# ON THE DETERMINATION OF THE STRENGTH OF VARIOUS HIGH EXPLOSIVES.

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This paper was suggested during a series of experiments undertaken some months ago for the purpose of reconciling apparently great inconsistencies with regard to the relative strengths claimed for various newly invented or patented explosives. No originality is claimed for the methods pursued, but it is thought that a summary of the results obtained may prove of value. The great facility with which an explosive can be invented, and the attraction that work of this character possesses for investigators, both great and small, may explain, in a measure, the annual outpour of so called new explosives. Presuming upon the ignorance or lack of scientific knowledge on the part of the practical miner, the most extravagant and misleading claims are made for the majority of these powers, not the least significant of which is that all are equally as strong as, and many of them much more powerful than liquid nitroglycerine. It was in order to verify or disprove this particular claim that the following experiments were undertaken, especially as strenuous efforts have been made by some of the inventors to have their powders adopted for military and naval purposes.

The first step in the work at hand was to provide apparatus for accurately registering the effects of the various explosives, and on account of the limited facilities at my disposal I had little latitude of choice.

Several methods have been devised for the purpose of testing the strength of explosives, but as yet none can be said to give perfect satisfaction. All of them are approximations, nor do the in-

ventors claim more for them. Even the *crusher* used by Berthelot in his elaborate investigations in this direction gave only approximate results, as demonstrated by M. M. Sarau and Vieille.

The majority of the methods pursued seek to determine merely the comparative strength of the explosives, some one explosive being selected as the standard with which all others are compared. It still remains to institute an accurate, absolute scale, by which the strength of explosives may be measured.

After due consideration, it was decided to use the Quinan pressure gauge, both on account of the degree of accuracy with which it registers the pressures developed by the explosives, or rather "by the gases resulting from the decomposition of the explosives," and because of the ease with which the apparatus is manipulated.

The instrument used in the following experiments consists of a heavy block of wood, upon which is bolted a cast iron block or base. In this base are inserted four wrought iron guides or standards, set around the circumference of a four inch circle. A steel plate is let into the iron block flush with its upper surface. A ring holds the guides in place at the top, their ends being reduced to screwbolts passing through the ring, which is held down by nuts.

The piston, which rests upon the plug or cylinder of lead (to be compressed) is a cylinder of tempered steel, four inches in diameter and five inches in length. It is turned away at the sides to lighten it as much as possible. It moves freely between the guides. In the top of the piston is a parabola-shaped cavity to hold the charge of explosive. The weight of the piston is twelve and one-quarter pounds. The shot, made of tempered steel, is four inches in diameter and ten inches in length, weighing thirty-four and one-half pounds. It is bored through its axis to receive a capped fuse.

To operate the instrument, a plug or cylinder of lead is placed upon the steel plate within the guides. The piston is put down gently upon it and the charge of explosive placed in the cavity. The shot is next lowered gently upon the piston and the capped fuse pushed down through the hole in the shot. The fuse being lighted, the charge is exploded when the fire reaches the cap, throwing out the shot and compressing the lead plug. The accu-

racy of the test is based upon the assumption that the lead plugs shall be of uniform density and homogeneous in structure. The form of plug adopted was a cylinder, one inch in diameter and one inch in length. In regard to the kind of plug, the choice lay between plugs cast in molds and plugs cut from a solid bar which could be obtained of the desired dimensions in the factories. This bar, though not made of perfectly pure lead, is manufactured from large masses of metal at a high temperature, is very dense and can be obtained in lengths of fifty feet.

It was decided that the desired uniformity would be more likely to obtain in this product than in plugs cast one at a time from small masses of metal. Having prepared plugs of both kinds, the next point was to test their relative merits for the object in view. The nature of this test was fixed by an additional and independent consideration. It should be borne in mind that, while being compressed by the explosion in the pressure gauge, the density of the plug as well as the lead surface opposed to the piston continually increases.

It is evident, therefore, that the amount of compression shown by the plug is not a direct measure of the strength of the explosive.

For example: if one powder exploded in the pressure gauge compresses a plug $\frac{250}{1000}$ths of an inch, and another powder compresses a plug $\frac{500}{1000}$ths of an inch, the latter powder would be twice as strong as the former if the compressions were direct measures of their relative strengths, but from what has preceded, it is evident that the second is much more than twice as strong as the first powder, and the difficulty arises in determining the relation existing between the two.

