MEMOIR

ON THE

EXPLOSIVENESS OF NITRE,

WITH A VIEW TO ELUCIDATE ITS AGENCY

IN THE

TREMENDOUS EXPLOSION OF JULY, 1845, IN NEW YORK.

BY ROBERT HARE, M.D.,

EMERITUS PROF. OF CHEMISTRY IN THE UNIVERSITY OF PENNSYLVANIA, AND ASSOCIATE OF THE SMITHSONIAN INSTITUTION.

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DR. JOHN TORREY, M.D.
COL. J. J. ABERT, *U. S. Top. Engineer.*

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MEMOIR

ON THE

EXPLOSIVENESS OF NITRE.

SUMMARY.

Statement of the Phenomena and Facts of the Great Explosion.—Attributed to Gunpowder —This disproved by competent Witnesses.—Failure of the Chemists employed by the City Government to produce an Explosion by Mixtures of Nitre with Combustibles, and their consequent Report against the explosive Efficacy of Nitre.—Opposing Opinion of respectable Chemists, especially Silliman and Hayes.—Experiments of the latter, showing that Nitre may explode with Water, confirmed by an Explosion which had happened in the Author's Laboratory.—Illustrative Reference to the Explosion consequent to the Combustion of Potassium upon Water.—Explosiveness of Nitre with Substances containing Water or Hydrogen, ascribed to the Affinity of Water for Bases being at a high Temperature, greater than that of Nitric Acid.—Discrimination between explosive Combinations of which the Ingredients are held in a State of Contiguity by chemical Affinity, and pulverulent Mixtures mechanically aggregated; compression being requisite to Explosiveness in the one Case, but not in the other. —Chemical Affinity, in the Case of Potassium oxidized and intensely heated upon Water, performs the Part of mechanical Force in the Explosion of Moisture by the Impact of incandescent Iron.—Nitre exploded with Sugar under incandescent Iron simultaneously struck with a Sledge.—Force of the Impact thus produced, less than that, for an equal Area, resulting from the dancing of 700,000 pounds of Merchandise upon 300,000 of incandescent Nitre within the Walls of the exploded Store.—Impossibility of exploding Gunpowder or Gun-Cotton in Vacuo.—Products of the Combustion of these Compounds ascertained and compared; also their projectile Power, which for equal Weights makes that of Gunpowder to Gun-Cotton, nearly as one to four; while the gaseous Products are as one to three nearly.

1. Among the conflagrations by which cities have been more or less devastated, there has been none, it is believed, of which the phenomena were more awful and mysterious than those of the great fire which took place in the city of New York, on the 19th of July, 1845.

2. The destruction of two hundred and thirty houses, containing merchandise amounting in value probably to two millions of dollars, made the calamity in question highly deplorable as a cause of pecuniary loss and embarrassment; while the characteristics which gave to it an unprecedented rapidity of extension, were of a nature to excite an enduring interest as well as temporary consternation.

3. A series of detonations, successively increasing in loudness, were followed by a final explosion of which, agreeably to an affidavit, the report resembled a "*loud clap of thunder*." This tore into pieces the building within which it took place, threw down seven houses in the vicinity, and drove in the fronts of the houses on the opposite side of the street, at the distance of eighty-seven feet. The whole of the space within which these tremendous effects took place, was filled with a dazzling flame, and various masses, intensely ignited and vividly luminous, were projected aloft as if expelled from a volcano, so as, on alighting, to spread the conflagration far and wide. Shipping anchored in the Hudson River, probably at the distance of more than a quarter of a mile, were greatly endangered by these deflagrating missiles.

4. So violent was the atmospheric concussion, that people were prostrated by the consequent blast, when too remote to be injured by the flames or flying fragments. Some persons were wounded or killed, but so small was the number, in comparison with that of the multitude which might have been mutilated or destroyed, that there was more gratulation for the escape of the many, than sorrow over the few who actually perished. This comparative immunity was due to the warning given by the detonations which, as already mentioned, preceded that by which the mischief was effected.

5. The natural inference arising from the detonations thus alluded to, was, that gunpowder had been stored in parcels of various amounts on the different floors of the store, the smaller portions above, the larger below, and that the detonations were the consequence of the successive ignition of the parcels thus situated. The cry of gunpowder was raised on the occurrence of the first explosion, and caused the retreat of almost everybody near the quarter whence it proceeded. Hence before the final catastrophe, the streets about the store were entirely vacated, so that scarcely any person was injured besides those in the houses opposite to the conflagration.

6. Notwithstanding the reasonableness of the belief at first created, as to the agency of gunpowder, there was the most conclusive evidence, so far as the oaths of worthy and well-informed witnesses could avail, that no gunpowder was contained in the building within which the explosions occurred. Of course, the real cause of the disaster became a subject of perplexing consideration for chemists in general, and especially for those adepts in chemistry, to whom the Corporation of the city concerned applied for an elucidation of the mystery.

7. It was fully established by the statements of the highly respectable proprietors, and that of their store-house clerk, that there were in the store more than three hundred thousand pounds of nitre, secured in double gunny bags, containing one hundred and eighty pounds of nitre each, in piles alternating with heaps of combustible merchandise; yet as, agreeably to ordinary experience, such combustibles deflagrate when ignited with nitre, without exploding, this did not remove the unfavorable impressions unjustly created respecting the occupants of the store. The stowing of any large quantity of gunpowder adequate to the effects produced, had been culpably imprudent and illegal; and coupled with a most solemn denial

on their part, would have involved them in the baseness of falsehood, if not the guilt of perjury.*

8. To everybody the elucidation of the mystery was desirable, since, without a correct knowledge of the causes, the proper means of guarding against a recurrence of such explosions could not be devised. It was interesting to men of

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* "The contents of the store, agreeably to the evidence of the clerk, whose business it was to keep an account of them, were as follows :—

In the cellar there were :

58 hogsheads of sugar.
16 barrels of molasses.
6 cases of indigo, four covered with gunny bags, two cases without gunny bags.
8 cases of lac dye—one case open, and seven not open.

