cans. He found that it gave only about eight-tenths of the intensity of Kieselguhr dynamite. Seeing that the dynamite contained only 75 per cent. of nitro-glycerine, the remainder of the composition being inert, this result seemed to show that a part was greater than the whole. General Abbott, though sorely puzzled, verified the fact by numerous experiments. Influenced possibly by Mowbray's opinions, he offered as an explanation this theory—that the action of the nitro-glycerine might be too quick to be transmitted by the water surrounding the charge. As a practical maker of explosives, I was not satisfied with this explanation. I knew that nitro-glycerine, at least under certain conditions, was not quick, but slow. I took the trouble to construct a special crusher gauge (a modification of the Quinan gauge), in which the nitro-glycerine acted upon the lead plug through a column of water—that is, the blow from the explosive was partly transmitted by a column of water enclosed between water-tight pistons. The crushing of the lead plug gave the usual result as compared with the action of dynamite, the relative energy indicated being a little more than 100 to 75. In a paper published in the proceedings of the United States Naval Institute, entitled "Crusher and Cutter Gauges for Explosives," I gave an account of my experiments, and suggested that the explanation for the anomaly noticed by General Abbott in the behaviour of nitro-glycerine was that a considerable portion of it was not detonated, but escaped explosion by being blown into the surrounding water. In the light of Dr. Comey's experiments, I have no doubt that this was the true explanation. The confinement in the tin can was not sufficient to develop a high rate of detonation—the can was burst and part of its contents scattered before the detonating wave reached the outer portions.

A curious observation made after an explosion at our factory in California receives some light from Dr. Comey's discovery that nitro-glycerine is subject to two widely different velocities of detonation apparently without intermediate steps. A decomposition of waste nitro-glycerine in a nitrating house started an explosion, which, following down a V gutter, carried the disaster to a mixing house, some 500 yards distant. The V gutter was made of two redwood boards about 8 inches wide, rough on the outside, nailed together at the angle, and lined with light sheet rubber packing. At the time of the disaster the gutter was carrying a stream of nitro-glycerine about  $\frac{3}{8}$  in. deep at the angle. The grade was about 14 in. in 100 ft. The gutter or flume was supported by wooden frames or horses of varying heights. At one point the gutter passed through the projecting toe of a hill, and to accommodate it a cut about 5 ft. in depth was made in a stiff, indurated clay, so solid that the walls of the cut were left nearly vertical. On one side of the gutter was a foot-walk for the cleaner, with its supporting trestle, hand-rail, and necessary framing. The other side was free except for the legs of the horses carrying the gutter. In the cut on this free side the gutter was perhaps 18 to 20 inches from the clay wall. After the explosion the usual minute study was made of the ground. The V gutter was found wholly-destroyed and the frame knocked to pieces. The sheet-rubber packing was picked up in long strips, usually cut as with a knife along the line that had marked the level of the stream of nitro-glycerine. The curious observation referred to above was made in the clay cut on the free side of the gutter. On the face of the clay wall was a perfect, nearly horizontal imprint of the redwood board forming that side of the V gutter. A plaster cast could not have brought out the rough grain of the wood better. This imprint extended some 16 feet, showing that the board had been thrown intact horizontally against the clay wall, while nearly preserving the angle it occupied in the gutter, the imprint being much deeper in the upper part. Another strange thing was that the board had been utterly destroyed after making the imprint. Nothing remained of it but matchwood or shavings in the bottom of the cut, which reminded one of the floor in a busy barber's shop.

The natural conclusion was that the explosion could not have been instantaneous, even in the ordinary sense; that it either occurred gradually or in stages. With Dr. Comey's results to guide us, it is possible to propound a fairly simple explanation. Some small part of the nitro-glycerine stream (probably a small section at the angle, as being the part under the greatest confinement) detonated at the high rate, giving time for the board to be thrown against the clay bank and to make its imprint while it was yet intact, before the bulk of the liquid detonated at the low rate and destroyed it. The explanation may seem far fetched, and if any better can be offered I will gladly accept it. It is hard to see how the flume could have been broken apart without scattering the liquid more or less, but we are dealing with very minute intervals of time, and this scattering would not necessarily prevent the subsequent explosion of all or the greater part of this nitro-glycerine. On the other hand, if the whole of the liquid in the gutter had been exploded as one body, the board would not have been carried over horizontally to the clay bank; it would have been driven at an angle of 45 deg. downwards, even if it had escaped immediate destruction, which is unbelievable. The other side of the cut, which was perhaps 3 ft. or more from the gutter, showed no imprint, as though the board on that side had been overtaken and destroyed before it reached the bank.



## CHAPTER III.

Nobel's Dynamite—Modern Dynamites—Gelatinous Explosives—Freezing—Sensitiveness—  
The "Hake Effect"—Australian Conditions.

Nobel's Dynamite, which normally contains 75 per cent. nitro-glycerine and 25 per cent. Kieselguhr or infusorial earth, is a paste, dryish and stiff, or soft and greasy, depending upon the absorbent power of the Kieselguhr. It has a slight compressibility which makes it quite safe against ordinary shocks, while it is readily detonated under confinement with a cap of moderate strength, such as a No. 5, though a No. 6 is believed to be better.

*Modern Dynamites.*—Kieselguhr dynamite has been generally replaced by more economical mixtures—Dynamites with active bases or nitro-glycerine mixed with a dope, consisting of an oxidising agent, and a carbonaceous element which serves to absorb the nitro-glycerine. The principle involved in these explosions is to make all the ingredients contribute to the working energy, the nitro-glycerine playing the role of detonating agent to the dope mixture. This principle was clearly recognised by Nobel in his patent for No. 2 dynamite, and is now universally accepted, being embodied also in modern gelignites and gelatine dynamites, but for a time it was decried by some authorities. Nobel's trade successors, possibly to uphold the supremacy of Kieselguhr dynamite, which was threatened by cheaper rival compositions, generally joined in the cry against it. Even Mowbray, enamoured of his liquid tri-nitro-glycerine, ridiculed it. He compared the linking of gunpowder elements with nitro-glycerine, to harnessing a locomotive to the electric current; one being relatively slow and the other quick, they could not pull together. Time and practical experience have completely refuted this *a priori* reasoning. The principle received the fullest recognition in America, where three-fourths of the explosives made are still compounded upon this principle. The dope first used approximated closely the composition of gunpowder, but experience proved that better results could be obtained by discarding the sulphur and replacing the charcoal with a cellulose ingredient, such as wood pulp.

These American or "straight dynamites" (as Dr. Comey calls them in his paper; or "Lig-Dyns," as they are called at the Cape Explosives Works in South Africa) are the most certain and regular of all forms of explosives in their response to the detonator; while they are also (when made with reasonable care) probably the safest explosives in use. The cushioning action of the cellulose absorbent in warding off the effect of friction or blows is extraordinary. This is due to the resilience of the absorbent. No matter how densely the cartridge is packed at the factory, there is a large margin of safe compressibility left to meet the exigencies of handling and use. I have made scores of tamping experiments by placing the cartridge in an iron pipe, putting in a hardwood tamping rod, and dropping a heavy weight (about 35 pounds) upon the head of the rod from varying and increasing heights up to 16ft. By prolonging this rough treatment, I have always succeeded in driving the rod entirely through the column of cartridges, wedging the stuff against the sides of the pipe, and subjecting it to great friction and sharp percussion at each blow—without one instance of accident. I have made a few experiments of the same kind upon Kieselguhr dynamite and upon a nitro-cellulose gelatine, which was nearly the equivalent of modern gelignite. I got one small, sharp explosion with the first, and the second in one test took fire and burnt without explosion before the experiment was completed. If the lower end of the pipe had been closed as in a borehole, it is possible that an explosion of low order would have resulted. While the Lig-Dyns shew themselves immune to ordinary friction and percussion, they are specially susceptible to the vibrations produced by the detonator, and detonation once properly started is transmitted with great certainty and regularity. Dr. Comey shows, moreover, that if two 1½ in. x 8 in. cartridges are confined in a strong paper tube, one cartridge will explode the other, though they are separated by a considerable air gap. The 60 per cent. has a range of about 48 in., and the 40 per cent. one of 40 in. Though the detonating wave in air is subject to a rapid deterioration in velocity, the second cartridge, if exploded at all, detonates at the normal rate. This peculiar susceptibility of the Lig-Dyns to detonation, I ascribe to their physical structure. This is more or less open and loose, and the minute, but intense, vibrations of the detonating wave can always penetrate the surface and find a multitude of points for molecular attack. Ordinary shock attacks the stuff in mass, and is absorbed without causing explosion.

*Gelatinous Explosives.*—The gelatines, including blasting gelatine, gelignites and gelatine-dynamites, contain nitro-cotton, which unites more or less perfectly with the nitro-glycerine, and converts it into a jelly. Blasting gelatine contains, or should contain, nothing but nitro-cotton and nitro-glycerine, usually about 8 per cent. of the former to 92 per cent. of the latter. There is no distinction between gelignites and gelatine-dynamites, except that of grade. Some manufacturers use the second name for a higher grade, others for a grade lower than the gelignites, which generally carry from 60 to 70 per cent. of nitro-glycerine. These gelatines contain a dope similar to that of American dynamite—usually wood pulp with a nitrate. They therefore need less nitro-cotton in proportion to the nitro-glycerine than blasting gelatine. The great advantage of these compositions is that the nitro-glycerine, being reduced to a jelly, requires less absorbent to hold it, and enough nitrate can be introduced to give very complete oxidation of the products. This can be done in the middle and

lower grades of Lig-Dyns or American dynamites, but is impossible in the higher grades unless some inert absorbent is used to help the wood pulp.

Blasting gelatine is the ideal explosive when a maximum of power is required. It was Nobel's crowning triumph in industrial explosives. Not only are its physical properties specially suited to its work, but as an embodiment of energy it is remarkable for uniting two explosives—nitro-glycerine and nitro-cotton—so that the defect of one is made to compensate for the defect of the other. Nitro-glycerine when fully detonated is wasteful of energy in giving an excess of oxygen—about 3.5 per cent. of its weight—while nitro-cotton is deficient in oxygen, and produces a large percentage of carbon monoxide. When the proportions in blasting gelatine are normal and the grade of nitro-cotton good, this excess and deficiency compensate each other very accurately, and there is no waste of energy. General Abbott found in his submarine experiments that blasting gelatine gave the greatest intensity of all the explosives tried. The gelignites partake in composition of the nature of blasting gelatine and of the Lig-Dyns. They are more plastic and denser than the latter, and have the advantage of being more easily oxidised, as before stated.

Neither blasting gelatine nor gelignite is very susceptible to detonation. Both require strong caps to start a proper detonation, and the wave is easily interrupted by air gaps or other obstructions. The wave is also subject under favourable circumstances to a deterioration in its own medium, as will be shown in a later article. Blasting gelatine under proper conditions gives a wave of high velocity, but it does not appear to have the detonating power of the Lig-Dyn wave, though this in its own medium is much slower. Gelignite has normally a slow rate, but this can be greatly increased by firing it with a Lig-Dyn primer. It can be laid down as a practical rule that all high explosives require strong confinement for complete detonation. (It has been seen that even so sensitive an explosive as mercury fulminate requires this first element of detonation.) Even if this condition, which applies with special force to gelatinous explosives, be fulfilled, a detonator of adequate strength must be used to develop the full power.

The Lig-Dyns, when confined, can be detonated with apparently full force by a No. 5 (12.3 grains) cap, but even in this case it is believed a No. 6, containing 1 grammme of fulminate composition, is better and surer. In connection with the subject of detonation there must be noticed a property peculiar to nitro-glycerine and its compounds.

*Freezing.*—Nitro-glycerine freezes, and becomes a solid at moderately low temperatures—about 45-46 deg. Fahr.—and all explosives containing it are subject to the same drawback, but in different degrees. When the liquid is solidly frozen it is virtually in explosive—the strongest detonator seems to have no effect upon it. Mowbray utilised this property in making it safe for transportation. He prepared special tin cans for holding it, with a centre cylinder to contain ice. He proved that in the frozen condition it would stand very rough treatment. Notwithstanding this, many accidents have happened with frozen dynamite and other explosives, and miners have a wholesome dread of handling them in this state.

An experiment which I made many years ago throws some light on the subject. I took a solid lump of frozen nitro-glycerine rather larger than a man's fist, scraped a groove in the top of it, brushed out the dust, and fired a strong detonator in the groove. The detonator broke the lump into perhaps half-a-dozen pieces, but there was no explosion. Without removing the dust and small bits, I gathered all the fragments and fired a detonator in the pile. This time there was a sharp explosion, and many fragments were made and scattered over the brick pavement, which served as a floor for the experiment. The fragments were carefully gathered up once more and fired. The result was apparently a full detonation. The brick upon which the pile was fired was smashed, and a small depression made in the pavement. The weather was very cold, and at no time during the experiment was even a trace of liquefied nitro-glycerine noticed.

The natural conclusion was that frozen nitro-glycerine is readily detonated if broken into small pieces. The danger in handling frozen dynamite probably comes from fine crystals of nitro-glycerine forming either inside or outside of the cartridge wrapper. These are reported to be specially susceptible to friction, like the fresh crystals of potassium chlorate, but the subject is very obscure and little is known about it.

Kieselguhr dynamite when solidly frozen (as in the packed cartridges) is practically in explosive, yet General Abbott adopted it as his standard explosive for submarine mines. In cold waters it naturally freezes in winter, and it puzzled some dynamite men to account for such an error of judgment on the part of this distinguished officer. General Abbott, however, discovered that by a simple expedient he could keep the dynamite sensitive to detonation. He loaded his torpedo cases loosely with granulated dynamite. Freezing in this condition made little or no difference to detonation with a strong exploder.



