SCIENCE LECTURES FOR THE PEOPLE.

SCIENCE LECTURES

DELIVERED IN MANCHESTER,

1873 AND 1874.

FIFTH AND SIXTH SERIES.

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PREFACE TO THE FIFTH SERIES.

About 5,500 persons attended the eight lectures which have been delivered this season, and the audiences exhibited the same interest and attention as they showed on former occasions.

It is to be understood that each lecturer is entirely responsible for the statements as they appear in print.

Again we all have to thank those who have by their kind contributions rendered a continuation of the lectures possible; and I have to acknowledge the services of our treasurer, Mr. Thos. Harrison, and to express my regret at his retirement.

H. E. ROSCOE.

January, 1874.

PREFACE TO THE SIXTH SERIES.

THE attendance at the opening lecture, held in the Free Trade Hall, was about 3,700, whilst at each of the subsequent lectures it has averaged 675.

We are indebted to all the Lecturers of the season, and to Professor Tyndall and Sir John Lubbock in addition, for their contribution to our funds.

The following is a list of the Lectures which have been delivered :—

CRYSTALLINE AND MOLECULAR FORCES. By Professor Tyndall, F.R.S. (President of the British Association).

JOHN DALTON. By Professor Roscoe, F.R.S.

ON THE TRANSIT OF VENUS. By Dr. Wm. Huggins, L.L.D., F.R.S.

JOSEPH PRIESTLEY: HIS LIFE AND CHEMICAL WORK. By Professor Thorpe, F.R.S.E.

GEOGRAPHICAL DISTRIBUTION OF MAMMALS. By P. L. Sclater, Esq., M.A., F.R.S. (Secretary to the Zoological Society).

EARTHQUAKES AND VOLCANOES. By Professor W. C. Williamson, F.R.S.

MODERN SAVAGES. By Sir John Lubbock, Bart., F.R.S., M.P.

PALESTINE EXPLORATION. By Major C. W. Wilson, R.E.

E. H. ROSCOE.

January, 1875.

GENERAL INDEX.

FIFTH SERIES.

SIXTH SERIES.

little cloud in the distance no bigger than a man's hand, which in ages yet to come, will develop into large clouds, sending down refreshing showers, that shall spread intelligence and life and knowledge over the whole surface of the earth.

I see my time is up; I can only say therefore, in conclusion, that if I apprehend rightly the essential objects of these lectures, they may be appropriately summed up as those of mutual improvement and the investigation of truth, the development of the seeds of knowledge and the detection of falsehood, the emancipation of the mind from the fetters of ignorance, and the cultivation of a true humanity by social gatherings and intellectual discourse.

GUN COTTON.

A LECTURE, Delivered in the Hulme Town Hall, Manchester, on Wednesday, November 19th, 1873.

By F. A. ABEL, Esq., F.R.S.

BEFORE I say a word to you about gun cotton, I should like to call your attention, for a few moments, to a substance with which it has, during the last forty years, attempted to stand in rivalry, namely, gunpowder; because I believe that if I can in a few words make you understand the nature of gunpowder, that of gun cotton will be much clearer to you afterwards. Now, gunpowder consists of three substances very intimately mixed together—the substance charcoal, made by charring wood; sulphur, a substance found in its elementary or native condition, and also extracted from several minerals; and saltpetre, a natural product originating in the gradual decomposition of a variety of vegetable and animal substances. Now, when gunpowder is subjected to the action of heat, or contact with flame, with a spark, or red-hot body of any kind, the following results are produced: both charcoal and sulphur are very readily oxidisable, or eager to burn at any time. We know how readily a piece of wood kindles when it is heated to a sufficient degree in air—we know how much more readily a piece of sulphur burns; both of them combining with a certain portion of the air which we call oxygen; and, therefore, we call these two bodies "combustible" bodies—charcoal, occurring in wood, and known to the chemist as carbon; sulphur, a substance extracted from various minerals.

These two bodies burn very readily if we heat them in air: they burn still more readily if we heat them in oxygen, or if brought into contact with some substance which is ready to give its oxygen to them; and this oxygen is derived, in the case of gunpowder, from the substance saltpetre. Saltpetre is a body which contains a large quantity of oxygen. It holds this oxygen in what we chemists call a feeble state of combination; that is to say, it is ready to give this oxygen to other substances greedy of it. And, therefore, if we heat sulphur or carbon (charcoal) in contact with saltpetre, it gives up to these bodies the oxygen which they require to burn, and then they burn rapidly and are converted in the course of that burning into gaseous substances. In passing from the state of solid to the state of gases, they assume many times their original volume; and at the moment at which they pass from the solid to the gaseous state a quantity of heat is generated by the chemical action that takes place between these substances. The result of all this is that the original solid mixture becomes expanded to very many times its volume, and this transformation occurs with great rapidity.

The almost sudden conversion of a solid, occupying little space, into gas occupying a great space, and which is, moreover, highly expanded by the heat developed during the transformation, gives rise to the development of a large amount of force, which has the power of overcoming great obstacles, or impediments to the violent expansion of the substance. The sudden or very rapid transformation of a solid or liquid into gas or vapour is generally productive of noise, and is attended by some more or less violent demonstration of force. It is called an explosion; and any substance which is susceptible of undergoing such transformation suddenly or very rapidly on the application of heat, or other disturbing cause, is called *explosive*. Therefore we call gunpowder an explosive substance.

