III. "Contributions to the History of Explosive Agents."—Second Memoir. By F. A. Abel, F.R.S., Treas. C.S. Received December 1, 1873.

(Abstract.)

The researches detailed in this memoir are in continuation of those described in the Memoir on Explosive Agents, published in 1869*, and relate chiefly to the investigation of the conditions to be fulfilled for accomplishing the detonation of explosive substances, and of the circumstances and results which attend the *transmission* of detonation.

The exceptional behaviour exhibited by certain explosive compounds with respect to their power of inducing the detonation of other substances by their explosion, which was demonstrated and discussed in the preceding memoir, has been confirmed by further experiments. The susceptibility of some substances to detonation, through the agency of certain compounds, and their remarkable inertness when subjected to the detonation of others, which at any rate do not rank lower as regards the mechanical force and heat developed by their explosion, led the author to suggest that a similarity in character, or synchronism, of the vibrations developed by the explosion of particular substances, might operate in favouring the detonation of one such substance by the initial detonation of a small quantity of another, while, in the absence of such synchronism, a much more powerful initiative detonation, or the application of much greater force, would be needed to effect the detonation of the material operated upon. This view, which has been favourably entertained by many, as affording a reasonable explanation of the apparently anomalous results referred to, appears to have received support from the results of experiments recently instituted by Champion and Pellet†, with iodide of nitrogen and some other explosive compounds, which indicated that the explosion of certain sensitive substances could be accomplished only by vibrations of a particular pitch, and by which they also demonstrated that particular explosions affected certain sensitive flames which were unaffected by others, unless the volume of the explosion was proportionately much increased.

Some few experiments were made by Champion and Pellet on the transmission of detonation to iodide of nitrogen through considerable spaces, by means of tubes, and some experiments of a purely practical character have also been instituted by Captain Trauzl, on the transmission of detonation to cartridges of dynamite, separated by spaces, in iron tubes, by the explosion of a charge of the material placed in one extremity of the tube. It appeared to the author that a systematic investigation of the transmission of detonation through the agency of tubes, with the employment of explosive agents less highly susceptible and more uniform

* Phil. Trans. 1869, vol. clix. p. 489.

† Comptes Rendus, vol. lxxv. pp. 210 & 712.

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and constant in composition than the iodide of nitrogen, might usefully contribute to our knowledge of the behaviour and relation to each other of explosive substances.

Experiments were first carried on with tubes of cast and wrought iron of different diameters and lengths. The explosive agents used were gun-cotton, in different mechanical conditions, dynamite, mercuric fulminate, and preparations containing the latter as an ingredient. Interesting results were obtained, among others, in the course of these experiments, demonstrating a want of reciprocity in behaviour between gun-cotton and mercuric fulminate, as regards the transmission of detonation from one to the other, similar to that previously observed in the case of nitro-glycerine, chloride of nitrogen and gun-cotton, and showing also how greatly the results, as regards transmission of detonation, may be altered when certain limits in respect to the quantity of material employed as the initiative detonator, are exceeded. Thus 7 grammes of strongly confined mercuric fulminate, inserted into one extremity of an iron tube only ·152 metre (6 inches) long and ·025 metre (1 inch) in diameter, was the minimum amount required to determine the detonation of gun-cotton placed in the other extremity of the tube, being at least fifty times the amount requisite to ensure detonation of compressed gun-cotton when exploded in close contact with the latter; but the detonation of 7 grammes of compressed gun-cotton in one extremity of a channel 2·128 metres (7 feet) long and ·031 metre (1·25 inch) in diameter, consisting of two iron tubes placed end to end, accomplished the detonation of fulminate inserted in the other extremity. When 14 grammes of confined fulminate were employed, detonation of gun-cotton was accomplished through a channel 2·129 metres (7 feet) long and ·031 metre (1·25 inch) in diameter, while 7 grammes only just sufficed to develop detonation through a tube of smaller diameter and only ·152 metre (6 inches) long, and 10 grammes, through a similar tube only ·228 metre (9 inches) long. The foregoing are quoted as illustrations of the instructive results obtained in these experiments.