As a practical measure of the strength, Mr. W. R. Quinan, the inventor of the gauge, to whom I am greatly indebted for valuable information on the subject, assumed that it was proportional to the work performed in reducing the height of the lead cylinder. To get an expression for the work, Mr. Quinan determined, by means of a simple apparatus, the number of foot pounds required to produce the different amounts of compression, and graphically represented the relations existing between the plug compressions and foot pounds by means of a diagram, which was constructed,

using the compressions as the ordinates, and the foot pounds as the abscissas of a curve. The extreme co-ordinates were fixed by nitroglycerine.

As it was impossible to secure one of these diagrams, and as I had not time to undertake the experiments necessary to construct one in time for use for the experiments at hand, it is unnecessary to enter at a greater length into the details of this portion of the subject, especially as the results recorded are referred directly to nitroglycerine as a standard, with no reference to the absolute strengths of the various explosives. While the results registered by the pressure gauge are very reliable as comparative measures for high explosives, they are not equally true and accurate for the lower class. "A triple charge of good black blasting powder, fixed with a fuse, will produce a scarcely perceptible effect on the plug, and yet we know that this powder is capable of great work under certain conditions.

"We may suppose, without an error affecting our principle, that in firing twenty-four grains, or 1.555 grammes, of high powder, the product of the amount of gas, multiplied by the temperature of the gases, gives a number equal to the product of the corresponding elements in the explosion of thrice the charge of black powder. But in one experiment we get a compression which is almost infinitely greater than in the other; for in the last we get a result too small to be measured. It is because the third factor in one formula for explosive effect, *time*, bears a similar but inverse ratio in the two cases: in the first being inconceivably short, and in the second case a sensible interval.

"In the explosion of the black powder, the force, though great, is developed so gradually that at no one instant is sufficient inertia developed in the shot to produce a sensible compression of the lead."

(Report on Vigorit Powder, by Wm. R. Quinan.)

Having decided the means of measurement and secured and tested the lead cylinders, the next step was to select the standard explosive with which to compare all others under examination. It has been shown that the pressure gauge is not an accurate test for the lower explosives, and, as nearly all of the explosives

to be tested belonged to the class of high explosives, nitroglycerine was selected as the standard. The lot of nitroglycerine to be used for this purpose was made some months beforehand, so as to allow it to "clear up" and attain its normal condition, as previous experiments had shown that, during the process of "clearing," nitroglycerine varied in strength from day to day.

The nitroglycerine prepared for use as the standard was very carefully made, the acids and glycerine being tested beforehand, on November 19, 1889, after the method originally pursued at the U. S. Naval Torpedo Station as follows:

$HNO_3$ (Sp. Gr. 1.50).....1 part.
$H_2SO_4$ (Sp. Gr. 1.84).....2 parts.

As soon as this acid mixture had cooled

Glycerine (puriss. anhyd.).....1 part

was gradually introduced with constant agitation into

Acid mixture.....6 parts.

Upon total conversion of the glycerine into the nitric ether, the latter was thoroughly freed from all traces of acid, and then poured into a large glass jar, covered with distilled water, and the jar loosely corked.

In about six weeks, the opaque appearance of the oily fluid had entirely disappeared, and it had assumed the normal appearance of pure glycerine. It was carefully tested from time to time and was found to be entirely satisfactory.

The uniformity of the lead cylinders was tested by carefully weighing and testing several taken at random, and all above or below a certain standard, as well as those showing any defects were rejected.

The mean of several weights and measurements gave

Weight of cylinder.....145.729 grm.
Length " " .....1".000 2.540 cm.
Diameter " " .....1".000 2.540 cm.

In the subsequent work, the difference in weight of the several cylinders did not exceed 10 or 15 mg., while the standard length and diameter of 1".000 2.540 cm. was absolutely maintained.

One other point was determined beforehand, namely, the relative strength of the caps to be used to explode the several charges. This step was deemed advisable lest it should be found necessary to use caps of different strength for the different explosives. The uniform charge of 24 grs., or 1.555 grm. was used in the gauge for all explosives.

