SCIENCE

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MSS. intended for publication and books, etc., intended for review should be sent to the responsible editor, Professor J. McKeen Cattell, Garrison-on-Hudson N. Y.

*EXPLOSIONS CAUSED BY COMMONLY OCCURRING SUBSTANCES.**

ON the sixth of November last the country was startled by learning that an explosion had occurred in the Capitol at Washington which had caused extensive damage to that magnificent and historic building, and which, with the ensuing fire, had destroyed some and jeopardized more of the valuable archives with which the building was stored. Occurrences of this kind have long had a particular interest for me, and I have found them to recur with great frequency and to cause extensive damage and destruction not only to property but to person. Notwithstanding, therefore, that much that I have to say is well known, it appears to be not inopportune to address you on the subject of 'Explosions Caused by Commonly Occurring Substances,' ommitting entirely from consideration the substances commonly known and used as explosives, and it is possible that this repetition may serve to some extent in preventing these accidents by leading to greater precautions being taken.

From the observations on the phenomena accompanying the combustion of solids it is well understood that the speed of the combustion is greatly accelerated by comminuting the combustible and mixing it in-

* Address of the President before The American Chemical Society, New York Meeting, December, 1898.

timately with the supporter of combustion, and it is also well recognized that many explosions are due solely to very rapid combustion, yet it is only within comparatively recent times, and since manufacturing operations have come to be carried on upon a very considerable scale, that we have had it strongly demonstrated that ordinarily combustible solids might, when finely divided and mixed with air, give rise, on ignition, to most violent and disastrous explosions, and it seems especially notable that the first well demonstrated cases of this kind should have arisen from the apparently harmless operations attending the grinding grain, and the more particularly as flour is not looked upon as a very readily combustible substance when compared with other commonly used solids.

Among the many instances of this kind which we have now on record we will cite that which occurred on the 9th of July, 1872,* when the inhabitants of Glasgow were startled by the report of an explosion which was heard to a considerable distance and which was found to have occurred in some very extensive flour mills, the front and back walls of which were blown out, while the interior was reduced to ruins, and speedily enveloped in flame which destroyed the remaining buildings. Several persons were killed, and a number of others were severely burned, or injured by the fall of masonry.

On May 2, 1878, a similar disaster occurred in the enormous flour mills in Minneapolis, but in this case it was observed that the explosion which originated in the Washburn mill was communicated by flame successively to the Diamond mill and to the Humboldt mill. As a consequence of these explosions, the walls of these mills, which were solid masonry, six feet thick at the base, were razed to the ground; sheets of corrugated iron roofing, two by six feet in area, were projected to a distance of more than two miles; a wooden building fifty feet from the center of explosion was burst open; stout plate glass windows one-fourth of a mile away were torn out bodily, sash and all, and projected into the street; an immense volume of smoke and flame was projected to an estimated height of six hundred to eight hundred feet, and finally persons by the edge of the adjacent river observed a displacement of water, producing a wave estimated to be eighteen inches high, before they heard the report of the explosion. The concurrent testimony of persons employed in the mills, and of the experts who were called, proved the absence in each case of any of the so-called explosive substances on the premises and that the boilers had not burst, and from the facts brought out the origin was conclusively traced to the striking of fire by a pair of mill-stones, through the stopping of the 'feed,' and the consequent friction of their bare surfaces against each other, with the result that the mixture of air and fine flour-dust surrounding the millstones became ignited.

This ignition alone would not suffice to develop any violent explosive effects; for similar ignitions which have been not infrequently observed in small mills, where they have been caused by the stones 'striking fire' or by the incautious use of a burning lamp near the millstones, or the meal-spout attached to them, have not been attended by any serious results. But in an extensive mill, where many pairs of stones may be at work at one time, each pair has a conduit attached, which leads to a common receptacle called an exhaust box; into this the mixture of air and very fine flour-dust which surrounds the millstones is drawn by means of an exhaust fan, which is sometimes aided by a system of air-blowers. The fine flour is allowed to deposit partially in this chamber or exhaust box, and the air then passes into a second cham-

* Abel, Roy. Inst., March 12, 1875.

ber, called a stive room, where a further quantity of dust is deposited. It follows that when the mill is at work, these chambers and the channels are all filled with an inflammable mixture of the finest flour-dust and air, and that the ignition of any portion of the inflammable mixture will result in the exceedingly rapid spread of the flame throughout the whole, and will thus develop an explosion. The violence of such explosions depends much upon the details of construction of the exhaust boxes and stive rooms, and upon the dimensions of the channels of communication; it must obviously be regulated by the volume of the inflammable mixture through which the fire rapidly spreads, and upon the degree of confinement. In the case of the catastrophe at Glasgow the production of a blaze at a pair of millstones was observed to be followed by a crackling noise as the flame spread rapidly through the conduits leading to the exhaust box upon an upper floor, and a loud report from that direction was almost immediately heard. Professors Rankine and Macadam, who carefully investigated the cause of this accident, report* that other flour-mill explosions which they had inquired into had been observed to have been attended by a similar succession of phenomena to those noticed upon this occasion. The bursting open of the exhaust box by a similar though less violent explosion, attended by injury of workmen, the blowing out of windows and loosening of tiles, appears to have taken place on a previous occasion at these particular mills. In the last and most disastrous accident, however, the more violent explosion appears to have been followed by others, the flame having spread with great rapidity to distant parts of the mills through the many channels of communication in which the air was charged with inflammable dust, resulting from the cleansing and sifting operations carried on in different parts of the building, and rapidly diffused through the air by the shock and blast of the first explosion.

*Abel, Roy. Inst., March 12, 1875.

In the experimental investigation of the Minneapolis explosion by Professor S. F. Peckham* it was shown that compacted masses of flour which had become heated and charred ignited readily and smouldered, but were inflamed only with considerable difficulty, though the atmosphere of the conduit from the stones, through which a strong current of air is being continually drawn and which is filled with a dense cloud of very fine particles of flour heated to a maximum temperature of 140° F, could be inflamed with comparative ease. White-hot wires and glowing charcoal were incapable of producing this inflammation, and only burned the particles in actual contact with them, and the only means by which the mixture, in the best proportions, could be made to burn explosively was by contact with flame.

The danger in the process was found to arise from the friction of the stones heating the last portion of the grist that remained between them to a temperature sufficient to char it or to convert it into a substance resembling tinder, which would readily ignite from a spark produced from the stones striking together. Although this burning mass could not inflame the dust-laden atmosphere, it did ignite wood, which a strong draught of air readily forced into a blaze. Under the conditions described with a draught of air passing through the dry stones strong enough to convey the pellets of smouldering tinder into the wooden conductor an explosion was a necessary consequence.

Knowing the chemical composition of flour, we may calculate approximately the mechanical work which a given mass of flour can perform, and find that the con-

*_Am. J. Sci._ 16 (3), 301–306; 1878.

tents of an ordinary sack, when mixed with 4,000 cubic feet of air, will degenerate force enough to throw 2,500 tons mass to a height of 100 feet. If we now consider the many tons of flour there must have been in a mill such as the Washburn 'A,' where as much as 1,000 pounds of dust per day was collected from a single pipe, we can readily comprehend how such great destruction could be wrought.

