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## Royal United Services Institution. Journal

Publication details, including instructions for authors and subscription information:  
<http://www.tandfonline.com/loi/rusi19>

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Published online: 11 Sep 2009.

To cite this article: F. A. Abel Esq., F.R.S. (1864) Some New Points in the History and Application of Gun-Cotton, Royal United Services Institution. Journal, 8:33, 345-366, DOI: [10.1080/03071846409417782](https://doi.org/10.1080/03071846409417782)

To link to this article: <http://dx.doi.org/10.1080/03071846409417782>

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# The Journal

## Royal United Service Institution.

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VOL. VIII.

1864.

No. XXXIII.

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### LECTURE.

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Friday, May 27th, 1864.

HIS GRACE THE DUKE OF SOMERSET, K.G., First Lord of the Admiralty, in the Chair.

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### SOME NEW POINTS IN THE HISTORY AND APPLICATION OF GUN-COTTON.

By F. A. ABEL, Esq., F.R.S., Chemist to the War Department, Royal Arsenal, Woolwich.

MR. ABEL: About thirty years ago two substances were discovered in France, possessing new and curious properties. These substances, though they have never received any important application, are interesting, inasmuch as they are the precursors of gun-cotton, and furnished the germ of the discovery of that material.

In 1832 a French chemist, Braconnet, made the discovery that, by dissolving common starch in nitric acid (or *aquâ fortis*), keeping the mixture cold, and then adding water, he again separated what appeared to be the starch from the solution. But this substance was found to have undergone a curious change. Instead of burning, as it ordinarily does, slowly, with a steady flame, and leaving a carbonaceous residue, it had become to a considerable extent explosive; that is to say, it burned rapidly upon the application of flame, and much more brilliantly than when in its original condition, leaving little, if any, residue. A few years afterwards, another French chemist, Pelouze, now Master of the Mint in France, found that if he immersed common unsized paper, or ordinary cotton- or linen-fabrics, in nitric acid, also keeping the latter perfectly cool, this treatment imparted to those substances highly inflammable and almost explosive properties,

though in their appearance they were little, if at all, changed. A piece of paper operated upon in this way burns with almost explosive violence; a piece of calico burns as though it were saturated with some one of our most powerful oxidising materials, such as chlorate of potash.

The substance obtained from starch was called *Xyloidin*, that furnished by linen or cotton was named *Pyroxilin*. The latter, prepared as just described, was obtained in an impure form; and it was not until 1846 that this substance was found by Schönbein to be produced in a much purer state by pouring cold nitric acid, or a cold mixture of nitric and sulphuric acids, upon ordinary carded cotton wool. The cotton wool appeared to undergo no change whatever; it still retained its ordinary form and appearance, feeling perhaps a little more crisp and harsh after the treatment. But it was converted into a powerful explosive substance, which Schönbein first described under the name of *gun-cotton*; a substance burning without smoke and without leaving any appreciable residue, and endowed with much higher explosive power than ordinary gunpowder.

Such a discovery as this naturally excited very considerable interest, particularly among military authorities; and experiments were at once set afloat, not only in Germany, but in France and in this country; experiments of very considerable interest and, some of them, carried out upon an extensive scale, for the purpose of determining the properties of this new explosive material.

In France, a factory was established; a considerable quantity of the material was prepared, and several of the most eminent military authorities, Piobert, Morin and others, carried on a series of most interesting experiments, the object of which was a strict comparison of gun-cotton with gunpowder. Unfortunately, these investigations, which were yielding very important practical results, and which promised before long to show clearly and definitely what was the value of this new material, were soon put a stop to by most lamentable accidents, which occurred, on two or three occasions, at or near the manufactory where this substance was being produced. Magazines containing gun-cotton, near which, it was stated, persons had not been for several days or weeks, exploded with very disastrous results; in short, the material was soon believed to be so utterly dangerous that no possible confidence could be placed in it.

In England, experiments, in the first instance of a scientific character, and afterwards of a practical nature, were instituted by chemists, gunpowder-manufacturers, artillery and other officers. Messrs. Hall, at Faversham, prepared the substance in considerable quantities; but not very long after their factory was established, a very lamentable explosion occurred there also. Large quantities of the material were ignited, it was believed (and is still, by the Messrs. Hall themselves), by the spontaneous combustion of the material, in consequence of some chemical change which it had undergone, and several lives were sacrificed by this calamity. This, of course, put a stop to the preparation of gun-cotton in this country, and since that period it has only occasionally received the attention of English

chemists, who have endeavoured to examine the substance more thoroughly. One of them especially, Mr. Hadow, has thrown more light on the nature of the substance than had previously been obtained by experiments in other countries.

In Germany, after a very short series of experiments, instituted immediately upon Schönbein's discovery, the material was pronounced to be altogether inapplicable to military purposes, by a committee appointed by the German Confederation. But, upon this committee there was an Austrian officer, Baron von Lenk, who considered the substance to possess certain valuable properties which rendered it worthy of further investigation. He continued to devote his attention to the subject, as is well known to many whom I am addressing, with varied success. At one time the material, which was again investigated by a committee appointed by the Austrian Government in 1852, was introduced to some considerable extent into the Austrian service; and experiments were carried out on its application to artillery, mining, and other purposes. Then some accidents occurred, or some discoveries unfavourable to its use were made, and it was discarded for a time. This varied success has continued almost up to the present time. A manufacturing establishment near Vienna was arranged, in 1852, for the preparation of the material on a large scale, and it is still produced there, I believe, abundantly, according to the improved system of manufacture, which is the result of Baron von Lenk's persevering labours. It is said that the material is used at the present time to some extent in the Austrian service, and that, after recent careful investigation, it is again likely to be adopted as a substitute for gunpowder for many military and industrial purposes.

About two years ago, the Austrian Government communicated confidentially to the Government of this country the general nature and preparation of gun-cotton, whereupon I was entrusted with the investigation of the manufacture of the material, and with the institution of such experiments as might suggest themselves to me, for the purpose of determining, in the first instance, whether it was really a safe material to operate with. In the course of the autumn in the same year, General Sabine, the president of the Royal Society, brought before the notice of the British Association the progress which appeared to have been made in the manufacture and application of gun-cotton by the Austrians; and a committee was appointed, consisting of chemists and engineers, for the purpose of investigating the subject. This committee placed itself in communication with the Government of this country, and also with General von Lenk, whom they invited over to meet them, and who was authorised by the Austrian Government to communicate to them full details with regard to the manufacture and the general effects and properties of the material. A preliminary report was presented by the British Association Committee at the general meeting last year, and the Council afterwards submitted to the Secretary of State for War a recommendation that a Royal Commission should be appointed to investigate the subject in all its bearings. Eventually, a special committee was appointed by the Government, consisting—partly of

scientific men, members of the British Association and Fellows of the Royal Society, and partly of military and naval men of eminence, to whom has been entrusted the examination into the manufactory of gun-cotton, into the permanence and general properties of the material, and into the possibility of applying it in the various directions in which gunpowder is used for military, naval, and industrial purposes.