A few experiments were made on a comparatively large scale with the above-named explosives, with the view of ascertaining the influence of *the material composing the tube*, upon the effect produced; and some striking results were also obtained by interposing very slight obstacles (*e. g.* loose tufts of cotton wool) in the path of the gas-wave, and thus checking the transmission of detonation, which was certain when the path was unobstructed. But these points were more closely investigated by a series of accurate experiments upon a small scale with silver fulminate, the tubes used being alike in diameter and thickness, but varying in length, and consisting of different materials, viz. glass, pewter, brass, paper, and vulcanized india-rubber. The principal results obtained by the larger operations with other explosives were confirmed by these small experiments, and several additional interesting observations were made.

A great difference appeared, at first, to be established in the power possessed by tubes of different materials of favouring the transmission of detonation, the glass tubes being far in advance of the others in this respect. It was eventually established, very clearly, by a series of experiments that this difference was not due, to any decisive extent, to the physical peculiarities (in regard to sonorosity, elasticity, &c.) of the materials composing the tubes, but chiefly to differences in the degree of roughness of their inner surfaces, and in the consequent variation of the resistance opposed by those surfaces to the gas-wave. Thus the power of a glass tube to favour the transmission of detonation was reduced, by about two thirds, by coating the inner surface with a film of French chalk, while the facility of transmission, through a brass tube, was nearly doubled by polishing its interior, and was increased threefold, with a paper tube, by coating the interior with glazed paper.

The following are some of the points established by these experiments on the transmission of detonation by tubes :—

1. The distance to which detonation may be transmitted through the agency of a tube to a distinct mass of explosive substance is regulated by the following conditions :

(*a*) by the nature and the quantity of the substance employed as the initiative detonator, and by the nature of the substance to be detonated, but not by the quantity of the latter, nor by *the mechanical condition* in which it is exposed by the action of the detonation ;

(*b*) by the relation which the *diameter* of the "detonator," and of the charge to be detonated, bear to that of the tube employed ;

(*c*) by the strength of the material composing the tube, and the consequent resistance which it offers to the lateral transmission of the force developed at the instant of detonation ;

(*d*) by the amount of force expended in overcoming the friction between the gas and the sides of the tubes, or other impediments introduced into the latter ;

(*e*) by the degree of completeness of the channel, and by the positions assigned to the detonator and the charge to be detonated.

2. The nature (apart from strength or power to resist opening up, or disintegration) of the material composing the tube through which detonation is transmitted, generally appears to exert no important influence upon the result obtained. At any rate the differences with respect to smoothness of the interior of the tubes far outweigh those which may prove traceable to differences in the nature of the materials composing them.

In the tube experiments with gun-cotton many instances occurred in which the mass operated upon was *exploded*, but with comparatively little if any destructive effect, portions of the gun-cotton being at the same time dispersed and occasionally inflamed. Similarly, the mercuric

fulminate was frequently exploded, through the agency of a transmitted detonation, in a manner quite distinct from the violent *detonation* at other times developed. Even the silver fulminate, which under all ordinary circumstances detonates violently even when only one particle of a mass is submitted to a sufficient disturbing influence, has on one or two occasions been exploded by the transmitted effect of a detonation of mercuric fulminate, without the usual destructive effect.

This remarkable difference in the behaviour of one and the same explosive substance, under nearly similar circumstances, has been made the subject of experimental investigation, in the course of which some interesting illustrations have been obtained of the manner in which variations in the resistance to mechanical motion influence the results obtained, by submitting some part of a mass of explosive material to sharp blows, by firing from a rifle (at different ranges) against masses of compressed gun-cotton of different weight and thickness, and either freely suspended in air or supported in various ways. An important exemplification of the difference between explosion and detonation was obtained in the course of subsequent experiments, instituted for the purpose of determining the velocity with which detonation is transmitted through tubes.