In America a speciality is made of low-grade dynamites for railway work, bank-blasting, etc., as cheap substitutes for black powder. A favourite grade is 5 per cent. The mass usually consists of a granulated mixture of nitrate and bituminous coal or the equivalent, to which 5 per cent. of nitro-glycerine is added. When finished the stuff is packed loose in the wooden cases. A Lig-Dyn primer is generally used to fire it. I have often noticed that this explosive detonates readily in the coldest weather.

In commenting upon the susceptibility of Lig-Dyn, I ascribed to its texture, which is comparatively loose and open. Lig-Dyn when frozen will still explode, though not perhaps with full force. In fact, the freezing of nitro-glycerine handicaps to some slight extent its detonation or the detonation of its mixtures or compounds. This is on account of the latent heat of fusion, which absorbs some of the heat of the detonating wave, but whether these explosives will detonate at all generally depends upon their state of aggregation. In solid mass they offer an extraordinary resistance to detonation, but if granulated or finely divided, detonation is comparatively easy. The explanation is that the intense vibrations of the detonator have a thousand points of attack at which an extensive molecular disturbance can be set up. A frozen cartridge of Kieselguhr dynamite is a type of the resistant condition. Certain substances have a slow, hardening action upon nitro-glycerine. Various resinous matters, like ordinary colophony (common resin), when present as ingredients in dynamites have this effect. The first No. 2 dynamites made in America generally contained a large percentage of resin. In the course of time the cartridges became as hard as wooden sticks, and nearly as inexplorable.

*Sensitiveness.*—This is a complicated subject into which many factors, both chemical and physical, enter. Every explosive may be considered to offer a specific resistance to detonation. The most important element in this is its chemical constitution, but to go into this would lead us into too broad a discussion. The heat of formation of a compound is, in a general sense, a measure of its stability—that is, a measure of the energy taken as heat which must be applied to it to bring about decomposition. I may here remark that detonation by heat itself so applied that all parts of the explosive body are brought to the critical temperature at the same time, is probably one of the most perfect forms of explosion. The atoms in their increasing swing reach the limit of stability nearly simultaneously, and the resistance to detonation is almost nil at the moment of the “let go.”

Some explosives by chemical nature are so unstable as to be of no practical use. Such are nitrogen chloride and iodide, which even give out heat in breaking up into their elements. These are called endotherms, which is equivalent to saying that they have minus heats of formation. But instability arising from chemical constitution does not concern us just now in a discussion of industrial high explosives. Our first point seems to be that these when in hard, solid masses offer great resistance to detonation, but if the masses are broken up and finely divided, they can be readily detonated. This was illustrated in the case of frozen nitro-glycerine and frozen dynamite. The susceptibility of Lig-Dyns to the detonator is also related to the state of aggregation. This has a loose, somewhat open, texture, and the vibrations of the detonating wave can penetrate the surface and make an effective attack. Coming now to gelatinous explosives, which from their nature resist this form of attack, it is found that the sensitiveness depends upon a different property—viz., the consistency. If this is either hard or elastic they will be difficult to detonate. India-rubber, or caoutchouc, is of known substances one of the most resistant to the disintegrating action of an explosion. Cloth faced with rubber, as noted in a previous paper, will preserve its structure when subjected to the cyclonic action of an explosion, in which stout timber will be completely destroyed. It is possible to make a gelatine of a consistency closely resembling caoutchouc by gelatinising the nitro-glycerine with an excess of nitro-cotton. Such a gelatine will need a very powerful cap for detonation. A still further excess of nitro-cotton will give products like hard rubber or gutta-percha—analagous to cordite or ballistite, both of which are incapable of detonation in mass.

Blasting gelatine and gelignites are by nature more insensitive to the detonator than Lig-Dyns. It may be laid down as a principle that they require stronger confinement and heavier caps for full detonation. Their sensitiveness, however, can be varied much in manufacture, as it depends chiefly upon the consistency. Soft, plastic gelatines are more easily exploded than hard elastic ones.

*The “Hake Effect.”*—These explosives, even when made of normal consistency, are subject under conditions that are somewhat obscure to a change during storage, by which they become very sensitive. I have called this the “Hake effect” in honour of Mr. C. Napier Hake, the late Inspector of Explosives for the State of Victoria—a gentleman to whom the manufacturers of gun-cotton owe several very valuable investigations. Though this effect is well-known to dynamite makers, I believe Mr. Hake to be the first man of science outside of their ranks to make a study of it. He has made this curious and interesting observation. If a small percentage of blasting gelatine that has become insensitive through this effect, be reworked and mixed with a large percentage of a fresh lot, it will infect the mass and the re-made blasting gelatine will soon undergo the change. Something more than a mechanical effect is therefore concerned; in fact, an obscure form of catalytic action seems to be indicated.

The usual view taken by the manufacturer is something like this: When a gelatine is made, a certain proportion of the nitro-glycerine enters into a firm union with the nitro-cotton while part of it remains free, occluded as it were in the pores of the jelly. It is mainly this free portion which gives plasticity and sensitiveness to the gelatine.

If now by a slow gelatinising action the free nitro-glycerine is taken up by the nitro-cotton, the gelatine stiffens, becomes harder and more elastic, and is likely to develop the “Hake effect” in storage.

Much depends upon the gelatinising power of the nitro-cotton. This varies greatly, and no absolute rule has been formulated for making it of the highest quality. Great care in the selection of the materials and accuracy in maintaining the proportions of these as well as the conditions of time and temperature during the processes of manufacture, are the elements of success. The percentage of nitrogen in the nitro-cotton is not a criterion of its gelatinising power, except in a general way. Now, seven per cent. of one nitro-cotton may give a gelatine of normal consistency, to obtain which would require nine or ten per cent. of another nitro-cotton of inferior gelatinising power. Nevertheless, it is held by some persons that it is always risky to use so much, because they believe that time may bring about a complete gelatinising effect even with the inferior quality. According to this view, a high quality differs mainly from the inferior quality in being quicker in its action. There are so many unknown factors concerned in the “Hake effect” that it is impossible to take them all into account. One of these is the condition of storage, especially the temperature. The manufacturer must make his stuff rapidly. At most, he can only give an hour or two to gelatinisation. His general aim is to make the highest quality of nitro-cotton possible, to use as little of this as will give the right consistency, and to exhaust its gelatinising powers by stimulating these with heat. He therefore gelatinises at a high temperature. The decision, whether the gelatine, when finished, is of the right consistency to meet the exigencies of storage and use, should be made under uniform conditions of temperature, summer and winter. If this point is neglected, summer-made gelatine is liable, in the exigencies of service, to prove insensitive—and that made in winter is apt to develop exudation. This is the practical observation of one of the inspectors in Australia. In my limited experience, the “Hake effect” is more likely to supervene if in storage a moderate temperature prevails—rather chilly than warm—though this may mean simply that heat tends to keep the gelatine sensitive. If, however, a gelatine of normal consistency and sensitiveness which has been stored in a comparatively high temperature, is subjected for a few months to a low temperature, it seems to develop the “Hake effect” very promptly. On the other hand, a gelatine which threatens to develop the “Hake effect” may show normal sensitiveness at least for a time if transferred to a warmer climate.

*Australian Conditions.*—These matters assume great importance in Australia, where in every State there is a strict system of inspection, and where storage may be unusually prolonged. The manufacturer is, in fact, between two fires. The inspectors favour firm, elastic gelatines in which the nitro-glycerine has been very completely taken up by the nitro-cotton. The miners, on the other hand, prefer gelatines which are soft and sensitive.

A gelatine of plastic consistency, when freshly made, will generally show in a little while after storage a narrow line of free nitro-glycerine along the edge of the inner fold of the wrapper. There seems to be a strong capillary attraction along this line, probably due to the double fold, which tends to draw out of the jelly the free nitro-glycerine near it. If this line shows more than a trace of free nitro-glycerine, the inspector will condemn the stuff as exuding, and order it to be re-wrapped. If the nitro-glycerine extends into the folds, it may be destroyed. If, on the other hand, this line is absolutely absent, then under the conditions prevailing in the mines at the present time, the stuff is likely to be condemned by the practical users as being insensitive. If such a stuff is stored for many months before use, it is likely to develop the “Hake effect,” and become very insensitive to even a proper detonator.

The trouble arising from the inspector and the practical miner being so far apart in their ideas as to the right thing has been aggravated in Australia by what I consider a false standard of sensitiveness. Unfortunately, it has become the fashion to use the minimum detonator for exploding gelatinous explosives. The miners' standard is the No. 6 cap. If the stuff does not work with this, he condemns it as no good. There is only one sure certificate that a gelatine will detonate with so light a cap as this. It must have been free nitro-glycerine in it to develop under ordinary conditions of storage, the line along the inner fold referred to above; but this is what the inspector objects to. In so practical a country as Australia, it seems strange that such a lack of co-ordination should exist. But the inspectors are conscientious, over-worked officials, who cannot find time to visit the mines and confer with the mining men. If they could do this, doubtless steps could be taken to bring the two standards into accord. The matter is a serious one. Several thousand cases of explosives made by conscientious manufacturers are “re-conditioned” and some hundreds destroyed every year. If the miner's standard must be accepted by the manufacturer, the inspector ought not to apply tests which were appropriate twenty years ago, but are now out of date. The tests laid down in the Regulations were adopted when blasting gelatine was a different thing from what it is now. The gelatine of Alfred Nobel and his immediate successors is not in vogue in Australia. The standard has been perverted. It is no longer a slightly elastic-translucent mass, without a trace of free nitro-glycerine on the surface, but usually a soft mushy substance with the line of nitro-glycerine well developed, even if it is not exuding or on the border line of exudation. If one examines the circulars issued by Nobel himself, or by his authority, giving the properties of blasting gelatine, he will find it stated that this explosive is not suited to breaking boulders by surface action or for chambering “bulling” holes where the confinement is not good, and there are still old-fashioned blasters who will not use it in this way. I found one such noble old patriarch at Mount Morgan, who insisted upon having



Kieselguhr dynamite for ("bulling") his holes, and got it, too. I was much surprised when I came to Australia to find that both blasting gelatine and gelignite were used for "plastering" or breaking boulders by surface blasting, and apparently with good effect. In fact, it has become the fashion to make the stuff sensitive enough to explode with great power under the slight confinement of a few handfulls of damp clay plastered over it. *C'est magnifique mais ce n'est pas la guerre.* The stuff that is capable of doing this is not blasting gelatine, as Nobel and even more modern "old fogies" like myself have understood and admired it. The point is that this degree of sensitiveness cannot be conferred upon it without sacrificing some of its greatest qualities, as I hope to show later. To an old "fogey" it savours of charlatanism to pervert a noble (Nobel) explosive from its real purpose, in order to fit it for such a

meretricious service as smashing boulders by "plastering"—especially in these days of hand-pneumatic drills for making "pop" holes.

The reform should begin at the bottom. A proper strength of detonator should be adopted as the standard for gelatinous explosives. In other words, the detonator should be made for the explosive, and not the explosive to suit the detonator. This should certainly not be less than No. 7, or better, No. 8. In South Africa, where a more progressive policy has been followed, No. 8 is nearly the universal standard. This gives the manufacturer a reasonable working margin. His product need not be so sensitive that it has to run the risk of rejection or "re-conditioning" by the inspector, while the latter can maintain his high standard without either penalising the manufacturer on the one hand, or, on the other, compelling the miner, with his weak detonator equipment, to accept stuff bordering upon insensitiveness.

## CHAPTER IV.

### Tests for Sensitiveness—Open Tests—Energy of Explosives—Theory of Explosive Energy—The Chemical Equation—Dissociation.

*Tests for Sensitiveness.*—Like the "proof of the pudding," the best test of an explosive is to fire it under the conditions of use, but this test is not always practicable, especially at the factories. The factory is fortunate that has even a quarry of hard rock near at hand in which trials can be made.

Speaking generally, the rifle bullet is a detonating agent for industrial explosives. A few, such as Tonite, now out of date, an explosive made of ground gun-cotton and barium nitrate, compressed into hard cartridges, would resist it, but these have not found favour in mining.

One of the earliest tests that I have adopted was to hang up a cartridge (1½ in. x 4 in.) by a string and blow it to pieces at, say, 10 paces with a shot gun. As an aside, I may say that it is easier to hit so small an object with a shot gun than with a rifle, but I found it, moreover, a good rough test of sensitiveness. If the cartridge seemed to explode fully, I concluded from previous experiments that it could be trusted to detonate perfectly in the bore hole with a No. 5 cap (about 12 grains of fulminate composition). At that time I made only one explosive (patented under the name of Detonite), which would resist this test. This contained a nitro-cellulose made from wood fibre mixed with 68 or 70 per cent. of nitro-glycerine and a nitrate—nearly the equivalent of modern gelignite. It was a dense, rather hard dryish mass absolutely free from exudation, with about the plasticity of moist plug tobacco. It required a very strong detonator, which I was fortunate enough to get from the local factory. This explosive was more than a match in energy for the strongest dynamites of the day, and showed good all-round qualities in use. The gelatinisation was in the cold, and gave time for the cartridge to be packed like ordinary American dynamite. The nitro-cellulose was a good absorbent as well as gelatinising agent for the nitro-glycerine. Not a trace of free nitro-glycerine was ever observed in the packed cartridge. Blasting gelatine can be made immune to the rifle bullet, but only at the expense of its general serviceability. It is said that a small percentage of camphor added to the composition will have this effect.