It is to be regretted that the experts who duly considered all the circumstances concluded that, while, by suitable precautions, the frequency of these flour-mill explosions may be diminished and the extent of the damage inflicted may be very much restricted, the nature of the operations is such that these explosions cannot be altogether prevented.

Since mixtures of wheat-dust with air have proved to be so explosive, we should naturally expect that analogous solids would form similar explosive mixtures with air, and, as a fact, we have recorded explosions of oatmeal in the Oliver mill in Chicago, of starch in a New York candy factory,* of rice in rice mills, of malt dust in breweries, of spice dust in spice mills, together with numerous instances of sawdust explosions, the more prominent being those which occurred in the Pullman car shops and at Geldowsky's furniture factory in Cambridge, Mass., still we should scarcely look for an explosion from such a cause in a soap factory. Yet a violent explosion occurred in 1890, in a Providence soap-works, in which the finely powdered saponaceous substance known by the trade name of 'Soapine' was being prepared, and the Coroner held in his finding that the explosion through which such injury was inflicted was caused by the ignition of soapine dust. Experiments made in this connection showed that this substance will explode under certain conditions with more violence than flour and apparently with the production of more heat.

*L. W. Peck, Explosions from Combustible Dusts, *Pop. Sci. Month.*, 14, 159-166 ; 1878.

The most unusual case of dust explosions, however, with which we have met was that of finely powdered metallic zinc which occurred at the Bethlehem Zinc Works in 1854. At that time Col. Wetherill devised a plan for utilizing the 'blue powder' which is the finely divided metallic zinc that is deposited in the prolongation of the condenser by swedging the powder into blocks and piling these blocks one above another in a furnace where they were melted down and run into spelter. The workmen in charge sought to facilitate the process by feeding the uncompressed powder directly into the furnace, but on trying to do so an explosion followed the loading of the first shovelful, and with such violence that the workman was blown from the top of the furnace and the blade of the shovel was driven into the roof of the building.

In pharmacy and the arts substances have been made either knowingly or accidentally from mixtures of combustible substances and supporters of combustion which have given rise to accidents, such as those from the parlor match and the chlorate troches,* or from sodium peroxide and sodium bisulphite mixtures, as in the Whitecross Street explosion,† and the latter class of mixtures are to be particularly dreaded as the chemical action and subsequent explosion may be incited not only by contact with fire, but also by contact with water. Cavazzi ‡ points out that mixtures of sodium nitrate and hypophosphite detonate on heating, while Violette § proposed to use a mixture of sodium nitrate and acetate as a substitute for gunpowder, and these are but a few among the many explosive mixtures which may be compounded.

* *U. S. Nav. Inst.* **11**, *774;* 1885.
† J. Soc. Chem. Ind. **13**, *198-200;* 1894.
‡ Gaz. Chim. Ital., 1886.
§ Berthelot sur la force de la poudre (3) **2**, *315*.

Still another source of danger arises from the production and use in laboratories, and, frequently in common life, of chemical substances which are explosive *per se*, though not generally recognized as such, and we have records of accidents, among others, from bleaching powder,* from erythryl nitrate, which has lately come into use in the treatment of Angina Pectoris,† from ammonia nitrate,‡ and there are many others, such as the organic nitrates,§ nitroso compounds,|| diazo bodies,¶ diamides,** hydrozoic acid and its derivatives, †† hydroxylamines, ‡‡ chlorates,§§ carbonyl compounds,|||| permanganates, ¶¶ peroxides,*** chlorides††† and iodides,‡‡‡ occurring in the laboratories and used to a varying extent in the arts that are so unstable as to give rise to serious accidents if incautiously handled. We may notice that so well known a compound as the cupric ammonium nitrate, a body which is often formed in the course of analysis, was deemed by Nobel to possess such value as an explosive that he took out patents for its use in blasting.

The liquid state conduces more particularly to accidents taking place since bodies in this state are liable to escape from their receptacles and to be found in unexpected places. If combustible, when mingled with the atmosphere or when saturating oxidizing agents they burn with extreme rapidity and produce very violent effects. When such liquids give off vapors at the ordinary temperatures, or those prevailing during use, the danger is very materially increased, as such vapors are more vagrant and, through diffusion, readily mingle with the atmosphere. These properties are especially characteristic of many of the products obtained from coal tar and from petroleum, bodies whose cheapness, abundance and special adaptability have led to their extended use for domestic heating and lighting and for many purposes in the arts, but which have, because of this widespread use and in consequence of their possessing the properties named, been the cause of an enormous number of casualties. Dr. C. F. Chandler* showed that much of the danger attending the use of these oils in lamps could be avoided by the elimination of the paraffines of low boiling points, and though not the pioneer, yet largely through his active efforts and the agitation which followed them, this principle has properly become widely embodied in legislation. This view as to the source of danger was confirmed by the experiments of Newbury and Cutter,† who found that all the paraffines below nonane formed explosive mixtures with air at the ordinary temperatures, notwithstanding that the boiling point of octane is 124°C., and that the limit of a safe oil as fixed by the 'flashing test' defined by the New York State statutes is reached only in decane. Yet this last-named compound formed a violently explosive mixture at the legal flashing temperature if but a small quantity of the liquid was placed in the copper testing vessel, thus indicating that entire safety is not assured in its use and that accidents might occur when it is used in lamps so constructed that the oil chamber becomes highly heated. Dewar‡

* Rept. H. M. Insp. Exp. pg. 47 ; 1897.
† Rept. H. M. Insp. Exp. pg. 50 ; 1898.
‡ J. Chem. Soc. 683 ; 1882.
§ Compt rend **109**, *92–95* ; 1889.
|| Comp. rend **108**, *857–859* ; 1889.
¶ Annalen **121**, *257* ; 1860.
** J. Prk. Chem. **30**, *27* ; 107.
†† Bericht. **23**, *3023* ; 1890.
‡‡ Rec. d. trav. Chim. Pays Bas **10**, *101*; 1891, and J. Chem. Soc. **54**, *425* ; 1888.
§§ Compte rend. **105**, *813* ; 1887.
|||| Bericht. **18**, *1833* ; 1885.
¶¶ J. Chem. Soc **54**, *230* ; 1888.
*** Compte rend. **106**, *100*; 1888.
††† Bull. Soc. Chim. **50**, *635–638*.
‡‡‡ J. Chem. Soc. **56**, *766* ; 1889.

* Petroleum as an Illuminator ; Rept. N. Y. City Board of Health for 1870.
† Am. Chem. J. **10**, 356-362 ; 1888.
‡ Rept. H. M. Insp. Exp. **21**, *55*; 1897.

holds that the relative volatility of petroleum oil is a subject which is not sufficiently known and appreciated. By comparing the loss of weight during 24 hours of oils exposed in shallow vessels under similar conditions, he found at 66°F. an American water white oil of 106° flash point lost 20.4 per cent., an oil of 75° flash point lost 27.4 per cent., and a Russian oil of 84° flash point lost 28 per cent.