## RECORD OF EXPERIMENTS.

I. *Nitroglycerine*, used as the standard of comparison.

Mode of preparation:

$HNO_3$ (Sp. Gr. 1.50)..... 1 part.
$H_2SO_4$ (Sp. Gr. 1.84)..... 2 parts.

and of this

Acid Mixture..... 6 parts.
Glycerine (puriss. anh.)..... 1 part.

| Number of Experiment. | Length of Cylinder before Compression. | Length of Cylinder after Compression. | Amount of Compression. |
|---|---|---|---|
| | 2.540 c. m. | | |
| 1 | 1″.000 | 0″.452 | 0″.548 |
| 2 | 1″.000 | 0″.450 | 0″.550 |
| 3 | 1″.000 | 0″.445 | 0″.555 |
| | | Mean..... | 0″.551 |

II. *Explosive Gelatine.*

Mode of preparation:

Nitroglycerine..... 92 parts.
Camphor..... 2 parts.
Gun-cotton (soluble)..... 6 parts.

Note.—The nitroglycerine used in the preparation of this sample of explosive gelatine was made according to the French method pursued at Vonges. Both the nitroglycerine and explosive gelatine were made and tested on the same day.

| Number of Experiment. | Length of Cylinder before Compression. | Length of Cylinder after Compression. | Amount of Compression. |
|---|---|---|---|
| 4 | 1″.000 | 0″.435 | 0″.565 |
| 5 | 1″.000 | 0″.410 | 0″.590 |
| 6 | 1″.000 | 0″.399 | 0″.601 |
| | | Mean..... | 0″.585 |

III. *Hellhoffite.*

Mode of preparation:

$HNO_3$ (Sp. Gr. 1.50) ..... 53 parts.
Dinitrobenzole ..... 47 parts.
($C_6H_4(NO_2)_2$ added to saturation.)

| Number of Experiment. | Length of Cylinder before Compression. | Length of Cylinder after Compression. | Amount of Compression. |
|---|---|---|---|
| 7 | 1″.000 | 0″.415 | 0″.585 |
| 8 | 1″.000 | 0″.415 | 0″.585 |
| 9 | 1″.000 | 0″.415 | 0″.585 |
| | | Mean ..... | 0″.585 |

IV. *Nobel's Smokeless Powder.*

Mode of preparation:

Nitroglycerine ..... 50 parts.
Camphor ..... 5 parts.
Benzole ..... 100 parts.
Gun-cotton (soluble) ..... 25 parts.

The camphor was dissolved in the nitroglycerine and the benzole added.

Gun-cotton was added and stirred until the whole became gelatinized. The benzole was next evaporated on a water bath, the mass rolled out into a sheet and finally cut up into small cubes.

| Number of Experiment. | Length of Cylinder before Compression. | Length of Cylinder after Compression. | Amount of Compression. |
|---|---|---|---|
| 10 | 1″.000 | 0″.500 | 0″.500 |
| 11 | 1″.000 | 0″.486 | 0″.514 |
| 12 | 1″.000 | 0″.485 | 0″.515 |
| | | Mean ..... | 0″.509 |

V. *Nitroglycerine.*

Mode of preparation:

According to U. S. Naval Torpedo Station process, and tested immediately upon completion.

| Number of Experiment. | Length of Cylinder before Compression. | Length of Cylinder after Compression. | Amount of Compression. |
|---|---|---|---|
| 13 | 1″.000 | 0″.491 | 0″.509 |
| 14 | 1″.000 | 0″.491 | 0″.509 |
| 15 | 1″.000 | 0″.491 | 0″.509 |
| | | Mean ..... | 0″.509 |

VI. *Explosive Gelatine.*

Mode of preparation :

Same as in II., Expts. 4, 5 and 6, except that the nitroglycerine was taken from that used in V., Expts. 13, 14 and 15.

| Number of Experiment. | Length of Cylinder before Compression. | Length of Cylinder after Compression. | Amount of Compression. |
|---|---|---|---|
| 16 | 1″.000 | 0″.520 | 0″.480 |
| 17 | 1″.000 | 0″.504 | 0″.496 |
| 18 | 1″.000 | 0″.506 | 0″.494 |
| | | Mean | 0″.490 |