This, then, is an outline of the history of the material up to the present period. Although the investigation of the subject in this country has only just been commenced, certain important and new results have already been arrived at, which throw considerable light upon the nature of the material, and also upon the uses to which it may be applied.

I shall now have the pleasure of giving you as connected an account as I can of the properties of gun-cotton, as far as we are at present acquainted with them. If you will allow me, I will first, without going into the chemistry of the matter, yet without altogether avoiding it, endeavour to make clear what gun-cotton really is. When we act upon such a substance as cotton-wool with nitric acid, which contains stored in it a large quantity of oxygen combined with the elements nitrogen and hydrogen, we bring the chemical activity of the nitric acid to bear upon certain constituent-particles of the cotton-wool. If I represent by this painted block an atom of cotton wool, and by this block a certain quantity of nitric acid, I shall be able in a simple manner to render apparent the change which the former undergoes. We have here cotton wool, composed of carbon, hydrogen, and oxygen; and here we have nitric acid, which, I say, contains a large quantity of oxygen, together with nitrogen and hydrogen. Now, when these substances are mixed together, the mixture being kept at a moderately low temperature, a certain portion of the cotton-wool is assailed by the nitric acid. The hydrogen, which is more easily oxidisable than the carbon in the cotton, is attacked by the nitric acid; a portion of it is removed from the little group of elementary atoms which form the cotton wool; and, as it is removed, a portion of the elements of the nitric acid (forming the group known as peroxide of nitrogen) enters into its place; the hydrogen that is thrown out or abstracted from the cotton is converted into water. We can go on in this way acting successively upon different atoms of the hydrogen contained in the cotton-wool; abstracting a second atom, for example, converting it into water, and introducing into its place a second molecule of the peroxide of nitrogen. By the substitution of the latter for hydrogen in the cotton, in this manner, we convert that substance into an explosive body; because we introduce a much larger proportion of oxygen into the cotton-wool than it originally contained; and this oxygen is ready at any moment, if aided by an elevation of temperature, or by other accelerating causes, to act upon the carbon and hydrogen, and convert them into gases and vapour, with almost instantaneous rapidity. In this way ordinary cotton may be converted into explosive substances, which vary in their composition and characters according to the number of atoms of hydrogen which have been acted upon. Thus, the substance obtained by the removal

of the lowest proportion of hydrogen is the least explosive, and has the same composition as the material which I described as being obtained from starch; while, by exposing the cotton to the action of a larger proportion of nitric acid, we obtain the most explosive product, the substance commonly known as gun-cotton, which has some puzzling names given to it by chemists. It is called trinitrocellulose; it is also called pyroxilin. Trinitrocellulose is the chemical term which accurately describes its composition, but "gun-cotton" will answer our purpose. We see, therefore, that this substance is produced by abstracting a certain proportion of hydrogen from the cotton-wool, and introducing peroxide of nitrogen in its place.

Intermediate between the most and least explosive bodies obtained from cotton, two other substances of analogous nature may be produced by employing different proportions of nitric acid. These substances are less explosive than gun-cotton, but more so than the starch compound, or the corresponding product from cotton. They dissolve in a mixture of ether and spirit, and produce that well-known substance collodion, which is of great importance to photographers, electricians, and medical men. I need hardly remind you that this collodion has been one of the most important agents in the development of photography. Here we have portions of cotton-wool which have been treated with different proportions of nitric acid. I am not able to distinguish between them, as they are identical in appearance, but the manner in which these substances burn will directly indicate which has been acted upon by the largest proportion of nitric acid. One is evidently the true gun-cotton; the other is the less explosive substance which furnishes collodion. We can, moreover, easily distinguish between the two by adding to each a small quantity of the mixed solvents used for preparing collodion. The gun-cotton becomes somewhat condensed by being soaked in that liquid, but the least explosive product is almost immediately dissolved.

According to Schönbein's original prescription, the cotton was to be saturated with a mixture of one part of nitric acid (of specific gravity 1.5) and three parts of sulphuric acid, (specific gravity 1.85) and allowed to stand for one hour. In operating upon a small scale, the treatment of cotton with the acid for that period is quite sufficient to effect its complete conversion into the most explosive product, pyroxilin, or trinitrocellulose. There is a small specimen of gun-cotton which I prepared strictly according to Schönbein's directions, soon after they were published in 1846. It is unquestionably pure gun-cotton or trinitrocellulose, and has undergone not the slightest change. But when the quantity of cotton treated at one time is considerable, especially if it be not very loose and open, its complete conversion into pyroxilin is not effected with certainty, unless it be allowed to remain in the acids for several hours. This accounts in great measure for the want of uniformity observed in the composition of gun-cotton, and its effects as an explosive, in the earlier experiments instituted; and it is, moreover, very possible that the want of stability, and consequently even some of the accidents which it was considered could only be ascribed to the spontaneous ignition of the material, might have been

due to the comparatively unstable character of the lower products of substitution, some of which existed in the imperfectly prepared gun-cotton.

The system of manufacture of gun-cotton elaborated by General von Lenk is founded upon that described by Schönbein; the improvements which the former has adopted all contribute importantly to the production of a thoroughly uniform and pure gun-cotton; there is only one step in his process which is certainly not essential, and about the possible utility of which chemical authorities are decidedly at variance with General von Lenk.

The following is an outline of the process of manufacture of gun-cotton as practised by Lenk. The cotton, in the form of loose yarn of different sizes, made up into hanks, is purified from certain foreign vegetable substances, by treatment for a brief period with a weak solution of potashes, and subsequent washing. It is then suspended in a well-ventilated hot-air chamber until all moisture has been expelled, when it is transferred to air-tight boxes or jars, and at once removed to the dipping tank, or vessel where its saturation with the mixed sulphuric and nitric acids is effected. The acids, of the specific gravity prescribed by Schönbein, are very intimately mixed in a suitable apparatus, in the proportions originally indicated by that chemist, *i.e.*; three parts by weight of sulphuric acid to one of nitric acid. I should explain that sulphuric acid is not used for the purpose of exerting any chemical action upon the cotton, but merely for promoting the action of the nitric acid. Strong sulphuric acid or oil of vitriol has a remarkable tendency to combine with water, and this property is usefully applied in the manufacture of gun-cotton, for the purpose of abstracting water, which the nitric acid contains, and thus rendering the latter more concentrated, and also for preventing the water, which, as you know, is produced in the chemical change, from interfering with the action of the nitric acid upon the cotton.