In observations that I have made it was very apparent that the form and material of the containing vessel are most important factors in these volatilization experiments. I have found, for instance, that a given volume of gasoline placed in an uncorked vial and exposed to the ordinary atmospheric conditions of a laboratory required 10 weeks for complete volatilization when the same volume of the same lot of gasoline placed in an evaporating dish standing beside the bottle volatilized completely in 8 hours. The rate of evaporation of various hydrocarbons under the same conditions has been studied by Boverton Redwood.*

A menace in the use, storage and transportation of these liquids rests in the rapidity with which their vapors diffuse through the air and form an explosive train which reaching out to a source of ignition flashes back with extreme rapidity through the entire train and to its point of origin. Sir Frederick Abel cited an instance of this† which happened at the Royal College of Chemistry in 1847 when a glass vessel in which benzene was being converted into nitro-benzine broke and allowed the warm liquid to escape and flow over a large surface. Though the apartment was 38 feet long, 30 feet wide and 10 feet high, and the only ignited gas jet was at the end of the room most remote from the glass vessel, yet, in a very brief space of time after the vessel broke, a sheet of flame flashed from the gas jet and traveled along the upper part of the room to the point where the fluid lay scattered.

* 'Detection of Inflammable Gas and Vapor in the Air,' Frank Clowes, p. 191, 1896; London.

† Roy. Inst. of Great Britain, March 13, 1885.

Also he cites the explosion of benzoline at the mineral oil store in Exeter in 1882. The store rooms were arched caves in the side of a bank facing a canal and separated from it by a roadway about 50 feet wide. There was a standing rule forbidding any light being taken to any of these store rooms when they contained petroleum spirit, but on the day in question it was desired to remove some of the benzoline in the early morning and the foreman visited the store rooms before daylight to make ready for the work. Forgetful of the rule, he carried a lighted lantern, which he placed on the ground some 27 feet away from the cave, and was proceeding to open the door when he observed a strong odor of benzoline and almost immediately noticed a flash of flame proceed from the lantern to the store and had barely time to turn to escape when an explosion took place which blew the doors and lantern across the canal and inflamed the spirits in the store rooms.

Of course, the distance that these vapors will travel will be determined by the circumstances of each individual case, but in the case of the fire at the L. & N. W. R. R. Co.'s gas factory in February, 1897, through which the hydrocarbons in a cylinder that was being rolled across the yard about the works became ignited, the nearest source of ignition was found in the boiler fires, which were 60 feet away.*

Conditions such as these are more likely still to obtain when these inflammable and volatile substances are stored in enclosed spaces, such as the hold of a vessel during transportation, and they have been the cause, under these conditions, of many frightful accidents. As an example of these we have the case of the explosion on Novem-

* Rept. H. M. Insp. Exp. **22**, *57;* 1898.

ber 21, 1888, on the petroleum-laden ketch 'United' at Bristol, England, through which the docks were blown up, three men killed and several injured, the glass in the windows shattered for a radius of upwards of 300 feet, and extensive damage done by fire.

The accident was made the subject of a special report by Col. V. D. Majendie* which contains the results of his investigation and the experiments by Dr. Dupré and Mr. Boverton Redwood, from which it appears that the material on the 'United' was 'deodorized naptha' in forty-two gallon barrels; that the average annual leakage on petroleum oil in barrels amounted, in 1874, to 8 per cent. and on petroleum spirit to double this quantity; and that, though there has since been a great improvement in the treatment of the barrels, it is still very large; that one volume of the liquid gives 141 volumes of vapor at ordinary temperature having a specific gravity of 3.5 to 3.8; that one volume of the liquid will render 16,000 volumes of air inflammable, 6,000 most violent explosive, 5,000 strongly explosive, and 3,000 scarcely explosive but combustible. The naptha vapor alone or when mixed with air in the best proportions was not ignited by a shower of sparks from flint and steel; by a stream of sparks from fireworks of various kinds burning without flame; by incandescent match ends, or by incandescent platinum heated by electricity to a red heat. Even red-hot coals held over and sometimes falling upon a small quantity of the spirit spilled on a wooden floor failed usually to ignite it, and the cause in those cases in which ignition did take place in these red-hot coal experiments was uncertain, as there was a fire burning in a near by room. Ignition was, however, certainly effected by the application of a flame or by contact with a platinum wire approaching incandescence.

* Eyre & Spottiswoode, London, 1889, 30 pp.

The 'fireworks' test makes a striking lecture experiment, especially the one devised by Mr. Redwood with 'vesuvians,' or incandescent cigar lighters. For this purpose he attaches two, of the glowing variety, to a wire so that the tip of one will be in contact with the base of the head of the other. The latter is lighted, and when it ceases to flame, and only glows, the mass is thrust into the explosive mixture, where it remains with the combustion, progressing from tip to base and base to tip without other effect until, when flame bursts from the tip of the second vesuvian, the vaporous mixture surrounding it is ignited and an explosion ensues.

Col. Majendie has properly called attention in this report to the fundamental distinctions between the danger arising in the transportation of a cargo of dynamite and one of petroleum spirits, since in the former case an explosion does not take place until fire is brought to the dynamite, while in the latter case the dangerous vapors will travel to a fire at a considerable distance and even through intervening bulkheads.

For this reason mixed cargoes of which volatile inflammable liquids and explosives constitute a part are particularly dangerous, as was long since shown in the explosion of the canal boat 'Tilbury,' in Regent Park, in 1874, having on board five tons of gunpowder and four barrels of benzoline and also having a small fire burning in the after cabin some 35 to 40 feet from the forehold in which the petroleum was stored. Notwithstanding that the cargo was covered with tarpaulins and that there was an intervening bulkhead, the vapors reached the fire and a most devastating explosion followed. The cargo was thus made up in spite of a similar disastrous experience from similar causes on the 'Lottie Sleigh,' at Liverpool, in 1864,* and neither of them have proved a sufficient warning to alto-

* Abel, *loc. cit.*

gether prevent subsequent reckless disregard of all dictates of common prudence.

Yet, because of these experiences, attempts have been made in some instances, where small lots of spirit were taken by vessels, to avert disaster by carrying them as deck loads, but the experience on the 'Solway,' which carried 24 barrels of this article on the main deck before the poop, shows that this does not ensure security, for, meeting with heavy weather, the casks broke adrift, their vapors reached the galley or cabin fires, and the vessel, with 19 persons, was lost.

Even where great precautions are taken to prevent accidents they not infrequently occur from inflammable substances being met with in unexpected places, or being introduced surreptitiously in admixture with harmless bodies. Nowhere, perhaps, is more care taken in this respect than on passenger steamships and in the naval service, yet 18 years ago a series of accidents occurred on board English ships, the cause of which was for a time veiled in mystery and which, in the then-existing state of feeling consequent on the dynamite outrages, aroused the gravest apprehensions.

In June, 1880, a violent explosion took place, without any warning or apparent cause, in the forepeak of the Pacific Steam Navigation Co.'s steamer 'Coquimbo,' shortly after her arrival in Valparaiso. Several plates were blown out of the bow, and other structural damage was inflicted while the ship's carpenter, who was the only person apparently who would have thrown any light on the cause of the accident, was killed.