First floor :—

About 300 or 400 bags of saltpetre, in double gunny bags, one bag outside of the other.
About 8 casks of madder.
About 5 bales of hides.
5 bales of safflour.
32 bags of mustard seed.
3 ceroons of Guayaquil hats.
1-2 chaldron of Cannel coal (Liverpool). Weighing geer.
A small lot of loose kindling wood ; about half a load.
4 desks and contents.
1 water-closet.
Small bags containing samples of saltpetre.
Samples of shellac, and a lot of books.

Second floor :—

About 1000 bags of saltpetre, and another lot of sumac.
150 boxes of sugar.
21 bales of raw silk.
Between 8000 and 9000 cigars, in half boxes.
2 casks of indigo.

Third floor :—

About 530 bags of saltpetre, in the same condition as that on the first floor.
Between 20 and 30 bales of gunny bags.
About 700 bags of coffee.

Fourth floor :—

Filled with coffee in bags. There was nothing else there.

Fifth floor :—

7 bales of gunny bags.
125 cases of shellac.
Some 15 or 20 pieces of fur.

Garret :—

About 200 bags of coffee."

The following summary, giving the weights, has been furnished to me by Messrs. Crocker and Warren.

science to have it ascertained wherefore their efforts to produce an explosion by similar ingredients, were unsuccessful.* To the occupants of the store it was important, since they were liable not only to ill opinion and legal prosecution as above stated, but likewise to a deprivation of their claims for insurance. Fortunately for them, in opposition to the opinions and experimental inferences of several chemists who were consulted, tending to extend or confirm the idea, that gunpowder, illegally and most culpably stored, must have been the cause of the catastrophe, the opinions of Silliman and Hayes, and other eminent chemists, were called forth, tending to sanction the inference that the result might be due to the reaction of nitre with contiguous merchandise.†

9. I owe it to my friend, Augustus A. Hayes, to state, that I might have adopted the more general impression, had it not been for his inferences and experiments made with the view of accounting for the explosion of a vessel, loaded with nitre, while lying at anchor in the harbor of Boston. It was ascertained by this able chemist, that when, by an experiment made in his laboratory, between one and

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By this it appears that there were in all more than a million of pounds of merchandise in the store, of which about one-third was nitre.

RECAPITULATION.

150 boxes and 58 hogsheads Sugar, gross weight,	127,183
16 barrels Molasses,	8,182
23 cases Indigo,	7,028
14 " Lac dye,	3,468
1799 bags Saltpetre,	347,207
1-2 ton Cannel Coal,	1,200
8 casks Madder,	13,176
32 bags Mustard seed,	5,213
299 " Sumac,	48,701
6 bales Hides,	4,102
5 " Safflour,	1,526
10 bundles Twine,	1,806
21 bales Raw Silk,	3,242
33 " Gunny bags,	16,079
3232 bags Coffee,	391,049
136 cases Shellac,	41,968
	1,021,040
Nitre,	347,207
Merchandise,	673,833

* With means furnished by the Councils, five eminent chemists made several experiments upon a large scale, in order to ascertain the effect of igniting nitre with such combustibles as were associated with it in the store of Messrs. Crocker and Warren; yet in no instance could they produce detonating reaction. The activity of the combustion never surpassed that degree of rapidity and consequent violence which may be designated by the word deflagration.

† The opinions of Silliman were given at length in a Report submitted to a Committee of the City Council, at whose instance it had been prepared.

two hundred pounds of nitre, intensely heated in a crucible, were suddenly sprinkled with water, an explosion ensued.*

This statement of Hayes caused me to recollect, that upon one occasion a mischievous explosion had occurred in my laboratory, when a fissure taking place in

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* The subjoined quotation from the Boston Daily Advertiser, will serve to show the point to which Mr. Hayes had attained, in elucidating the mysterious explosions produced by incandescent nitre, when my efforts to afford a further elucidation commenced. It seems, from the language of the editor, quoted below, that the cause of the explosion, in the store of Messrs. Crocker and Warren, had been previously a subject of discussion in his newspaper, the conflagration having occurred a short time previously.

"EXPLOSIVENESS OF SALTPETRE.

"The following correspondence contains the information in reference to this subject, to which we alluded in our paper on Saturday. The statement of Mr. Hayes, we conceive, can leave no doubt that the saltpetre in the store of Messrs. Crocker and Warren, at New York, surrounded as it was with combustible materials, and exposed to the water thrown from the engines, was the cause of the explosion which has been the subject of so much discussion, and that it is quite unnecessary to suppose that there was any gunpowder in the store." * * * * * * *

The following particulars are stated by Captain Cotting, of the ship Virginia, of the burning of that ship on the fifth of May last. This ship contained a cargo of linseed and saltpetre. In his letter, published in the Newburyport Herald, he says:

"In about ten minutes from the time the fire was first discovered, the after hatch blew off, and at the same time the fire forced its way through the ship's side, on the starboard quarter, a short distance from the water-line. In about ten minutes from this time, the boats having been got out, the crew, feeling the deck rising, jumped into the sea, and succeeded in getting into the boats, cut the painters, and shoved off Almost at the same time an awful explosion took place, the fire rising to the height of 200 feet from the main and after hatches, and a few seconds afterwards from the fore hatch. At the same time the main and mizen masts went by the board. Five minutes from this time, the ship disappeared with all her cargo. In twenty-five to thirty minutes from the time the fire was first discovered, no trace of the ship was visible. All that was saved was two boats, chronometer, sextant, and one compass."