The influence of dilution, by solids and liquids, on the susceptibility of explosive compounds to detonation has been made the subject of systematic experiments, and some of the results obtained have already acquired considerable importance. The dilution of a liquid and of a solid explosive compound by inert solid substances produces very different results. Thus the liquid (nitroglycerine) may be very largely diluted (as in the case of *dynamite* and similar preparations) by inert solids, without any modification of its sensitiveness to detonation, because this dilution does not interrupt the continuity of the explosive substance. The initiative detonator, when surrounded by such a mixture, is therefore in contact at all points with some portion of the nitroglycerine, and the latter is in continuous connexion throughout; hence detonation is as readily established and transmitted through the mixture as though the liquid were undiluted. But when a *solid* explosive agent is similarly diluted, there must obviously be complete separation of its particles at a number of points proportionate to the extent of dilution and the state of division; the establishment of detonation, or its transmission, is therefore impeded either by a diminution of the extent of contact between the initiative detonator and the substance to be exploded, or by the barrier which the interposed non-explosive particles oppose to the transmission of the detonation, or by both causes.

Intimate mixtures of a finely divided sensitive explosive compound with an inert solid, if compressed into compact masses, become much more susceptible of detonation than if they be in the loose pulverulent condition; thus compressed mixtures of finely divided gun-cotton, with large proportions of inert solids, were found but little inferior in sensitiveness to the undiluted explosive agents. If the diluent consists of a

soluble salt (*e.g.* potassium chloride) the well-incorporated mixture being compressed with the aid of the solvent (*e.g.* water), and then dried, the material is obtained in a condition of great rigidity, the particles being cemented together by the crystallized salt; it is therefore in a form more favourable to the action of detonation than undiluted gun-cotton submitted to considerably greater compression.

When the solid substance with which gun-cotton is diluted consists of *an oxidizing agent* (a nitrate or chlorate), the predisposition to chemical reaction between the two substances so far increases the susceptibility to detonation that, operating in conjunction with the effect of the soluble salt in imparting rigidity to the mixture, it renders the latter quite as sensitive to the detonating action of the minimum fulminate-charge as undiluted gun-cotton is, when highly compressed. This fact has given additional importance to results which the author obtained some time since in availing himself of the facility with which finely divided gun-cotton, as obtained by the pulping process, may be intimately mixed with the proportion of an oxidizing agent (such as potassium nitrate) required to completely oxidize the carbon. If about three fourths of the theoretical requirements of the salts be employed, the resulting products will perform fully the amount of work obtained from a corresponding weight of undiluted gun-cotton; and as nearly one third of this substance has been replaced in them by material of very much less cost, a considerable advantage is gained in point of economy. Moreover the greater rigidity of the compressed masses of "nitrated" gun-cotton, already explained, renders them less susceptible to injury by transport and rough usage than ordinary compressed gun-cotton.

These compressed mixtures being found quite as sensitive to detonation by fulminate as the pure explosive compound, it became interesting to compare their behaviour with that of the latter, when exposed to the detonation of nitroglycerine. The results demonstrated that they are much more readily susceptible of detonation by it than compressed gun-cotton; thus, in only one instance was the latter detonated by the explosion of 62·4 grammes (two ounces) of nitroglycerine in close contact with it, but that quantity invariably detonated "nitrated" gun-cotton. The same result was obtained with only 31·2 grammes (one ounce) of nitroglycerine in three out of four experiments; in the fourth the nitrated preparation was *exploded*, but without the destructive effect produced in the other experiments; similar explosions of the substance were developed by means of 15·6 grammes (0·5 ounce) of nitroglycerine. In the case of pure gun-cotton, the results obtained were always either simple disintegration of the mass, or else detonation, if sufficient nitroglycerine were used.

To ascertain whether the different behaviour of the "nitrate" (and "chlorate") preparations was due to their greater hardness and rigidity, some corresponding experiments were made with compressed masses pro-

duced in a precisely similar manner, but containing an inert salt, potassium chloride, in place of the oxidizing agent. These were more susceptible of explosion by nitroglycerine than pure gun-cotton, but decidedly less so than the "nitrate" preparations. It appears, therefore, that the explosion of gun-cotton by the detonation of nitroglycerine is, to some extent, facilitated by the greater resistance it opposes to disintegration when incorporated with a salt, as described; but that the higher susceptibility to detonation by nitroglycerine of the "nitrate" (and "chlorate") preparations is probably chiefly due to some predisposing influence exerted by the oxidizing agent.