This explosion was followed on April 26, 1881, by a much more serious one on the man-of-war 'Doterel' (while at anchor off Sandy Point, in the Straits of Magellan), through which eight officers and 135 men lost their lives and the vessel was destroyed.

In May, of the same year, an explosion of trifling character happened on H. M. S. 'Cockatrice,' in Sheerness Dockyard; while in November one, which was sufficiently severe to kill two men, dangerously wound two more (one fatally) and injure six others, besides doing much damage to the ship, occurred on H. M. S. 'Triumph,' then at Coquimbo.

The first suggestion as to the real cause of these accidents was obtained in the investigation of that on the 'Cockatrice,' when it was developed that, just previous to the explosion, a man went into the store room with a naked light which he held close to a small can, that was uncorked at the time, and which contained a preparation recently introduced into the naval service (as a 'drier' for use with paint) under the name of Xerotine Siccative, and that this largely consisted of a most volatile petroleum product. As it had been issued without knowledge of this fact, instructions were at once sent out by the Admirality directing that it should be stored and treated with the same precautions as turpentine and other highly inflammable liquids or preparations; and these instructions had but recently reached the 'Triumph' when the accident narrated happened to her. Inquiry here developed the fact that the explosion originated in the paint room through bringing a lantern to a compartment in which a leaky can of Siccative had been stored, and following up this clue the explosions on the 'Coquimbo' and 'Doterel' were fully and definitely proved to have been due to the presence on board of this same substance; while experiments with the material showed that it was capable of producing all the destructive effects observed, except, perhaps, in the case of the 'Doterel,' where, from the two reports noted and the other resemblances to the Regent Park explosion, there was but little doubt that the powder magazine was also exploded.

Such accidents were not, however, confined to British vessels, for on October 13 1891, while the U. S. S. ' Atlanta ' was going to the rescue of the wrecked ' Tallapoosa ' an explosion occurred on the ' Atlanta,' which caused her immediate return to New York. I was at once ordered by the Secretary of Navy to proceed to New York and investigate the accident.

I learned that while the 'Atlanta' was laboring in a heavy sea she sprung a leak through the hawse pipes and the forward collision compartment began to fill with water; that a handy-billy was rigged to pump the compartment; that about midnight the suction pipe became plugged, and that on lowering a common lantern into the compartment an explosion ensued, severely injuring two men, slightly injuring four others and bulging the steel collision bulkhead. I found that the collision compartment had been used as a store room for paints; that among them were spar and damar varnishes and Japan dryer, each of which gave off inflammable vapors at ordinary temperatures; that the packages were sealed in a very insecure manner, and that, as this compartment filled and the vessel tossed, the cans were opened and their contents churned up so as to readily form explosive mixtures with the air.

I learned further that on June 15th previous a fire and explosion had taken place on board the U. S. S. ' Philadelphia ' in close proximity to her powder magazine, and that another had occurred on the U. S. S. ' Bennington,' all being evidently due to the same material.

But notwithstanding these vigorous lessons the tale continues, and on April 14, 1896,* a ' petroleum accident ' occurred on board the Cunarder S. S. ' Servia ' when a party of men were engaged in painting the inside of a water-ballast tank. The tank, which was 3 feet 6 inches deep, was divided into 16 compartments, with 18 inches aperture between each. The farthest compartment was being painted at the time, and it was necessary to crawl through 15 of the small apertures to reach it. The paint used was styled Patent Bitumastic Solution, and one of the survivors testified that it took him four or five minutes to reach the compartments, ten minutes to do the painting, and four or five minutes to return, and that he could not stoop down any longer, as it made him dazed and queer in his head. All the witnesses testified that the use of the solution in confined spaces made them drunk and delirious if they remained any length of time at work. This is a well-known effect of the lighter petroleums, and it is not surprising that the solution was found to consist of coal tar dissolved in crude oil, having a flashing point of 45° F. Abel, and containing so much volatile matter that one gallon spread over a large surface would render 48 cubic feet of air inflammable.

Notwithstanding this the workman went into this inner compartment, which was already partly covered with the freshly-laid solution and containing a partly-filled bucket of it, with a lighted candle. Some time having passed without hearing from him, another workman went to his assistance and found the place on fire and the man burned and delirious. He was so delirious as to fight against coming out, and it took an hour and a-half with assistance to get him through the apertures and up the manhole, and he afterwards died in the hospital from the effects of the disaster.

Even while writing this we learn from the local press that a fire, preceded by an explosion, due to the use of Bitumastic Solution, occurred at the Central Market House, Washington, D. C., on November 16, 1898.

The notorious ' Hair Dresser's Accident ' of June 26, 1897, through which Mrs. Samuelson was fatally injured in London, by the ignition of a petroleum hair wash

* Rept. H. M. Insp. Exp. **21**, *53;* 1897.

which was being used as a shampoo, illustrates anew the manifold uses to which these hydrocarbons are being put, and it brought out strongly the belief of competent authorities, like Lord Kelvin, that these substances could be ignited by frictional electricity; a theory which had been offered before in explanation of accidents in which there was no other apparent source of ignition.

The widespread distribution of these spirits in the hands of retailers, or as used for carburetters in isolated vapor-lighting plants and as employed in the arts for solvents, cleansing agents and for other purposes has led to their accumulation, through leakage or by being discharged after use, in low places, such as cellars, cisterns, wells, sewers and the bilges of ships, where they have remained, in some instances for long periods of time, unknown and unnoticed, their origin even being completely forgotten and untraceable, until, when, in the course of events, these out-of-the-way places have been reentered, these bodies have given rise to accidents. It is a well-known precaution of the past before entering a well or cave to test its atmosphere for carbon dioxide by means of a naked candle, but this very method of procedure has, since the introduction of petroleum, been the cause of accidents, and to be assured of security we must now remove and test the air before entering.

The extended consumption of naphtha for carburretting water gas, and the ease with which it is conveyed through pipes, has resulted in the use of systems of pipe lines in our cities to carry the oil from the transportation lines or store tanks to the works. Such a line was laid in Rochester, New York, and on December 21, 1887, it gave rise to an explosion which killed three men, seriously injured twenty, destroyed three large flour mills, tore up the streets for a considerable distance and inflicted an estimated loss of $250,000. This pipe line, which was made of 3-inch wrought-iron pipe, one and one-half miles in length, had been in successful use for six years, the spirits being pumped through it every two weeks in lots of from twelve to fifteen thousand gallons each. From the Appeal Book *in re* Ann Lee *vs.* The Vacuum Oil Co., Rochester, 1889, we learn that the conveyance of the naptha was complete on December 7th; on December 8th the contractors constructing a sewer exposed a section of the pipe line for several feet, and in blasting beneath it a piece of rock struck the pipe with sufficient force to bend it up nearly nine inches at the point struck and to separate it at a joint farther on underground and closely connected with a sewer; that on the day fixed for the next delivery, December 21st, the Oil Company, being unaware of the then-existing conditions, pumped the full supply into the pipe, none of which reached the gas works, but, on the contrary, found its way, by the broken joint, into the sewers, and was thus distributed over the city; that the pumping of the oil began at 12:15 p. m.; the odor was noticed shortly after 1 p. m., coming from a sewer at a point nearly a mile distant from the break; the first explosion occurred at this point at 3:20 p. m., and immediately extended westward back to the break and eastward to the outlet of the sewers, tossing up manhole plates, uplifting roadways and overturning buildings; that the explosive mixture was ignited by a fire under a steam boiler, and that this vapor found its way from the sewer to the fire through an untrapped water closet at a point where exhaust steam was being injected into the sewer.