Now the oxidising or burning component of gunpowder—saltpetre—contains a metal possessed of some very interesting properties, into which I cannot now enter; and this metal holds in combination with it a substance consisting of nitrogen combined with a large quantity of oxygen, both of which are gases existing in the air, as you may remember. Oxygen is ready to escape in the form of gas from any compound in which it is contained in a solid condition, combined, but not very strongly, with other substances. Thus, if we heat this saltpetre sufficiently, we can make it give up its oxygen without the assistance of the sulphur or the charcoal. If we continue to heat it very strongly we can also liberate the nitrogen from it. But if we heat it only moderately, when mixed with some substance which has a very great liking for the metal it contains, such as this powerful acid,

known as oil of vitriol, we then obtain from this saltpetre, not oxygen and nitrogen separately, but a combination of them with water—a fluid called nitric acid, which used to be called by old chemists *aquafortis*, or strong water, on account of its highly corrosive properties. Now nitric acid behaves very much in the same way towards sulphur and charcoal as the original saltpetre does. If we drop a piece of saltpetre upon red-hot charcoal it begins to deflagrate; that is, the charcoal begins to be burned very violently by the oxygen contained in the saltpetre. If we allow a drop of this nitric acid to fall upon red-hot charcoal, the action is just the same as if we allowed saltpetre to fall upon it. Nitric acid acts upon substances which are easily burned or oxidised even more readily than saltpetre. It does not require the assistance of heat to such an extent to develope its action, and to cause it to burn up the sulphur and charcoal. This nitric acid is manufactured by putting saltpetre and oil of vitriol into a retort together and applying heat, when this most valuable chemical agent distils over as a pale yellow fuming liquid. It is one of the most useful agents in manufacturing and scientific chemistry. I hope now I have made you understand generally what gunpowder is, and what nitric acid is, and, if so, I believe you will have little difficulty in understanding what gun cotton is. I will, therefore, proceed with my history of this remarkable substance.

About forty years ago some new substances were first produced in France which excited considerable curiosity amongst chemists. They were obtained by acting, with the highly corrosive liquid which we obtain from saltpetre, upon the well-known substance, starch, and upon cotton fabrics, such as muslin or calico, and even paper. When cold nitric acid was added to starch this substance was dissolved, and, upon adding water, the starch appeared to be separated again, but it had no longer the properties of the original substance—it had become endowed with explosive properties. When muslin or paper were dipped into nitric acid, allowed to remain for a very short time in that liquid, and then taken out and washed, though they appeared to be unaltered in character, except that they had become somewhat tender, there was a most remarkable alteration in their chemical properties, for, instead of being simply inflammable, that is, instead of burning quietly when set fire to, they burned very rapidly after this treatment, and almost with explosive violence. I have here specimens of paper and of calico which have been submitted to this kind of treatment, and you perceive how very quickly and brilliantly they burn. [The lecturer ignited the paper and muslin, which were instantly consumed. These and numerous subsequent experiments were very successful, and were much applauded.]

The discovery of these substances was very interesting, because they were really the foundation of the discovery of gun cotton. About fourteen years afterwards a German chemist, Schönbein, found that if common cotton wool was submitted for a short time to the action of cold very strong nitric acid, its weight was increased about 80 per cent; that is, 100 parts of the original cotton, after having been steeped in acid and washed and dried, furnished about 180 parts of what still appeared to be cotton wool. But this substance, when thus treated, was found to have the properties of the paper and muslin products which have been described, only to a more marked extent. Here is a portion of finely-carded cotton wool which has been treated in this way. As you perceive, it burns almost instantaneously. We observe no smoke; and, if we light a piece upon a perfectly clean plate, we shall find that there is nothing left—that the whole goes off in the form of gas and vapour. Gunpowder, when it is set fire to, leaves a considerable black residuum, which consists of certain solid substances formed besides the gases, which are generated as I have described. You have noticed how rapidly this gun cotton burns. It burns so very rapidly that, if I am successful in the experiment—which I never fail in when performing it by myself—I may even wrap some grains of gunpowder in gun cotton, which, when set fire to, will burn, leaving the gunpowder unburnt, simply because the gun cotton burns so rapidly that there is no time for the flame produced to set fire to the mixture of charcoal, sulphur, and saltpetre. [Experiment.]

Now, this gun cotton ignites at a very much lower heat than gunpowder, which will not inflame at a heat lower than that at which sulphur begins to burn, about 560 degrees on Fahrenheit's scale, and will then only ignite gradually. Gun cotton will ignite at a temperature of about 300 degrees Fahrenheit, which is still a high temperature, though very low as compared with that at which gunpowder inflames. I will heat a small quantity of this gun cotton in a tube, which I have lightly closed with a cork. You see in how very short a time the gun cotton ignites, with a slight explosion, accompanied by a sudden flash of flame, which I daresay many of you did not see, as you were not prepared for it.

There is another peculiarity about gun cotton when compared with gunpowder, namely, that it is comparatively readily ignited by a blow. I say comparatively, because, though

it is really not very readily ignited, it is much more easily exploded in this way than gunpowder. I will wrap a small quantity of gun cotton in this piece of tinfoil, for the purpose of confining it, and then give it a smart blow, after a gentle tap or two, and we shall hear a loud noise, showing that the gun cotton has exploded. In order to insure the production of this most highly explosive gun cotton the nitric acid used is first mixed with a large proportion of the strongest oil of vitriol, or sulphuric acid. The effect which this has is twofold: firstly, the nitric acid itself is rendered stronger, as will presently be shown, and, secondly, the oil of vitriol appropriates water which is set free during the production of the gun cotton, and which, were it not so appropriated, would reduce the strength of the nitric acid. Oil of vitriol is very greedy of water, and if exposed to the air the oily liquid gradually becomes thinner and thinner from the absorption of moisture which exists in the air. If we mix this liquid with strong nitric acid (which, however, still contains water), it is made stronger still, because the water goes by preference to the oil of vitriol.