BOSTON, 25th *July*, 1845.

A. A. HAYES, ESQ.:

Dear Sir,—Our mutual friend, Mr. Ralph Smith, informs me that you have made some experiments with a view of ascertaining whether, and under what circumstances, saltpetre, when ignited, will produce explosions.

Much curiosity exists at this time in the community upon this subject, and divers opinions have their advocates. To me it seems strange that among our numerous scientific men and professed chemists, no one has stood forth, sustained by nice experiments, with a view of settling this much-vexed question.

Perhaps you have already satisfied yourself in the matter. If you have, you will greatly oblige me, and the public, by furnishing for publication the results of your investigations. If you have not sufficiently investigated already, I beg of you the favor of instituting such a course of experiments as will throw the much needed light upon the subject.

I am, respectfully,

Your obedient servant,

HENRY WILLIAMS.

ROXBURY LABORATORY, 28th *July*, 1845.

HENRY WILLIAMS, ESQ.:

Dear Sir,—Your note of yesterday, in relation to the explosive action of saltpetre, has this moment come to hand. I most cheerfully comply with your request in placing an iron alembic holding about twenty pounds of fused nitre, on hoisting the alembic off the fire, a jet of the liquefied salt fell accidentally upon some water in a tub, which was unfortunately too near. It also brought to mind that potassium, when thrown upon the surface of water, is, by combustion with the oxygen of that liquid, converted into a fused globule of red-hot oxide, which, in the act of combining with water, detonates violently. This detonation struck me as being clearly owing to a sort of double reaction, in which, while one portion of water, by uniting with the oxide of potassium, converts it into hydrate of potash, another portion, uniting with the heat, flies off explosively as steam.

10. In a letter to Hayes, immediately after his explanation appeared, I stated these

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before you the facts connected with the subject of the action of saltpetre on substances usually called combustible.

Saltpetre, or the nitrate of potash, or soda, *alone*, does not burn, or explode by heat, however intense. It parts with one of its constituents, oxygen, by heat, and it is to the combination of its oxygen with other bodies that it owes its power of burning with them. Wood and other fibrous substances do not burn with saltpetre until they have become partially charred; they then produce *deflagration*, or burn with sparks. A large quantity of saltpetre, enclosed in gunny bags, as it is usually stored, after fire was communicated to it, would burn with the bags, emitting much smoke and sparks, precisely as paper which has imbibed saltpetre would. It would not be consumed; only the small quantity required to burn with the bags would be changed. If an addition of burning wood or charcoal were made to the extent of one-fifth the weight of the saltpetre, an intense and continued deflagration would result, and all the saltpetre would be changed. *No explosion would follow from applying fire to mixtures of charcoal, or wood and saltpetre;* the rapid combustion called deflagration would be produced, but, unlike explosion, time would be required for the mutual actions; and where the quantities were large, many hours would be necessary before they would cease. The recent destruction of life and property in New York, the loss of a homeward-bound Indiaman and her cargo, by a similar cause, have created an anxiety which has led to many inquiries respecting the origin of the *explosions* attending the burning of saltpetre. I need not remind you of a case which occurred at Central Wharf, about ten years since, when the Hartford Packet was destroyed. The testimony obtained in the last instance led me to make some experiments on the effects produced by dropping water on a burning mixture of saltpetre and charcoal. It was ascertained that a very small weight of water, relatively to the saltpetre, caused explosions, which might be made successive, so long as the materials remained. The quantities of the substances acting, being increased to between one and two hundred pounds, the addition of water, in the form of spray, caused an explosion which destroyed the vessel, and shook all the buildings in the vicinity. The temperature of a burning mixture of saltpetre and charcoal, at the points of contact, is superior to that of "white hot" iron, and the form is that of a bubbling fluid. Water falling on the mass is instantly converted into steam, having the elastic force of that used in steam-guns; exceeding gunpowder in destructive energy. The red-hot particles, dispersed by the sudden action, pass over considerable spaces, and the appearance of flame is produced.

In cases where water falls on highly heated polished surfaces, such as melted glass, copper, or silver, steam is formed rapidly, but silently; the water does not touch the hot surface. The spreading of a film or crust over the polished surface, instantly alters its relation to water, and causes steam to form with explosive violence, attended by a loud report.

I do not hesitate in expressing my belief, that the disastrous effects produced in New York were caused by water or other fluid falling on saltpetre, while burning with the bags investing it. The facts which I have stated may have interest or importance in connection with attempts made to extinguish fire in buildings containing saltpetre. The danger of throwing water on the fire is manifest, while the loss to the owner of the saltpetre would doubtless be greater from water than from fire.

Respectfully, A. A. Hayes.

facts and inferences; and moreover, I endeavored to illustrate the subject by referring to the explosion so frequently produced by blacksmiths, through the forcible contact with moisture, of incandescent iron struck by a hammer. It has been ascertained that globules of oxide of iron, as they fall in a state of fusion from a wire ignited in oxygen, do not at first produce any commotion in water. This arises from the generation of a protecting atmosphere of rarefied aqueous vapor, which renders contact with the liquid water impossible. Widely different would be the result, were the liquid suddenly forced into contact with the globule by a blow from a hammer, as above mentioned. Analogous causes operate when globules of the most volatile liquids or solids are retained for a time in the cavity of an incandescent metallic ladle, meanwhile evaporating much more slowly than if the temperature were less. In any one of these instances an explosion would follow from a contact being coerced between the heated surface and the liquid. When a hammer is employed as above described, mechanical force produces that contact, which, in the explosive union of incandescent oxide of potassium with water, is caused by intense chemical affinity.