At the trial, Mr. F. L. King, p. 173, stated that crude naphtha, flashing point 13°F., percolated through earth six times as fast as water at the same temperature, his several experiments being made with temperatures varying for the liquids from 38°F. to 60°F. and for the earths from 32°F. to 60°F. Mr. George B. Selden, p. 178, found the mixture of naptha and air in the best proportions, to give, on explosion, a pressure of 140 pounds per square inch, while coal gas and air in the best proportions gave 160 pounds per square inch, and that the ignition point of the naphtha mixture was 950°C. while that of the coal gas mixture was 800°C.

I have already referred to the means taken for ensuring the removal of the more volatile hydrocarbons from domestic kerosene, a subject which has been very exhaustively treated by Rudolph Weber.* It has, however, been seriously stated that the lighter oils, such as benzoline or naphtha, might be rendered safe for use in lamps by adding alum, sal ammoniac or camphor to them, and many innocent persons have suffered in consequence of their belief in the efficacy of these substances. Some years since† I tested the effect of these bodies by determining their solubility in benzoline, the flashing points of benzoline and commercial kerosene when treated with these bodies and when in their original state, and also the readiness with which mixtures of the oils, in the two conditions, with air could be exploded. The results showed that alum and sal ammoniac were practically insoluble in the oils and produced no effect whatever upon them ; that the camphor was soluble, one gram of benzoline dissolving about 1.5 grams of camphor; that an equal weight of camphor raised the flashing point of a kerosene 12° ; but that, on the other hand, the vapor of this camphorated kerosene, when mixed with air, had a lower point of ignition, and hence exploded with greater readiness than the original kerosene.

What is true regarding the use, storage

* Ding. poly. J. **241**, *277 and 383;* 1881.

† *Proc. A. A. A. S.* **33**, *174;* 1885.

and transportation of petroleum products holds for other easily volatile liquids. Professor Thomas Graham, in his report* on the cause of the loss of the 'Amazon' on January 4, 1852, pointed out clearly the danger in transporting turpentine, while the destruction of the 'Livadia,' of Liverpool, May 11, 1891, carrying a cargo of carbon disulphide, emphasizes the hazard attending this substance, for this heavy and very mobile liquid gives off quite rapidly at ordinary temperatures a vapor which is 2.64 times heavier than air, and which not only readily collects at the bottom of any space in which it is produced, but follows in a stream like water.

One of the more striking characteristics of the mixture which this vapor forms with air is its low point of ignition. The tiniest spark; a cinder after it has ceased to glow, or the striking together of two pieces of iron without sparking, are sufficient to determine its ignition. This property may be exhibited by plunging a glass rod heated to 231° C., (450° F.) (a temperature at which it can be touched with the bare hand) into the mixture.

The use of ether, alcohol, acetone and aldehyde, with nitroglycerine and guncotton, for the manufacture of smokeless powders, and of the esters as solvents for pyroxylin in the making of the varnishes that are largely used in household decoration, are some of the more modern forms of hazard, while the explosion at the Hotel Endicott, in New York, and at Newark, N. J., indicate what may be expected from the more extended use of liquefied air and liquefied acetylene.

Although Dr. John Clayton, the Dean of Kildare, in the sixteenth century, effected the destructive distillation of coal and collected and burned the gas from it, † it was

* Spontaneous Combustion and Explosions occurring in Coal Cargoes, Thomas Rowan, p. 40, 1882.

† Treatise on Coal Gas, William Richards, 1877.

not till 1792 that William Murdock devised the means for utilizing the substance and erected a plant at Cornwall, England, with which to light his house and office, and after several years of active agitation by the energetic promoter, F. A. Winsor, that in 1810 an Act of Incorporation was obtained for the London and Westminster Gas-Light and Coke Co., and the first installation on a large scale for lighting the streets of a city and supplying the public began, and through the ingenuity and resources of Samuel Clegg, the engineer, the devices were invented or assembled by which the practical manufacture, storage, distribution and use was successfully accomplished.

From this source the use of gas for lighting and heating extended over the world, reaching New York in 1834 and bringing in its train comfort and cheer, increased security, and added power to man, so long as the substance was confined to its proper channels and used in proper devices, but carrying also the possibility of working harm if the vigilance of its keepers was relaxed and it escaped from bounds; therefore beginning with the explosion at the lime purifier of the Peter Street Station, London, in 1814, through which Mr. Clegg was injured and two 9-inch walls thrown down, we have a vast army of explosive accidents originating in the ignition of mixtures of illuminating gas with air.

Owing to the circumstances attending some of these explosions there has arisen a vulgar opinion that illuminating gas is an explosive; in fact, in a recent case* counsel cited opinions of courts deciding 'gas' to be explosive; yet every chemist knows that it is not explosive *per se* and that it cannot even be made to ignite unless in contact with air or other supporter of combustion.

While we know the truth and may be able to demonstrate the fact, it is very satisfactory to be able also to cite the results of experience on a large scale; therefore the following from the *Journal of Gaslighting*, August 1, 1871, may be welcome. It appears that at the bombardment of Paris the Governor of the city feared that the gas holders of La Villette would endanger the fortifications. He was assured that there was not the smallest risk; that if a projectile penetrated a gas holder and set fire to the gas the latter would only burn out as a jet of flame, and that there could be no such thing as an explosion, since the constant pressure would effectually prevent any access of air. Shortly after a shell pierced the holder at Ivry and lighted the gas. There was a huge jet of flame for eight minutes; the holder sank slowly and all was over. At La Villette a shell penetrated a filled gas holder and burst in the interior without igniting the gas. At Vaugirard another shell entered, and again there was neither ignition nor explosion.

Many of the accidents from coal gas and its congeners, 'water gas,' 'producer gas,' and 'generator gas,' have been due to the escape of the gases from the interred pipes and mains from which they have reached sewers, cesspools, cellars and other enclosed places, for, though these gas conduits may be sound and tight when laid, leakage will in time be caused by the corrosive action of materials in the soil, by electrolysis, by fluctuations in temperature, by settlement in filled ground and by seismic changes.* The extent of this leakage from the mains in New York City was discussed in a Legislative investigation some nine years ago, and, while the Chemist and Health Department claimed that ten per cent. of the entire annual product or one thousand million cubic feet escaped, the gas companies' representatives denied that more than one hundred million feet were lost in each year.

* Proc. U. S. Nav. Inst. **22**, *638;* 1896.

* Milne, McClure's Magazine, **11**, *17–27;* 1898.

W. C. Holmes & Co.* give the allowed leakage as five per cent. and the average leakage as tēn per cent., while H. Tobey, in his paper on 'Elusive Leakages from Mains and Services,'† which was warmly discussed by the gas association before which it was read, shows that the condition still exists, and he gives illustrations showing the danger consequent on leaving abandoned sewers in place.