The mixture of acids is always prepared some time before it is required, in order that it may become perfectly cool. The thoroughly dry cotton is immersed in a bath of the mixed acids, one skein at a time, and stirred about for a few minutes until it has become thoroughly saturated with the acids; it is then transferred to a shelf in this dipping trough, where it is allowed to drain, and slightly pressed, to remove any large excess of acid; and is afterwards placed in an earthenware jar, provided with a tightly fitting lid, which receives six or eight skeins, weighing from two to four ounces each. The cotton is tightly pressed down in the jar, and if there be not sufficient acid present just to cover the mass, a little more is added; the proportion of acid to be left in contact with the cotton being about  $10\frac{1}{2}$  pounds to one pound of the latter. The charged jars are set aside for 48 hours in a cool place, where, moreover, they are kept surrounded by water to prevent the occurrence of any elevation of temperature, and consequent destructive action of the acids upon the gun-cotton. The same precaution is also taken with the dipping-trough, as considerable heat is generated during the first saturation of the cotton with the acids. At the expiration of 48 hours, the gun-cotton is transferred from the



jars to a centrifugal machine, by the aid of which the excess of acid is removed as perfectly as is possible by mechanical means, the gun-cotton being afterwards only slightly moist to the touch. The skeins are then immersed singly in water, and moved about briskly, so as to become completely saturated with it as quickly as possible. This result is best accomplished by plunging the skeins under a fall of water, so that they become at once thoroughly drenched. If they were simply thrown into water and allowed to remain at rest, the heat produced by the union of a portion of the free acids with a little water would be so great as to establish at once a destructive action upon the gun-cotton by the acid present. The washing of the separate skeins is continued until no acidity can be detected in them by the taste; they are then arranged in frames or crates and immersed in a rapid stream of water, where they remain undisturbed for two or three weeks. They are afterwards washed by hand, to free them from mechanical impurities derived from the stream, and are immersed for a short time in a dilute boiling solution of potashes. After this treatment they are returned to the stream, where they again remain for several days. Upon their removal they are once more washed by hand, with soap if necessary; the pure gun-cotton then only requires drying to render it ready for use. A supplementary process is, however, adopted by General von Lenk, about the possible advantage or use of which his opinion is not shared by others, as already stated. This treatment consists in immersing the air-dried gun-cotton in a moderately strong hot solution of soluble glass (silicate of potassa or soda), for a sufficient period to allow it to become completely impregnated; removing the excess of liquid by means of the centrifugal machine; thoroughly drying the gun cotton, thus "silicated," and finally washing it once more for some time, until all alkali is abstracted. Lenk considers that, by this treatment, some silica becomes deposited within the fibre of the gun-cotton, which, on the one hand, assists in moderating the rapidity with which the material burns, and, on the other hand, exercises (in some not very evident manner) a preservative effect upon the gun-cotton, rendering it less prone to undergo even slight changes, by keeping. The mineral matter contained in pure gun-cotton which has not been submitted to this particular treatment amounts to about one per cent. The proportion found in specimens which have been "silicated" in Austria and in this country, according to Lenk's directions, varies between 1.5 and 2 per cent. It is difficult to understand how the addition of one per cent. to the mineral matter, in the form chiefly of silicates of lime and magnesia (the bases being derived from the water used in the final washing), which are deposited upon and between the fibres in a pulverulent form, can influence, to any material extent, either the rate of combustion or the keeping qualities of the product obtained by Lenk's system of manufacture.

The gun-cotton, when thus prepared, is carefully dried and stored in well ventilated rooms, heated to about 80° Fahrenheit. This is the only operation where there is any possibility of danger. The manufacture of this material possesses most important advantages over that of gunpowder. In the manufacture of the latter, the opera-

tions are all of a dangerous character, from the moment the materials are mixed up to the final drying process; while this is the case with gunpowder, the processes to which cotton-wool is submitted for conversion into pure gun-cotton are all harmless; and it is only when it reaches the drying process that any risk of accident can occur. But if this drying process be conducted with care, the temperature of the room being carefully regulated, there is really no actual danger, even in this operation. It merely requires attention to the precautions ordinarily used in the manufacture of gunpowder, such as the exclusion of possible sources of fire, to ensure the safety of the drying process.

The question of the permanence and keeping properties of the pure gun-cotton, and, therefore, of its safety as a material to be preserved in store, or used in military or naval service, is still enveloped in uncertainty. We know that gun-cotton may be preserved for a great length of time without undergoing any change. The small specimen, prepared in 1846, which I just now showed you, is one example of the possibility of keeping gun-cotton without change. That sample was kept in a box, generally closed, and but rarely exposed to light. But here is another specimen, which I did not prepare myself, but which was given to me two or three years ago as a specimen of very carefully prepared gun-cotton. I should rather say, this *was* a specimen of gun-cotton, for the only evidence we have of the existence of that material is the presence, in the bottle, of certain products which chemists know to be formed during the spontaneous change which imperfectly prepared gun-cotton will undergo. Here, again, are specimens, prepared in 1847, by Messrs. Hall, about the time they had that lamentable explosion at their works. A quantity of gun-cotton existed in store, and they, anxious to get rid of this dangerous material, at once buried the whole quantity in a hole dug in the ground; and there it has been ever since. They were kind enough to have a small quantity dug up for me a short time ago, and this is a specimen of the material. It appears to have undergone no chemical change whatever, having been preserved in a wet or thoroughly damp condition for about 17 years. Though not the most explosive form of gun-cotton, and therefore possibly a comparatively unstable material, yet, buried in this way, it has kept perfectly well. Upon examining it by means of test-papers, and soon after its disinterment, I found that there was no trace of free acid in it. But as soon as I exposed a portion of it to light, or very shortly afterwards, it began to exert an action upon test-paper. This gun-cotton, which has been so permanent in its character for a number of years, begins therefore to change as soon as it is exposed to the light, and this change is much accelerated by the action of heat. It is found to take place, not only in this particular gun-cotton, which has been imperfectly prepared, but also in the material produced strictly according to Lenk's directions. If I expose gun-cotton in an exhausted glass globe to the action of air and light, some gaseous matter is generated; if I modify that experiment by exposing the globe to heat, which I can do by keeping it surrounded with hot water, the change takes place more rapidly and to a greater extent.

Whether this change is so important as to influence vitally the permanence of the material,—whether gun cotton, when exposed to light or heat until it begins to undergo this slight change, and then stored in the dark, will continue to decompose,—whether the changes which it may therefore undergo by travelling in limber-boxes in tropical countries, are likely to continue if the material should be returned into magazines,—these are most important points, which will require very careful investigation at the hands of the Government committee. They are naturally points of the highest interest in connection with the possible susceptibility of gun-cotton to application in warfare, inasmuch as, unless we can positively prove, without any chance of dispute, that the material is thoroughly permanent, any advantages which it may possess as an explosive agent over gunpowder will go for nothing at all.