VII. *Gun-cotton.*

Mode of preparation :

Sample or charge was taken from a disk of U. S. Naval Torpedo Station, Lot No. 100, 1889.

| Number of Experiment. | Length of Cylinder before Compression. | Length of Cylinder after Compression. | Amount of Compression. |
|---|---|---|---|
| 19 | 1″.000 | 0″.543 | 0″.457 |
| 20 | 1″.000 | 0″.543 | 0″.457 |
| 21 | 1″.000 | 0″.540 | 0″.460 |
| | | Mean | 0″.458 |

VIII. *Gun-cotton.*

Mode of preparation :

Charge taken from a disk of Stowmarket cotton made in 1885.

| Number of Experiment. | Length of Cylinder before Compression. | Length of Cylinder after Compression. | Amount of Compression. |
|---|---|---|---|
| 22 | 1″.000 | 0″.545 | 0″.455 |
| 23 | 1″.000 | 0″.541 | 0″.459 |
| 24 | 1″.000 | 0″.541 | 0″.459 |
| | | Mean | 0″.458 |

IX. *Nitroglycerine.*

Mode of preparation :

According to the process pursued at Vonges as follows :

The following mixtures were made and allowed to cool :

$HNO_3$ (Sp. Gr. 1.50)..... 1 part.

$H_2SO_4$ (Sp. Gr. 1.84)..... 1 part.

and

$H_2SO_4$ (Sp. Gr. 1.84)..... 3.2 parts.

Glycerine (puriss. anhyd.)..... 1.0 part.

As soon as cool, 4.2 parts of the sulpho-glycerol was added to 5.6 parts of the acid mixture, the vessel was loosely covered, and the reaction allowed to proceed under a hood for 12 hours.

The nitroglycerine was then separated from the acids and thoroughly washed.

| Number of Experiment. | Length of Cylinder before Compression. | Length of Cylinder after Compression. | Amount of Compression. |
|---|---|---|---|
| 25 | 1″.000 | 0″.550 | 0″.450 |
| 26 | 1″.000 | 0″.548 | 0″.452 |
| 27 | 1″.000 | 0″.549 | 0″.451 |
| | | Mean | 0″.451 |

X. *Gun-cotton.*

Mode of preparation :

This explosive was made in the laboratory according to the U. S. Torpedo Station process, but no effort was made to pulp, poach or press it. It was simply pure trinitrocellulose.

| Number of Experiment. | Length of Cylinder before Compression. | Length of Cylinder after Compression. | Amount of Compression. |
|---|---|---|---|
| 28 | 1″.000 | 0″.552 | 0″.448 |
| 29 | 1″.000 | 0″.552 | 0″.448 |
| 30 | 1″.000 | 0″.552 | 0″.448 |
| | | Mean | 0″.448 |

XI. *Dynamite No. 1.*

Mode of preparation :

Nitroglycerine (same as V.) ..... 6 parts.
Kieselguhr ..... 2 parts.
$MgCO_3$ ..... 0.14 parts.

| Number of Experiment. | Length of Cylinder before Compression. | Length of Cylinder after Compression. | Amount of Compression. |
|---|---|---|---|
| 31 | 1″.000 | 0″.552 | 0″.448 |
| 32 | 1″.000 | 0″.552 | 0″.448 |
| 33 | 1″.000 | 0″.552 | 0″.448 |
| | | Mean | 0″.448 |

XII. *Dynamite de Trauzl.*

Mode of preparation :

Nitroglycerine (same as V.) ..... 75 parts.
Gun-cotton ..... 25 parts.
Charcoal ..... 2 parts.

The gun-cotton and charcoal were very finely divided before being added to the nitroglycerine.

| Number of Experiment. | Length of Cylinder before Compression. | Length of Cylinder after Compression. | Amount of Compression. |
|---|---|---|---|
| 34 | 1″.000 | 0″.563 | 0″.437 |
| 35 | 1″.000 | 0″.563 | 0″.437 |
| 36 | 1″.000 | 0″.563 | 0″.437 |
| | | Mean | 0″.437 |

XIII. *Emmensite.*

Mode of preparation :

"Emmens Acid" was first made by dissolving commercial picric acid, at a gentle heat, in nitric acid (Sp. Gr. 1.50) and evaporating. The explosive itself was made by fusing together in a paraffin bath

Emmens Acid ..... 5 parts.
$NH_4 (NO_3)$ ..... 5 parts.