I will dip this cotton wool into a mixture of nitric acid and oil of vitriol, and take care to keep the mixture quite cool. This is necessary, because when any chemical change takes place heat is developed, and it is necessary to remove this heat by keeping the mixture cool, in order that the heat may not establish other chemical changes. You have seen that heat has the power of establishing violent changes.

The cotton sustains no change in appearance by this treatment, as I have said, but it has greatly increased in weight. A definite quantity of water is set free from the cotton, which consists of carbon, hydrogen, and oxygen. A corresponding quantity of the nitric acid elements pass into its place, weighing much more than the water displaced. In this way a large quantity of oxygen is introduced into the cotton, which is ready at any moment, when the necessary impulse is imparted, through the agency of heat or a blow, to form comparatively simple gaseous compounds with the carbon (or charcoal) of the cotton wool. At the moment of such change the hydrogen and oxygen contained in the cotton are liberated as vapour of water, and the nitrogen from the nitric acid escapes as gas. This is how cotton becomes transformed into an explosive substance.

If we employ a weaker nitric acid (or acid mixture) we shall obtain gun cotton of a less explosive character, as I think you will see when I set fire to this particular kind of gun cotton which has been produced by weaker acid from cotton wool. You see that that is a very poor explosive substance as compared with the first sample. This less explosive gun cotton possesses, however, some peculiar and valuable properties. It is readily soluble in a mixture of ether and spirit, or alcohol; which mixture has no effect upon ordinary gun cotton. I add some of the mixture to the less explosive gun cotton, and you see that it is nearly dissolved already.

The liquid I obtain in this way is that valuable preparation known as collodion, which, besides having important medical uses, is an invaluable agent in photography. When we allow the solvent to evaporate, the gun cotton is deposited in the form of beautiful transparent films, of which I have specimens here. You see they are only very slightly explosive. This substance is used for the production of transparent films upon glass plates or paper, so as to make them sensitive to light, through the aid of certain chemicals which are dissolved in it. I shall have an opportunity at the close of the lecture of showing you illustrations of this application of one of the forms of gun cotton.

Now, when the German chemist discovered the facts I have named, he saw at once that the highly explosive gun cotton might become a very useful material if its explosive power could be tamed. I say "tamed," because, as you have seen, it is a very violent explosive substance. Schönbein saw that if it could be tamed it might possess considerable advantages over gunpowder, from the fact of its leaving no residue, whilst gunpowder leaves a quantity of dirt, and from the fact of its giving no smoke. It also appeared to promise other advantages; but neither its German discoverer, nor the English and French chemists who at that time experimented with it, were able to realise their anticipations of making it take the place of gunpowder. Amongst the earliest experimenters and manufacturers of gun cotton were the great powder-makers, Messrs. Hall, of Faversham, in Kent. They established works for its production, and made some attempts at its application. They soon observed that gun cotton was too bulky, and that if it was to be utilised it must be compressed. They did not probably fully appreciate the full importance of their endeavours in compressing gun cotton into a small space. Here is a cartridge made by these gentlemen in 1846. It is a case like a Roman candle, made of paper, and rammed very tightly with gun-cotton wool, compressed to such an extent that this case is very heavy, and weighs nearly as much as it would if filled with gunpowder. Well, by this act of compression very important

results were attained, for compression at once modifies the character of gun cotton as an explosive agent. You probably will laugh at me when I say that if we compress this violently explosive material sufficiently, we can make it non-explosive—that is, stop its burning altogether. I will try to show you this, but I do not know that I shall succeed. I have here a piece of gun cotton, which I will compress very firmly at one part by means of this card, and then set fire to it. You see, burning stops at the point where I have compressed the gun cotton, and the rest of the piece is all safe. This proves that if I sufficiently compress gun cotton it will stop its burning. I shall have to inquire directly into the cause of this. I must first finish the history of gun cotton in its first form, that of wool, by telling you that, although its discovery was received with great enthusiasm by military men in England and France, and to some extent also in Germany, factories being established for its production upon a large scale, with a view to test its applicability for all kinds of purposes, a number of serious accidents, attended by loss of life, occurred within a short period, and there arose in consequence such mistrust of the character of the new explosive agent, that within two years of its original discovery its manufacture and the attempts to apply it as a substitute for gunpowder were utterly abandoned.

The fact is, that at that time the makers of gun cotton were unaware of the great importance of thoroughly purifying the substance in order to ensure the permanence and stability of its character, or its freedom from such liability to undergo changes, which might lead to its spontaneous explosion, as to enable it to be as safely handled as gunpowder. If a small quantity of free acid is allowed to remain in gun cotton, this acid will, after a time, begin to exert chemical action, or carry on the action which was interrupted by the washing of the cotton; and this action will proceed until the gun cotton loses its original properties altogether and passes into a kind of gum, of which I have a specimen here. This is gun cotton which was made about ten years ago by an operator who did not understand this very important matter of thoroughly purifying the cotton, and it has consequently passed into the gummy material which you see. But this change or decomposition of the gun cotton does not always proceed harmlessly as in this particular instance. All chemical changes, as I have already reminded you, are attended by the development of heat. Now, if gun cotton be closely packed in boxes containing many pounds each, the heat which is developed can only pass off very slowly, the gun cotton being a bad conductor of heat. Hence the contents of a package becomes warmer and warmer, until eventually the heat may accumulate sufficiently to lead to spontaneous ignition of the substance. This is what occurred during the early history of gun cotton, and also at later periods. One of the most dreadful of these explosions which occurred with gun cotton was at Faversham, and originated in the spontaneous development of heat in the gun cotton, owing to its imperfect purification. Gun cotton was therefore set aside altogether for a long time in England and France; but in Austria there were two or three men who still believed in the future of gun cotton, and amongst them was an officer in the Austrian artillery—General von Lenk—who had experimented with it on its first discovery. This officer considerably improved the manufacture and purification of gun cotton, and the modifications which he eventually introduced into the mode of applying it to the various purposes for which gunpowder is used were most ingenious, although they did not lead, as was at first expected, to its superseding gunpowder in any one direction.