Now, let me pass to the properties of gun-cotton, and first of all to those by which we have until lately been in the habit of recognising it. You perceive that cotton, when thus treated with nitric acid, does not appear at first sight to have undergone any change. It appears a little more crisp and harsh than the original cotton; and another indication of its having undergone some physical change, is furnished by the fact, that it absorbs less moisture. Carded cotton-wool, in its purest form, absorbs from the air about six per cent. of water; gun-cotton absorbs two per cent. of moisture. If it is dried, it speedily takes up that proportion of moisture again. If it is exposed to a very damp atmosphere, it absorbs about six per cent. of moisture; but when exposed again to ordinarily dry air, it soon loses all above two per cent. This is an important advantage which it has over gunpowder. We know that, if we expose gunpowder to a moist atmosphere, or store it in a damp magazine, it will gradually and continuously absorb moisture, until it becomes perfectly pasty; and that it is necessary again to submit powder which has become damp, to the manufacturing processes, in order to reconvert it into good gunpowder.

Gun-cotton explodes readily without smoke, and without leaving any appreciable residue. It inflames at a very low temperature as compared with gunpowder, although not at so low a temperature as was originally supposed. It is found that gun-cotton may be raised to 280 or even 300 degrees of Fahrenheit, without undergoing explosion; but these are low temperatures compared with that to which gunpowder may be heated before it explodes. I will show you the ready explosibility of gun-cotton, by introducing some, contained in this glass tube, into a vessel containing a saline solution, which is heated to a temperature of 300 degrees. You will see that the gun-cotton is in a very short time raised to a temperature at which it explodes. Gun-cotton also explodes by friction; when submitted to the friction produced by a powerful blow, it is easily ignited, with explosive violence, and converted into gaseous matter. If I take a small piece of gun-cotton, and hit it a moderate blow on this anvil, I have no doubt I shall succeed in detonating that portion of it which is immediately under the hammer, but that portion which projects beyond will remain

unexploded. Gunpowder is not generally believed to be exploded by detonation, nor is it so in the ordinary acceptation of the term. We may hit gunpowder very hard indeed on an anvil, and we shall fail to explode it, unless we happen to strike a spark with the hammer out of the anvil. In this instance, you hear that I produce a very slight detonation; and I could increase it by wrapping the powder up in tinfoil, so as to confine the heat. A short time ago, Mr. Scott Russell, in a lecture which he delivered on gun-cotton, stated and showed experimentally that gunpowder was more detonating than gun-cotton. This was a new fact to those who know what gunpowder is; and Mr. Scott Russell, in performing his experiments, must have got hold of a very remarkable specimen of that material.

Gun-cotton exhibits another curious property, one which was demonstrated just now when I showed that, in striking a mass of gun-cotton with a hammer, I do not explode that portion which is not immediately under the hammer. When gun-cotton is compressed at any particular part, powerfully or even moderately, and lighted at any other portion, the compressed part will not burn, and therefore the combustion will not extend beyond it. If I press with a card upon the centre of a piece of gun-cotton laid upon a flat surface, I can fire the gun-cotton on one side of the card, and it will not burn on the other.

Gun-cotton, in its ordinary condition, explodes much more rapidly than gunpowder. This has been evident in the one or two experiments I have already made. If I ignite gun-cotton, the flame produced is far more instantaneous in its character than that produced by the explosion of gunpowder. I may give you an illustration of the difference between the rapidity of the burning of gunpowder and of gun-cotton. I place a small portion of gunpowder on the centre of a tuft of gun-cotton, and then apply flame to the gun-cotton; if I am successful, I shall ignite the gun-cotton, and the flash of flame produced will not have time to ignite the gunpowder. Now this great rapidity of combustion constituted one of the most important objections that have been raised against the employment of gun-cotton in firearms. Although many attempts have been made at different times to modify the rapidity of the explosive action of gun-cotton, so as to render it applicable to general military purposes, only one system, and that the most simple of all, has been attended with success. By modifying the mechanical condition of the material, so as to render it more or less compact in its character, the rapidity with which it explodes, in open air, may be regulated to almost any extent. If I render a piece of this tuft of gun-cotton more compact, by twisting it up between my fingers in this way, and then apply a light to it, the heat cannot penetrate so instantaneously into the small spaces existing between the fibres of the cotton, as it would if applied to the loose carded gun-cotton. You observe the great difference in the rapidity with which the gun-cotton in the two conditions burns. Therefore, this is manifestly a simple and effective method of modifying the explosive action of the material; and it is upon this simple modification of the mechanical condition of gun-cotton, that all the improvements effected in its application by General von Lenk, in Austria, depend. Instead of employing cotton-

wool in a carded condition, for conversion into gun-cotton, it is used in a loosely spun form; being converted into roving or yarn of different sizes, regulated by the purposes to which it has to be applied. Here is a large hank of gun-cotton, the cotton-wool having been, before the treatment with acids, converted into this very loose form of yarn. Having the material once in this form, we are now enabled to let it burn comparatively speaking slowly, and with great regularity. You will readily believe, from the manner in which you perceive that this piece of gun-cotton burns, that it could be accurately timed to burn a given length per second in the open air. We have here a finer description of gun-cotton yarn, and if I inflame a portion of it, you will perceive that it is a quicker burning material than the coarser and more open yarn.

The gun-cotton in this form of twisted yarn, is presented to us in a condition in which it can be converted into a variety of forms, suitable for different purposes. If we want to employ it in cannon, where it is to exert its explosive force gradually, the coarse yarn is rolled or twisted with moderate tightness round a reel or hollow cylinder of wood, the size of which is determined by that of the chamber of the gun and by the weight of the charge to be used; the best result being obtained by so arranging the latter that the cartridge entirely fills the space allotted to the charge in the gun. Similarly, small-arm cartridges are made of cylindrical plaits of fine yarn or thread, which are fitted compactly in layers, one over the other, upon a small cylinder or spindle of wood. In both of these arrangements the combustion of the charge can proceed only from the external surfaces towards the interior of the cartridge. On the other hand, the charges for shells, in which the most rapid explosion is most effective, and the priming for quick matches, which are intended for firing several charges simultaneously, and almost immediately upon the application of flame, consist of cylindrical, hollow, and moderately compact braids (similar to lamp-wicks) made of gun-cotton thread, or very fine yarn.

I will show you how rapidly the gun-cotton burns when in the plaited form, which is that employed for quick match, in shells, and for small-arm cartridges. You observe this large mass of gun-cotton is almost instantaneously converted into gaseous matter, with explosive violence. Here we have a similar plait confined in a waterproof case, in which form it is used as a quick match for mining purposes. Its combustion takes place so rapidly, that small portions are scattered without being burnt. This circumstance, by the way, constitutes one of the objections to gun-cotton, and requires to be very carefully inquired into, for the purpose of ascertaining whether the scattering of small particles by an explosion in this manner may not be a serious cause of accident in mining operations.