And then incorporating

Picric Acid ..... 6 parts.

| Number of Experiment. | Length of Cylinder before Compression. | Length of Cylinder after Compression. | Amount of Compression. |
|---|---|---|---|
| 37 | 1″.000 | 0″.571 | 0″.429 |
| 38 | 1″.000 | 0″.571 | 0″.429 |
| 39 | 1″.000 | 0″.571 | 0″.429 |
| | | Mean | 0″.429 |

XIV. *Amide Powder.*

Mode of preparation :

$KNO_3$ ..... 101 parts.
$NH_4 (NO_3)$ ..... 80 parts.
Charcoal ..... 40 parts.

| Number of Experiment. | Length of Cylinder before Compression. | Length of Cylinder after Compression. | Amount of Compression. |
|---|---|---|---|
| 40 | 1″.000 | 0″.614 | 0″.386 |
| 41 | 1″.000 | 0″.615 | 0″.385 |
| 42 | 1″.000 | 0″.616 | 0″.384 |
| | | Mean | 0″.385 |

XV. *Oxonite.*

Mode of preparation :

$HNO_3$ (Sp. Gr. 1.50).....54 parts.
Picric Acid.....46 parts.

[$C_6H_3O(NO_2)_3$ added to saturation.]

| Number of Experiment. | Length of Cylinder before Compression. | Length of Cylinder after Compression. | Amount of Compression. |
|---|---|---|---|
| 43 | 1″.000 | 0″.617 | 0″.383 |
| 44 | 1″.000 | 0″.617 | 0″.383 |
| 45 | 1″.000 | 0″.617 | 0″.383 |
| | | Mean..... | 0″.383 |

Note.—In this particular explosive, the picric acid was fused before being added to the $HNO_3$.

XVI. *Tonite.*

Mode of preparation :

Gun-cotton (finely divided).....52.5 parts.
Barium Nitrate.....47.5 parts.

| Number of Experiment. | Length of Cylinder before Compression. | Length of Cylinder after Compression. | Amount of Compression. |
|---|---|---|---|
| 46 | 1″.000 | 0″.624 | 0.″376 |
| 47 | 1″.000 | 0″.624 | 0.″376 |
| 48 | 1″.000 | 0″.624 | 0.″376 |
| | | Mean..... | 0″.376 |

XVII. *Bellite.*

Mode of preparation :

$NH_4(NO_3)$.....5 parts.
Metadinitrobenzene.....1 part.

The ammonium nitrate was melted in a paraffin bath, and the $C_6H_4(NO_2)_2$, finely pulverized, gradually added and mixed with a wooden spatula until the entire mass became pasty. It was then allowed to cool and was granulated.

| Number of Experiment. | Length of Cylinder before Compression. | Length of Cylinder after Compression. | Amount of Compression. |
|---|---|---|---|
| 52 | 1″.000 | 0″.638 | 0″.362 |
| 53 | 1″.000 | 0″.640 | 0″.360 |
| 54 | 1″.000 | 0″.636 | 0″.364 |
| | | Mean..... | 0″.362 |

XVIII. *Oxonite.*

Mode of preparation :

Same as in XV., Experiments 43, 44 and 45, except that the picric acid was not fused before being added to the nitric acid.

| Number of Experiment. | Length of Cylinder before Compression. | Length of Cylinder after Compression. | Amount of Compression. |
|---|---|---|---|
| 49 | 1″.000 | 0″.646 | 0″.354 |
| 50 | 1″.000 | 0″.646 | 0″.354 |
| 51 | 1″.000 | 0″.646 | 0″.354 |
| | | Mean | 0″.354 |

XIX. *Rack-a-Rock.*

Mode of preparation :

$KClO_3$ ..... 79 parts.
Mononitrobenzene ..... 21 parts.