11. The explosion produced by Hayes, as above mentioned, and that which took place in my laboratory, as well as the explosive reaction of oxide of potassium with water, gave a practical confirmation to the inference, that the meeting of water with the base of incandescent nitre could cause tremendous results. Subsequently, in the winter of 1845–6, I found that when nitre, by the flame of a hydro-oxygen blow-pipe supplied with atmospheric air and oxygen, is heated to incandescence, and then quickly submerged in water previously situated beneath the containing ladle, a sharp explosion ensues. I found, nevertheless, that when thrown, under like circumstances, upon molasses or sugar, the effects were those of deflagration rather than explosion. Yet, latterly, I have fallen upon contrivances, by which pulverized sugar and nitre may be made to explode. The first expedient which succeeded, was that of pouring melted sugar upon the face of a hammer, so as to make a disk of commensurate size. Such a disk, if it should not adhere, is easily made to do so by slightly moistening the face of the hammer. Some nitre was put into a thin shallow platina capsule, situated over a small anvil, near one of its edges, so that the bottom of the capsule might be reached obliquely by a hydro-atmospheric blow-pipe flame. Under these circumstances, the nitre having been heated until its potash began to be volatilized, was struck with the sugar-faced hammer. A smart detonation was the consequence. This experiment may fail sometimes from the blow not being properly given; from the nitre not being sufficiently hot; or the capsule being ill situated. The explosion of fulminating mercury by a hammer fails sometimes, from the blow not being so given as to produce a due degree of parallelism between the surfaces.

12. Another method of producing explosive reaction is as follows:—Nitre and sugar being coarsely powdered, let disks of paper, about three inches in width, be prepared. Place one of the disks upon an anvil, and cover it with a stratum of sugar. Then cover the sugar with a stratum of nitre, placing over this another of the disks. Heat a flat iron bar, wider than the disks, to a welding heat, and quickly withdrawing it from the fire, and holding it above the paper, strike it down

thereon with a sledge. An explosion will ensue, with a very loud report. Of course the operator's face should be protected by a mask, his hands and legs by a leathern or woollen apron, and gloves. The operation may be performed by one person, but more advantageously by two, as it is difficult for one to hold the iron in the position most suitable for bringing the surfaces together with the requisite degree of parallelism.

13. In a letter in reply to one from Mr. Durant, of New York, respecting the explosions which are the principal objects of these communications, I adverted to the superiority of the affinity which exists between water and oxide of potassium over that which exists between nitric acid and the same base,* as a reason why the presence of the elements of water, or of hydrogen in union with carbon, should, on ignition with nitre, give rise to explosive reaction. Obviously, the consequence of the displacement of nitric acid by water must be, that the gaseous constituents of the acid, incapable of remaining in combination without a base, would escape, either as nitrogen, nitric oxide, or oxygen gas, or, carbon being present, partially, as carbonic oxide, or carbonic acid.

14. Gum, sugar, starch, and lignin, consist of carbon in union with the elements

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* It may be well here to advert to the fact, that one of our young countrymen, Tilghman, has, without any hint from me, not only perceived the property of water on which I have insisted, but likewise has had the sagacity to suggest its application in various useful processes. These have all been founded on that superior affinity of water for certain bases, on which, in my letter to Hayes, I had insisted as affording the rationale of the explosion of nitre either with this liquid, or with any substance containing its elements.

From the preceding suggestions, and some experiments, of which an account will be subjoined, it appears that the explosive violence of a mixture of nitre with substances containing carbon in union with hydrogen, or with hydrogen and oxygen, so as to be competent to convert the base into a hydrate or carbonate, is dependent on the force with which they may be held or brought together in a state of ignition, being sufficient to permit of that increase of temperature which is necessary to explosive reaction.

Probably at the temperature thus alluded to, the ingredients are all in a condition analogous to that of a very dense explosive gaseous mixture. It is well known that such mixtures detonate with a velocity apparently not less than that of an electrical discharge. A single electrical spark, a particle of platina sponge, even a sunbeam, may cause an explosion so instantaneous, that it is the collapse only that can be observed. The dilatation which precedes the collapse escapes scrutiny. However large the volume, ignition in any one part seems to affect the whole at once.

I infer, then, that when, nitre and certain compounds of carbon with hydrogen and oxygen, reach a temperature at which the whole mixture, if not restrained mechanically, would take the aëriform state by a sudden revolution in the electro-chemical polarities, that detonating combination ensues, to which, when ignited, various gaseous mixtures are liable. A few cubic inches of olefiant gas, with twice the bulk of oxygen, included in soap-bubbles and inflamed, will produce a report equal to that of a musket. The accidental explosion of a half gallon of a similar mixture created a thundering noise like a field-piece, so as to alarm the whole neighborhood within a furlong of my laboratory.

Aware of the influence of confinement in augmenting the force of reaction between nitre and combustibles, the distinguished chemists above mentioned (as having been called upon by the Corporation of New York to investigate the phenomena under consideration,) treated the absence of this condition as a reason for discrediting the idea that the reaction of nitre with combustibles could account for them. But agreeably to the facts, I propose to show that there must have been a mechanical force in operation sufficient to bring the matter into a state analogous to that which enables fulminating combinations, or explosive mixtures of gas, to detonate either from ignition, from exposure to an electric spark, or, in some instances, from a blow or catalysis; in other words, from some influence like that exercised by platina sponge.

of water, being virtually hydrates of carbon. Oils, resins, or bitumens, consist of carbon and hydrogen, with but little oxygen. Of course either, when heated with nitre, can supply water to the base of this salt, *with*, if not *without*, assistance from its oxygen, which constitutes nearly half of the matter in nitre. Such substances may, therefore, under favorable circumstances, perform the part performed by sulphur in gunpowder, which I conceive to be that of seizing the potassium and liberating the acid, so as to enable its oxygen to react freely with the carbon and the resulting sulphide of potassium. Considerations analogous to those advanced respecting the agency of the elements of water in exploding with nitrates, will apply with respect to those of carbonic acid; since carbonated alkalies, no less than the hydrated, being indecomposable *per se* by heat, carbon as well as hydrogen must, by uniting with one portion of the oxygen of the nitric acid and taking hold of the base, expel all the nitrogen with the rest of the oxygen.