I will give you a striking illustration of the difference in the rapidity with which gun-cotton may be made to burn. If we take the material in the form of a tight cord, without any perforation at all, and if we introduce the cord into a case of paper, glass, or any other material, into which it fits tightly, we can make the gun-cotton burn so slowly

that it almost appears to smoulder. It is, in fact, converted in this manner into a material adapted for fuzes. By thus simply allowing the cotton to burn only at one particular point, it burns with a very great degree of slowness and regularity. I have here a small fuze made in a glass case, so that what takes place in the interior may be readily seen. I will apply a light to one end of it. You see it burns very slowly; it is only smouldering inside the tube. There is a jet of inflammable gas burning at the opening of the fuze, just as in the case of a gunpowder fuze. Thus, you perceive, we may readily employ gun-cotton for the manufacture of fuzes, if it should offer any advantages in that direction. This experiment affords a remarkable contrast to the rapidity with which the gun-cotton burned just now when in the form of plait. But I can make it burn even more rapidly than it did in the latter form, simply by modifying very slightly its mechanical condition in the interior of the tube. If, instead of using it in the form of a tightly twisted cord, fitting tightly in the tube, we insert loosely into the tube two or three pieces of the coarse yarn, placed side by side, upon applying heat to the gun-cotton thus arranged, we perceive that the explosion of the entire mass takes place instantaneously, and the result of that instantaneous explosion is the shattering of the tube into innumerable minute fragments. We see, therefore, that gun-cotton is susceptible of very great variation in its mechanical arrangement, and consequently in the rapidity with which it burns.

I should now like to investigate experimentally a few of the phenomena attending the combustion of gun-cotton under different circumstances, because they serve to throw considerable light upon the different effects which the material exerts as an explosive agent, as shown by the experiments which we have just instituted.

In speaking just now of the general properties of gun-cotton, I omitted to show you that, when it is exploded in the ordinary manner in open air, it furnishes a large body of flame, and a mixture of gases and vapour, exhibiting acid properties. The production of acid vapour by the ignition of gun-cotton, has always been regarded as one very great objection against its employment as a propelling agent in arms of any description. One of the gaseous products obtained by burning gun-cotton in the open air is exceedingly corrosive; it acts on metals very powerfully indeed. If I introduce into the vessel in which I have burned gun-cotton, a small quantity of paper dyed with a vegetable blue, that blue will very speedily become red, in consequence of the acid nature of one of the products. Another result observed when gun-cotton is burned in an open vessel is, that the first flash produced by its combustion is followed by a pale bluish flickering flame, lasting for a second or two. That flame is due to the burning in the air of inflammable gas evolved by the explosion of the gun-cotton.

If we exclude air from gun-cotton, and then inflame it, the combustion of the material will appear very different, simply because there is no air present to furnish the oxygen necessary for the burning of the inflammable gas evolved. I will just compare the effect of burning gun-cotton in air, and in a vessel containing another gas in place of air, in order to show you that this large flash of flame, when gun-cotton is burned in air,

has nothing whatever to do with the actual burning of the substance itself. Here we have the gun-cotton in two vessels; one is open at the top, communicating with the air, and is filled with ordinary air. I ask you to notice once more the large body of flame, in addition to the first flash. Here we have another vessel filled with carbonic acid gas; we have therefore excluded air, and you observe what appears to be a different kind of combustion. Again, if I burn gun-cotton in a closed vessel which originally contained air, but from which I have exhausted the latter by means of an air-pump, the gases evolved by the gun-cotton when it is inflamed by voltaic agency, are prevented from burning, because oxygen has been practically removed from the apparatus. Moreover, the gun-cotton burns very slowly indeed, because the atmosphere in the vessel is so very highly rarefied, that the gases expand enormously as they are evolved, and abstract the heat necessary for rapid combustion, as they escape from the gun-cotton. You perceive when heat is applied to the gun-cotton in this exhausted globe, we have no flash of flame, and the gun-cotton burns very slowly, appearing only to smoulder. This is, as I have said, simply because those gases generated by the decomposition of gun-cotton—not burned, but generated very slowly indeed—expand into the rarefied space, and carry away the heat which we are applying to the gun-cotton, as well as the heat developed by the combustion of the latter.

It will be readily conceived that the mechanical state of the gun-cotton (*i.e.*, the particular form in which it is employed) will greatly influence the nature of phenomena observed, when this substance is ignited in air, or in various gases, either at ordinary or diminished pressures. We have seen that when a tuft of carded gun-cotton is ignited in carbonic acid (and I might have employed carbonic oxide, nitrogen, coal-gas, hydrogen, and other gases), it burns only with a pale yellow flame; this flame, when furnished by equal quantities of gun-cotton, is much smaller in an atmosphere of hydrogen than it is, for example, in carbonic acid; a fact which must be ascribed to the comparatively very rapid diffusion of the generated gases when hydrogen is used. In operating with pieces of gun-cotton yarn, instead of employing loose tufts, the material, when ignited by a red-hot wire in atmospheres of carbonic acid, nitrogen or carbonic oxide, burns much more slowly than it does in air under the same conditions; and its combustion is accompanied only by a very small jet or pointed tongue of pale flame, which is thrown out in a line with the burning extremities of the piece of yarn. In the same way, if the yarn is enclosed in a tube or other vessel, through which those gases are circulating, and from which one extremity of the gun-cotton protrudes, when the latter is lighted it will burn in the ordinary manner only until it reaches the opening of the tube, when the form of combustion will at once be changed to that just described. If, however, corresponding experiments are made in atmospheres of hydrogen or coal-gas, the gun-cotton yarn will burn in the slow manner described, but only for a very brief period; indeed, it ceases to burn at all almost instantaneously. This result is not due to the high diffusive powers

of the gas in which the gun-cotton is burned, as it may be obtained equally in open and in perfectly closed vessels; it can therefore only be ascribed to the high cooling powers, by convection, of the gases employed. Pure nitrogen is one of the gases which allows gun-cotton yarn to burn in the slow manner, but if mixed with one-fourth its volume of hydrogen, it arrests the combustion of the material, just like coal-gas or pure hydrogen.

A rapid current of air will also effect the transformation of the combustion of gun-cotton from the ordinary to the slow form, if the yarn be enclosed in a moderately wide glass tube, with one end protruding from the tube, so that it may be inflamed in the ordinary manner; but, unless the current be very rapid, an explosive mixture of air and the inflammable gases generated from the gun-cotton may be produced in the tube, and become ignited, in which case the gun-cotton will flash into flame instantaneously, and the tube will be shattered by the explosion. If, however, I pass a long piece of thin gun-cotton yarn through this small narrow glass tube, which is about two inches long, into which it fits so loosely that it may be drawn through very easily, upon lighting it in the ordinary manner at one end, you will find that when the flame reaches the tube through which the yarn is passed, its character will change at once; it will burn in the slow manner in the tube; and when the combustion reaches the other side, the gun-cotton actually continues to burn, with the small tongue of pale flame, in the air, just as it did when I took such precautions to exclude the air. I may produce this change from the quick to the slow combustion even more simply. By perforating a card, and passing a piece of gun-cotton through the small perforation, in which it fits loosely, you will find that I can make the gun-cotton pass from one form of combustion to the other with the greatest ease; for as soon as the ordinary large flame of burning gun-cotton reaches the perforation, it is transformed into the small tongue of pale flame.