*Open Tests.*—The co-called "open tests" for sensitiveness made with detonators are instructive, but the results are apt to lead to wrong conclusions if the general principles of detonation are not kept in mind. In 1904 I made some experiments on the Ferreira Deep slimes dump, at Johannesburg, which illustrate some of the properties of the gelatines in regard to detonation. The explosive was a rather sensitive blasting gelatine, in fact, some of the cartridges showed signs of exudation. The site was a level stretch of compact damp sand. A piece of timber 3 in. x 9 in., 24 ft. long, was laid down, and the cartridges—¾ in. x 4 in.—forming a long string, were placed on it and pressed together end to end, but without removing the wrappers. About 18 in. of damp sand taken from a bank near by was shovelled over the string as it was formed. An attempt was made to detonate the string from one end. Out of about a dozen trials, in only one case did we succeed in exploding the whole string—some 20 ft. in length, and this was with a No. 6 cap. The timber and the compact sand gave very good records of the energy of the detonation in its progress along the string. The excavation, which was sharply and clearly defined, reached a maximum about 4 or 5 ft. from the detonator end. Here it was about 5 ft. wide and about 3 ft. deep. From this point it tapered pretty regularly in both width and depth to nearly nothing at the further end. The timber gave equally clear indications. For the first 5 or 6 ft. it was reduced to match wood and splinters. The splinters became larger along the line, then the timber was broken into short lengths, then into longer lengths, and at the further end a piece some 4 ft. long was barely split. In all the other trials, made some with No. 6 and some with No. 8 detonators, the detonation broke off short from 2 ft. to 2 ft. 6 in. from the detonator.

The conclusion is that under conditions of poor confinement, the detonating wave in gelatines is subject either to a sharp break or to a dying out. The exact point of the break off was probably determined by an obstruction such as an extra thickness of paper in the end cartridge fold, but it is very remarkable that this point should have varied so little in the different experiments, as if the detonating impulse of the cap had something like a definite range. The dying out or deterioration in the detonating wave is still more interesting in showing an enormous possible variation in the ratio of detonation of gelatines. This phenomenon is rare, and I was fortunate in obtaining the effect in the open.

Both effects, the break-off and the dying-out, undoubtedly obtain in rare cases, even in the bore holes, where unexploded cartridges are sometimes found, especially when a charge has not broken to the bottom, but has left a "socket." This may be the result of either insensitiveness in the explosive or to the use of a defective or inadequate detonator. This should be carefully distinguished from another form of accident in which unexploded cartridges may also be found. An explosive is sometimes credited with a "socket" and unexploded cartridges, when it is not in fault, and the foreman or shift boss should report a cut hole—that is, a hole which has not been fired normally by the detonator, but by an adjoining blast, the rocks from which have cut the fuse. In prosecuting open tests, I have exploded many cartridges on a sandy beach, noting the air gaps necessary to prevent the detonation of one cartridge by another. The most striking observations are the small excavation made even by the primary cartridge, and the minute air gap sufficient to break the communication of the detonation.

Another form of open test is sometimes practised. A certain number of cartridges, say, six 1½ in. x 4 in., stripped of their wrappers, are welded together end to end on the ground, and then the string is fired from one end. If 4 or 5 out of the 6 explode, no matter how, the stuff is pronounced good. If only 2 or 3 out of the 6 explode, it is pronounced insensitive. This test has its value in the hands of the expert, though it is remarkable for ignoring the conditions of the bore hole, where the wrappers are not removed, the cartridges are not welded (it would be a good thing if they were), and the confinement, instead of being nil, is perfect. The objection to the test is that absolutely wrong conclusions may be drawn from it. For under this unnatural condition of no confinement, a No. 6 detonator shows as much power as a No. 7 or No. 8. In fact, in my experience, for all tests made without proper confinement, the No. 6 gives generally the best results, and it is not hard to conceive a reason for it. The column of explosive not being confined, the portion surrounding the cap is likely to be blown away by the action of the strong detonator, without contributing to the creation of a normal wave in the column. Many experimenters have noticed an effort of this kind when detonating explosives under slight confinement, and some have concluded that a detonator may be too strong. This conclusion is warranted when it is limited to the conditions of the experiment, but in the bore hole where the dissipating effect just noticed cannot take place, the detonator cannot well be too strong. I believe that the employment of the "open test" for sensitiveness has had much to do in Australia with fixing the grade of detonator for gelatinous explosives so low as the No. 6 and again this has reacted upon the standard of gelatines as to consistency.

To be fair to the older explosives companies who have had much to do with fixing these standards, it is well to take into account the conditions of the country with its great range of latitude and variations of climate as well as the long storage to which explosives are often subject. It may be that the "Hake effect" caused such large losses in storage under the old standard of consistency that they found it a choice of evils to make a soft sensitive gelatine



less subject to this effect, although in doing so they ran counter to the standards set by the Inspector, and have had to suffer from occasional "reconditioning," or even total loss by exudation.

*Energy and Explosives.*—As this is a subject which I have been studying both practically and theoretically for thirty years, I can talk about it pretty glibly. But it is too big a subject to be handled in a few columns of a journal. If one attempts it, he finds himself in trouble. Besides, the difficulty of condensing a treatise into so small a compass, the writer is forced to state propositions which no one disputes, in the same off hand way that he states those which his study has led him to adopt, but which may not be acceptable as orthodox to some of his readers. He may have strong arguments and abundance of facts to support his views, but he cannot bring these forward without being tiresome. He must appear to dogmatise when he would prefer to demonstrate.

Energy is the only thing we know to exist. Our impressions regarding everything else are derived from the action of energy in its varied forms upon our senses. Therefore, energy is the only reality. All other things may be such stuff as dreams are made of. Matter may be holes in the ether, or local condensations, or vortices in the ether or portions of the ether carrying more or less, or a different kind of energy from the usual, but in the last analysis we know nothing about its constitution. As to the ether itself, its properties surpass our comprehension. We know it has a reality, as the vehicle and store house of the energy of the universe, but we cannot form a conception that will cover it. A thing that is more than a million times lighter than rarified hydrogen and yet has an elasticity comparable with tempered steel, is too difficult for our minds to grasp. However, I propose to avail myself of some old-fashioned ideas which are fortunately not yet extinct. The conception of matter as substance, distinct from energy, is one that has grown up with and taken firm root in the human mind. We have accumulated a mass of impressions in regard to the two, which we consider knowledge, and we have classified and arranged some of this and called it Science. Twenty, thirty, or even forty years ago, our Science was more cocksure than it is to-day. We had something we could tie to. The Conservation of Energy, the Permanence of the Atom, the Indestructibility of Matter—these were the sheet anchors—some of which seem to be dragging to-day.

*Theory of Explosive Energy.*—For inspiration we accordingly hark back to the good old days when we held settled notions. The view which I have adopted in my study of explosive energy runs something like this: Matter has a grained structure, is built up, in fact, of atoms and molecules. The gaseous form of matter is that in which its properties are the least complicated. The action of heat or energy upon this form of matter is governed by simple laws. A gas which obeys these laws with accuracy is called a perfect gas. The conversion of solids into liquids, liquids into vapours, and vapours into permanent gases by elevation of temperature, shows a progressive approach towards this state of perfection which we believe to be attained by all gases at temperatures sufficiently removed from their critical points. We therefore hold that the laws of gases are applicable to the products of an explosion—provided the first condition of these laws—equilibrium or uniform distribution of the energy obtains in the products.

The law of Avogadro-Gerhardt that equal volumes of all gases contain at the same temperature and pressure equal numbers of molecules, as well as the hypothesis which we owe to Clausius that the specific heats of gases in the perfect gaseous state are constant, and the same for those containing equal numbers of atoms in the molecule is each, according to our view, a rigid deduction from the ideal behaviour of gases in the perfect gaseous condition.

Explosive energy can be studied under two different aspects depending upon whether the energy is developed without the performance of mechanical work or whether the development is accompanied or followed by the performance of mechanical work. We have two corresponding ideal conditions:—

- (1) Confinement of the products at constant volume.
- (2) Adiabatic expansion of the products.

Both involve the ideal conception of an "initial state" in which the energy is fully developed. The first is fulfilled by supposing the explosive to be fired in a closed vacuum vessel impervious to heat, strong enough to retain the products. The second by supposing the products to develop their energy fully and then to expand so as to perform mechanical work without communication of their heat as such to surrounding bodies.

In the first case, if the vessel be impervious to heat, the energy will be conserved indefinitely. In practice, the greater part of the energy will be dissipated in the form of heat communicated by radiation and conduction to surrounding bodies. A portion of the energy, however, will be retained. It is that which pertains to the gaseous products in their ordinary or standard state. The portion lost which can be directly measured is the heat of decomposition or heat of the reaction.

In case (2), if we suppose the expansion to be continued indefinitely, the whole of the energy will be transformed into work. The condition of indefinite expansion is irrealisable. The limit of the expansion is fixed by the presence of a subtle medium—the atmosphere which surrounds all terrestrial objects. The pressure of the

expanding products cannot fall below the pressure of the medium. This gives a natural limit to the work that can be realised.

Returning to case (1), confinement of the products to a closed vessel, we find that the most marked manifestation of the energy is the pressure on the interior walls of the vessel. This is sometimes erroneously confounded with the energy itself. Only a portion of the energy of the products is concerned in the pressure. This we may call the Kinetic energy. There is another portion which is dormant so far as the dynamic effort of the gases is concerned. This we may call the Internal energy. The pressure is the intensity factor of the Kinetic energy, the capacity factor being volume. One cannot be increased except at the expense of the other—that is, the pressure will be higher as the confining volume is less. The Kinetic energy, however, remains constant.

When the products expand adiabatically, it is the Kinetic energy which performs mechanical work, but gases have this wonderful property—as the Kinetic energy is expended in work it is replenished by drawing upon the stock of Internal energy, so that the two diminish together, and if the expansion could be continued indefinitely, the whole energy could be transferred into mechanical work.

If we consider the work as limited by some condition, such as the attainment of a certain degree of expansion by the products, then the work done will depend upon a general principle of energy—viz., that its availability increases with its intensity factor. That is, the higher the initial pressure or tension, the greater will be the proportion of the energy that can be transformed into work.

The potential of an explosive is its total energy, or the dynamical equivalent of the heat of decomposition, plus the energy which the products possess in the standard state. The necessity for this addition arises from the fact that the heat is measured from the standard state of the products, and does not include their energy in this state. The standard state may be taken as 0° C. and one atmosphere, or, to be exact, a barometric pressure of 760mm. of mercury, or about 216.3 pounds on the square foot.

The Available Energy or Maximum Work is that portion of the potential which theoretically can be converted into mechanical work. This is limited by a general condition, the presence of an atmosphere with a definite pressure which surrounds all terrestrial operations. For a given initial state of tension, the available energy is therefore that portion of the potential which can be converted into work by an adiabatic expansion from the given state of tension down to an equilibrium with the atmosphere. The available energy will be found greater as the initial state is taken nearer the state of absolute density of loading, or that in which the products are confined to the volume occupied by the explosive itself. The Useful energy or Useful work is that portion of the available energy of the product which can be applied to any special object. It is equal to the available energy less the dynamical equivalent of the heat lost as such by communication to other bodies and the energy expended in useless work.

*The Chemical Equation.*—If we can write the chemical equation of metamorphosis of the explosive and have at command certain physical data, we can make an interesting study of its energy. If we write the gaseous products in molecules, double the exponents, and place the figures above the corresponding symbols and also write the molecular masses below the symbols in both members of the equation, it will facilitate our study. We can take these masses in any units we please, grammes, pounds, etc. If we take them in Criths, the figures above the symbols will represent units of volume in the standard state—a crith being the mass of hydrogen corresponding to the unit volume. The French crith is .0896 grammes, the mass of a litre of hydrogen at 0° C. and 760mm. The British crith is .005592 pounds—the mass of one cubic foot under the same conditions. In this way we can readily calculate that one pound of nitro-glycerine will give 11.423 cubic feet of gas when the products are cooled down to 0° C., and are under one atmosphere of pressure. The study being theoretical, we take water (H<sub>2</sub>O), which is one of the products as a gas in this state—that is, we apply Avogadro's law as though all the products were perfect gases. This volume, 11.423 cubic feet corresponding to one pound, may be called V, the specific volume.

To calculate the heat of decomposition, we must have the heat of formation of the explosive itself if it is a chemical compound, or the heat of its several elements if it is a mixture. We must also have the heats of formation of the products. By adding the heats of each member of the equation together, and deducting the sum for the first member from that of the second, we get the heat of decomposition, H. Dividing this by the molecular mass of the explosive, we get the heat h for one unit of mass. The thermochemists do not agree exactly in the experimental determinations of heats. According to the researches of McNab and Ristori, the heat of decomposition of one unit of nitro-glycerine (H<sub>2</sub>O taken gaseous—as it should be in energy calculations) is 1535 heat units. Relying upon earlier experiments, I have usually taken it lower in my calculations, viz., about 1483 units. The heat unit is the specific heat of water. Theoretically, this is taken at its maximum density, so that there is no internal work done by expansion during the rise of temperature 1° C.



The potential or total energy for unit of mass is

$$E = J.T.kv. = J.t.kv. + J.273, kv.,$$

in which J (called a Joule, in honour of Dr. Joule, of Manchester) is the dynamical equivalent of the heat unit (as we use centigrade degrees, when the unit of mass is one pound, this is about 1396 foot-pounds); T is the absolute initial temperature of the explosion, t is the rise in temperature from 0° C. and kv. is the mean specific heat (at constant volume) of the products. The energy due to the heat is J.t.kv. The energy of the products in the standard state is J.273, kv.

$$T = t + 273\text{deg. } t = \frac{h}{kv.} \text{ or } \frac{H}{Kv.}, \text{ in which } h \text{ is the heat for}$$

one unit of mass (we take this as one pound) and H the heat of the reaction, kv. is the mean specific heat and Kv. is the total specific heat of the products of the reaction.

Considering the case of confinement at constant volume, the Kinetic energy Ek. of the products in such a state is equal to

$\frac{3}{2}PV$ , in which, for the purpose of simplifying calculation, P is taken as the pressure when the products are confined to V, the specific volume. P can be readily calculated from the formula

$$P = \left( \frac{h}{273kv.} + 1 \right) 2116.3$$

in which P is taken as the pressure on the square foot for the unit of mass, one pound detonated in the specific volume of the products expressed in cubic feet. The term within the parenthesis is the pressure in atmosphere, the whole term is the pressure in pounds. As defined in foot-pounds the Kinetic energy is independent of any conditions except that unit mass (1 pound) shall be considered and the volume to which the products are confined shall be expressed in cubic feet. The product PV is constant. If the gases are confined to a smaller or larger volume, the pressure is correspondingly increased or decreased according to Boyle's law.