I have pointed out to you that by sufficiently compressing gun cotton I can stop its burning altogether. I will now show you a few experiments with gun cotton in different mechanical conditions, in order to illustrate the nature of the improvements which were believed in Austria to have been made in its application. Here we have some loosely-spun yarn or roving, which has been converted into gun cotton. Of this piece I have simply twisted one-half a little tighter than the remainder. I hope to show you by this that the tighter twisting of one part has an important effect upon the rapidity with which this cotton will burn in the open air. I shall apply a light to the centre of this train of gun cotton, and it will burn more rapidly towards one end than the other, because it has been less tightly twisted in that direction.

I have some gun-cotton roving here of two different degrees of coarseness, and I want you to observe that in burning it will behave differently, though the same source of heat is applied to both specimens. These two pieces of gun-cotton yarn I will not ignite with flame, as in the first experiments, but by means of a spark. This piece, which is very loosely spun, burns with flame, you see. I light the other piece, and it does not burn as the former piece did, but only appears to smoulder. Perhaps you will say, "How do we know that it is gun cotton?" In order to show you that it really is gun cotton, I will light the other end with a flame, and you see it burns like the other piece did, though, as it is not so thick, it does not produce so large a flame. Now

to what is due this remarkable difference between the two pieces of gun-cotton yarn? They were both lighted in the same way. It is simply due to this, that one kind of cotton is more closely twisted than the other; and the reason why this very trifling difference makes so great a difference in the behaviour of the gun cotton will, I think, soon be evident to you. When we burn gun cotton in the open air we see a bright flash of flame; but if I burn it in such a way as not to allow the gas developed by its explosion to pass away at once, by igniting it in this large glass jar, you will see, if you will be kind enough to watch closely, that there are really two stages in the burning of this gun cotton. We first see the bright flash of flame, and afterwards we see a comparatively pale flickering flame linger in this vessel.

Now, in gun cotton, as in gunpowder, the carbon, as I have told you, is burned by means of the oxygen derived from the nitric acid; but we have not been able to devise any means of introducing into the composition of gun cotton sufficient oxygen to burn the carbon *thoroughly*. If we do not burn the coal in our grates completely we do not obtain the maximum of heat, converting the carbon into the well-known gas carbonic acid—we obtain a partly-burnt product, the inflammable gas called carbonic oxide. In the case of gun cotton, as we cannot introduce enough oxygen to burn the carbon entirely, we produce by its decomposition a quantity of the inflammable gas carbonic oxide. When we set fire to gun cotton in open air, a considerable part of the body of flame produced is due to this gas, which is at once ignited by the flame of the gun cotton, adding to the volume of the flame and promoting the rapidity of burning of the gun cotton. In the case of a lightly twisted yarn, this burning gas insinuates itself amongst the fibres of gun cotton contiguous to the burning part, and thus promotes rapidity of combustion. But if we twist up the gun-cotton yarn so that this gas cannot penetrate between the fibres, but must pass away only in one direction, namely, in a direct line with the burning surface of gun cotton from which it is given off, the gun cotton is no longer, after the first application of heat, maintained at the temperature necessary for its rapid combustion, and the gas, in turn, is not supplied with the heat necessary for its ignition, while, as it escapes, it carries away heat from the burning part of the gun-cotton thread, and thus still further retards the rapidity with which this burning proceeds. A few experiments will illustrate this better than any amount of speaking. Here is a long piece of this comparatively tightly-twisted cotton yarn, and I will set fire to one extremity by means of a flame in the usual way.

But I will first pass it through a perforation which I make in this card. These experiments take a little time preparing, but I think they are much more instructive when prepared in view of the audience, because you see the whole of the proceeding. Having pulled the piece of yarn partly through the perforation of the card, I lay it flat upon this board, inserting the further end into this small tube. I will tell you beforehand what I hope will take place, because the experiment wants watching. When I set fire to the gun cotton by means of the flame it will burn rapidly, but when the flame reaches that part which is passed through the card, I hope that the gun cotton will at once cease to burn with a quick flame, and will then burn on the other side of the card with a very small tongue-like flame; and for this reason, because the flame having to pass through that perforation, the burning gas is prevented, for an instant, from surrounding the burning cotton, and therefore this is not heated to the same extent, and the gas is extinguished; hence the gun cotton passes from quick to slow burning. I allow it to continue to burn in this slow manner into this tube, and I think I shall be able to show you that as it burns slowly in that tube, I shall be able to light the gas which is disengaged and is retained within the tube. There is the gun cotton burning quickly, and there it is burning slowly; and now the gun cotton is burning slowly within the tube and the gas is burning at the opening. I will give you this experiment in another form—a very simple one. Its success will depend upon steadiness of hand. I am going to light this gun cotton, and will try if I cannot brush out the flame of *the gas* with my hand; that is, not extinguish the gun cotton, but make it pass from quick to slow burning.