The cause of these phenomena is extremely simple; and these curious results will very likely throw considerable light on the various effects produced by the explosion of gun-cotton under different circumstances. The gun-cotton, when it is employed in the form of this thin yarn, which is laid upon a flat surface and inflamed, burns only at the one point where the heat or flame is applied. But the gases that are evolved produce a large flame by burning in the air; this flame surrounds the portions of gun-cotton which are next to be burned, and heats them to the temperature necessary for their rapid combustion. But if I prevent those gases, even for an instant, from enveloping the portions of the gun-cotton in immediate proximity to those which are burning; in other words, if I force them to escape, for a moment, only in one direction, namely, in a direct line with the burning surface of gun-cotton from which they are emitted, the latter is no longer *continuously* heated to the temperature necessary for its rapid and more complete combustion, and hence the gases themselves are in turn not supplied with sufficient heat for their ignition. Now, as the gases which escape unburned convey away a very large portion of the heat developed by the metamorphosis of the gun-cotton, it is impossible for the latter to



continue to burn otherwise than in the slow and imperfect manner. If, however, I hold a flame or highly-heated body in the path of the gases as they escape, they will at once be ignited, and the yarn will burst into the ordinary form of combustion. The correctness of this explanation may readily be demonstrated by two or three simple experiments. Thus, if a piece of loose or open gun-cotton yarn is employed, in place of the compact material which furnishes these results just described, it is very difficult, or even impossible, to cause the rapid combustion to pass over into the slow form, because the escaping gases cannot be diverted all into one direction, and cannot, therefore, be prevented from transmitting the heat necessary for perfect combustion from particle to particle of the material. Again, if I place a piece of the compactly twisted gun-cotton yarn, upon a flat surface, inflame it in the usual manner, and then direct a jet of air, by means of this glass tube, in a line with the gun-cotton, so as to meet the flame, the latter appears to be blown out, though the cotton still burns; in fact, the burning gases are prevented for an instant from completely enveloping the extremity of the gun-cotton, and hence the combustion at once passes from the quick to the slow form.

Now if, while the yarn is burning in this slow manner, I direct a very gentle current of air *against* the burning portion, so as to force back upon it the gases which are escaping, and thus impede the rapid abstraction of heat, the gun-cotton soon bursts again into the ordinary form of combustion, because, under these circumstances, the gases are almost immediately raised to the temperature necessary for their combustion. And here is one more experiment of this kind. I place a piece of the yarn upon a board, make it burn in the slow manner, and then raise one end of the board gradually, so that the burning extremity of the gun-cotton is the lowest; the latter bursts into flame as soon as the board has been raised to a position nearly vertical, so that the escaping gases flow back upon the burning surface.

I have still to show you that I can produce the slow or imperfect form of combustion of gun-cotton in open air, by applying to any part of a piece of the thin compact yarn a source of heat not sufficiently great to inflame the gases generated. A wire or metal rod, heated to any temperature between  $280^{\circ}$  F. to just below visible redness, or the spark of a thin piece of smouldering string, will invariably produce the result described. Of course, this effect, like most of the phenomena described, is to a considerable extent dependent upon the mechanical condition of the gun-cotton, and upon the relation between the *quantity* as well as the *degree* of heat applied, the amount of surface of the gun-cotton, and other conditions. While a small spark, or a thin platinum wire heated to full redness, only induces slow combustion in the compact gun-cotton yarn, a thick rod of iron, heated only to dull redness, will invariably inflame it in the ordinary manner. A piece of open yarn cannot be ignited so as to burn in the slow manner; on the other hand, the more compactly the gun-cotton is twisted, the more superficial is the slow form of combustion induced in it; indeed, the gun-cotton may be rendered so compact that it will simply smoulder in open air if ignited as described, leaving a considerable carbonaceous

residue; and the heat resulting from this most imperfect combustion will sometimes be abstracted by the escaping gases more rapidly than it is developed, so that the gun-cotton will then actually cease to burn, even in open air, after a short time.

The remarkable facility with which the effect of heat upon gun-cotton may be modified, so as even to produce results totally opposite in their characters, as exemplified by some of the experiments which have been exhibited, renders it easily conceivable that this material may be made to produce the most varied mechanical effects, when applied to practical purposes; that it may, indeed, be so applied as, on the one hand, to develop a force very gradual in its action, which may be directed and controlled at least as readily as that obtained by the explosion of gunpowder, while on the other hand, it may be made to exert a violence of action and a destructive effect far surpassing those of which gunpowder is susceptible. The results arrived at in Austria, which show that gun-cotton can be made to produce effects from three to eight times greater than those of gunpowder, cease to be surprising after a study of the chemical and physical characteristics of this interesting explosive agent.

I should like to say a few words with regard to the nature of the products of combustion of gun-cotton, this being a branch of the subject of very considerable importance.

There is no doubt that the products of combustion of gun-cotton vary in their nature almost as greatly as the phenomena which attend the exposure of the material to heat under different circumstances. We have seen that, when gun-cotton is inflamed in the open air, there is produced (in addition to water, carbonic oxide, carbonic acid, and nitrogen), a considerable proportion of the gas known as binoxide of nitrogen, which assumes a red-brown tinge, and becomes very acid when it mixes with air. The products of the different forms of imperfect combustion which gun-cotton has been described as susceptible of undergoing, are undoubtedly much more complex in their character than those just referred to. They include at times a proportion of some substances, not yet examined, which make their appearance as a white vapour or smoke; cyanogen can readily be detected in all the products of imperfect combustion; the proportion of binoxide of nitrogen is generally so large that the gaseous product becomes very highly coloured when mixed with air; peroxide of nitrogen has also been observed in some instances; lastly, there is little doubt that the products occasionally include a proportion of oxidising gases (probably oxygen.)

The products which have just been spoken of are the results either of the decomposition of gun-cotton, in air under ordinary conditions, or of its imperfect combustion under various circumstances. But when the explosion of material is effected in a confined space, in such a manner that the main decomposition takes place under pressure, the metamorphosis which the material undergoes is of a more simple and complete character.

It has been found by Karolyi that, when gun-cotton is exploded by voltaic agency in a shell which is burst by the explosion, and which is

enclosed within an exhausted chamber so that the products of decomposition are collected without danger, the results obtained under these conditions are comparatively simple; the analysis of the contents of the chamber, after the explosion, showed that they consisted of carbonic acid 20·82 per cent., carbonic oxide 28·95, nitrogen 12·67, hydrogen 3·16, marsh gas 7·24, water 25·34, and carbon 1·82 p.c.