Considering equal volumes, the Kinetic energies of all gases are the same at equal temperatures. The total energy which is proportional to the specific heat or energy—that is, the increment corresponding to 1 degree of temperature, depends upon the number of atoms in the molecule. If we take the specific heat of a diatomic gas as the standard of measure—that is, unity—the specific heat of a triatomic gas such as CO<sub>2</sub> or H<sub>2</sub>O will be  $\frac{3}{2}$ —that of a tetraatomic gas such as NH<sub>3</sub> will be 2, and so on. A monatomic gas which is rare in explosion products has the same Kinetic energy as the others, but there being no interatomic energy the Kinetic is its total energy, and is proportional to its specific heat. Referred to the diatomic standard, this is 0.615.

The specific heat kv. hydrogen is 2.422. This is the specific heat of unit mass, and also the specific heat of the volume corresponding to unit mass. Volumes equal to this of all other diatomic gases have the same specific heat—2.422. This gives us a ready means of calculating from the data furnished by the chemical equation, the total specific heat of the products or their mean specific heat. We take the volumes (figures written over the symbols) and reduce them first to the diatomic standard, and multiply their sum by 2.422. In the case of nitro-glycerine the volumes are 14.5—reduced to the diatomic standard, they add up 20. This multiplied by 2.422 gives 48.44, the total specific heat Kv. for 227 units—227 being the molecular mass of nitro-glycerine. The mean specific

heat kv is  $\frac{48.44}{227} = 0.2134$  nearly.

The specific heat we have so far used is that at constant volume kv. This is the true specific heat because no work is done. It is therefore the real increment of energy for 1 degree of temperature. There is another specific heat—that at constant pressure, kp. This is larger because part of the energy is expended in the work of expansion of the gas against the constant pressure during the rise of temperature of 1 degree. The difference between the two is the work of this expansion. Hence we have the fundamental equation—

$$(A) \text{ kp.} - \text{kv} = \frac{PoVo}{J.273}$$

in which Po is the standard pressure on the unit of surface, Vo the specific volume of unit of mass,  $\frac{1}{273}$  is the increment of volume

for 1 degree in temperature, and J the dynamical equivalent of the heat unit. This is introduced to reduce the mechanical work to its heat terms.

In my calculations I have taken Po = 2116.3 pounds as the standard atmospheric pressure on the square foot, and J = 1395.846 foot pounds.

Equation (A) gives us a means of calculating either specific heat if we know the other, and also the ratio  $\frac{kp.}{kv.} = y$  a very important quantity in thermodynamics, and also in the study of explosive energy.

Applying equation (A) to hydrogen, in which Vo, the specific volume of unit mass 1 pound is equal to 178.827 cubic feet we find kp. = 3.41514, when kv. is taken as 2.422, and the ratio

$\frac{kp.}{kv.} = y$  is equal to 1.410049. This ratio is the same for all diatomic

gases. It is usually taken as 1.41. Another useful element in our calculations is B, the ratio of the whole energy of a gas to its Kinetic energy. According to the Kinetic theory of gases, the molecules are in rapid motion, which is augmented by a rise in temperature. When a gas confined at constant volume receives a certain amount of heat, the increase in its energy may be taken as the dynamical equivalent of the heat. All of this energy (except in monatomic gases) does not take the Kinetic form, or that due to the motion of the molecules as entities. A part takes the form of Internal energy, or that due to the motion of the parts of the molecules with reference to their respective centres of mass. There is a constant conversion of one form into the other due to collision between the molecules, but in a perfect gas the relation between them tends to a constant value at all temperatures.

We saw that the Kinetic energy Ek in any state is expressed

$$\text{by Ek} = \frac{3}{2}PV, \text{ the total energy E of the gas or gases is therefore } E = \frac{3}{2}BPV.$$

The fraction of the energy which takes the form of Internal energy is larger as the molecule is the more complicated. All gases having the same number of atoms to the molecule have the same ratio between the two energies. The ratio of the specific heats

$\frac{kp.}{kv.} = y$  is also dependent upon the number of atoms in the mole-

cule. For a monatomic gas this ratio is  $\frac{5}{3}$ .

For all gases except monatomic the relations which these ratios bear to each other and to the number of atoms in the molecule are given in the following equations:—

$$Y = \frac{1 + 0.41}{\frac{1}{2}N} \quad B = \frac{2}{3(y - 1)}$$

Hence  $B = \frac{N}{1.23}$  in which N is the number of atoms to the molecule.

These ratios can be computed not only for a single gas, but for any given mixture of gases such as the products of an explosive. In this case the specific heats are mean or average quantities, and N is the average number of atoms to the molecule.

The experimental determination of the specific heats of gases is very difficult. We owe the most reliable measures to the skill of Regnault, who determined the specific heat at constant pressure of various permanent gases. The most interesting method of getting

the ratio of the specific heats  $\frac{kp.}{kv.}$  is from the velocity of sound in

the gas. This is based upon the Laplace formula, in which the velocity is shown to be proportional to the product of this ratio and the square root of the pressure divided by the density. The practical method is due to Kundt—a long glass tube filled with the gas also contains lycopodium dust or very fine sand. By creating sustained sound waves in the tube of a definite note or pitch, the wave length, which is proportional to the velocity, is defined by the disposition of the dust which gathers at the nodes. The velocity can be compared with the corresponding velocity in air, for which  $\frac{kp.}{kv.} = 1.41$ . It was in this way that mercury vapour was shown

to have the ratio 1.666 by Kundt and Warburg, and more recently Argon and Helium were declared to be monatomic on the same ground.

**Dissociation.**—One of the stumbling blocks in the theory of explosive energy is dissociation of the gaseous products by heat. When an explosive is fired in a closed vessel and an attempt is made to measure the maximum temperature attained, the actual temperature as determined by the rough means at our command (we have no scale that can be relied upon) is found to be much lower than the theoretical or that which we compute from the heat of decomposition (which we can measure accurately), and the mean



normal specific heat of the products. The French school of experimenters, of which the great Berthelot was the head, generally got over the difficulty by supposing that the specific heats of the gases increase with the temperature, and even empiric formulas have been proposed to calculate the actual temperatures. There is a better explanation—viz., dissociation of the products by heat. Practically it makes little difference so far as the actual temperature is concerned, whether the heat is rendered latent in this way or by an increasing absorbing capacity in the products due to increase of specific heat, but from the point of view of theory one explanation strikes at its root while the other is in accordance with it.

Beyond a few hundred degrees centigrade we have no scale of temperature that is authentic. The air thermometer, through a limited range, has been proved very correct by Joule and Thompson (afterwards Lord Kelvin), by an appeal to thermodynamical principles, which are independent of the properties of any particular substance. The melting points of the refractory metals such as gold, iron, platinum, etc., which have been used to determine the temperature of fired gunpowder and other explosives, are merely uncertain guesses. Thus the melting point of platinum varies according to different authorities from 1460 to 2534 degrees C.

In the Journal of the American Chemical Society, I published, some 13 years ago, a short paper entitled, "Argon—an ideal thermometrical substance." Air is composed of two diatomic gases, and theoretically it is subject at high temperature to thermolysis or dissociation by heat. Argon, according to the Kinetic theory, is a monatomic gas and not subject to this. If some skilled experimentalist would take this gas and construct a thermometer of it, its expansion under constant pressure, or increment of pressure at constant volume, would give us a scale of temperature that would be absolutely authentic if the Kinetic theory can be relied upon. The Kinetic theory is only a working hypothesis to explain the behaviour of matter in the gaseous state. I have taken it as one of the guides in my study. In this I have been following in the footsteps of such men as Joule, Kelvin, Maxwell and Clausius.

I have given considerable time to the study of dissociation or thermolysis as one of the most important elements of a sound theory of explosive energy. My reasoning is briefly as follows:—Heat is the decomposing agent in nature. Every gas containing more than one atom to the molecule is subject to thermolysis or decomposition by heat.

When a gas is heated a portion of the energy takes the form of Kinetic energy or movement of the molecules as entities. This can have no tendency to decompose them. Another portion is converted into internal or interatomic energy, which consists in the motions of the parts of the molecules. We believe that the decomposing influence of the heat lies in this portion of it. This idea is supported by common observation. In a general way it is known that the susceptibility of a gas to thermolysis increases with its complexity or number of atoms to the molecule, which according to the Kinetic theory also increases the internal energy. Since a gas generally produces by its formation a heat sufficient to partly dissociate it, it follows that the complete and instantaneous formation of a gas without cooling of the products of the chemical action is an ideal thing impossible of attainment. We therefore indulge the conception of a certain percentage of dissociation which is normal to the formation of the gas. This "normal dissociation" depends upon the ratio between the interatomic energy and the whole energy or upon the molecular constitution. Following certain relations deduced from the Kinetic theory, I have been able to propose formulas for the normal amount of dissociation in both triatomic and diatomic gases and in a mixture of the two, and have tested these formulas in the case of detonating gaseous mixtures such as a hydrogen and oxygen, hydrogen and chlorine, carbonic oxide and oxygen, etc., in which the pressure can be accurately measured. The pressure calculated from the dissociated system shown by the formulas gives a close agreement with that found experimentally.

In the next paper I propose to give some calculations as to the available energy of several explosives.

CHAPTER V.

Available Energy—Some Calculations for Nitro-glycerine—Diagram of Available Energy of Nitro-glycerine when the Expansion is from the Specific Volume of the Products—Tables for Several Explosives, Showing Dependence of Available Energy upon Density of Loading—Available Energy as Affected by Dissociation.

*The Available Energy of an Explosive.*—This is the part of the total energy which theoretically can be converted into external mechanical work. So long as the explosive is confined to constant volume no work in this sense is done. To study the available energy, let us conceive an initial state in which the energy is fully developed, and then suppose the gases to expand without gain or loss of heat as such till the pressure is reduced to that of the atmosphere. This is the maximum work which the products expanding from the given initial state can do under terrestrial condi-

tions. The efficiency of the explosive is  $\frac{W}{E}$  in which W is the available energy or maximum work, and E is the total energy or potential. The efficiency calculated to the heat is  $\frac{W}{Jh}$ , in which Jh is the dynamical equivalent of the heat.

The work of adiabatic expansion may be calculated in several different ways. One is by integrating a differential expression for the work—PdV. A simple method is supplied by the equation—

$$(1) W = KvJ (T' - T'')$$

in which T' is the initial and T'' is the final absolute temperature, and Kv the mean specific heat of the gas or gaseous mixture. The initial energy is KvJT', the final energy is KvJT'', and the work

$$\text{is the difference between them. } T' = 273^\circ + \frac{h}{kv}.$$

\* T'' the final absolute temperature is obtained from the relation

$$\frac{T}{p^{\frac{y-1}{y}}} = \text{constant, whence } T'' = T' \left( \frac{p''}{p'} \right)^{\frac{y-1}{y}}, \text{ in which}$$

$$y = \frac{kp}{kv} \text{ and } \frac{p''}{p'} \text{ is the ratio of the final to the initial pressure.}$$

If we take these pressures in atmospheres ( $p'' = 1$ ) and suppose the products in the initial state to be confined to their specific volume,  $p'$  the initial pressure is equal to  $\frac{T'}{273}$ , and we have therefore

$$T'' = T' \left( \frac{273}{T'} \right)^{\frac{y-1}{y}} \text{ and } (2) W = KvJ \left( T' - T' \left( \frac{273}{T'} \right)^{\frac{y-1}{y}} \right)$$

We have another expression for the work as the difference between the initial and final energies. The kinetic energy in any state is equal numerically to  $\frac{3}{2}$  of the rectangle of the pressure and volume. B being the ratio of the whole energy to this energy, the total energy will be  $\frac{3}{2} B pv$ . From which we have (3)  $W = \frac{3}{2} B (p'v' - p''v'')$ .

V'' is easily obtained since  $p'v' = \text{constant}$  in adiabatic expansion. In this formula W being in foot-pounds, p' and p'' are expressed in pounds, v' and v'' in cubic feet.

In paper No. 4 I showed how the ratio y and B could be obtained from the number of atoms to the molecule of the gas—or average number to the molecule in a gaseous mixture.

We now give some of the elements in the calculation for nitro-glycerine. The data obtained from the chemical equation of metamorphosis are as follows:—

- 227 British criths give 14.50 cubic feet.
- 1 pound gives 11.423 cubic feet = V' the specific volume.
- H = 336,550 heat units.
- $\frac{H}{227} = 1482.6$  heat units.