15. Having submitted the preceding facts and considerations, my explanation of the stupendous explosion which forms the topic of this communication is as follows:

Of the enormous quantity of nitre which the store held, more than 56,000 pounds were on the first floor, about 180,000 pounds on the second floor, and about 100,000 on the third floor. The weight of combustible merchandise was about 700,000 pounds. As it was alleged by some of the witnesses examined that the iron window shutters of an upper story became red hot by the conflagration of an adjoining house, it is probable that fire was communicated to some of the gunny bags holding the nitre, or some other combustibles, which, as stated in evidence, were piled against the shutters. As soon, however, as a single bag became ignited, the nitre with which the inner bag must have been imbued, would give the greatest deflagrating intensity to the consequent combustion; while the interstices between the bags, like those between grains of gunpowder, would enable the flame to pervade the whole heap of bags. As nitre fuses at a low red heat, very soon a great quantity, in a state of liquefaction, must have run down upon the wooden floor, which would immediately burst into an intense state of reaction with the oxygen of the salt. To this combustion the merchandise adjoining would add fuel, causing a still more extensive liquefaction of the nitre. The deflagrating mass thus created, on burning its way through the floor, or falling through the scuttles, which were all open agreeably to the evidence, must have received an enormous reinforcement from the subjacent nitre or combustible merchandise. On the giving way of each floor in succession, the conflagration must have received a reinforcement of deflagrating fuel, so as to have grown rapidly with its growth, and strengthened with its strength. Under these circumstances, the whole of the nitre becoming liquefied, must have found its way to the cellar. Meanwhile, the merchandise and the charcoal of the wood-work must have been conglomerated by the fusibility of the sugar, shellac, and bitumen, aided by the molasses, and formed thus an antagonistic mass of more than half a million of pounds in weight, deflagrating intensely with the nitre. But whenever, by these means, a portion of the deflagrating congeries attained the fulminating temperature, a detonation must have ensued, causing a temporary lifting of the combustible mass; only, however, to be followed by a more active collision, resulting from the subsequent falling back of the conglomerated combustible mass upon the melted nitre. After every such collision, the combustible congeries must have been blown up to a height augmenting with the temperature, the force of the fall, and extent of reciprocal penetration. The force of the fall would, of course, be as the height. Hence the twelve or thirteen successive detonations indicate as many explosive collisions; while the successive augmentation of the loudness of the reports indicates a proportionable growth of their violence, arising from successively greater elevation and descent.

16. If I am right in supposing that in fulminating power, the intensely heated nitre and the combustible merchandise were for equal weights equivalent to gunpowder, if only a sixth of the 300,000 pounds of nitre held in the store was engaged in the final explosion, it would be equivalent to sixty thousand pounds of gunpowder.

17. No better way of estimating the force with which the nitre and combustibles were brought into collision for the last time, at which the finishing explosion took place, has occurred, than that of comparing it with the blow by which nitre and sugar were exploded as above mentioned, in one of my experiments.

The weight of the combustible matter contained within the store was 700,000 pounds. The store was ninety feet deep by twenty-four wide. Supposing the horizontal area of the sledge as applied, to have been $3 \times 3 = 9$ square inches, it seems that for every equivalent horizontal area within the store, there must have been twenty-two pounds, or about three times the weight of the sledge. Hence, in descending from a height of twenty or thirty feet, which there was ample room for it to reach, the combustible congeries may have attained a much greater velocity than could be imparted to the sledge, and may consequently have produced a much more forcible impact. At the same time, this must have caused an intimate penetration and intensity of compression, which by a dead weight it is almost impossible to create.

This explanation, so far as it rests upon the assumption that the combustibles were made to dance upon the surface of the melted nitre, is supported by the fact that any combustible mass, when thrown upon the surface of incandescent nitre, will undergo a dancing motion, so as sometimes to leap out of a deep pot within which the experiment may be made.

The phenomena are not irreconcilable with the idea that some of the earlier explosions arose from the falling of the liquid nitre upon the combustibles before all the floors gave way; but it should be recollected that nitre fuses at a low red heat, and at a cherry red gives out oxygen gas. The presence of this gas, as well as the deflagration resulting from contact with the liquid nitre, must have caused the floors to be oxidized with a rapidity far exceeding that which takes place during ordinary conflagrations.* To the causes of quick destruction thus suggested, must be added the mechanical force of the explosions directly at war with

* See Note to paragraph 9.

the persistence of the floors. That, prior to the last explosion, the nitre must have been collected in the cellar, may be assumed from the fact, that the temperature being inevitably far above its fusing point, the salt must have been all liquefied, and occupying the lowest accessible cavity, on account of its superior specific gravity. This assumption is moreover justified by the circumstance that the force of the explosion appears to have been especially exerted upon the parietes of the cellar, the walls and surrounding earth having given way in a manner which created astonishment.