If gun-cotton is diluted by impregnation with a *liquid*, or with a body solid, at ordinary temperatures, which is introduced as a liquid into the mass, its sensitiveness to detonation is reduced to a far greater extent than by a corresponding weight of a solid, incorporated *as such*, with the gun-cotton. The cause of this is evidently the converse of that which operates in preventing the reduction of sensitiveness of nitroglycerine by its considerable dilution with an inert *solid*; the liquid *diluent* which envelopes each particle of the solid explosive material isolates it from its neighbours, and thus opposes resistance to the transmission of detonation, while with nitroglycerine the liquid *explosive agent* envelopes the solid diluent, and thus remains continuous throughout the mass.

The absorption of three per cent. of water by gun-cotton (in addition to the two per cent. which it normally contains) rendered its detonation doubtful by the "detonator" ordinarily used. Dry disks which had been impregnated with oil or tallow, could not be exploded by means of one gramme of mercuric fulminate, applied in a metal case in the usual way. By considerably increasing the initiative charge of fulminate, damp gun-cotton could, however, be detonated; and it occurred to Mr. Abel's assistant, Mr. E. O. Brown, to apply the detonation of dry gun-cotton itself to the development of the explosive force of the compressed material, when in a moist state.

A series of precise experiments showed that when compressed gun-cotton contained as much as 17 per cent. of water, it could be detonated, though not with absolute certainty, by 6·5 grammes (100 grains) of compact air-dry gun-cotton exploded by means of the usual "detonator," in close contact with it. When the proportion was increased to 20 per cent. detonation was not accomplished with certainty by employing less than 31·2 grammes (1 ounce) of the air-dry material; and when the maximum amount of water (30 to 35 per cent.) was absorbed, detonation conld not be absolutely relied upon with the employment of less than 124·8 grammes (4 ounces) of air-dry gun-cotton applied *in close contact.*

Moist and wet compressed gun-cotton are decidedly more readily susceptible of detonation by means of air-dry gun-cotton, freely exposed and exploded by the usual "detonator" of mercuric fulminate, than by means of the confined fulminate applied alone; thus, when the material contained

17 per cent. of water, its detonation by fulminate direct was not certain with the employment of less than about 13 grammes (200 grains), whereas the result was absolutely certain with employment of about 10 grammes of air-dry gun-cotton.

The transmission of detonation from dry to wet gun-cotton, through the agency of a tube, appears to take place with the same facility as though the mass to be detonated were dry; and the same is the case with regard to the propagation of detonation from one mass of moist gun-cotton to others freely exposed to air, but touching each other, provided the one first detonated contained *not less* water than the others to which detonation is to be transmitted; but this is not the case, if even small spaces intervene between the separate masses, and in this respect the moist gun-cotton behaves very differently from the air-dry material.

The "nitrated" and "chlorated" preparations of gun-cotton are as readily detonated, in the moist state, as ordinary compressed gun-cotton. With respect to the mechanical effects obtained by the detonation of these materials in the moist or wet state, numerous small and large comparative experiments have demonstrated that there is no falling off in the work done by them when used wet.

Decided evidence has, moreover, been obtained of greater sharpness of action, when gun-cotton and its preparations are detonated in the wet state; and this accords with the observations made in the earlier of these researches, that the less susceptible a mass of given explosive material is of compression, when submitted to the action of a sufficient initiative detonation, the more readily will detonation be transmitted, and the more suddenly will the transformation from solid to gas and vapour take place. When air is replaced by water in the compressed masses, the transmission of detonation is obviously favoured by the increased resistance of the particles to motion, at the instant of their exposure to the detonative force.

The freezing of wet compressed gun-cotton renders it as readily susceptible of detonation as the mixtures of gun-cotton with soluble (crystallized) salts, to which the wet material obviously becomes quite similar in structure by the solidification of the water.