Kv — total for 227 units = 48.44 (using 2.422 as the atomic heat of hydrogen).



$$kv \text{ mean} = \frac{48.44}{227} = 0.21339.$$

$$t \text{ rise in temp.} = \frac{336.550}{48.44} = 6947^{\circ}.77.$$

$$T' \text{ the initial absolute temp.} = t + 273^{\circ} = 7220^{\circ}.77.$$

$$P' \text{ a initial pressure in atmospheres} = \frac{7220.77}{273} = 26.4497.$$

$$p' \text{ initial pressure in pounds} = p' \text{ a} \times 2116.3 = 55975.5.$$

$$kp \text{ mean} = 0.276823.$$

$$- = y = 1.29728.$$

$$kv$$

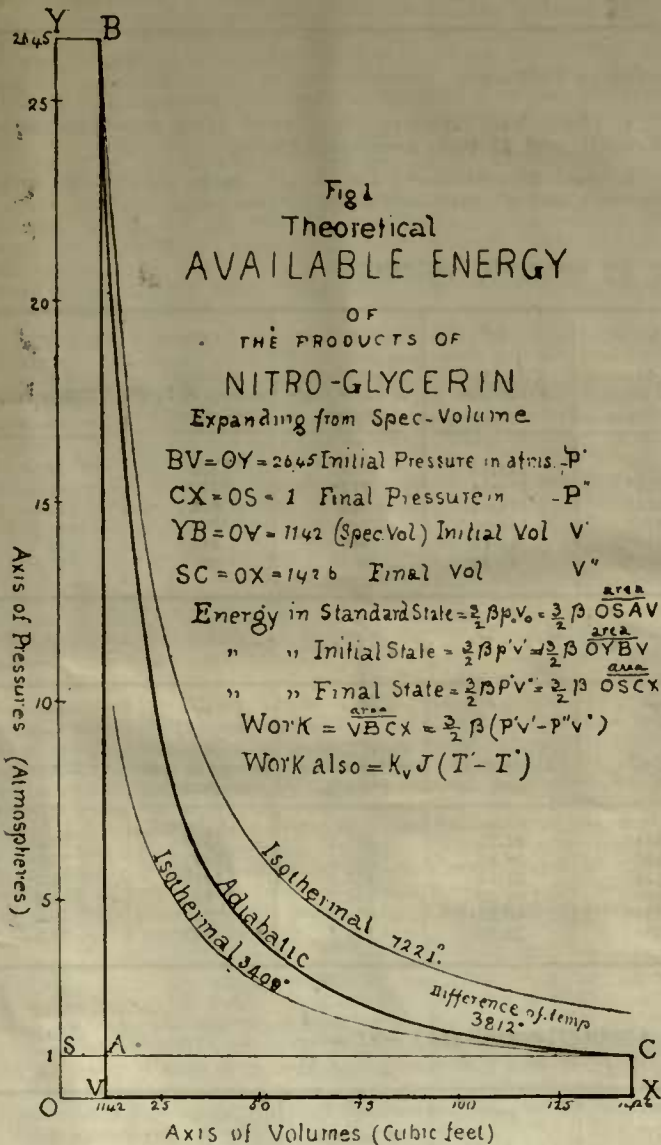
$$B = \frac{2}{3(y-1)} = 2.2427.$$

Computing the work first by equation (2)

$$W = \left( T' - T' \left( \frac{273}{T'} \right)^{\frac{y-1}{y}} \right) kv J, \text{ in which } \frac{y-1}{y} = 0.229156, \text{ we}$$

$$\text{have } T'' = T' \left( \frac{273}{T'} \right)^{\frac{y-1}{y}} = 3409^{\circ}.0 \text{ the final temp., and } W =$$

$$1,135,385 \text{ foot pounds.}$$



By formula (3) we have  $W = \frac{3}{2} B (p'v' - p''v'')$ , in which

$p' = 55975.5$   $v' = 11.423$  cubic feet,  $p'' = 2116.3$  pounds, we obtain  $v''$  from  $p'v'y = p''v''y$ .

$v'' = 142.64$  cubic feet, the final volume.

Initial or total energy  $\frac{3}{2} B p''v'' = 2,150,836$  foot pounds.

Final energy  $\frac{3}{2} B p'v' = 1,015,433$  foot pounds.

Difference or work  $W = 1,135,403$  foot pounds.

The difference between the two calculations for the value of  $W$  is 18 foot pounds.

The mechanical equivalent  $J_h$  of the heat = 2,069,480 foot pounds.

The efficiency calculated to the heat = 54.86 per cent.

Calculated to the potential or total energy = 52.79 per cent.

Diagram.—We have illustrated the available energy of nitro-glycerine under the condition of expansion of the products from their specific volume by a diagram (see Fig. 1). The work during adiabatic expansion equal to the available energy under the conditions, is represented by the area enclosed in heavy lines  $VBCX$ . The diagram is made self-explanatory.

It must be kept in mind that this calculation of available energy is strictly theoretical even dissociation of the products being ignored.

So far, in computing the work, we suppose the adiabatic expansion to start from the state represented by  $p'v'$  (see point B in the diagram).  $v'$  is the specific volume of the products. To make the diagram clear, we may first suppose the products to possess this volume in the standard state (point A), and that the heat  $h$  is applied to them. Then, by the laws of gases, the products having a certain specific heat  $kv$  (at constant volume) will have their temperature increased a certain number of degrees  $t$ , and this will give a certain increase of pressure  $p = AB$ . Now  $t$  being increased by standard absolute temperature  $273^{\circ}$ , and  $p$  being increased by the standard pressure (1 atmosphere), we get  $T'$  and  $p'$ , the absolute temperature and the pressure in the state of maximum development of energy (point B). We have called this the potential, also the initial energy. The product  $p'v'$  (point B) also defines the same

$$\text{energy since this is equal to } \frac{3}{2} B p'v'.$$

The isothermal through the point defined by  $p'v'$  ( $B$ ) when indefinitely extended in both directions defines all the states in which the products would have this initial energy or potential. We will call this the potential isothermal. We can begin the adiabatic expansion from any point on the potential isothermal. The available energy will vary accordingly. It will be the greater the higher the initial tension.

In our calculation we have taken the initial tension as  $p'$  corresponding to  $v'$  the specific volume, in which case  $T'' = T'$

$$\left( \frac{p''}{p'} \right)^{\frac{y-1}{y}} \text{ generally } T'' = T' \left( \frac{p''}{p'} \right)^{\frac{y-1}{y}}. \text{ The final tempera-}$$

ture, therefore, diminishes, and the work increases as the initial pressure is the greater. The available energy approaches the potential in value as the initial pressure increases or the initial volume is taken smaller. The limit of increase is fixed by the absolute pressure of the explosive. The initial pressure depends upon the density of charge, and the limit is fixed by the density of the explosive. When the explosive is detonated in its own volume, we have the highest possible pressure, which may be called the absolute pressure.

The greater the initial tension the less the final volume and final temperature. These principles can be best illustrated by examples. We therefore consider the work of nitro-glycerine at different densities of loading.

The figures already obtained apply when the initial volume of the adiabatic expansion is the specific volume of the products.

Making similar calculations for adiabatic expansion from unit volume (in which case the initial pressure may be called the specific pressure), we have—

$$p' = 639,409 \text{ pounds.}$$

$$v' = 1 \text{ cubic foot.}$$

$$T' = 7220^{\circ}.77 \text{ (this is constant).}$$

$$p'' = 2116.3 \text{ pounds (this is constant).}$$

$$v'' = 82.76 \text{ cubic feet.}$$

$$T'' = 1951^{\circ}.$$

$$\text{Available energy } W = \frac{T' - T''}{T'} = 73 \text{ per cent. of potential.}$$

For the initial state of confinement of the products to the volume occupied by the explosive itself giving the absolute pressure (since 100 pounds of nitro-glycerine occupy very exactly one cubic foot), we have—

$$p' = 63,940,900 \text{ pounds.}$$

$$v' = 0.01 \text{ cubic foot.}$$

$$T' \text{ and } P'' \text{ the same as before.}$$

$$v'' = 28.41 \text{ cubic feet.}$$

$$T'' = 680^{\circ}.$$

$$\text{Available energy } W = \frac{T' - T''}{T''} = 90.6 \text{ per cent of potential.}$$

We see from this that the theoretical limit for  $W$  which corresponds to initial absolute pressure is about 91 per cent. of the potential.



The accompanying tables give the available energies of six explosives, considered under three conditions of initial confinement, viz., at the specific volume of the products, at unit density of loading ( $V' = 1$ ), and at absolute density. The mass of explosive considered in each case is one pound. Table No. 1 gives the elements of the calculations, potential, initial temperature, mean specific heat of the products, the ratios of  $y$  and  $B$  and the density of the explosive, which in this sense is the number of pounds occupying one cubic foot. The other tables give the initial pressure, the initial volume, the final temperature, final volume, final energy, available

energy or work done, also the efficiency calculated to the potential  $W$ . The fourth table also gives the efficiency calculated to the  $E$  heat  $Jh$ .

TABLES.

Available energies of different explosives expanding adiabatically from different initial states down to atmospheric pressure, assuming that the initial energy is the potential:—

TABLE I.—ELEMENTS OF THE CALCULATION.

Explosive.	E Potential in 1,000 foot-pounds.	T' Potential temp.	kv Mean Spec. heat.	v kp kv	B E Ek	D Density of Explosive—lbs. in cubic foot.
1. Nitro-glycerine .. ..	2151	7221°	0.21339	1.297	2.2425	100
2. Gun-cotton .. ..	1463	4666°	0.22461	1.340	1.958	68.75
3. Picrate Am. Mixture ..	1484	4094°	0.25969	1.302	2.206	70
4. Am. Nit. Mixture, No. 1	1333	3568°	0.26755	1.302	2.206	62.5
5. Am. Nit. Mixture, No. 2	960	2611°	0.26326	1.328	2.032	62.5
6. Mercury Fulminate ..	618	6018°	0.61660	1.454	1.469	276.0

Notes in Regard to Composition of Explosives.

2. Gun-cotton.—This is compressed military gun-cotton taken as  $C_{24}H_{29}N_{11}O_{42}$  (13.47 per cent. of N.).

3. Picrate Am. Mixture.—This contains 72.2 parts Ammonium Nitrate, and 27.8 parts Ammonium Picrate.

4. Am. Nit. Mixture, No. 1.—7 parts amorphous carbon (charcoal), and 93 parts ammonium nitrate.

5. Am. Nit. Mixture, No. 2.—13 parts amorphous carbon (charcoal), and 87 parts ammonium nitrate

TABLE II.—AVAILABLE ENERGY AT SPECIFIC VOLUME.

Explosive.	P' Initial pressure in pounds.	V' Initial vol. cubic feet.	T' Final temp.	V'' Final vol. cubic feet.	E'' Final Energy in 1,000 foot- pounds.	W Available energy in 1,000 foot-pounds.	W E Efficiency.
1. Nitro-glycerine .. ..	55975	11.42	3409°	142.64	1015	1135	52.8
2. Gun-cotton .. ..	36172	13.77	2269°	114.44	711	762	51.3
3. Pic. Am. Mixture .. ..	31735	14.13	2184°	113.03	792	692	46.6
4. Am. Nit. Mixture, No. 1	27661	14.56	1965°	104.80	749	593	44.9
5. Am. Nit. Mixture, No. 2	20241	15.55	1495°	85.15	549	410	42.7
6. Mercury Fulminate ..	46651	5.04	2292°	42.29	197	321	61.9

TABLE III.—AVAILABLE ENERGY AT UNIT VOLUME— $V' = \text{unity} = 1$  cubic foot.

Explosive.	P' in 1000 pounds.	V' Initial vol. cubic feet.	T' Final temp.	V'' Final vol. cubic feet.	E'' Final Energy in 1,000 foot- pounds.	W Available energy in 1,000 foot-pounds.	W E Efficiency.
1. N.G. .. ..	639.4	1	1951°	82.76	581.1	1570	73.0
2. G.C. .. ..	498.0	1	1166°	58.80	365.5	1097	75.0
3. Pic. Am. Mixture .. ..	448.4	1	1178°	61.14	428.2	1055	71.1
4. Am. Nit. Mixture, No. 1	402.6	1	1055°	56.29	394.3	938	70.4
5. Am. Nit. Mixture, No. 2	314.8	1	759°	43.23	278.9	671	70.9
6. Merc. Fulm. .. ..	235.0	1	1384°	25.53	110.1	399	77.0

TABLE IV.—AVAILABLE ENERGY AT ABSOLUTE DENSITY— $V' = \frac{1}{D}$ .

Explosive.	P' in 1000 lbs.	V' in cubic feet.	T'	V''	E 1000 ft. lbs.	W in 1000 ft. lbs.	W E	W Jh
1. N.G. .. ..	63941	0.01	680°	28.41	202	1948	90.6	94.1
2. G.C. .. ..	34239	0.0145	398°	20.08	125	1338	91.4	97.1
3. Pic. Am. Mixt. .. ..	31386	0.0143	441°	22.81	160	1324	89.2	95.7
4. Am. Nit. Mixt. No. 1	25164	0.016	404°	21.56	151	1182	88.7	96.4
5. Am. Nit. Mixt. No. 2	19673	0.016	273° 2	15.56	100	859	89.5	100.0
6. Merc. Fulm. .. ..	64860	0.00362	239°	4.41	21	497	96.0	100.5
			273°*	3.31	23	494	95.5	100.

\* In this case P' = 3222 pounds.



Though based entirely upon a theoretical consideration of the subject, these tables are both interesting and instructive.

To roughly summarise the results, we can say for each high explosive considered that, ignoring dissociation, the available energy when it is detonated at specific volume is about 50 per cent.; at unit density of loading about 70 per cent., while the absolute available energy is about 90 per cent. of the total energy or potential.

The first condition is theoretical. The second—one pound detonated in a cubic foot of space is very light charging. The third condition—one pound confined to its own volume is always approached, and often reached in practical work. Hereafter, in referring to the available energy, unless otherwise specified, we shall consider this the condition of confinement.

The list of explosives is selected to give as great a range to the elements as possible—thus the total energy of mercury fulminate is less than one-fourth that of nitro-glycerine. Its absolute pressure (the greatest of all explosives) is  $3\frac{1}{2}$  times that of No. 5—the Am. Nit. Mixture No. 2, while its specific volume is less than one-third of that of No. 5, and its density is  $4\frac{1}{2}$  times as great.

Mercury fulminate excels all other explosives in efficiency under the three conditions. It owes this partly to the simplicity of its products, but chiefly to their great initial tension.