The chlorate was pulverized and saturated with nitro-benzene just before being used.

| Number of Experiment. | Length of Cylinder before Compression. | Length of Cylinder after Compression. | Amount of Compression. |
|---|---|---|---|
| 55 | 1″.000 | 0″.660 | 0″.340 |
| 56 | 1″.000 | 0″.660 | 0″.340 |
| 57 | 1″.000 | 0″.660 | 0″.340 |
| | | Mean | 0″.340 |

XX. *Atlas Powder.*

Mode of preparation :

Sodium Nitrate ..... 34 parts.
Sawdust (fine) ..... 14 parts.
Magnesium Carbonate ..... 2 parts.
Nitroglycerine ..... 50 parts.

This explosive goes by the trade name of Atlas B.

| Number of Experiment. | Length of Cylinder before Compression. | Length of Cylinder after Compression. | Amount of Compression. |
|---|---|---|---|
| 58 | 1″.000 | 0″.665 | 0″.335 |
| 59 | 1″.000 | 0″.667 | 0″.333 |
| 60 | 1″.000 | 0″.669 | 0″.331 |
| | | Mean | 0″.333 |

XXI. *Ammonia Dynamite.*

Mode of preparation :

Ammonium Nitrate.....75 parts.
Paraffin.....4 parts.
Charcoal.....3 parts.
Nitroglycerine.....18 parts.

| Number of Experiment. | Length of Cylinder before Compression. | Length of Cylinder after Compression. | Amount of Compression. |
|---|---|---|---|
| 61 | 1″.000 | 0″.696 | 0″.304 |
| 62 | 1″.000 | 0″.696 | 0″.304 |
| 63 | 1″.000 | 0″.612 | 0″.388 |
| | | Mean..... | 0″.332 |

XXII. *Volney's Powder, No. 1.*

Mode of preparation :

Nitrated naphthalene No. 1 was first prepared as follows : Nitro-sulphuric Acid, consisting of

$H_2SO_4$ (Sp. Gr. 1.84).....2 parts,
$HNO_3$ (Sp. Gr. 1.50).....1 part,

was made and allowed to cool. Of this

Acid mixture.....4 parts,
Naphthalene.....1 part,

were introduced into a vessel and the reaction allowed to proceed for about one hour. The yellow crystalline mass was then thoroughly washed, dried and pulverized.

Volney Powder, No. 1, as made, consisted of

Nitrated Naphthalene, No. 1.....2.18 parts.
$KNO_3$.....0.19 parts.
Sulphur.....0.16 parts.

| Number of Experiment. | Length of Cylinder before Compression. | Length of Cylinder after Compression. | Amount of Compression. |
|---|---|---|---|
| 64 | 1″.000 | 0″.678 | 0″.322 |
| 65 | 1″.000 | 0″.675 | 0″.325 |
| 66 | 1″.000 | 0″.681 | 0″.319 |
| | | Mean..... | 0″.322 |

XXIII. *Volney's Powder, No. 2.*

Mode of preparation :

Nitrated naphthalene No. 2 was prepared by treating naphthalene with nitric acid as follows :

Naphthalene.....1 part.
$HNO_3$ (Sp. Gr. 1.40).....4 parts.

The reaction was allowed to proceed slowly for four or five days, and the brown crystalline mass was then thoroughly washed, dried and pulverized.

Volney's Powder No. 2, as made, consisted of

Nitrated naphthalene No. 2.....1 part.
$KNO_3$.....3.30 parts.
Sulphur.....0.51 parts.

| Number of Experiment. | Length of Cylinder before Compression. | Length of Cylinder after Compression. | Amount of Compression. |
|---|---|---|---|
| 67 | 1″.000 | 0″.707 | 0″.293 |
| 68 | 1″.000 | 0″.707 | 0″.293 |
| 69 | 1″.000 | 0″.706 | 0″.294 |
| | | Mean..... | 0″.294 |

XXIV. *Melinite.*

Mode of preparation :

Picric Acid (fused).....70 parts.
Gun-cotton (soluble).....30 parts.

The gun-cotton was dissolved in a mixture of

Ether.....2 parts.
Alcohol.....1 part.