Owing to the fact that Bunsen, Angus-Smith, Letheby and Durand-Claye found large quantities of methane, hydrogen sulphide, and sometimes carbon monoxide, in the gases from stagnant sewage decomposing under water, there has arisen a belief that 'sewer gas' is explosive. Simple consideration of the facts that such stagnation cannot occur in a properly constructed sewer, and that such a change does not take place in flowing sewage, is sufficient to cast doubt on the existence of such a gas. It has been completely shown by Professor Wm. Ripley Nichols, in his Chemical Examination of Sewer Air,‡ as the result of his own extended observations, and from the discussion of numerous data by other investigators, that sewer air differs from ordinary air only in containing a larger percentage of carbon dioxide, and that 'sewer air is neither inflammable nor explosive.' The air of vaults and cesspools is, of course, a different thing, as the material in these may become stagnant.

It was as early as 1819 that an English patent was granted to David Gordon and Edward Heard for compressing gas in strong copper or other vessels fitted with ingenious reducing valves for regulating its rate of emission; 30 feet of gas being compressed into a volume of one cubic foot, and gas so compressed in cylinders of two cubic feet capacity were conveyed to the houses of consumers, with which to operate an isolated plant. Sometimes the pressure was sufficient to liquefy the gas, and it is interesting to note that it was in the liquid from one of these reservoirs that Faraday discovered benzene.

* Instructions for the Management of Gas Works, p. 41, London, 1874.

† Am. Gas Light J. **64**, *767;* 1896.

‡ Rept. Supt. of Sewers, Boston, Mass., 1879.

Naturally the tension of the gas itself tends to rupture the receptacle, and many accidents from explosions of this nature have occurred owing to defects in the cylinders, or to the exposure of the filled cylinders to unduly high temperatures, or to shocks; a recent accident that could not be explained in any other way occurred at Albany, N. Y. on December 6, 1893.*

With the increased demand for compressed gases of various kinds under high tensions, such as carbon dioxide, sulphur dioxide, ammonia, chlorine, nitrogen monoxide, acetylene, air and others which are being used or introduced for commercial, scientific or domestic purposes, there is being developed a continued improvement in the strength and homogeneity of the cylinders, so that the danger from this cause is diminishing.

Although Dr. Robert Hare had invented his oxyhydrogen blowpipe in 1801,† yet in 1834 Gordon and Deville were granted a patent for their calcium or 'lime' light. It was expected by the projectors that this form of light would replace gas, as burned from ordinary burners, for lighting streets, and it caused the holders of gas securities much anxiety, but as we are now aware the device came to be used for geodetic, scientific and exhibition purposes only.

Where the gases stored in vessels are of an inflammable nature there is an additional risk to that due to the tension of the gas, since by admixture with air or oxygen an explosion occurs on ignition. One source of these accidents arises from the diffusion

* Proc. U. S. Nav. Inst. **22**, *638;* 1896.

† J. Am. Chem. Soc. **19**, *719;* 1897.

of one gas back into the reservoir of another gas, but this is entirely prevented by proper regulation of the pressure and size of the orifice. Another arises from confusing the cylinders when filling them, and to prevent this the cylinders have been painted different colors. Yet, as shown by the fatal accident described by W. N. Hartley,* this has not prevented the deliberate interchange of the cylinders under the pressing demands of trade, and the usual causalty has followed. Therefore, he proposes that the fittings for the two classes of cylinders be made so entirely different that it will be practically impossible to charge the cylinder with the wrong gas, and in view of the probable increased use of gas in this form, as indicated by Mr. Thomas Fletcher,† the change should be made. Yet I doubt if it will be, except under compulsion of law, for I have learned in my efforts to introduce safety explosives in this country that the great majority will not secure the assurance of safety if this entails a little inconvenience and the taking of a little more pains.

A more common source of accident has come from impurities introduced in the making of the oxygen, as, at Nahant, Mass., where pulverized stibnite was mistaken for pyrolusite, and mixed with the potassium chlorate. Limonsin describes an accident at Cannes in 1880, which attracted unusual attention from the factitious circumstance that the gas was being prepared for the Empress of Russia,‡ and found the cause in the evolution of hydrocarbons from the rubber connecting tube by particles of heated potassium perchlorate carried into it through the turbulence of the reaction. While Professor C. A. Young gives an account § of the explosion at Princeton while filling a steel cylinder with oxygen by means of a water-jacketed, steam force pump, and finds the cause in oil used for lubricating the pump being sprayed into the gas cylinder so as to form an explosive mixture with the oxygen. He recommends the use of soap suds as a lubricant in place of oil. Frankland* describes a similar instance and gives a similar explanation.

* Chem. News, **59**, *75*: 1889.

† 'On a New Commercial Application of Oxygen.' J. Soc. Chem. Ind. **7**, *182*; 1888.

‡ U. S. Nav. Inst. **14**, *167*; 1888.

§ Sci. Am., p. 369, June 11, 1887.

Recently my attention has been called to several accidental explosions of oxyhydrogen mixtures formed in the operation of storage batteries, the detonating gas being fired by the spark formed on breaking connections at the battery.

But of all circumstances under which explosions occur the most awful are those which so frequently happen in mines, for if the miner escapes instant death it too often is but to die from suffocation, or, worse yet, to be entombed and perish from starvation preceded perhaps by insanity.

It has long been known that fire damp found its way into coal mines, and in 1674 Mr. Jessop communicated to the Royal Society a description of the accident met with by Mr. Michel, who penetrated into the gallery of a coal pit, in Yorkshire, with a naked torch and was severely burned. It is interesting to note† that, when rescued, he declared he had heard no noise, though the workmen in the vicinity had been terrified by a tremendous report accompanied by a vibration of the earth. As is to be expected, from what we now know of natural gas, inflammable gases are not confined to coal mines, but, as shown by B. H. Brough,‡ they are met with in metalliferous mines and other excavations also.

The appalling nature of these catastrophes led to efforts being made to at least reduce their frequency, if not to prevent them altogether, an extended account of these being

* Am. Gas Light J. **5**, *289*; 1864.

† Treatise on Coal Gas, Wm. Richards, p. 4, 1877.

‡ *School of Mines Quarterly* **12**, *13–22*; 1890.

given in Mining Accidents and their Prevention by Sir Frederick Abel, N. Y., 1889. It was early recognized that the presence of naked light was a constant source of danger, and hence the invention of the safety lamp by Sir Humphrey Davy, in 1816,* was hailed as a most beneficent gift of science, and this was soon followed by the lamps of George Stephenson and Dr. Clauny. When exposed but a short time in at atmosphere rich in gas and which is moving at a low velocity these lamps protected the miner, but if allowed to remain for some time in the gas-rich atmosphere the gauze becomes heated to the ignition point of the gas, from the gas mixture burning within it. By the introduction of ventilating appliances to remove the gas the currents of air in the mainways frequently reach a velocity of between twenty and twenty-five feet, and between two airways it may rise to thirty-five feet per second. In breaking down the coal the confined gas may rush out at a very high velocity, it being found by experiment at the Boldon Colliery that the gas may be under as great a pressure as 461 pounds to the square inch. And, finally, the air and gas may be set in motion at a high velocity by the firing of explosives to bring down the rock or coal, and more especially by a 'blown out' shot. Under such conditions the primitive safety lamps above described failed, but protected lamps have been invented which have resisted currents of even fifty feet per second for a brief period, though it is said that these are insecure in certain positions to which they may be tilted in practice, and that the glass cylinders are liable to fracture.