19. In order to amplify the practical basis upon which the preceding inferences had been founded, I made some experiments on the combustion of gunpowder in an exhausted receiver, so as to secure the gaseous products evolved. A cylindrical glass receiver, such as is usually employed as a candle shade, was ground upon a lap-wheel, so as to fit air-tight between two disks of sheet brass. The disk for closing the upper opening of the receiver was furnished with two cocks severally, for communicating with an air-pump and barometer gauge. The disk for closing the lower opening of the receiver, so as to form the bottom of the space included, was furnished with an arch of platinum wire soldered to two stouter brass wires, of which one was soldered to the disk, the other secured and insulated in passing through it by a collet of leather, compressed about it by an appropriate screw. These preparations being made, a portion of gunpowder, weighing about 25 grains, was so supported on a tray, as to include the middle portion of the platinum wire. The receiver being put into its place, so as to be duly supported by the lower disk and covered by the other, the air was withdrawn as far as practicable, with a good air-pump. In the next place, the wire was ignited to incandescence. To my surprise, the gunpowder only smoked at first, and did not flash until a perceptible interval had elapsed. When this result ensued, it appeared to be owing to the radiant heat, as the early volatilization of a portion of sulphur had driven the granules away from the wire, so that it did not touch any of them. Subsequently, on allowing the air to enter, and removing the receiver, it appeared that the gunpowder was only partially burned. Thus it became evident that in this way a complete combustion could not be effected. The feebleness of the flash in vacuo shows how much confinement is essential to give energy to the explosion of this powerful agent, and its not being forthwith ignited by an incandescent wire, demonstrates that, as in the case of the apparent quiescence of a globule of volatile matter in an intensely heated cavity, a capability of volatilization delays this process, by preventing the contiguity requisite to a communication of heat.

20. This leads to a discrimination which has not, to the best of my knowledge, been made heretofore. I allude to the difference existing between fulminating *combinations* and fulminating *mixtures*. As an example of the latter, we have gunpowder and other pulverulent mixtures consisting partially of nitre, or chlorate of potash, while, as an exemplification of the former, we may advert to aurum or argentum fulminans, or to the fulminates of mercury or silver; also to the chloride or iodide of nitrogen, or perchloric ether. Compounds of the last-mentioned kind, without confinement, break the vessel on which they are exploded. They cannot be used in gunnery, because the force in their immediate vicinity, in proportion to its durability, is too great, so that they burst the chamber before the

ball moves an available distance. The elements in these combinations are in a state of intense chemical union, and can only leave that state for another, by which gases and vapors are produced with an instantaneous and almost irresistible expansibility. They require no confinement, because already confined by their reciprocal affinities. In gunpowder and analogous mixtures, the ingredients exist without any forcible coherence, so that an incipient reaction causes a tendency to move apart, which prevents the reaction from extending itself when there is no confinement. This was strikingly shown by attempting to burn in vacuo a small cylinder of consolidated gunpowder, made by intense pressure within a metallic tube by a steel piston. This cylinder, about a half inch in diameter and an inch in length, was placed in contact with a platinum wire within an exhausted receiver. The wire being ignited, a feeble combustion ensued. Subsequent examination showed that the cylinder was only about half deflagrated, the unburnt portion remaining unchanged. It had been extinguished spontaneously, after being completely ignited at the end in contact with the incandescent wire.

21. This was, no doubt, in consequence of the process being effected in a rarefied medium. In order to compare these observations with those which might be made by combustion in pleno, I made a larger cylinder of gunpowder, two inches in diameter and two inches in height, by similar means, and set fire to it by an iron rod ignited at one end. This I caused to touch the top of the cylinder while standing upright at the bottom of a cast-iron pot about four inches in diameter, and a foot in depth. The combustion very much resembled that of a rocket, commencing feebly, however, yet terminating with a deflagration so rapid as to be almost explosive. The augmentation of intensity, I ascribe to the increased resistance from reaction with the gas evolved, which pressed upon the cylinder with a force like that which elevates a rocket.

22. Finding that, in vacuo, a perfect combustion could not be accomplished by the means above mentioned, I resorted to an arrangement through which a cylinder of consolidated gunpowder might be so supported by a rod sliding in a stuffing box as to be pushed upwards against a wire ignited by a galvanic battery within an exhausted receiver. When, by these means, the ignition of gunpowder was attempted, it was not very readily accomplished. The part touching the wire appeared to burn feebly; nevertheless, by turning the rod so as to cause the cylinder to revolve, and consequently to be assailed at various points, combustion was induced and gradually extended, and at last completed satisfactorily.

23. The receiver employed was held between two metallic plates, one forming the bottom, the other the cap. Through the middle of the bottom the sliding rod was introduced, so as to be in the axis of the cavity. It was secured by two stuffing boxes, the object of the outer one being to enable the rod to pass through the orifice of a vessel of oil, employed to prevent the possibility of air entering through that next the cavity. The juncture of the cap with the receiver was covered by cold water, which served to prevent leakage, and keep down the temperature. This was ascertained by a thermometer within the receiver, yet accessible to inspection. The cavity, thus secured against leakage, held 240 cubic inches; the contents being indicated by a column of mercury in a barometer tube

situated before a scale graduated into 480 parts. Of course, the whole contents being 240 cubic inches, as above stated, each graduation represented half a cubic inch.

24. The igniting wire was soldered to the ends of brass rods, of which one was soldered to the cap, the other secured by collets of leather, so as to pass through the cap without metallic contact. Consequently, connection being made between this insulated rod and one pole of a battery, while the other pole had a metallic communication with the cap, the wire might at any moment be made the medium of a circuit competent for its intense ignition.

25. The upper end of the sliding rod supported a little disk of sheet copper, and a little below that disk was supported, in like manner, a larger disk of the same material perforated like a colander.

26. Upon the upper disk, the consolidated gunpowder being supported with all the above-mentioned arrangements, the receiver was replaced.

27. The air was withdrawn until the mercury in the gauge tube attained nearly the height of the column within an adjoining Torricellian tube, or that of a neighboring barometer. The height was recorded, likewise the temperature indicated by the thermometer. The fall of the barometrical column of mercury in the gauge tube, resulting from the operation, was not estimated until the mercury in the thermometer was in statu quo. The difference in degrees caused in the height of the barometric column, divided by two, gave the number of cubic inches of gaseous matter evolved. This difference was of course set down.