Mercuric fulminate and mixtures of it with potassium chlorate, when mixed with water to such an extent as to convert them into pasty masses and freely exposed, are readily detonated by small quantities (0·2 grm. or 3 grains) of the confined fulminate, even when not in contact. Finely divided gun-cotton, made up into a pulp with water, was found not to be susceptible of detonation, even under very much more favourable conditions than the above, the mixture being placed in thin metal cylinders, open at one end, and a large disk of dry gun-cotton detonated in the centre. But if wet *compressed* gun-cotton is packed into receptacles of wrought iron, so that the initiative charge of dry gun-cotton is closely surrounded by it, and the small spaces intervening between the several

masses are filled up with water, the charge being then submerged, it is exploded with certainty and with results equal to those furnished under similar conditions by the dry material. Provided the escape of force, by transmission through the water, be retarded at the instant of the first detonation, either by the resistance which the material of the case offers, or by the pressure of a considerable column of water, the detonation of wet gun-cotton immersed in water, and separated by thin layers of the fluid from the contiguous masses, is accomplished with certainty. Results fully equal to those furnished by charges enclosed in strong wrought-iron cases, have been obtained by the employment of sheet-tin cases or of bags, or even of simple fishing-nets, these only serving to hold the masses composing the charge tightly together. If, however, the latter condition is not attended to, or the depth of the immersion of the charge is insufficient, its detonation will not take place, even if a comparatively large initiative detonator be employed.

The suddenness and completeness with which detonation was transmitted through small water-spaces in the experiments with wrought-iron cases, led the author to attempt the application of water as a vehicle for the efficient employment of only small denotating charges for bursting or breaking up cast-iron shells into numerous and comparatively uniform fragments (and thus to employ a hollow projectile of the most simple construction to fulfil the functions of the comparatively complicated "shrapnel"- or "segment"-shell). The results afforded remarkable illustrations of the transmission of force by water, and may prove of considerable practical importance. The destructive effects produced by small detonating charges, when exploded in shells which were filled up with water and entirely closed, were proportionate, not simply to the amount of explosive agent used, but also to the suddenness of the concussion imparted to the water by the explosion. Thus 7 grammes (0·25 ounce) of compressed gun-cotton, detonated in a shell filled with water, broke it up into nearly eight times the number of fragments obtained by exploding a shell of the same kind full of gunpowder (viz. containing 367·9 grammes = 13 ounces). When picric powder, which is also a very violent explosive agent, though much less sudden in its action, was detonated in one of these shells, in the same way as the small charge of gun-cotton, 28·3 grammes (= 1 ounce), or an amount four times greater than that employed of the latter substance, burst the shell into about the same number of fragments as were produced by the 13 ounces of gunpowder (instead of about 8 times the number, produced by means of 0·25 ounce of gun-cotton). Other observations of interest were made in the course of these shell-experiments; they led, moreover, to some cognate experiments which furnished interesting results.

In developing detonation, in a perfectly closed and sufficiently strong vessel, completely filled with water besides the detonating charge, the resistance offered by the liquid at the instant of detonation may be re-

garded as similar to that which would be presented by a perfectly solid mass. Similarly, if the strong vessel be completely filled with a mixture of water and a solid (*e. g.* a fine powder or a fibre reduced to a fine state of division), such a mixture should also, at the instant of detonation, behave as a very compact solid with regard to the resistance which it opposes to the detonating charge which it surrounds. If this be so, a mixture of finely divided gun-gotton with water, if enclosed in a shell, should be in a condition readily susceptible of detonation, because at the instant of explosion of the initiative charge, the particles of gun-cotton must offer great resistance to mechanical motion. Experiment has fully established the correctness of this conclusion, having demonstrated that, while it is indispensable to employ gun-cotton in a highly compressed form, to ensure its detonation under all other conditions, it may, if enclosed in strong vessels, such as shells, be employed with equal efficiency in a finely divided state, provided the spaces between the particles be *completely* filled with water, the small detonating charge being immersed in the aqueous mixture.