This is so tempting a subject for experiments that I cannot help giving you various illustrations of it. I take a little piece of *compressed* gun cotton (of which I shall have something further to say directly) and put it inside the lower end of this long open glass tube, which is held in a vertical position. Now I will ask Dr. Roscoe to be so good as to give me that heated iron I used just now. I am going to light this, but to make it burn only slowly, which I can do by touching the upper surface of the confined pellet of gun cotton with the hot rod of iron. Now the gun cotton is burning at the bottom of the tube, and you see I can inflame the gases evolved from it by applying a light to the upper end of the tube. There is a tall pale flame produced, as you see, while the gun cotton itself is burning at the bottom of the tube.

Let me now tell you the bearing of these experiments.

General von Lenk, the Austrian officer, found that if he twisted gun cotton up tightly it burned more slowly than if he had it loosely twisted; so by winding it more or less tightly on reels, such as I have here, he was able to control its burning in the open air to a very considerable extent. He concluded that if it burned comparatively slowly or gradually in the open air it would do the same in a confined space. Here are specimens of the forms in which he proposed to use gun cotton. Here is a cartridge made for artillery purposes, and the cotton is very tightly twisted, so that it may burn slowly. By this arrangement it was expected that we should no longer have that violent action in the gun which precluded the use of gun cotton for artillery purposes. Here it is twisted up in another way, with a hole in the centre. Here is a loose hollow plait, which will allow the gas to permeate readily between the threads of the plait, and thus cause the gun cotton to burn very quickly. I will take a small piece of this plait and show you the contrast in its burning with that firmly-twisted yarn which you saw just now. This will burn, comparatively speaking, moderately, and when its flame reaches the plait you see the latter bursts into flame suddenly with explosive violence. Unfortunately, it proved in practice that Von Lenk's method of arranging gun cotton, in the form of tightly-wound reels or balls, was of no real practical value. When these were confined in a gun there was little or no retardation of the burning, for then the pressure developed by the confinement was always sufficient to bring about a rapid penetration of the burning gas into the centre of the tightly-twisted gun cotton, which, therefore, burned nearly as rapidly as if the gun had been loaded with gun-cotton wool. Moreover, in those forms of gun cotton which were so arranged as to burn most quickly, he did not get over the difficulty that it was necessary to confine the gun cotton very closely, in order to develope its explosive power thoroughly.

The Austrian experiments, however, led to the study of gun cotton being resumed in this country ten years ago, and the result of numerous experiments led to the conclusion that the system of arranging gun cotton which I have described could be advantageously superseded by another plan, which secured a much more thorough and uniform compression of the material. Upon the principle that the more nearly we convert the substance into a thoroughly solid, compact mass, the more thoroughly we must be able to control its action, it was proposed to convert gun cotton into as dense and compact a state as gunpowder.

For this purpose it was necessary to reduce gun cotton to a very fine state of division. This was done by very simple means, and the new mode of preparation at once led to an important cheapening of the gun cotton. In preparing gun cotton according to the Austrian process it was necessary to use very long staple cotton, which, I need not tell a Manchester audience, is a comparatively very expensive article, in order to obtain the right description of roving. But to obtain gun cotton suitable for conversion into a fine state of division, we were not compelled to use long staple cotton, but were enabled to use the cheapest description of manufactured cotton, namely, common machinery waste. I need hardly tell you that we buy this cotton waste in Manchester at a very low figure indeed as compared with the price of long staple cotton. We found no difficulty in converting cotton waste into gun cotton, by steeping it in the mixed acids at a low temperature, as readily and perfectly as we could long staple cotton. In purifying the gun cotton thus obtained, a variety of improvements in washing were elaborated. The washed gun cotton was then passed through the ordinary machine used to tear up rags and fibres into pulp for paper-making, and in this way it was obtained in the requisite finely-divided condition. Here is gun cotton reduced to this fine state of division; it corresponds exactly to paper pulp, but it is explosive. Here is some dry. I place a little of it upon a plate, and apply a heated iron; you see there is no doubt about its being gun cotton. In this fine state of division it burns very rapidly. Having obtained it in this form we have it in a condition readily convertible, by compression in powerful hydraulic presses, into solid masses of any shape, such as cylinders, triangles, or cubes of any required density or hardness; indeed there is no difficulty in thus converting gun cotton into masses nearly as hard as gunpowder. This process also enabled us to convert gun cotton into the form of paper, and into granulated gun cotton for sporting purposes. Here we have gun-cotton paper, and here are gun-cotton grains.

I may give you other illustrations of the value of this particular way of manufacturing gun cotton. By incorporating the finely-pulped gun cotton with saltpetre and similar salts, we can obtain comparatively cheaper mixtures, which can be compressed like ordinary gun cotton, and a given weight of which will be equal, in explosive force, to the same weight of the pure, more expensive gun cotton. If we want to make gun cotton for the use of small arms less explosive and violent, we may dilute it with common paper pulp. This is a piece of gun-cotton paper used for making sporting cartridges. It burns slowly, because it is mixed with a

certain quantity of ordinary paper pulp. We can also convert it into light cylinders or grains, and impregnate these with paraffin, or indiarubber, or stearine, or even with sugar, as Mr. Punshon does, in order to retard the rapidity of their explosion. In this way gun cotton can be made more controllable for small arm purposes, but we have not yet been able to tame it sufficiently to allow of its being used with any degree of confidence in great guns. The attempts made up to the present time to moderate its action have only been partially successful in the smallest cannon, and there appears no prospect whatever of our taming it sufficiently for use in larger guns.