It will be noticed that in the last table (No. IV.), there are two separate calculations for this explosive. We have already stated the general law that the available energy is limited by the isobaric of the atmosphere, and not by the standard isothermal,  $273^{\circ}$ . Generally in adiabatic expansion, the pressure of the products reaches an equilibrium with the pressure of the surrounding medium (2116.3 pounds on the sq. foot) before their temperature is reduced to the absolute temperature of the medium  $273^{\circ}$ . If we assume that the expansion continues to be strictly adiabatic (for instance, that a non-conducting substance separates the products from the medium), the general law is correct in every case. It therefore appears that under this condition mercury fulminate is capable of cooling its products below the standard temperature of the atmosphere. In this, it appears to be unique. However, it would be too much to say no other explosive possesses this power, since one of the others in the table, No. 5—the Nit. Am. Mixture No. 2, all but reaches this temperature. These two explosives present, in some respects, a decided contrast, one having the greatest, the other the least specific volume in the table. These two are the most efficient in converting heat into work, each giving 100 per cent.

Ignoring dissociation, it appears that all high explosives are capable of converting from 94 to 100 per cent. of the heat into work, so that they do not differ much in this regard. There is a law of compensation here which is easy of comprehension. The efficiency, other things being equal, is the greater as the specific volume is larger and the products simpler. The efficiency is also increased by a higher initial tension. As a general rule complex products, while lessening the efficiency according to the first consideration, increase it according to the second by giving greater heat and consequently greater initial tension.

Comparing the final volumes  $V''$  (Table IV.) with specific volumes  $V'$  (Table II.), it will be noticed that nitro-glycerine nearly trebles the specific volume of its products before their pressure is reduced to that of the atmosphere. Guncotton adds 50 per cent. only to the specific volume of its products. The ammonium nitrate mixture No. 2 just reaches its specific volume, while the fulminate falls notably short of this amount of expansion. These figures help to explain the different actions of various explosives. An explosive with a high initial tension which yields up its available energy within narrow limits of expansion is essentially intense and shattering in its effects. If the action is intensified by a rapid rate of detonation, we get the characteristics of a fulminate. Fulminate of mercury strikes a short but intense blow. Its high initial tension is chiefly due to its great density. Its potential is small. Nitro-glycerine combines immense energy, a high initial tension with great length of stroke. Guncotton is very intense (more so than appears from the table, on account of its great speed of detonation). Its energy is great, and its stroke only moderately long.

We pause to note that the maximum pressure is given by mercury fulminate, nearly 65 million pounds on the square foot, or 450,000 pounds on the square inch. That of nitro-glycerine is, theoretically, nearly as high, but this must be diminished something like one-half by dissociation. The other is approximately correct; dissociation will not lessen it more than, say, 10 per cent. as a guess.

*Available Energy as Affected by Dissociation.*—So far we have ignored dissociation in considering the available energy. The general effect of dissociation will be to lessen this so that the figures we have obtained are too high. Nevertheless, these figures as they stand have a value as a limit. For at least one explosive in the list, the fulminate, they may be taken as approximately correct. When this is closely confined it probably converts at least 90 per cent. of its heat into work. No other explosive yields up its energy so completely and within such narrow limits of expansion. Its energy, however, is very small.

Generally dissociation will have two opposite tendencies—first, by lessening the initial tension, it will reduce the available energy, but it will simplify the products and thus render them more efficient in converting a given amount of energy into work. The latter effect

will not counterbalance the first, however, and in all cases the available energy will be reduced by dissociation. The expansion can no longer be considered adiabatic, since the heat or part of it (that rendered latent by dissociation) will be received during the expansion and cooling of the products.

If, however, we could know the initial state (defined on a diagram by a point having certain co-ordinates pressure and volume) and could draw the adiabatic for this initial state, then the work so defined would be an inferior limit for the available energy just as that calculated (or determined graphically) for the potential initial state would be a superior limit. The real curve defining the states through which the products passed in reaching an equilibrium with the atmosphere, would lie, for the greater part of its course, between these two adiabatics. However, in the lower part of its course it will intersect the potential adiabatic and give a greater final volume than pertains to the latter.

We can state the case in the form of a general equation. Suppose, for simplicity, that in the final state of the expansion the products are those given in the chemical equation of metamorphosis—that is, dissociation is absent in this state. This is highly probable from the values of the final temperatures given in Table 4, and although these do not govern the case, the real temperatures being higher, the supposition is still justifiable.

Let  $E$  be the potential.

$E'$  be the initial active energy developed.

Then  $E - E' = L'$ , in which  $L'$  is the energy rendered latent by dissociation in the initial state—which energy is also the sum of the energies received by the products during expansion. Let  $E''$  be the final energy of the products in the expansion.

Then  $E'' = E' + L' - W$ ;

Or  $E'' + W = E$ .

That is, if dissociation is absent in the final state of the expansion the potential is still developed, and this is divided between the work done and the final energy.

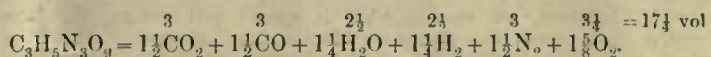
The expansion being no longer adiabatic, we cannot calculate the final energy or the work. The general effect of dissociation will be to increase the final energy at the expense of the work—more work will be done at lower tension and less at higher. In the ex-

pression for the final energy,  $-B p''v''^{\frac{3}{2}}$ , the final pressure is fixed at one atmosphere;  $B$  is peculiar to the products of the explosive (dissociation by hypothesis being absent in the final state), the final energy can therefore only be increased by increasing the final volume  $v''$ .

Again in the expression for the final energy,  $J. kv T''$ ,  $J.$  is a constant, and  $kv$  is peculiar to the products (being independent of dissociation unless monatomic products are present, which is unlikely in the final state); the final energy, as dependent upon these elements, can only be increased by increasing the final temperatures.

We illustrate these principles by making a calculation for the adiabatic expansion of nitro-glycerine, assuming that in the initial state (absolute density of loading  $V' = 0.01$  cubic feet), there is a dissociation of one-half the triatomic products (given in the normal equation of metamorphosis) into diatomic products. Of course there is no authority for this particular amount of dissociation. It is taken merely as an illustration, and also great enough as we think to furnish an inferior limit for the work.

The products under this supposition would be as follows:—



Now supposing there is an adiabatic expansion from this initial dissociated state, the elements of the calculation would be as follows:—

The heat developed per unit of mass,  $h' = 716.2$ .

The heat energy,  $Jh' = 999,692$  ft. lbs.

The initial energy,  $E' = 1,081,008$  ft. lbs.

The heat energy rendered latent by dissociation,  $L' = 1,069,788$  ft. lbs.

The spec. vol. of the products = 13.39 cubic feet.

The corresponding pressure = 28,134 pounds.

The initial temperature  $T'$  (absolute) =  $3629^{\circ}$ .

The rectangle of pressure and volume  $pv = 382,317$ .

The ratio  $\frac{kp}{kv} = y = 1.3537$ .

The ratio  $B = 1.885$ .

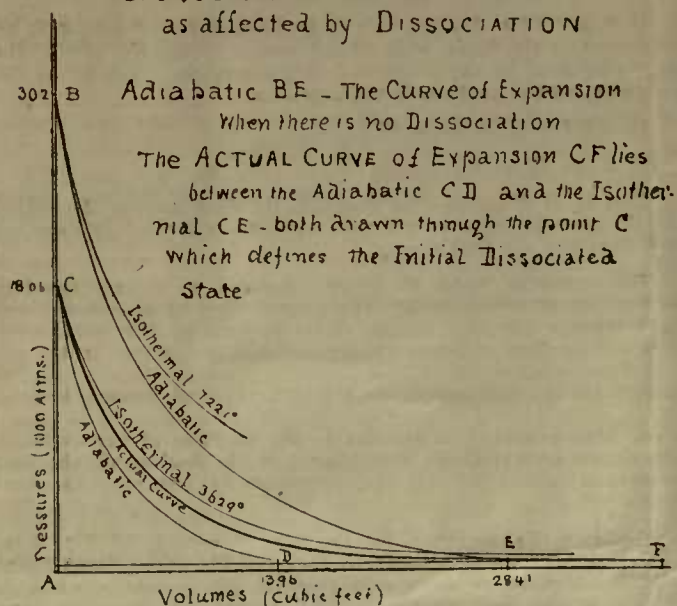


Making the calculation for the adiabatic expansion, we have—

P'	T'	V'	E'	W	$\frac{W}{E'}$	$\frac{W}{Jh'}$	$\frac{W}{E}$
1000lbs.	Final Temp.	Final Vol.	Final Energy, 1000 ft. lbs.	Work, 1000 ft. lbs.	%	%	%
38,232	280°	1,396	88.4	997	92.3	99.8	46.3

The calculation shows that the efficiency calculated either to the active initial heat or to the initial energy developed, has been slightly increased. This is owing to the simplification of the products (note change in  $y$  and  $B$  as compared with former tables). But the efficiency calculated to the potential is found to be lessened nearly one-half (46 against 91 per cent.).

Fig 2  
Diagram to Illustrate  
The ABSOLUTE WORK of NITRO-GLYCERIN  
as affected by DISSOCIATION



The work under this supposition is about one million foot pounds, and this may be considered as an inferior limit to the available energy.

This calculation takes no account of the energy rendered latent by dissociation. By hypothesis this energy is given out or developed during the expansion of the products, so that the expansion is not adiabatic, and the work defined by the adiabatic curve through the point representing the initial dissociated state is certainly too small.

If, however, we assume what is almost self-evident, that the initial state gives the maximum development of energy—then the isothermal through the point which represents the initial state forms a superior limit for the expansion and the actual curve of expansion, lies between the adiabatic and isothermal through this point.

We may imagine various forms for the actual curve. For instance, that it coincides with the isothermal for part of its course.

Then the only work done would be by conversion of the latent heat as fast as it developed as active energy into work. The limit of conversion should be about 1,070,000 foot-pounds (see value of  $L'$  above). When this was reached the actual curve would fall away from the isothermal and take the course of an adiabatic.

However, this supposition seems entirely uncalled for. The actual curve probably never reaches the isothermal after leaving the initial state. We have endeavoured to illustrate the natural view in the case of nitro-glycerine by a diagram (Fig. 2), in which dissociation is assumed as above. This diagram cannot be drawn to a scale like the preceding one, and all the curves are accordingly very much distorted. Two adiabatics are given, the higher one for the case of no dissociation.

The explosive being at absolute density of loading the volume in the initial states in both cases is 0.01 cubic feet. The work corresponding to each curve is the area included between the curve, its extreme ordinates and the axis of volumes. The work corresponding to the adiabatic BE is 91 per cent. of the potential. That corresponding to the adiabatic CD is 46 per cent. of the potential. That of the actual curve is between these limits and can only be guessed at.

It will be noticed that the actual curve CF lies below the isothermal CE throughout its course, and also that it intersects the greater adiabatic BE and gives a final volume AF considerably greater than that corresponding to the adiabatic's final volume AE.

We repeat once more that the assumption in regard to the amount and character of the dissociation is simply used as an illustration. However, if at some future day we are able to calculate the dissociation in the initial state, the principles enunciated will apply.

The general view we take of dissociation is that it is determined by the nature of the products—the more complex these are, the greater the dissociation. It is also a question of temperature and not of pressure—being the same for different densities of loading. Whatever may be the amount of dissociation in the initial state (the amount is measured by the heat rendered latent), both the energy developed and the energy rendered latent are at a maximum in this state—that is, both the active and latent energies diminish during the expansion of the products. The law of diminution is something between that of adiabatic and isothermal expansion.

The general effect of dissociation will be to lower the absolute work or available energy of an explosive by increasing the final temperature and the final volume. It will diminish the shattering effect of an explosive and lengthen its reach. In many cases it will increase the useful work—a point to be noticed later.

While it will modify the characteristics of an explosive deduced from the theoretical study, it will not obliterate them.

There is one point which is not well covered by our theory. We were careful to say that the laws of gases can only apply to the products of an explosive when there is equilibrium or uniform distribution of energy among them. In the initial state of tension of a fired explosive, especially one with a high rate of detonation, this condition of equal distribution of energy does not obtain, and we cannot say that the laws of gases hold good for the system. The action exerted on the walls of a containing vessel is not in the strict sense a pressure. We even know that the action is not equal in all directions. It is held by some students that a greater part of the energy takes the Kinetic form than called for by the laws of gases. If this were so, it would tend to offset the effect of dissociation in lessening the initial tension and in reducing the percentage of the potential, which can be converted into work. This idea has been carried to the limit of supposing that in the first instants of detonation, the dissociation is complete, leaving all the products reduced to atoms, in which case the whole energy would be Kinetic. Nothing could be more unphilosophical than such a supposition. Where does the energy come from if not from the union of atoms? If the molecules are all dissociated, there is no active energy to be considered. In regard to the Kinetic energy being in excess of that required by theory, we can, with just as much, if not more, reason, suppose the internal energy greater than theory calls for. The simplest way to get over the difficulty is to suppose that the mean of the actions in all directions is equal to the pressure, which we could deduce if the energy were uniformly distributed. The state of uniform distribution is reached in any case in a short space of time if the products remain in one body. While the theory is unable to cover the condition of irregular distribution of the energy, this condition is not a serious obstacle to its practical application.



## CHAPTER VI.

## Useful Work—General Principle for Hard Rock—Bank Blasting—Classification of Explosives—Tests for Energy—Quinan Crusher Gauge—Work in the Mortar.

*Useful Work.*—This is defined in paper No. 4 as that portion of the available energy of an explosive which can be applied to a special object. It is equal to the available energy less the dynamical equivalent of the heat lost as such by communication to other bodies and the energy expended in useless work. It is therefore dependent in a general way upon the available energy. From our calculations of available energy or maximum work we reach the conclusion which, however, is hardly of more than theoretical interest that it increases as the atmospheric pressure is lower.