I will try to produce before you the results of the most perfect decomposition of gun-cotton. In this stout iron sphere a small shell containing gun-cotton is enclosed, which I will explode; but, in order to do it safely, I will exhaust the air from the large sphere, and this will enable me to collect the gases produced by the explosion of the shell within. If I burst the shell, we shall know it by the production of a slight sound in the interior of the vessel. The shell is now exploded, and I allow the gases to escape through this tube. You see that they burn with a pure blue flame, indicating that the carbonic oxide produced is not mixed with binoxide of nitrogen, which gave it the green tinge in our former experiments on the explosion of gun-cotton. You shall also see that we have no acid in the gaseous mixture. I will just allow the gas to impinge for a short time upon this piece of blue paper. You may take it for granted that a long continuance of this application will produce no appreciable change upon the appearance of the paper. Lastly, if I pass the gas through a solution of salt of iron, you will see that it will produce no discolouration, while if I shake up some of the same solution with gases produced by burning gun-cotton in air, it rapidly becomes of a dark brown colour. Thus we see that, although when we explode gun-cotton in air we produce nitric oxide vapours (which become acid when they mix with air), when we explode the material under pressure, as it is exploded in practice, these acids are not produced in any appreciable quantity. It is evident, therefore, that, just as the decomposition of this material is of a more complicated and intermediate character, when its combustion is rendered imperfect by diminution of pressure or other circumstances, so, conversely, the change which it undergoes will be the more simple, and its conversion into gaseous products the more complete, the greater the pressure, beyond normal limits, under which it is exploded, that is to say, the greater the resistance offered to the generated gases upon the first ignition of a charge of gun-cotton (and consequently the higher the temperature at which the decomposition of the confined gun-cotton is effected). The notions hitherto generally entertained with regard to the very noxious character of the products of explosion of gun-cotton and their powerfully corrosive action upon metals— notions which were based upon the effects observed on exploding gun-cotton in the open air—have unquestionably been already proved to be erroneous by the results of actual application of gun-cotton to artillery, and other purposes.

There are two very important points of difference between the products of the decomposition of gunpowder and those formed on the explosion of gun-cotton. In the first place there is, practically speaking, no water produced by the explosion of gunpowder, while, in the case of gun-cotton, that substance constitutes no less than about 25

per cent. of the total products of metamorphosis. It can hardly be questioned that this water exerts functions of the highest importance in the application of gun-cotton as an explosive agent. The proportion of permanent gas furnished by a given volume of gun-cotton, in a very compact condition, is considerably less than that produced from an equal volume of gunpowder, but this difference must be far more than counterbalanced by the large volume of highly elastic vapour furnished, at the moment of the explosion, by the water formed. In fact, the heat generated by the chemical change which the gun-cotton undergoes enables the water to act as a permanent gas. Moreover, the circumstance that fire-arms, in which gun-cotton is employed do not become heated by repeated firing to anything approaching the extent observed when gunpowder is employed, must be ascribed, at any rate in great part, to the fact that the heat is principally expended, immediately upon its development, in the conversion of the water into vapour of high tension. If you recall to mind the comparatively low temperature at which gun-cotton explodes, you will realise the great importance of the fact that the fire-arm does not become heated by repeated firing with gun-cotton to anything approaching the extent observed when gunpowder is used.

The second and equally important difference between the results of metamorphosis of gun-cotton and of gunpowder is to be found in the fact that the former is completely transformed into substances which are either permanent gases, or which exist as gases or vapours at the moment of explosion. No solid residue nor smoke is produced by the explosion of gun-cotton. The serious inconveniences attending the employment of gunpowder, which arise from the fouling of fire-arms and from the dense smoke produced upon their discharge, would be altogether set aside by the substitution of gun-cotton for that material. It is asserted that there are circumstances under which the smoke produced upon firing guns, offers advantages in warfare. I will not pretend to discuss this point, but I feel sure you will admit that, in casemates, or between decks on board ship, in a naval action, it would be one of the greatest boons which could be conferred upon the soldier or sailor, if the dense, stifling, and enshrouding smoke of powder could be abolished.

The proportion of solid matter produced upon the explosion of gunpowder has been fixed at very different amounts by different authorities. According to the views of the decomposition of gunpowder which were generally accepted, until recently, war-powder of average composition, was considered to furnish from 40 to 50 per cent. of its weight of matter, *solid at ordinary temperatures*. The earlier investigators (Gay-Lussac, Chevreul, &c.) of the decomposition of gunpowder, who fixed the solid products at that amount, represented the results of the explosion of this material as being of a very simple character, and in harmony with the theory that gunpowder is converted essentially, by its explosion, into carbonic acid (or a mixture of that gas and carbonic oxide), nitrogen, and sulphide of potassium. But more recent experimentors, Bunsen and Schischkoff, who have made a very elaborate examination of the products which they

obtained by the explosion of gunpowder, represent the change to be one of a very complicated character; fix the percentage of solid substances found at from 68 to 70 per cent. of the gunpowder used, and show that the sulphide of potassium, which has been considered as the principal of these products, was only formed in very small proportion in their experiments. The conditions under which these chemists exploded the gunpowder did not, however, correspond at all in their character to those under which gunpowder is exploded in actual practice, and would, therefore, be very likely to furnish results greatly at variance with those produced when a charge of powder is fired in a gun, a shell, or a mine. That sulphide of potassium is abundantly produced upon the discharge of a fire-arm appears beyond doubt; it may be readily detected in the solid matter which remains in the barrel near the breech; it may be found deposited in considerable quantity near the muzzle of the arm, and there appears strong reason for believing that the flash of flame, observed at the mouth of a fire-arm upon its discharge, is due in part to the ignition, as it comes into contact with the air, of sulphide of potassium, which has been vaporised by the heat of the explosion, and is thus mixed with the escaping gases. It is well known that a red heat is sufficient to convert sulphide of potassium into vapour, and the heat resulting from the explosion of gunpowder is far above that temperature; it is, therefore, not yet proved that a considerable proportion of the products of the decomposition of gunpowder, though solid at ordinary temperatures, does not exist in the form of perfect vapour at the moment of the explosion in a fire-arm, just as the water produced from gun-cotton, though liquid at ordinary temperatures, exists as a vapour at the moment of the explosion. Mr. Scott Russell, in his interesting lecture at the Royal Institution, pronounced the 40 or 68 per cent. of solid matter produced from gunpowder to be so much "filthy rubbish," but I am confident you will concur with me, after what I have said on this subject, in thinking that this wholesale condemnation is somewhat premature; that it is necessary we should possess more definite information than now exists with regard to the nature of the products furnished by charges of gunpowder at the moment of explosion, under circumstances assimilating to those of its actual employment, before the fairness of the argument can be admitted, that certain products of the decomposition of gunpowder must be regarded entirely as waste matter, simply because they are *solid at ordinary temperatures*.