The results obtained in the several experiments bearing on the transmission of detonation led the author to attempt to determine its velocity, or the rate at which it proceeds along a continuous mass, or from one mass of an explosive body to another, under various conditions. For this purpose he availed himself of the electric chronoscope devised by Captain A. Noble, F.R.S., which had furnished satisfactory results in determinations of the rate of motion of projectiles in the bore of a gun, made by the Government Committee on explosive substances. The experiments were carried out with compressed gun-cotton in the dry and wet state, with "nitrated" gun-cotton, with nitroglycerine and dynamite, and with small charges of gun-cotton inserted into tubes, with considerable intervening spaces*. The disks of gun-cotton, dry, wet, and nitrated, were arranged either in continuous rows or trains, the disks either touching each other, or a definite and uniform space or interval intervening between each. At the commencement of the row a fine insulated wire, forming part of the primary circuit (by the sudden severance of which the electric record of the rate of transmission was obtained on the chronoscope), was tightly stretched across the first disk. Other wires were similarly fixed at uniform distances (of one, two, four, or six feet) from each other. In determining the velocity of transmission of detonation through tubes, wrought iron gas-pipes of 0·032 metre (1·25 inch) diameter were used, with small perforations at the desired intervals, through which the insulated wires were passed; the disks of gun-cotton, to which detonation was to be transmitted, were inserted into the tubes so as to be in close contact with these tightly stretched

* In carrying on these experiments, Mr. Abel received valuable assistance at different times from Captain Singer, R.N., Major Maitland, R.A., and Captains W. H. Noble and Jones, R.A.

wires. The trains of dynamite were arranged like those of gun-cotton, compressed charges of this material, 3 inches (·0759 metre) long and 1 inch (·0253 metre) in diameter, being placed end to end or with definite spaces intervening between them. The nitroglycerine was placed in V-shaped troughs of thin sheet metal, through which the insulated wires were passed transversely at the requisite intervals, so as to be immersed in the liquid.

A number of experiments with dry gun-cotton compressed, demonstrated that the rate at which detonation is transmitted from mass to mass, when these are in actual contact with each other, is between 17,500 and 20,000 feet (5320 metres and 6080 metres) per second, and that the rate of transmission is affected by the compactness of the material, but not by a difference in the form and arrangement of the individual masses, nor by very considerable variations in their weight. By the experiments with *spaced* gun-cotton disks, it was demonstrated that the separation of the masses may retard the rate at which detonation is transmitted, the extent of such retardation being, of course, determined by the relation between the size of the individual masses and the extent of space intervening between them. With compressed gun-cotton, containing fifteen per cent. of water, detonation was transmitted at a slightly higher velocity than with the dry substance of the same compactness; but when gun-cotton *saturated* with water was employed, the increase in the rate of transmission was very marked, being equal to about 20,000 feet per second, with disks which, when dry, detonated at a rate of about 17,500 feet per second. With "nitrated" gun-cotton the rate of transmission was, as might have been anticipated, decidedly slower than with the pure dry material; it ranged between 15,500 and 16,000 feet (4712 metres and 4864 metres) per second.

The results obtained with dynamite and nitroglycerine presented some very interesting points of difference from those furnished by compressed gun-cotton, which are ascribable to the liquid nature of the explosive material. The dynamite used was in the form of compressed rolls or cylinders, similar in firmness or solidity to stiff but not very plastic clay. Rows or trains of these charges, pressed together end to end, so as to form perfectly continuous masses 28 feet (8·533 metres) and 42 feet (12·8 metres) in length, were detonated by means of a fulminate detonator of the kind used with gun-cotton, which was inserted into a small cylinder of gun-cotton, or into a small cartridge of dynamite, and placed upon one extremity of the train. The rate at which detonation was transmitted ranged between 19,500 and 21,600 feet (5928 and 6566 metres) per second; it was therefore decidedly higher than with compressed gun-cotton. The separation of the individual cartridges or cylinders by spaces of 0·5 inch (·013 metre) produced, however, a very much greater retarding effect than was the case with a separation to the same extent of masses of compressed gun-cotton; the