If we designate the potential or total energy of the explosive by  $E$ , the available energy by  $W_a$ , and the final energy, when the pressure of the products has reached an equilibrium with that of the atmosphere by  $E_f$ , our theory of available energy may be expressed as follows:—

$$W_a = E - E_f$$

This simple formula applies whether dissociation be considered or not. If we take it into consideration,  $E_f$  is larger and  $W_a$  smaller than the theoretical values. If dissociation be absent in the final state of the products,  $E_f$  represents both the active and the total energies of the products, these quantities being the same. If dissociation be present in the final state, then  $E_f$  represents the total energy—that is the sum of the active and latent energies.

In the following discussion we will suppose  $W_a$  to have the practical value due to dissociation. The available energy or maximum work has been calculated under a condition which cannot be practically realised, namely, that no energy is lost by communication of heat as such to surrounding bodies, during the expansion of the products. If we denote the energy so lost by  $J_h$ , this gives us one element to be subtracted from the available energy. Making this allowance, we have

$$W = W_a - J_h.$$

This value  $W$  is realised in one form or another of mechanical work.

In regard to the loss of heat as such, we can arrive at some idea of its magnitude by the following course of reasoning. Other things being equal, it will be greater as the temperature of the products is the higher, and we might therefore conclude that explosives, which depend chiefly for their energy upon high temperatures (class 1) are subject to a greater loss than explosives which are energetic chiefly by reason of the great volume of their products (class 2); but it will not do to jump at conclusions. There are several other factors concerned in the loss of heat, the chief ones being the conductivity of the surrounding bodies and the time of contact. In detonating explosives, this time is usually very short. For instance, when nitro-glycerine is detonated in contact with wood, the wood is generally reduced to minute splinters, but there is rarely the slightest sign of charring, though this only requires a temperature of about  $350^\circ$  C. Moreover, there is a law of compensation which justifies us in believing that in the ordinary case the loss is not only small, but that it is something like equal for different explosives. Explosives of class 1 having high temperatures are generally much quicker than those of class 2.

Without great error, we can therefore neglect the loss of heat and write

$$W = W_a$$

A part of this is not generally useful; for instance, the portion expended in displacing large masses of the surrounding air is ordinarily wasted.

If we denote by  $U$  the useful energy and by  $W_x$  the energy expended in all other kinds of work not useful in the particular case, we have

$$U = W_a - W_x$$

We are compelled to treat the subject in this general way because the useful work of an explosive is a chameleon-like thing, which varies with every different application. What is useful work in one case is useless work in another. The noise made by an explosive is generally its most useful effect, but in firing salutes this is the only useful work accomplished by it.

Sometimes in hard rock when the explosive is not intense enough or is not properly stemmed, it will blow out the tamping and expend the greater part of its energy uselessly, through the borehole. But this action is the useful one if we desire to give motion to a projectile.

Mechanical work, like every other form of energy, is made up of two factors—intensity and capacity. The intensity factor is the resistance—the capacity factor is the path. The first determines whether or not the action takes place—the second measures its

extent. By offering a resistance greater than the intensity of the explosive in every direction but one, we may compel it to perform its work chiefly in that direction. This is the cardinal principle of gun construction, and is also utilised to a certain extent in blasting. The blaster locates his charge, if possible, so that the line of least resistance is not through the tamping, but in some other direction, so as to get a maximum disruption and displacement of rock.

If the resistance has great intensity, a very small path may involve great work—work being the product of the two. Intense explosives develop intense resistances, and consequently tend to short paths in mechanical work.

We have already shown in discussing available energy that each explosive has its peculiar characteristics in regard to intensity and path, and also how for any explosive one factor can be increased only at the expense of the other; as the initial tension is higher, the final volume of the products is lessened.

The selection of an explosive is mainly determined by the intensity of the resistance to be overcome—hard, tough rock demands an intense explosive.

*General Principle for Hard Rock.*—In regard to useful work in hard rock, a general principle can be deduced from our formula.

$$U = W_a - W_x$$

We see that generally  $U$  is the greater, as  $W_a$ , the available energy is the greater. For every explosive  $W_a$  increases as the initial tension is higher or as the density of charge increases. Therefore the careful blaster compresses his charge into the smallest possible compass in the bottom of the borehole, and secures it with a tamping packed tight and hard to the mouth of the hole. Experience has taught him that "the better the tamping the better the blast."

This is the ordinary case of blasting in hard rock. The object is to expend the available energy on the rock itself—that is, to perform as much work locally and at as high resistance as possible. The work expended outside of the sphere of the blast, either in projecting fragments of rock or in giving motion to the atmosphere, is wasted energy.

In this special case, the shorter the path (this corresponds to the final volume of the products in our previous discussion) the less energy is wasted. This path is shortened by increasing the initial tension.

*Bank Blasting.*—There are cases, however, in which it is necessary for the gases to work over a longer path. Although the available energy is lessened thereby, the useful work is increased. In bank blasting, where large masses of earth and loose rock or gravel are to be broken up and displaced, if the charge expends its energy at high tension in the interior of the mass, we will get a small expansion of the gases, and the mass will not be broken up nor moved as desired, and the blast will be a failure.

For this sort of blasting intense explosives are not desirable. Blasting powder (especially that made with sodium nitrate base) has been used with good effect, but still better is a class of detonating explosives that has been specially developed for the work. These explosives, which are peculiar to the United States of America, are essentially low dynamites usually containing about 5 per cent. of nitro-glycerine.

When moderate charges are to be used, as in the progressive destruction of a bank of earth, the drilling is done from the top. A chamber at the bottom of the drill hole is made by firing a small charge of dynamite without tamping. This chamber is filled loosely with the low grade explosive.

When a large mass of material is to be moved or broken up by a single great blast, a tunnel is run into the hill and a  $T$  is cut at the end to hold the charge. Generally speaking, close confinement of the charge itself or great density of loading is not necessary—in fact, would injure the efficiency of the blast. The tunnel, however, is carefully closed with bags of sand or by some other effective method. In this way the products retain sufficient final energy to tear their way through the mass and break it up. Each particular case, however, requires special treatment depending upon the object aimed at. This method of blasting (which found formerly an extensive field in connection with hydraulic mining), as well as the class of explosives most suitable for it, may be considered the invention of Egbert Judson, an early American friend of Alfred Nobel's, and one of the great industrial pioneers of California.

One is somewhat at a loss to explain the great efficiency in this sort of work of these low grade detonating explosives as compared with their energy equivalents in blasting powders. I think it is due



to the fact that the initial explosion is accompanied by a shock which tends to break and fissure the ground, making paths for the disrupting action of the gases. These low grades have a velocity of detonation of from 3,000 to 5,000 ft. a second. They are at their best in loose rock, shales and the like, cemented gravel or a mixture of earth and rock. They do not work well in wet or mucky ground or in hard homogeneous rock.

*Classification of Explosives.*—We see that the useful work varies in kind in different forms of blasting. In order to treat the subject to advantage, we must make a broad distinction between explosives that work best at high intensity with short paths—that is, with relatively small expansion of volume, and those which are intended to work at a lower intensity—and with relatively large expansion of volume. The simplest division we can make is into—

- (1) High grades.
- (2) Low grades.

There is no absolute distinction between these classes, for they run into each other in what may be called the medium grades—nitro-glycerine, blasting gelatine, gun cotton, gelignites, and both high grade gelatine dynamites and dynamites of the Lig-Dyn or Keisselguhr type belong to the first class. The 50 and 40 per cent. as possible, give the useful work of his explosive under what may be classed as low grades.

*Tests for Energy.*—It is a necessity to the manufacturer to have some means of rating explosives. One of the tests should, as far as possible, give the useful work of the explosive under what may be called the average conditions of blasting. In this sense the best general test that I know of is the mortar.

*Mortar.*—This as I use it is a short heavy gun bedded in a thick block of concrete at an angle of elevation of 45°. The shot being heavy and its velocity low, the resistance of the air may be neglected and the trajectory be considered a parabola. According to a principle of mechanics, the work done in foot pounds is  $\frac{1}{2} M.R.$ , in which M is the mass of the shot in pounds and R the range in feet. I do not contend that the range in the mortar determines the relative value of the explosive in every kind of blasting. I regard it, however, as a good all round test in a general sense.

*Quinn Crusher Gauge.*—When it is desired to test explosives with reference to their use in hard rock, I prefer the crusher gauge described in "Cutter and Crusher Gauges for Explosives," published in the Proceedings of the U.S. Naval Institute, No. 64, and also described in Guttman's "Explosives."

This consists of a piston, 4in. in diameter, moving between upright guides and containing a small cavity in the upper end for the charge. A shot weighing about 35lb., with a fuse hole directly on the charge is placed upon the piston and the latter rests upon a cylindrical lead plug, which is crushed by the piston when the charge is fired. The compressions of the lead plug are translated into foot-pounds according to a dynamic scale—a scale made by crushing similar lead plugs by a falling weight.

In the mortar the gases act upon the shot till the latter clears the muzzle. Owing to the construction of the "crusher gauge," there is almost an immediate release of the gases which act only for an instant on the piston. The gases therefore do their work on the lead while they are at very high tension. In the mortar they have a chance to expand somewhat, and work down to a lower tension.

Notwithstanding this difference of action, the indications of the two instruments in rating explosions argue more nearly than one might anticipate. Considering explosives of the same nature—that is, mixtures of the same ingredients in different proportions—no case has fallen under my observation in which the rank of any two explosives is reversed by the tests.

In a general way the mortar is more favourable to lower grades and the crusher gauge to the higher. If the relative rank of two explosives is reversed in the two instruments, we draw certain conclusions as to their intensity. For instance, the useful work in the mortar of the Picrate mixtures (72.2 Am. Nit. and 27.8 Am. Picrate—see tables in Paper No. 5), compared with the guncotton is 235 : 226.

In the crusher gauge the guncotton takes precedence, the relative numbers being 370 : 350.

This means that the guncotton does relatively more work at high tension. It is therefore better suited to hard rock, while for average conditions the Picrate mixture would do more useful work.

*Work in the Mortar.*—I have thought it instructive to make a comparison for different explosives between the actual work done in the mortar and the theoretical energy available under the conditions of firing. It is necessary to consider the theoretical available energy—dissociation being ignored, as otherwise we cannot make the calculation. The sketch, Fig. 3, shows the mortar and its chamber, in which the charge is placed. The diameter of the bore is 4.4in. The weight or mass (which is the better term) of the shot is 33.7 pounds. The uniform charge of explosive used is 70 grains,

or 1-100 of a pound. The capacity of the little chamber was originally 210 grains of water, giving a density of loading of 0.333. The chamber at the time of the experiments was somewhat enlarged. I have taken its capacity at 233.3 grains of water, giving a density of loading of 0.3. The density of loading is based upon a convenient expression for it proposed by the French experimenters—viz., the mass of the charge in grammes divided by the capacity of the vessel (or space in which the charge is detonated) expressed in cubic centimetres.

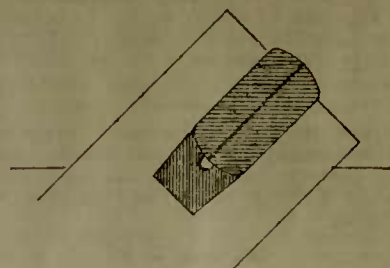


Fig 3 — Mortar

The body of the mortar is of cast iron. The chamber is formed in a block of hard steel. This block is tapered, and when first used must be driven into its seat by firing heavy charges. A wedge to remove the block when the chamber is worn out is not shown. This wedge passes entirely through the body of the mortar just below the seat of the chamber block.

In order to make the calculation, I assume that the charge is completely detonated in the chamber before the shot begins to move, also that the gases act usefully in giving energy to the shot till the latter just clears the muzzle. Therefore in the adiabatic expansion the initial volume will be .000533 cubic feet. This is the volume of the chamber. The final volume of the gases will be 0.0785 cubic feet. This is the capacity of both chamber and bore. We now propose to calculate the energy which is theoretically available between these limits—that is, the work of adiabatic expansion between this initial and final volume for several explosives, and to compare the results with the actual or useful work in each case. The methods of making the calculations have already been explained.

We select four explosives from the list already given in paper No. 5. For the Ammonium Nitrate mixtures No. 1 and No. 2 we have substituted a mixture No. 3, consisting of Ammonium Nitrate about 87 per cent. and a soft paraffine about 13 per cent. This latter gave by ultimate analysis very nearly the composition  $C_{14}H_{30}$ , so that it may be considered vaseline.

In regard to the equation of metamorphosis, as the products are very deficient in oxygen there is some question about their exact composition; but by applying certain principles (which cannot be cited here), I have been able to get an equation which I have no doubt is substantially correct.

The heat  $h$  for unit of mass = 550 heat units.

The specific volume  $V$  (for 1 pound) = 18.495 cubic feet.

$kv$ , the mean specific heat of the products = 0.30714.

$kp$

$- = y = 1.3344$ .

$kv$

$B = 1.9937$ .

E potential = 884,710 foot pounds (for 1 pound).

$N$ , the average No. atoms to the molecule = 2.452.

This explosive is a remarkable instance of low heat and great specific volume. It is not a practicable explosive, however, as it stands. It will not transmit the detonating impulse in mass, but a small quantity of it can be fully exploded in the mortar or crusher gauge, and its detonation on a working scale can be insured by the addition of a small or large percentage of nitro-glycerine. Explosives of this kind are well known in the United States, where their advantages are fully appreciated. Their rates of detonation are lower than the Lig-Dyns (see Dr. Comey's paper, Article No. 1 of this series).

As the composition given produces a large percentage of carbon monoxide (CO) in detonation, it would be objectionable in deep mining, unless the ventilation were very active. However, an extreme case of the type is chosen to bring out certain principles.



CHAPTER VII.

Comparison of Different Explosives—Relation or Intensity and Capacity—Factors in Useful Work—Effect of Dissociation—Effect of Rate of Detonation—Economy in Blasting—Conditions in Australia.