28. In the next place, the temperature being carefully observed and recorded, about two cubic inches of a strong solution of caustic potash was added. The consequent absorption, as it declined in rapidity, was assisted by an agitation consequent to moving up and down the rod, and the perforated disk attached to it. When no more absorption could be observed to take place, judging by the quiescence of the mercurial column in the gauge, and when the temperature had returned to the starting point, from which it had been disturbed by the heat generated through the reaction between the alkali and carbonic acid, the height of the column was again recorded, and the difference of degrees, divided by two, were estimated to give the number of cubic inches of carbonic acid generated. Allowance was made for the mechanical effect of the bulk of the alkaline liquid in lowering the mercurial column founded on actual measurement of the effect of a like quantity of water; the mercury being brought to the same height in the gauge tube, in an experiment made for the purpose with atmospheric air.

29. Three samples of Dupont's powder were obtained from the United States Arsenal, severally designated cannon, musket, and rifle powder. Of each, 75 grains were pressed into an indurated cylindrical mass, as above described, and successively burned in the exhausted receiver.

The following are the results :—

Cannon powder, gas evolved,	55	cubic inches.
" " absorbed,	23½	"
Musket powder, " evolved,	52	"
" " absorbed,	21¼	"

Rifle powder, gas evolved, ...	51½ cubic inches.
" " absorbed, ...	20½ "
Sporting powder, average of two experiments,	
Gas evolved, ...	51 cubic inches.
" absorbed, ...	25 "

30. As the gas left after the removal of the carbonic acid had all the negative characteristics of nitrogen, it may be concluded from the results above given, that the gaseous products of deflagrated gunpowder consist of nearly equal volumes of carbonic acid and nitrogen.

31. I was naturally led to compare the results of the deflagration of gun-cotton with those of gunpowder. Accordingly, I exposed a tuft of gun-cotton, weighing twenty-five grains, in the exhausted receiver in a similar way. I found a retardation in the activity of the combustion arising, as in the case of gunpowder, from the absence of mechanical confinement, diminution of atmospheric pressure tending to lessen the contiguity indispensable to intense chemical reaction.

32. The deflagration of the tuft being effected, it caused an evolution of gas equal to 19½ cubic inches.

33. In order to concentrate the combustible ingredients, resort was had to the apparatus employed in the case of gunpowder, by which means twenty-five grains of the cotton could be condensed into a cylinder of about half an inch in width, and of a like length.

34. Two specimens of gun-cotton, of the manufacture of Lennig, of fifty-four grains each, prepared and ignited as above described, gave an evolution equal to 126½ cubic inches.

35. As seventy-five grains of gunpowder gave only fifty-five cubic inches of gas at most, it appears that equal weights being employed, gun-cotton causes a gaseous evolution more than three times as great as gunpowder.

36. As seventy-five grains of gunpowder produces, taking the largest amount in the above table, only fifty-five cubic inches of gas, it follows, that to produce an effect equal to fifty-four grains of gun-cotton, one hundred and seventy-two and a half grains of gunpowder would be requisite.

37. The gunpowder evolved little more than seven-tenths of a cubic inch per grain, while the gun-cotton evolved more than two cubic inches per grain.

38. The gas arising from the gun-cotton did not admit of an examination so simple as that given out by gunpowder.

39. By the introduction of one hundred cubic inches of oxygen gas, it appeared from the consequent red fumes, and absorption by water, that about thirty-five cubic inches of nitric oxide had been formed: by the introduction of caustic potash, about twenty-five cubic inches of carbonic acid was indicated. One third of the residual gas being exploded with oxygen, appeared to consist of three volumes of hydrogen to four of carbon vapor. The washings gave indications of cyanogen.

40. The coexistence of nitric oxide, carburetted hydrogen and cyanogen, in the products, justifies the idea, that were the heat greater, the expansive effect would be augmented by the transfer of the two atoms of oxygen in the oxide, to the hydrogen and carbon, producing augmentation of temperature, carbonic acid and

aqueous vapor. In order to bring the explosive power of gun-cotton to its maximum, I infer that immense resistance would be necessary, thus concentrating and expediting the reaction.

41. The residue of the explosion of gunpowder appears, from a qualitative analysis, to consist of sulpho-cyanide and sulphide of potassium, with carbonate and sulphate of potash. The two latter are by much the more abundant products. Probably sulphur is the primary and most energetic ingredient, as when in excess it is, *per se*, known to be capable of completely decomposing potash at a moderate heat, while carbon can only partially effect an analogous change at the highes heat of a furnace. Faraday has recently alleged, that the production of the flame of sulphide of potassium is an important agent in the explosive ignition of gunpowder. It is likely that from the reaction of oxygen with sulphur and potassium, a temperature results sufficiently high for the combustion of the charcoal with oxygen, and of nitrogen with sulphur and carbon, whence ensues carbonic acid and sulpho-cyanogen, in union with potassium in the one case, and with potash in the other.

42. I have already distinguished the explosion of mixtures like gunpowder from fulminating combinations, of which the constituents being held together by intense chemical affinity, require no mechanical confinement nor impact to bring or keep them sufficiently near each other for reciprocal reaction. There is, however, another distinction to be made. The explosion of vessels by high steam is altogether the effect of heat and confinement. The resulting violence, when the vessel bursts, is directly as its strength; so that, knowing how many pounds per square inch the vessel was capable of bearing, we know the explosive force to have been exactly equal thereto. But the strength of the containing vessel, in the case of gunpowder, may be very far short of that generated by the gunpowder ignited within it. When held together until the temperature is attained which is requisite for the play of affinities into which the ingredients are disposed to enter, a sudden evolution of heat and gaseous matter takes place, producing a diruptive force far beyond the retaining power of the vessel.