Instead of relying upon the safety lamps for protection a better method of procedure is to test the atmosphere of workings for the presence of fire damp before allowing the workmen to operate. Various methods have been pursued, and these are resumed in 'The Detection and Measurement of Inflammable Gas and Vapor in Air, by Dr. Frank Clowes, 1896, London,' and he there describes a very ingenious and efficient fire damp detector which he has devised. This consists of a simple and convenient hydrogen lamp by which one can detect 1/10 of one per cent. of methane or 25/100 of one per cent. of coal gas in air. He attaches a small steel cylinder (weighing about fourteen ounces) charged with hydrogen under 100 atmospheres of pressure to the side of a safety lamp, and leads the gas through a minute copper tube up beside the wick holder of the lamp, there being a reducing valve attached to the cylinder by which to feed the hydrogen to the lamp as desired in order to control the height of the flame.

* Trans. Roy. Sec. **106**, 1.

The lamp is lighted as usual at the oil wick and covered; then, when the atmosphere which it is desired to test is reached, the hydrogen is turned on and ignited, the oil flame is pricked out, the hydrogen flame adjusted to a regulation height of 10 mm. and the flame observed through the chimney against a black background. If an inflammable gas be present it will produce a pale blue cap about the hydrogen flame, and the height of this cap will increase with the per cent. of the gas in the atmophere. By means of a scale on the chimney the height is measured and the per cent. determined.

In his experiments Clowes obtained the following:

LIMITING EXPLOSIVE MIXTURES OF VARIOUS GASES WITH AIR.

Combustible gas used.	Percentage of Gas in Air. Lower Explosive Limit.	Higher Explosive Limit.	Method of Kindling
Methane	5	13	Upward.
	6	11	Downward.
Coal gas Nottingham	6	29	Upward.
	9	22	Downward.
Water gas	9	55	Upward.
Hydrogen	5	72	"
Carbon monoxide	13	75	"
Ethylene	4	22	"
Acetylene	3	82	Downward.

The lower 'limit' of inflammable gas represents the minimum proportion which, when mixed with air under ordinary conditions, will burn rapidly, and will, under certain conditions, produce explosions. If the proportion of inflammable gas mixed with the air is less than this in amount the mixture will only burn in the immediate neighborhood of the kindling flame, and will not burn throughout. If, on the other hand, the proportion of inflammable gas in the air exceeds the maximum 'limit' the gas will only be kindled and burn where it is in contact with an additional supply of air.

All proportions of gas intermediate between these limits are explosive when mixed with air, consequently the chance of an explosion resulting from the presence of one of these gases in the air is the greater, the more widely the 'limits' are apart, since this gives rise to the possibility of a larger number of explosive mixtures being produced. Therefore, the danger of explosion is least with methane and greatest with acetylene. Methane is a safer gas also because it has a high temperature and a slow rate of ignition. All of these condititions tend to lessen the number of colliery explosions. It is to be noted that mixtures that cannot be ignited when the flame is applied to their upper surface may be fired from below, and this is the method of firing most probable to occur in coal mines.

Few of the gases mentioned occur singly under conditions likely to give rise to danger. More commonly the combustible gases are present in a state of mixture, as in water gas and in coal gas.

In giving 'limits' it is assumed that the temperature of the mixture is not above 18°C. and that the pressure does not exceed 76 cm., for a gaseous mixture which is not inflammable under these conditions may become inflammable under increased temperature or pressure, and also that a mixture that by ordinary test appears uninflammable will propagate flame if a considerable volume of gas be projected into it, owing to the resulting increase in temperature and pressure.

It will be observed that Clowes' detector reveals the presence of gas in proportions much below the danger point and gives timely warning.

The ignition of the fire damp has been frequently caused by the gunpowder and 'straw' used in blasting, for the outbursts of gas from the shaken coal and the outrush of flame and incandescent particles from the blast were often coincident. The use of electric primers and detonators remedied entirely the evils following the use of straws and naked fuse, and the employment of the high explosives gave greater immunity by reducing the frequency of the blasts. Greater security still has followed the use of the flameless explosives made from nitro-substitution compounds, or dynamites in which crystalline salts, like sodium carbonate and alum, containing a larger amount of water of crystallization, are incorporated in the mass, or water cartridges, in which the explosive in the bore holes is placed in a water bag or surrounded by moss, or other porous substances, saturated with water.

The occurrence of these mining accidents has caused the authorities grave concern, and several of the European governments, notably Prussia, France and England, have appointed many commissions, some temporary and others continuous, to investigate the reasons for the accidents and the methods of prevention. Many of the most prominent chemists of these countries have been called to serve upon the commissions, and their reports have proved not only useful in the solution of the problem in hand, but have been valuable contributions to chemical science. One of the more recent consequences of their deliberations is the establishment at Woolwich, England, of a station for testing all explosives offered for use in coal mines, and hereafter no explosives but those which successfully pass these tests can be used, and then only in the manner minutely described in governmental authorization.*

The closer study of the phenomena of explosions in gases, consequent on these investigations, has developed many interesting facts. Bunsen found that when mixtures of hydrogen and oxygen and of carbon monoxide and oxygen in equivalent proportions were inflamed the union went on by fits and starts, and that the velocity of propagation of the reaction, through narrow orifices, was 34 meters per second in the hydrogen-oxygen mixture, and but one meter per second in the carbon monoxide-oxygen mixture.† Mallard tested various mixtures of methane and air, and coal gas and air, in the same way finding the velocity of combustion to diminish rapidly as the proportion of inert gases present increased, and obtaining a maximum speed in the case of eight volumes of air to one volume of marsh gas of 0.56 meters per second.‡

Berthelot, using tubes of 40 meters in length and 5 millimeters in diameter, obtained velocities of 2,810 meters per second for hydrogen-oxygen, 1,089 for carbon monoxide-oxygen and 2,287 for methane-oxygen, § and found that the reaction could be propagated in three different ways: First, by combustion, as observed by Bunsen, in which the heat evolved is being continually lost through radiation and conduction, and in which, consequently, the pressure is exerted by the layer of burning molecules on their adjacent molecules, and hence their velocity of translation tends constantly toward a minimum. Second, by detonation in which the heat evolved, the pressure produced by the reacting molecules on contiguous molecules, and the velocity of translation of the explosive reaction all tend toward the maximum. And, finally, an intermediate stage; all three being marked by distinct waves. Von Octtinger and von Gernet* have, by a very ingenious arrangement, succeeded in photographing, first, a fundamental one, which they style Berthelot's wave; second, more or less, parallel secondary waves, whose existence they explain on Bunsen's hypothesis of the reflex action of waves due to successive explosions produced by the electric spark, and which they style Bunsen's waves; and third, polygonal waves of smaller amplitude. They obtained a velocity of 2,800 meters per second, which is of the same magnitude as those obtained by Berthelot.