I have here a diagram representing different kinds of gunpowder now in use, and here are also specimens of the different descriptions used for heavy artillery. Twenty years ago these small grains of powder represented the cannon powder in universal use. Then we began to build larger guns, and after some time this larger-grained powder was introduced as a safer powder to use in such guns. Powder burns rapidly in proportion to the size and density of its grains or masses, and the fine powder was found to act injuriously upon the big guns, although we had then only got up to the 100-pounder Armstrong gun. We considered we had taken a great stride when we passed from that small grain to this larger grain; but rapid progress was made in developing the size of our artillery, and it was found necessary to pass from grains of powder to pellets or pebbles and prisms of powder—that is to say, we converted powder into masses, which burned, comparatively speaking, very slowly when ignited in the air, but which, when ignited in charges of 80 to 120 lbs., still burned very rapidly in the gun, and produced occasionally an unduly violent action, which it was desirable to moderate. We are talking of building very much bigger guns than the 35-ton gun, which requires a charge of powder weighing 120lbs., and we shall therefore want a much tamer powder for those guns. I am consequently pretty certain that, as far as big guns are concerned, gun cotton has no future; but as regards other very important uses, its future is already thoroughly secured. Now, to show you how this has come about, I must endeavour, in the next twenty minutes, to discuss what I regard as the most interesting subjects of this lecture.

Let me call your attention for a minute to this viscous sugar-like substance which is obtained as a secondary product when oils or fats are converted into soap, and to which we give the name of glycerine. Soon after the discovery of gun cotton it was found by an Italian chemist that when this substance was acted upon by nitric acid, or its mixture with oil of vitriol, it was converted into a powerful and explosive material even more violent than gun cotton, which he called nitro-glycerine. I have a little of this substance here in a safe condition, dissolved in a spirit obtained by the distillation of wood: in this form we can carry it about safely. If I pour it into this water you see there is a cloudiness upon the water, caused by the separation of the nitro-glycerine, in consequence of the spirit becoming diluted. We will allow it to stand there for a short time, when a small quantity of a heavy liquid will collect at the bottom of the vessel. This liquid is the powerful explosive substance called nitro-glycerine. It detonates even more readily than gun cotton if struck; but burns quietly when simply inflamed.

It was a long time before this substance was looked upon otherwise than as a chemical curiosity. But a Swedish engineer, Mr. Nobel, conceived the idea of substituting it for gunpowder, as a more powerful explosive. First of all he mixed it with gunpowder and exploded it in strong vessels, but the action was uncertain. Eventually he hit upon the idea of exploding it by means of a large percussion cap. He imbedded the cap in the centre of the substance, and he found by then detonating the cap he could explode the material violently. Now what holds good in this respect with regard to nitro-glycerine holds good equally with respect to gun cotton. If we place it into close contact with a powerfully detonating substance, such as fulminating mercury, we can by the explosion of the latter develope the violently explosive properties of gun cotton without in any way confining it, provided the latter be in a sufficiently compact compressed form. When we explode a detonating cap or tube in contact with compressed gun cotton, we hit some portion of it a violent blow, which blow suddenly converts the particle of gun cotton surrounding the cap or tube into gas. The force thus developed is transmitted almost instantly to every other particle; and thus the mass may be detonated with extreme velocity, and with the development of its full explosive form, without any confinement whatever. Thus, instead of having to confine our gun cotton in strong shells or boxes, as was formerly the case, we have now only to lay it against the stockade, or place it in a building, quite unconfined, or under a ship, and its explosive property is effectually developed by means of detonation. But this detonation or blow must be of a certain kind. Although we can detonate gun cotton readily by means of fulminating mercury, some other substances which make

as much noise and appear as destructive will not develope the same action, unless used in overwhelming quantities.

I have here two illustrations of the extraordinary effects developed by detonating gun cotton. One diagram represents part of a fortification at Portsmouth, which it was desired to remove. It was a solid mass of masonry, 5ft. to 7ft. thick, and 250ft. long. Inside the gallery we placed 66lbs. of gun cotton, quite loose, against the wall. You see there are a number of loopholes and places of escape for force, and there was a large door at each end, closed in with wrought iron gratings. This gun cotton was detonated by means of a large percussion cap, or tube, and the result of that detonation was the heap of ruins you see represented there. The most curious part of the affair was the effect of the tremendous rush of gas which took place and caused the destruction of the other end of the mass of masonry. This kind of action could not have been attained without gun cotton, or a similarly violent material; and if it had been placed in the centre of the gallery the whole would have been demolished. Here we have another illustration of the explosive effects of gun cotton. It was an experiment tried upon one of the Martello towers put up for the defence of our coast against the French. A charge of 180lbs. of gun cotton was placed upon the floor of this building, the walls of which were 7ft. to 12ft. thick. Upon the ignition of the cotton the tower was transformed into the heap of ruins you see pictured there.