There is one more subject upon which I ought to say a few words. It is stated, upon the authority of the military committees who, in Austria, have experimented upon the application of gun-cotton to artillery purposes, that the recoil of a gun is considerably less with gun-cotton than when gunpowder is used. That such should be the case when the two explosive agents are applied to produce equal effects, (*i.e.*, to furnish equal ranges) is readily intelligible, as the weight of material used as the charge is, in the case of gun-cotton, only about one-third of that of the gunpowder employed. But, it is also stated that, in using equal weights of the two materials, the recoil of the gun is greater with gunpowder than with gun-cotton. It is impossible, in the

present state of our knowledge, to venture upon an explanation of such a fact. Mr. Scott Russell has put forward with great confidence a reason why gunpowder must produce the greater recoil. If I understand him rightly, he considers the increased reaction upon the gun to be due to the great resistance offered by, or the work done upon, the *solid* products formed on the explosion of gunpowder, which have to be projected from the gun, just as the shot or shell is. This explanation is not satisfactory to many besides myself, and an ingenious experiment which he exhibited to us a short time ago, at the Royal Institution, to demonstrate the difference in the recoil produced by the two agents, though it was very striking, as far as Mr. Scott Russell carried it out, shows, when pursued somewhat further, that this subject cannot be quite so simply and readily disposed of as he would lead us to believe. Equal weights of ordinary gunpowder and of gun-cotton in the form of coarse yarn, were successively placed in one scale of a balance, of which the other scale was loaded with a greater weight than that of the explosive. Upon igniting the gunpowder, the scale-pan which contained it was violently depressed, to such an extent as completely to raise the other over-weighted scale-pan; but, when an equal weight of gun-cotton was exploded under the same circumstances, the weighted scale-pan was hardly sensibly raised. I will perform this experiment before you with this pair of scales. The long arm or indicator of card-board, which projects in a line with the beam, from that end to which the weighted scale-pan is suspended, will, by travelling up this vertical index, enable those at a distance to observe any slight depression of the scale-pan in which the explosive is burned. Now, I will explode, successively, equal weights of ordinary gunpowder and of coarse gun-cotton yarn in the scale-pan, and you will observe the results which I have already described. But I will now ignite in the pan an equal weight of gun-cotton made up in the form of a hollow braid, and you will observe that the pan is depressed to a considerable extent; in fact the force exerted upon the loaded scale-pan was, as you saw, not very inferior to that developed by the gunpowder. Now, let me again take some of the same gunpowder used in the first experiment: I will reduce it from the granular to the pulverulent condition by crushing it with this pestle and mortar, and I will now explode in the scale-pan an amount of this equal to the gunpowder and gun-cotton already used. You perceive that, this time, the balance hardly moves; you could scarcely perceive any difference whatever between this effect and that produced, in the first instance, with gun-cotton. Just one more experiment. Here is the explosive known as fulminate of mercury, which, on the instant of its ignition, furnishes simply gases and vapour of mercury, just as gun-cotton furnishes gases and vapour of water. I will explode in the scale-pan an amount of this substance equal to only one-half the weight of the gunpowder and gun-cotton used. You will observe that the scale-pan is far more violently depressed in this instance, where we are using an explosive which furnishes no solid products, than it was when we employed double the weight of granulated gunpowder. I must refrain at this late hour from offering

any explanation of these different results; indeed, I have only made those experiments for the purpose of showing you that there are evidently other circumstances, apart from the formation of solid products, to which we must look for an explanation of what appears to be a difference in the recoil, or reaction produced by different explosives.

And now I must conclude this imperfect outline of the history of gun-cotton from its discovery to the present day. There are several other points of considerable importance included in our present knowledge of this interesting and remarkable substance, to which, had time permitted, I would have much liked to refer, but I feel that I have already trespassed too much upon your patience. I think, however, it has been made evident to you that, although gun-cotton has been known to us since 1846, we are only now really becoming acquainted with its properties and its true nature as an explosive agent.

It will, I believe, be generally conceded that gun-cotton, as it may now be manufactured, possesses several most important advantages over gunpowder. The great control which may be exercised over its explosive action; its property of exploding without producing either smoke or residue, and the safety of its manufacture, are unquestionably attributes of the very highest value in a material of the class to which gun-cotton belongs, and may combine to fulfil the expectations of its most sanguine friends. But it is imperative that we should not lose sight of the fact that, unless the stability of gun-cotton is proved by the most searching investigations to be beyond doubt, not all the advantages which are claimed for it, in addition to those which it has been proved to possess, would warrant its substitution for gunpowder in naval, military, or engineering operations.

The CHAIRMAN: I am sure I only express the opinion of all present when I say we have had a most interesting lecture. Not only is the subject itself very interesting, but the manner in which the lecture has been delivered, and in which the experiments have been performed, has added very much to the pleasure of the meeting. I may say that I once asked an eminent lecturer and professor in London, what made his experiments so very attractive. He said he always took care now and then to fail a little, because it added very much to the interest of the experiments. If experiments were always successful, he said, people would expect them to succeed as a matter of course, and they would lose half their attractions. I can only add to this, that from what we have heard to-day, it is clear that there is yet a great deal to be learned upon the subject of gun-cotton. Therefore, I shall look forward at some future time to another interesting lecture upon the same subject, when science has made further advances in this direction.

NOTE.—Since the delivery of the above lecture, some progress has been made in experiments instituted by me for the committee on gun-cotton, for the purpose of examining into the conditions which may affect the stability of that substance. Several French chemists of eminence have also recently been occupied with this subject, and two communications, embodying the conclusions arrived at by them, have

been made within a few weeks to the Academy of France. One of these is in the form of an official report, prepared by MM. Pérouze and Maurey, who had been entrusted by the French Government with the study of gun-cotton as prepared by von Lenk; the other is an account of the results obtained by M. de Lucca, on exposure of gun-cotton to heat, under various conditions.

The conclusion to which these chemists have been led by the results of their experiments is, that gun-cotton is not applicable as a substitute for gunpowder, on account of its being so susceptible to change as to render it liable to spontaneous ignition.

The results arrived at, up to the present time, in this country, both with Austrian gun-cotton and with material prepared in England at different establishments, according to the Austrian system, differ in several most important respects from those described in the memoirs of the French chemists. The investigation of the effects of heat, light, and of storage, under a variety of conditions upon gun-cotton, must necessarily extend over a very considerable period of time, but the data already obtained indicate decisively that the unfavourable results arrived at by the French chemists, in a comparatively short space of time, cannot be accepted as conclusively establishing such a want of permanence in gun-cotton as to preclude its application as an explosive agent.

October, 1864.

F. A. A.

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