43. Although gun-cotton is a chemical combination, consisting of nitric acid and lignin, yet it does not explode, when unconfined, with a violence approaching to that of other fulminating combinations above mentioned. This may be attributed to the fact that neither the elements of nitric acid, nor those of lignin, are held together by a strong affinity; and consequently the forces which resist explosion are but feeble.

EXPERIMENT.

COMPARATIVE STRENGTH OF GUN-COTTON AND GUNPOWDER.

Agreeably to some recent experiments made in my presence by Captain Mordecai, of the Regulars, at the U. S. Arsenal, Washington, at about thirty feet distance, a cylinder of gun-cotton, weighing twenty-five grains, condensed as above described, drove a musket-ball through seven white pine boards, of about an inch inthickness. One hundred and ten grains of gunpowder caused the ball to pass through eight boards of the same target. Two cylinders of gun-cotton of the same size, that is to say, twenty-five grains in weight each, caused a musket to burst. The iron of the musket, judging from its coarse crystalline texture, does not appear to be of the best quality.

These results seem to show, that while the force of gun-cotton, in gunnery, is to that of gunpowder as four to one, the ratio of the quantity of gas generated by the former, to that generated by the latter, is as three to one

The greater quickness of the deflagration of the gun-cotton may be the cause, in part, of this diversity of ratio. Another cause may be, a more thorough combustion. Of a large discharge of gunpowder, some portion escapes unburnt; in the case of gun-cotton, in the form employed in the experiments above mentioned, none escapes.

SUMMARY.

It is an old and well accredited maxim in chemistry, to which there are but few exceptions, that fluidity is requisite to chemical reaction. The fluid state, of which the necessity is thus asserted, is with few exceptions attained only through water, or heat, or both. In truth, however, when it is considered that without heat there could be no fluidity, heat may be viewed as the sole solvent. As respects the induction of the state requisite to chemical reaction, we may consider the solution in which water is the ostensible agent, or igneous fusion in which it is absent, as the only means of bringing the atoms of solids into the state requisite for chemical reaction, through which decompositions and recompositions are effected.

It is well known that the affinities which prevail among the same set of bodies when liquefied by aqueous solution, may be the opposite of those which they exert when indebted to heat solely, for liquefaction. Thus there is scarcely any acid which will not displace silicic or boric acid from alkaline bases when in aqueous solution, yet when salts, consisting in part of the most energetic acids, are fused with silicic or boric acid, decomposition ensues in consequence of the union of the acids last-mentioned, with the bases ignited with them.

The sulphates, carbonates, or hydrates of potash, soda, and of some other bases, are *per se* indecomposable at any heat at which their bases cannot be volatilized; yet the nitrates of the same bases, are decomposed at the temperature of incandescence. It follows that if a nitrate be exposed to igneous fusion with any substance consisting more or less, of hydrogen, carbon, or sulphur, and the oxygen of the nitrate will, by forming water with the hydrogen, carbonic acid with the carbon, or sulphuric acid with the sulphur, cause the nitrate to be replaced by a hydrate, a carbonate, or sulphate.*

But as in every atom of nitrate, there are, independently of the base, five atoms of oxygen, and since to convert hydrogen into water requires one atom, to convert carbon into carbonic acid requires two atoms, and to effect an analogous change in sulphur requires three atoms, it follows that for every atom of hydrogen there will be four atoms of oxygen liberated, for every atom of carbon three atoms, and for every atom of sulphur, two atoms. Each atom of oxygen is to the weight of nitrate of potash as 8 to 102; hence there will be by hydrogen nearly 32 per cent., by carbon nearly 24 per cent., by sulphur 16 per cent. of oxygen evolved to act upon the excess of the contiguous combustible matter. Meanwhile it must be recollected that gum, sugar, starch, and lignin, (or fibre of wood, cotton, or linen) both hydrogen and oxygen, exist in due proportion to generate water; and besides these compounds formed with oxygen, we have nitrogen to aid,† which is more incoercible than water or carbonic acid. Since at the heat produced by the combustion of hydrogen or carbon, with pure oxygen, iron, the most tenacious of all the materials at our command, is perfectly fusible, it is evident that by mechanism we cannot restrain the expansive force of the gaseous products producible as above represented. I believe, I may say, that water has never been confined under a white heat. Yet the expansive force of liquid carbonic acid is at the freezing point of water, thirty-six times as great as the pressure of this liquid at its boiling point It has already been observed, that nitrogen, in expansive violence must go beyond carbonic acid. It follows, that excepting the blow of a hammer, or the force created by gravitation in falling bodies, we have no means by which we can enable nitre, in the state of incandescent igneous fluidity, to come into close contact, *even for an instant*, with masses of combustible matter, like those which it was made to encounter in the store of Messrs. Crocker and Warren.

It is to be presumed that it has been the want of this force which has caused efforts to produce explosions between nitre and combustibles, to fail; and it is to the presence of this force, where the fall of enormous masses of agglutinated combustible matter upon incandescent liquified nitre, may be reiterated, that I ascribe the destructive explosions, which, under such circumstances, have been so prolific of impoverishment, mutilation, and death.

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* The power of decomposing incandescent nitre by aqueous vapor, which was inferred by me to exis in 1845, has since been fully verified by the employment of this vapor by an American chemist, Tilghman, to effect the decomposition of compounds containing potash, or other alkaline bases capable of forming hydrates, *per se*, indecomposable by heat. (See Note, p. 10.)

† Nitric acid consists of one atom of nitrogen as well as five of of oxygen.