This will give you an idea of the force developed when detonation is applied to gun cotton. I have lately had the curiosity to examine into the rapidity with which this detonation is transmitted or propagated from one mass of gun cotton to another; and this I was enabled to do by the employment of a most ingenious and important instrument, devised by a late officer in the Artillery, Captain Noble, for determining the velocity with which a projectile travels along the bore of a gun. By means of this instrument, called a chronoscope, it was proved that the rate at which a detonation travels from particle to particle of compressed gun cotton, whether the mass be large or small, ranges between 17,000 and 19,000 feet in a second; that is to say, the mean velocity of its detonation is rather more than 200 miles in a minute, which is just the distance from here to London; so that, if we imagine a continuous train load of gun cotton reaching from here to London, the detonation would be transmitted to London in one minute after it had been started here. Now, that is an extraordinary velocity; though it is small as compared with that of electricity, which travels at the rate of about 288,000 miles per second, it is a remarkable speed compared with the velocity of sound, which travels only at the rate of about 1,100 feet per second.

And now I must tell you with regard to this detonation, that it is essential to its successful development that the gun cotton should be in a dense, compact, or compressed condition, so that its particles may be in a position to resist tendency to motion when they are exposed to a blow or concussion. If I hit this piece of gun-cotton wool a single blow on the anvil, I am not able to detonate it, because the force of the blow is greatly expended in causing the loose fibres to move; but when the gun cotton has thus been rendered compact, its detonation by a blow is readily accomplished; consequently the more highly gun cotton is compressed, the more sensitive it is to detonation. Loose gun-cotton wool, or even gun-cotton yarn, very tightly wound, cannot be detonated in the open air by means of even a very powerful detonating cap or fuse, but compressed gun cotton is able to resist the tendency of detonation to break it up mechanically and disperse it; therefore, it is disintegrated chemically or blown into gas. You see, therefore, that this compression of gun cotton has led to very important results.

I must briefly point out to you a few more illustrations of the effects produced by this plan of exploding gun cotton by detonation. Here are some wrought iron plates, one inch thick, which were fractured by detonating four ounces of gun cotton, placed upon the upper surface; and this strong piece of railway-bar was broken, as you see, both across and lengthways, also by the detonation of four ounces of gun cotton. This large cylinder of wood represents a solid mass of iron, with a small perforation in the centre, which was blown in all directions by four ounces of gun cotton just inserted into the perforation.

One important point I should call your attention to with regard to compressed gun cotton—that is, the safety of its manufacture. I told you just now that after we have produced gun cotton from cotton waste—which is a perfectly safe operation—we wash it thoroughly—that is, of course, a safe operation; so is that of reducing it to pulp in the common rag-engine, the gun cotton being there mixed up with many hundred times its volume of water. Then the pulped or finely-chopped material is washed in a very much larger quantity of water, which is a thoroughly safe operation. After that it is pressed at a low power, and is then converted into these compact forms in a very powerful press. When

it comes out of that press the gun cotton is so wet as to be uninflammable, and these pressing operations, with proper machinery, are perfectly safe. You have seen how readily gun cotton burns when a heat, even much below that of a red-hot iron, is applied to it. Now, here I apply a red-hot iron to a disc of the gun cotton, in the damp condition, as we obtain it after it has been pressed, and I think you will admit that, in this condition, it is evidently by no means dangerous. I am boring a hole in it by means of the red-hot iron. You must take my word for it that this is gun cotton; but I am now putting my mark upon it, and as it has become an historical specimen, through having been operated upon in your presence, I shall hand it to my friend, Professor Roscoe, that it may be placed in the museum of Owens College in recollection of this lecture. No doubt he will find, when this disc is dried, that it is very good gun cotton indeed. And now I think you have an indisputable illustration of the safety of wet compressed gun cotton; but I can give you other illustrations of it. Here I have a sort of Chinese puzzle made out of a gun-cotton disc. All these various pieces have been cut out of the entire disc by means of an ordinary circular saw while the gun cotton was wet. Here is a disc of the kind made for holding the detonating fuses in submarine mines. The fuses fit into these holes and are fired by electricity. These perforations are cut into the gun cotton by drilling machines, which rotate at a speed of about one thousand revolutions per minute. So that you see we are able to do almost anything with gun cotton when we have it in this wet condition. Instead of storing our gun cotton in strong magazines surrounded by moats and guarded jealously by sentries, we pack it in the wet state into bins, very much like corn bins, which are lined with pitch inside to prevent the evaporation of the water. We can thus store many tons of gun cotton in ordinary buildings without fear. In order to determine whether wet gun cotton might thus be stored without danger of explosion, even in case of fire, the Government lately had erected two strong buildings and stored in each of them one ton of gun cotton. After filling up these buildings with combustible material this was set fire to. A fierce fire raged in each building for two hours, and the gun cotton all that time was gradually smouldering away—that is to say, as the outer portions of the discs dried a little they burnt away very quietly indeed, as you saw just now when I applied the hot iron to the damp gun cotton, and at the end of the two hours there was nothing left but the walls of the buildings and the iron bars upon which the packages of gun cotton had rested, and which had become bent by the heat. From the above it is concluded that we may store gun cotton wet with perfect safety, and postpone the drying of it until the dry material is actually required.