TABLE V.—COMPARISON OF DIFFERENT EXPLOSIVES.—Theoretical Energy Available in the Mortar.—Charge, 70 grains (1-100lb.).—Density of charge, 0.3.—Initial Vol.  $V'$  = 0.000533 cubic feet.—Final Vol.  $V''$  = 0.0785 cubic feet.

Explosive.	Initial Energy, foot-lbs.	Initial Temp.	Initial Pres- sure (1000lbs.)	Final Temp.	Final Pressure (lbs.)	Final Energy, foot-lbs.	Energy Avail- foot-lbs.	$\frac{W_a}{E}$ Percentage.
	E		P'		P''	Ef	W <sub>a</sub>	
Nitro-glycerine .. ..	21,508	7221°	11,989	1637°	18,468	4877	16,631	77
Guncotton .. ..	14,630	4666°	9,338	853°	11,598	2675	11,955	82
Pic. Am. Mixt. .. ..	14,840	4094°	8,407	906°	12,640	3284	11,556	78
Am. Nit. Mixt. No. 3..	8,847	2064°	5,551	385°	6,816	1648	7,199	81

This table shows that roughly about 80 per cent. of the total energy of each explosive is theoretically available under these conditions in the mortar, so that the available energies preserve nearly the same relations to each other as the total energies bear to each other.

Taking the available energy of nitro-glycerine as 100, we have the following numbers:—

Relative available energies in the mortar—

Nitro-glycerine .. .. .	100
Guncotton .. .. .	72
Pic. Am. Mixt. .. .. .	69.5
Am. Nit. Mixt. No. 3 .. .	43

The actual ranges of the different explosions with a closely fitting shot weighing 33.7 pounds were as follows:—

Nitro-glycerine .. .. .	290 ft.
Guncotton .. .. .	226 ft.
Pic. Am. Mixt. .. .. .	235 ft.
Am. Nit. Mixt. No. 3 .. .	230 ft.

Calling the work (or range to which it is proportional) of nitro-glycerine 100, we have—

Relative Useful Work.

Nitro-glycerine .. .. .	100
Guncotton .. .. .	78
Pic. Am. Mixt. .. .. .	81
Am. Nit. Mixt. No. 3 .. .	79

Some further comparisons are shown in the following table. The useful work in foot-pounds is computed from the formula  $U = \frac{1}{2}MR$ . — M, being the weight of the shot 33.7 pounds, and R the range in feet. We give the percentage values of U, E and W<sub>a</sub>, taking that of nitro-glycerine as 100:—

TABLE VI.—USEFUL WORK IN THE MORTAR—Charge, 70 grains (1-100 pound) weight of shot, 33.7 pounds.

Explosive.	U		E		W <sub>a</sub>		$\frac{U}{E}$ per Cent.	$\frac{U}{W_a}$ per Cent.
	Useful Work, foot-pounds.		Initial Energy or Potential.		Theoretical.			
	$\frac{1}{2}$ MR.	N.G. 100	Foot-pounds.	N.G. 100	Foot-pounds.	N.G. 100		
Nitro-glycerine .. ..	4,886	100	21,508	100	16,631	100	23	29
Guncotton .. ..	3,808	78	14,630	68	11,955	72	26	32
Pic. Am. Mixt. .. ..	3,960	81	14,840	69	11,556	69.5	27	34
Am. Nit. Mixt., No. 3..	3,875	79	8,847	41	7,199	43	44	54

This table shows that the useful work compared with both the potential and with the energy theoretically available in the mortar is greatest for the ammonium nitrate mixture and least for nitro-glycerine.

Relation of Intensity and Capacity of Factors to Useful Work.—In this discussion we shall use the term useful work or useful energy in a broad sense, viz., as that portion of the energy which can be realised in ordinary mechanical work. We do not include the work expended in very minute paths, and great intensity, such as the erosion or graving of metals or the reduction of hard rock to powder. The work done in the mortar is a type of useful work in this general sense, though the term as we intend it also includes work done at much higher tension.

We can draw certain general conclusions from our tables as follows. There is no direct relation between the maximum work or theoretical available energy and the useful work. Indeed, in a general way, the useful work efficiency  $\frac{U}{E}$  is greater as the available work W<sub>a</sub> is less. As we saw before, the available energy for a given potential is greater as the intensity factor of the latter is the greater,

whereas the useful energy is greater as the capacity factor is the greater. Maximum work efficiency  $\frac{W_a}{E}$  implies a high initial tension and a sudden running down of the energy. Useful work efficiency implies a more sustained effort. Mercury fulminate exceeds all other explosives in maximum work efficiency. Its useful efficiency is very low.

The elements relating to "intensity" are temperature, pressure, density of loading, and rate of detonation. These form one class. Rate of detonation we have yet to consider.

The elements relating to "capacity" are the specific volume and specific heat. Temperature is the most general of the first elements. It is independent of all the others of this class, being even independent of mass. The pressure is independent of mass for the same density of loading. The "capacity" elements increase directly with the mass. The intensity and capacity factors of the energy can be readily distinguished when the latter is expressed directly in mechanical unit or in terms of PV. P is the intensity and V the capacity factor.



The most general expressions for the energy is obtained by translating its thermal value into mechanical units as  $J.T.kv$ . In this  $T$  is the intensity factor and  $Jkv$  is the capacity factor.  $J$  is constant for the same mass— $kv$  is peculiar to the products and increases with their specific volume.

The relation between the intensity and capacity factors of the potential determines the general character of the explosive in regard to useful work efficiency. Comparing these factors for the different explosives in the tables, we see that the Ammonium Nitrate mixture presents a decided contrast to the nitro-glycerine and guncotton.

The initial temperature is less than  $\frac{1}{3}$  of that of nitro-glycerine, while the capacity factor  $kv$  is nearly 50 per cent. greater. Compared with guncotton, the temperature is considerably less than half, while the capacity factor is 40 per cent. greater.

There are certain effects involved in the mortar experiments which our theory cannot take into account. One of these is the influence upon the useful work of the rate of decomposition. There is probably a certain rate which is most favourable to the useful work on the shot. Nearly all high explosives when fired with a detonating fuse exceed this useful rate and suffer in consequence a loss of work.

In regard to this loss, guncotton suffers most, and the Ammonium Nitrate mixture least.

*Effect of Dissociation.*—This is brought out clearly by a study of the tables. Dissociation increases with the initial temperature and the complexity of the products. For the explosives given in the tables, it is the greatest for nitro-glycerine, and the least for the

ammonium nitrate mixture. The apparent low value  $\frac{U}{W_a}$  for nitro-

glycerine is chiefly due to the effect of dissociation.  $W_a$  in the tables is a theoretical value, which ignores dissociation, that is, the explosives are credited with an available energy larger than the active energy developed would justify. This explains the poor showing that the nitro-glycerine makes in regard to useful energy efficiency. The actual tension of the products is lowered by the heat rendered latent, and undoubtedly the gases escape from the mortar with a part of the energy in the potential or latent state. The loss from this source amounts to something for all the explosives, but is much greater for nitro-glycerine than the others. The others suffer losses in the following order:—Picrate mixture, guncotton and ammonium nitrate mixtures. As the last consists mostly of diatomic products, with a low initial temperature, the loss is probably very small.

In the case of explosives like nitro-glycerine with complex products, and a theoretical high initial temperature, we believe that the useful work in the sense we are giving the term is in all cases increased by dissociation. The influence of dissociation is to moderate the "fulminate effect," by which we mean a very high initial tension, with a sudden running down of the energy. Dissociation lengthens the stroke and increases the useful energy.

*Effect of Rate of Detonation on Useful Work.*—This subject is debateable ground. In a general sense a high rate of detonation has the opposite effect to dissociation. The first has a tendency to favour the "fulminate effect," while the second lessens it.

The principles we have deduced for nitro-glycerine (which is not regarded nowadays as a practical explosive in mining) hold good for blasting gelatine and high-grade gelatines and dynamite. Blasting gelatine is nearly the energy equivalent of nitro-glycerine, being slightly superior to it. Gelignite, gelatine dynamites, and high-grade dynamites are inferior to it in energy, but belong to the same class.

The rates of detonation of these explosives, however, vary greatly. Blasting gelatine may be said to have normally a high rate, the dynamites a medium rate, and the gelignites a low rate. In the case of the gelatinous explosives, the matter is complicated by physical condition, as well as by the degree of confinement and the strength of the detonator. The gelatinous explosives vary in velocity of detonation from about 6,000 to 28,000 ft. a second.

In these notes I have persistently advocated good confinement, and strong detonators, especially for gelatinous explosives. This is on account of their peculiar nature. Under conditions that are slightly unfavourable they are subject both to a breaking off or a dying out of the detonating wave, so that special precautions should be taken to insure their complete detonation. This does not make me, however, an advocate of the highest rate of detonation, though I admit that there is this argument in its favour, or in favour of the physical condition of the explosive most conducive to it. A high rate is probably less liable to an interruption or dying out of the wave. Another question is bound up with the main one. How does the velocity of detonation affect the chemical metamorphosis? We know that very low rates of detonation (due either to insensitiveness of the explosive, non-confinement, or inadequate detonators), even in explosives containing a sufficiency of oxygen, lead to incomplete oxidation of the products—some oxygen unites with the nitrogen, leaving the carbon deficient and producing the poisonous carbon monoxide—but we think this condition pertains to abnormally low rates. The question should be made the subject of a special investigation, but our opinion seems to be justified, because experiments in the Bichel and Golaz bombs show a normal metamorphosis, although the small quantities of explosive are detonated

at a very moderate rate, if we can judge from the circumstances of the firing.

Assuming that a rate of, say, 7,000 or 8,000 ft. a second, a velocity rarely exceeded by gelignite, is sufficient to give normal chemical metamorphosis, the most interesting question is this—is the useful work in the average case of hard rock blasting increased or lessened by a high rate? If it is increased, what is the limit of velocity which will give the best effect? We know that a gelignite with a velocity of 7,000 ft. seems to do good work, but so does a blasting gelatine with a rate three times as great. Possibly, within wide limits, the useful work is not seriously affected. Our belief is that the useful work of gelignite in hard rock can be increased by increasing its rate of detonation—even to doubling it, which can be readily done with a small primer of Lig-Dyn. But we do not believe in making either gelignite or blasting gelatine so sensitive that they can be detonated at a high rate without confinement. I believe that blasting gelatine was at its best in the days of Alfred Nobel, and his immediate successors, so far as its efficiency in very hard rock was concerned. As a guess, it had a velocity of detonation not extending 18,000 ft. a second, when it was well confined, and was fired with a strong detonator. The soft sensitive blasting gelatine that has become the standard in Australia probably has the maximum rate of 27 or 28,000 ft. in the borehole. In spite of dissociation (which we have always with us), I think there is in such a case a certain degree of the "fulminate effect," which does too much molecular work on the rock—work of high intensity and short paths—grinding it to dust—an expenditure of energy that could be more usefully employed in disrupting and displacing it. This opinion is based upon my experience and observation, but both are liable to error, and the opinion must be taken for what it is worth. Absolute proof is wanting.

*Economy in Blasting.*—The useful energy of an explosive is measured by its rock getting capacity—the number of cubic feet or tons of rock that a pound of it will remove. In nearly all cases the stronger of two explosives, other things being equal, will show a better return, but this does not necessarily make it the more economical. The measure of economy is the cost of the unit of useful energy in the particular case. In very hard refractory rock the ideal explosive is blasting gelatine. Under such conditions practical trials always show it to be the most economical explosive that can be used. But all sorts of rock are encountered in mining, and to meet the needs of the industry there should be low and medium, as well as high, grades. It is wasteful in more senses than one to use high-grade gelatinous explosives in soft rock. Not only are they unnecessarily expensive, but the confinement is not good, and great care is requisite to insure their complete detonation. One is always hearing of unexploded cartridges being found in the debris. This is so common that it is looked upon as a matter of course, and they are searched for as a part of the routine work.

The employment of these explosives in all kinds of rock without reference to its resistance tends to make the miners careless and wasteful. Blasting is an art which is never learned by the man who always uses a surplus of energy to accomplish his task, while the one who uses a grade adjusted to the resistance naturally acquires the skill necessary to make it do its work. He learns to take advantage of the lay of the ground, to study the planes of cleavage, and to get all the help he can from a proper location of his bore-holes. He gauges carefully the depth of his holes, their burden, and the necessary charge. He never puts in a "pinched hole"—that is, one that can only break in the general direction of the tamping, if it is possible to avoid it. A skilled blaster in an extended trial will make an inferior explosive remove more rock per pound than one 20 per cent. stronger in the hands of a poor blaster, trained in the school of surplus explosive energy.

*Conditions in Australia.*—It is strange that in so enterprising a country as Australia there should be an almost utter lack of the medium and lower grades of explosives for general mining. The gelatinous explosives, the lowest grade of which is the ordinary gelignite, practically monopolise the field. It is true that lower grades are found in coal mining, but this seems to be for a special reason. High temperatures must be avoided in "safety explosives," and the grades seem to be lowered for this reason, and not to adjust the energy to the work. Where the coal mines are not "fiery," I have in several instances found gelignite used even for coal getting.

In the matter of grades, the United States presents a strong contrast to Australia. At the large dynamite factory which I managed years ago in California, the average grade manufactured contained 42.5 per cent. of nitro-glycerine. In Australia the average grade consumed must be about double this. In America the chief aim is to produce the limit of useful work at the lowest possible cost. If we understand useful energy to apply to the average conditions in mining, then this unit can be more cheaply produced in the form of Lig-Dyn, or straight dynamite (Dr. Corney's designation) than in gelatinous explosives. In California the amount of blasting gelatine produced and consumed was insignificant—such is the power of fashion. Each country, America and Australia, could have well taken a lesson from the other. If Australia would make more use of the medium and lower grades, and America would use blasting gelatine for the special case of very refractory rock, economy would accrue in both instances. As I left California 12 years ago, I am not competent to speak of the conditions prevailing there at present. In Australia they are far from ideal.















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