The acid was fused and pulverized, and then thoroughly incorporated in the gun-cotton solution. The ether-alcohol mixture was afterwards evaporated.

| Number of Experiment. | Length of Cylinder before Compression. | Length of Cylinder after Compression. | Amount of Compression. |
|---|---|---|---|
| 70 | 1″.000 | 0″.718 | 0″.282 |
| 71 | 1″.000 | 0″.720 | 0″.280 |
| 72 | 1″.000 | 0″.722 | 0″.278 |
| | | Mean..... | 0″.280 |

XXV. *Silver Fulminate.*

Mode of preparation :

Silver (gran.)..... 1 part,

was dissolved in

$HNO_3$ (Sp. Gr. 1.308).....20 parts,

and the solution thus obtained was poured into a flask containing

Alcohol (87%).....27 parts.

Reaction was promoted by bringing this last solution to a temperature of 212° F. As soon as the solution became turbid, it was allowed to cool, and

Alcohol (87%).....27 parts,

was again introduced into the flask, and the reaction again started. As soon as all reaction ceased, the opaque, white crystals were thoroughly washed and preserved in a black jar.

| Number of Experiment. | Length of Cylinder before Compression. | Length of Cylinder after Compression. | Amount of Compression. |
|---|---|---|---|
| 73 | 1".000 | 0".723 | 0".277 |
| 74 | 1".000 | 0".723 | 0".277 |
| 75 | 1".000 | 0".723 | 0".277 |
| | | Mean..... | 0".277 |

XXVI. *Mercury Fulminate.*

Mode of preparation :

Same in general as in XXV., except as to proportions as follows :

Mercury..... 10 parts.

$HNO_3$ (Sp. Gr. 1.40).....120 parts.

Alcohol (95%).....110 parts.

| Number of Experiment. | Length of Cylinder before Compression. | Length of Cylinder after Compression. | Amount of Compression. |
|---|---|---|---|
| 76 | 1".000 | 0".725 | 0".275 |
| 77 | 1".000 | 0".725 | 0".275 |
| 78 | 1".000 | 0".725 | 0".275 |
| | | Mean..... | 0".275 |

XXVII. *Mortar Powder.*

Dupont's Manufacture.

| Number of Experiment. | Length of Cylinder before Compression. | Length of Cylinder after Compression. | Amount of Compression. |
|---|---|---|---|
| 79 | 1".000 | 0".845 | 0".155 |
| 80 | 1".000 | 0".845 | 0".155 |
| 81 | 1".000 | 0".845 | 0".155 |
| | | Mean..... | 0".155 |

Assuming then the nitroglycerine made on November 19, 1889, as the standard, and assigning to it, for the purpose of comparison, the value of 100, the results of the foregoing experiments may be conveniently recapitulated in the following table:

| Name of Explosive. | Compression of Cylinder. | Order of Strength. |
|---|---|---|
| I<br>Explosive Gelatine.....<br>(Made from nitroglycerine after the Vonges Process.) | 0″.585 | 106.17 |
| II<br>Hellhoffite..... | 0″.585 | 106.17 |
| III<br>Nitroglycerine.....<br>(Made Nov. 19, 1889, tested Jan. 6, 1890.) | 0″.551 | 100.00 |
| IV<br>Nobel's Smokeless Powder | 0″.509 | 92.38 |
| V<br>Nitroglycerine.....<br>(Made Jan. 29, 1890, and tested on the same day. U. S. N. Torpedo Station Process.) | 0″.509 | 92.37 |
| VI<br>Explosive Gelatine.....<br>(Made from the last nitroglycerine.) | 0″.490 | 88.93 |
| VII<br>Gun-cotton.....<br>(U. S. N. Torpedo Station, Lot 100, 1889.) | 0″.458 | 83.12 |
| VIII<br>Gun-cotton.....<br>(Stowmarket 1885.) | 0″.458 | 83.12 |
| IX<br>Nitroglycerine.....<br>(Made according to the French process and tested on the same day.) | 0″.451 | 81.85 |
| X<br>Gun-cotton.....<br>(Made in Artillery School laboratory.) | 0″.448 | 81.31 |
| XI<br>Dynamite No. 1..... | 0″.448 | 81.31 |
| XII<br>Dynamite de Trauzl..... | 0″.437 | 79.31 |