Berthelot and Vieille's experiments show that when an explosion occurs in a gaseous mixture a number of ignited molecules are projected forward with a velocity corresponding with the maximum temperature produced by the chemical combination. The impact of these molecules causes the ignition of the adjacent particles, and the rate of progression of the combustion is thus dependent upon the activity of the chemical action.

Mallard and Le Châtelier find that the rate of propagation of flame through an inflammable gaseous mixture is affected not only by the temperature and size of the igniting flame, but also by the mechanical agitation or disturbance of the mixture itself. These results are not surprising when it is considered that for the spread of combustion in an inflammable gaseous mixture it is necessary that the temperature of the combustion should be sufficient to ignite the uninflamed portion.

* Rept. Com. to inquire into the History of Explosives for Use in Coal Mines, London, 1897.

† Ann. Chim. Phys. (4) **14**, *449*.

‡ Ann de Mines **8**, *1871*.

§ Sur la force de la poudre, 1, **153**.

* Ann. der Phys.

Dr. W. H. Birchmore* has devised an apparatus for firing gaseous mixtures which shows many of those phenomena. He uses two large bulbs connected by a tube of determined dimension for his explosion chamber and a large tin foil condenser for igniting the mixture, and he finds the phenomena to be different from those observed in tubes ignited in the ordinary way. The reaction takes place more promptly and sharply, and when using hydrogen and air in variable amount not only is some of the oxygen ozonized, but hydrogen dioxide is produced with the water of the reaction.

When using acetylene, with sufficient air to consume it theoretically, some of the carbon is separated out in the solid form, although free oxygen was found in the residues, and it was not until he had reached eight times the volume of air required by the theory that he got the theoretical amount of carbon dioxide.

He also describes a form of experiment which very cleverly illustrates the successive phenomena occurring in the acetylene explosion at Paris.

The minimum volume of an inflammable gas which forms an explosive mixture with air is very considerably reduced if fine dust is present in the air. Buddle directed attention some 90 years ago, in an account of the Wallsend Colliery explosion, to the destructive effect produced by the ignited coal dust at a distance from the point of first explosion. Robert Bald, in 1828, pointed out† that the blast of flame from a fire-damp explosion might ignite the coal dust on the floor of the pit. Faraday and Lyell, in their report on the Haswell Colliery explosion of September, 1844,‡ demonstrated that coal dust may be instrumental in greatly extending and in increasing the disastrous effects of fire-damp explosions.

*Am. Gas Light J. **67**, 563-565 ; 1897.

†Ed. Phil. J. **5**, *101;* 1828.

‡Inst. C. E. Tracts, vol. 284.

Abel* has shown that the presence of finely divided incombustible mineral matter in air containing less than 2 per cent. of fire damp causes the latter to become explosive on ignition, and Galloway has proved that a mixture of air containing less than one per cent. of fire damp can be made to explode when charged with finely divided coal dust. I have applied this observation of the effect of the dust in facilitating explosions to lecture experiments with inflammable gaseous mixtures.†

The explosion at the Capitol on November 6th was confined to that portion of the building known as the Supreme Court section and which joins the Senate wing to the central structure. In the center of this section is a dome which is rarely noticed, as it is completely overshadowed by the central dome of the Capitol. This dome is supported in the sub-basement on piers, while all about these piers are brick vaults and arches of varying heights, carrying the many partition walls and floors above them, and these, with those radiating from under the big dome and the connecting passages, form a perfect labyrinth. The complexity is increased by several of the spaces having been enclosed with brick walls so as to carry steam-heating coils and for other purposes. A large part of the wall space had been fitted with shelving, and these were filled to overflowing with pamphlets. One space was used as an engine room, from which to operate a Sturtevant blower that fed air over the coils. This engine was provided with a woven guard screen to protect passers-by, made from 5/16-inch wrought-iron rods, riveted on each edge into two wrought-iron bars, each of which was 7/8 inches wide by 7/16 inches thick. Directly opposite this screen and leading south was a low, narrow passage that opened into one of the largest and highest of the vaults, in which was stowed, in the open spaces be-

*Accident in Mines, Proc. Inst. Civ. Eng., 1888.

†Proc. U. S. Nav. Inst. **12**, *429;* 1886.

hind two supporting walls or piers, the ash from the wood fires which were burned in the rooms above. These hickory ash pits, as they were styled, were south of and directly in line with the passage leading toward the iron screen. This series of compartments was on the extreme west of the sub-basement. A few of the exterior compartments of the sub-basement received a very little daylight, but all the rest was wholly dependent on artificial light and several gas jets were kept constantly lighted. In the center of the sub-basement, under the dome, was a large gas meter connected to a 4-inch main and having on its outlet end a 200-light glycerine gas governor. This meter had not been in use for some time, and the inlet valve was closed, but the outlet valve was open, and it was discovered afterwards that this outlet pipe was also connected with a live 4-inch main. The explosion occurred about 5:15 p. m., and its effects were observed over 47,000 cubic feet of the basement and upward quite to the dome. By the explosion the brick arches, covered with earth and then with heavy stone pavement slabs, were torn up, brick partitions and supporting walls were overthrown, stout locked doors on the upper floors were torn open, and there was a general wrecking of all the lighter structural parts. Observation of the lay of the wreckage showed conclusively that it radiated in all directions from a point about the gas meter, and that the most violent effects were in general at the points most distant from this center. The most violent effect of all was on the west, where the heavy granite screen wall forming the façade of the building was displaced by 1½ inches, and the stout wire protecting screen about the engine was forced into a depth of two feet from the original plane for an area of three feet in diameter, and many of the stout rods were ruptured. Searching examination showed that no explosive or other explosive-forming material than illuminating gas could have been present; that for thirty minutes prior to the explosion there was for some reason a gas pressure of twice the normal; that under an excessive pressure gas would flow through the governor, and that this could furnish sufficient gas to do the work accomplished

The gas had a specific gravity of 0.601, and as it escaped it flowed through the devious passages and compartments, filling first the pockets with mixtures of various proportions and settling lower and lower until the stratum reached down to the level of the burning gas jets where it was fired. These were near the meter, where, of course, the gas would be richest. Here was the region of combustion. As the tongue of flame rushed under the low archways and through the passageways to the higher vaults beyond, it produced a violent disturbance of the atmosphere, thoroughly commingling the gas and air and throwing a mass of inflamed gas into their midst, thus producing a greatly accelerated combustion and explosion. When this tongue of flame burst into the compartment containing the hickory ash this dust was also intimately commingled with the gas-laden atmosphere, and here was produced the most violent of all the effects manifested; for the granite screen wall that was displaced was on the right side of the hickory ash pits, and the stout wire screen that was perforated was directly in front of them and at the end of the low and narrow passage leading from the vault containing these pits; and further the most violent effects produced on the upper floors, quite to the top of the building, were about the spiral staircase leading from the compartment containing the wire screen and which was but a continuation, through the low, narrow passages of the compartment containing the hickory ash.

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