mean rate at which velocity was transmitted along the spaced masses of dynamite (in an experiment remarkable for the great uniformity of the records at different parts of the train) was only = 6239 feet (1896 metres) per second; the mean rate of transmission along masses of gun-cotton of the same weight and length as the dynamite cartridges, and separated by 0·5 inch spaces, was (in two experiments) nearly = 17,000 feet (5179·9 metres) per second. When *nitroglycerine* was employed in the pure and, therefore, liquid state, detonation being established at one extremity of the trains by means of a cartridge of dynamite, the mean rate at which it was transmitted was only about 5500 feet (1672 metres) per second, the same result being obtained in two experiments, in one of which the quantity of nitroglycerine, in a given length of the train, was double that employed in the other*. It may be possible that, by very greatly increasing the quantity of nitroglycerine used, the rate of transmission of detonation would be increased; but there is no doubt that the mobility and elasticity of the liquid, and the consequent facility with which it yields to mechanical force when unconfined, act antagonistically to the transmission of detonation in a mass of *freely exposed* nitroglycerine. The author hopes that he may have the means and opportunity of extending these interesting experiments, by ascertaining the effect of confinement, both of nitroglycerine and gun-cotton, on the transmission of detonation along continuous masses of the explosive agent.

The numerical details given in the memoir afford proof of the trustworthiness of the results obtained in the velocity determinations, and of the uniform rate at which detonation is transmitted along rows of considerable length, composed of distinct masses of the explosive material, even when these are separated from each other by spaces. With trains 12·16 metres to 15·20 metres (40 to 50 feet) in length, the rate at which detonation travelled along the last few feet was equal to that observed in the first portion of the train. This was not the case with the transmission of detonation through *tubes* to *widely separated* masses of gun-cotton. The time intervening between the detonation of the initiative charge at one extremity of the tube and that of the first distinct charge (separated by a space of 3 feet 3 inches, or 1 metre) was somewhat variable, and ranged between 10,000 and 13,000 feet (3000 to 3900 metres) per second; the subsequent transmission, from charge to charge, along the tubes proceeded at a tolerably uniform but considerably reduced rate, the average being 1800 metres (6000 feet) per second. In one experiment, with reduced charges, the detonation was transmitted, as usual, to the first three separate masses; but the fourth and succeeding charges, though they *exploded*, did not detonate; the tube containing them was uninjured at those parts, but the wires were severed at the seat of each charge, and the records ob-

* The amount of nitroglycerine employed in a given length of the train corresponded to that used in certain of the gun-cotton experiments, in which the rate of transmission of detonation ranged between 18,000 and 21,000 feet.

tained indicated that the *explosion* was transmitted from charge to charge at the rate of between 450 and 640 metres (1500 and 1800 feet) per second. These experiments with tubes showed that, when the relations between the amount of explosive material, the diameter of the tube, and the space intervening between the charges are such as to ensure the transmission of detonation, its rate is about one third of that at which it travels along a continuous mass, or continuous row of distinct masses, of the same material.

The concluding part of this memoir deals with a subject only incidentally referred to in the former memoir on explosive agents, and which has since that time acquired considerable importance—namely, the manner in which the accumulation of heat in a mass of explosive material, and other conditions, may operate in bringing about or promoting violent explosion or detonation.

February 12, 1874.

JOSEPH DALTON HOOKER, C.B., President, in the Chair.

The Presents received were laid on the table, and thanks ordered for them.

The following communications were read:—

I. "Note on the Synthesis of Formic Aldehyde." By Sir B. C. Brodie, Bart., F.R.S. Received February 5, 1874.

In a former note I communicated to the Society the result of an experiment in which a mixture of equal (or nearly equal) volumes of hydrogen and carbonic oxide had been submitted, in the induction-tube, to the electric action. My expectation in making the experiment had been that the synthesis of formic aldehyde would be thus effected according to the equation $CO+H_2=COH_2$. The only permanent gas, however, other than the gases originally present in the induction-tube, which appeared in the result of the experiment was marsh-gas. When a mixture of hydrogen and carbonic acid gas was similarly operated upon, the same hydrocarbon, together with carbonic oxide, was formed. I have now, however, succeeded, by a modification in the conditions of the latter experiment, in attaining the object which I originally had in view. Evidence of this is afforded by the following analysis:—The gas analyzed was the result of submitting to the electric action about equal volumes of hydrogen and carbonic acid. After removal from the gas of carbonic acid and carbonic oxide, and also of a trace of oxygen, 191·2 volumes of gas remained, in which were found, at the conclusion of the analysis, 2·6 volumes of nitrogen. Deducting this amount of nitrogen, 188·6 volumes of gas remain, containing the residual hydrogen in the gas, together with