| Name of Explosive. | Compression of Cylinder. | Order of Strength. |
|---|---|---|
| XIII | | |
| Emmensite | 0".429 | 77.86 |
| XIV | | |
| Amide Powder | 0".385 | 69.87 |
| XV | | |
| Oxonite (Picric acid fused before being added.) | 0".383 | 69.51 |
| XVI | | |
| Tonite | 0".376 | 68.24 |
| XVII | | |
| Bellite | 0".362 | 65.70 |
| XVIII | | |
| Oxonite (Picric acid not fused.) | 0".354 | 64.24 |
| XIX | | |
| Rack-a-Rock | 0".340 | 61.71 |
| XX | | |
| Atlas Powder | 0".333 | 60.43 |
| XXI | | |
| Ammonia Dynamite | 0".332 | 60.25 |
| XXII | | |
| Volney's Powder No. 1 | 0".322 | 58.44 |
| XXIII | | |
| Volney's Powder No. 2 | 0".294 | 53.18 |
| XXIV | | |
| Melinite | 0".280 | 50.82 |
| XXV | | |
| Silver Fulminate | 0".277 | 50.27 |
| XXVI | | |
| Mercury Fulminate | 0".275 | 49.91 |
| XXVII | | |
| Mortar Powder (Dupont.) | 0".155 | 28.13 |

While the foregoing table gives correctly the *order of strength* of the various explosives contained in it, it cannot be said to give their actual *relative strengths*, since it was, for reasons given, impossible to arrive at their absolute strengths expressed in any unit of force. The true relations existing between them would be expressed by the relative amounts of work required to compress

the cylinders to the lengths shown in the second column, and, as already shown, the greater the amount of compression, so much greater the ratio for each additional 1-1000th of an inch of compression. From the results recorded in the above table, we may conclude that whatever other claims may be advanced for the various explosives tested, that with regard to their strength as compared with nitroglycerine is misleading. Under certain conditions, readily understood, some of these new inventions are capable of accomplishing more work than pure nitroglycerine, and as the performance of mechanical work may also be considered a measure of strength, it would at first sight appear that such claims are in so far sustained. But in by far the majority of such cases the additional strength is derived from the physical condition of the explosive rather than from any inherent property of the active principle. Let us look into this briefly.

Prof. C. E. Munroe, chemist to the U. S. Naval Torpedo Corps, in a hasty review of a "Report upon Experiments and Investigations to develop a System of Submarine Mines for defending the Harbors of the United States," submitted to the War Department by General Henry L. Abbot, Eng. Corps, U. S. A., says :

"In comparing the results obtained for pure nitroglycerine with those for Dynamite No. 1, there was revealed what at first sight appears to be a paradox.

"One pound of pure nitroglycerine was found to exert only 81 per cent. of the intensity of action of three-fourths of a pound absorbed by an inert substance which could add nothing to the heat or gases developed.

"This fact, which was discovered early in the trials, was considered so extraordinary as to require careful verification and study.

"The first explanation suggested was that it was due to a possible variation in the strength of the nitroglycerine itself depending upon a difference in the chemical composition of different samples.

"This was tested practically with different nitroglycerines, and with nitroglycerine and dynamite made from it, and it was shown, beyond question, that variations in the quality of the nitroglycerine

had nothing to do with it, and that the explanation must be sought in the physical conditions of the problems.

"General Abbot, therefore, suggests that in granulating nitroglycerine, by absorbing it in kieselguhr, the particles of silica slightly retard chemical action—since, in detonations, the reactions occur within the molecules—and as the resistance opposed by water is of a slightly yielding character, more time may be required to reach this condition than is afforded by nitroglycerine, pure and simple.

"This view is confirmed by the action of certain dynamites which are made so as to explode with exceeding rapidity, and which fall very low in the scale."

(Notes on the Literature of Explosives, by Prof. C. E. Munroe, B. S., May, 1883.)

This explanation is given as applying to the most extreme case in which nitroglycerine is the active principle in both explosives, the inert absorbent in the case of dynamite in no way contributing to its strength. Subjecting the explosives contained in the above table to a further test of strength by a comparison of the actual performance of mechanical work by proportional charges of each taken from the third column of the same table, the results of the previous experiments were fully verified.