Well, I intended giving you much more of the history of gun cotton, but, as is usual with lecturers, the time has slipped by too rapidly. I have endeavoured to make my explanation clear and my experiments successful, hence my time has not reached so far as I had hoped. I must not detain you much longer, but I would like to say a few words more about the force of gun cotton. The effects produced by its detonation, which I described to you just now, were all obtained with *dry* gun cotton. But we have recently found that we can use it in a *wet* condition as an explosive agent, and that, if simple measures be adopted, it is, if anything, rather stronger in this state than if dry. All we want is a small piece of dry gun cotton to give the wet cotton a sufficiently sharp blow to cause detonation, and then, when detonation is once established, it proceeds more rapidly with wet than with dry gun cotton, the reason being that the air spaces in the compressed gun cotton are filled up by water, which is practically incompressible; hence the gun cotton is more solid or compact when wet at the moment it is hit the blow than when dry, and it therefore yields less to the blow, consequently the detonation progresses at the increased rate of 18,000 to 21,000 feet per second, or about 240 miles per minute. If we want to demolish a strong building, all we have to do is to put this wet gun cotton on the floor, and place in contact with it a small piece of dry gun cotton containing the detonating fuse. If we want to use gun cotton to remove a wreck or sunken rock, or to blow up a ship, we can place the charge in a bag, or even in a fishing net, so that the water can penetrate the whole of the cotton. Results have been obtained as violent, as regards destructive force, by gun cotton thus confined as when placed in the strongest cases we could use. I think you will concur with me in the opinion that these results are very remarkable.

Lastly, it has lately been found that detonation of gun cotton, and of other explosives, may be transmitted through considerable distances by very simple means. I did hope to show you an illustration of this—and I have given my friend, Mr. Harrison, a great deal of trouble to prepare a voltaic battery for this purpose—but I really cannot detain you longer. (Much applause.) You give me so much encouragement that I think I must really show you one experiment on the transmission of detonation.

I have here a substance called the fulminate of silver, which I can deal with in a lecture more readily than with gun cotton, because I can produce the desired results with much smaller quantities of it than I should have to use of gun cotton.

If I were to take one of these small discs of gun cotton, weighing about an ounce, and were to place it in one end of a gas-pipe three feet long and one inch and a quarter in diameter, introducing another disc into the other end of the tube, by detonating the one at this end I should also detonate the one at the other extremity of the tube. If I were to attempt to detonate one disc by another at this distance, in the open air, I should utterly fail. It would be necessary to put these discs of gun cotton not more than about half-an-inch apart. I will illustrate the power of a tube to transmit detonation by means of this glass tube three feet long, using, instead of an ounce of gun cotton, only three-fourths of a grain of fulminate of silver, which I insert into one end, placing a similar quantity of the fulminate in the other extremity. By means of this battery I hope to be able to detonate this fulminate of silver, and to show you that the detonation is transmitted from it to the fulminate at the other extremity. [The explosion shattered the tube at both ends.] Here are two similar quantities of the fulminate placed upon a plate of metal only four inches apart; you see that when I detonate one the other heap remains unaffected.

I must now somewhat abruptly conclude this long lecture, thanking you most heartily for the patient attention you have paid me, and expressing the hope that the small and imperfect history I have given you of gun cotton will have sufficed to excite some interest in your minds for a substance which, during the 27 years of its existence, has passed through very many vicissitudes. Received at first with enthusiasm, too much was expected of the ill-matured discovery, and it soon fell into disrepute, only one or two patient workers clinging to it through all evil repute, and not losing faith in its ultimately proving a really serviceable material. Its study being resumed in England ten years ago, at a time when it was being abandoned even by its staunchest friends, the Austrians, its most valuable properties began to be really developed for the first time, and it was rapidly growing into great importance, when the accident at Stowmarket, two years ago, once more shook the general faith in the reliability of the substance as a safe explosive agent. Fortunately the cause of that accident admitted of being most thoroughly investigated and cleared up, and was proved to be in no way connected with any liability to spontaneous decomposition of the material as now manufactured. Fortunately, also, the two or three who had battled for gun cotton during the few previous years did not lose heart in consequence of this sad accident, and were not deterred from further efforts by shakes of the head and shrugged shoulders, by the "I told you so" of wise friends, the petty malignity of others who chose to constitute themselves foes, or the worse than discouragement where encouragement should have been hoped for. And thus it has come to pass, that in spite of all casualties, all discouragement, and all forebodings to the contrary, gun cotton has now attained an unassailable position as one of the safest and most efficient of explosive agents.

I think you will agree with me that we are taught by this history of gun cotton the very wholesome lesson never to allow ourselves to be deterred by difficulties and adversity, however severe, from steadily pursuing any labour to which we have once devoted ourselves as being worthy of our energies. Even if we fail to realise our anticipations of the immediate value and importance of our work, depend upon it our labour will not have been in vain, but will in time bear lasting fruit, by having contributed to the advancement of knowledge and the development of truth.

And now let me, in conclusion, endeavour to show you the difference between the ordinary burning of gun cotton and its detonation.

Professor Abel then took a disc of gun cotton and set fire to it. The cotton burned a considerable time, with an intense light and considerable heat. This experiment illustrated that gun cotton could be made to burn steadily in open air, and that it was under perfect control. The cotton burned weighed nine ounces. The lecturer remarked that had as many hundredweight been ignited in a heap its burning would most probably have raised some portion rapidly to the heat at which it would explode.

The last experiment consisted in using a small charge (about one-fiftieth part of the weight of the disc) and firing it with a large percussion cap exploded by electricity. The result was what the lecturer termed a "respectable explosion," the concussion being a very sharp one, and a brick, upon which the little charge rested, being shattered by the explosion.

ANIMAL MECHANICS.

A LECTURE, Delivered in the Hulme Town Hall, Manchester, on Wednesday, November 26th, 1873.

By S. M. BRADLEY, Esq., F.R.C.S.

THERE is nothing of which we are so justly proud as our mechanical inventions, yet every time a sparrow hops from a house-top we have an illustration of animal mechanics, which both in the construction of the machine and the mechanism of its movements transcends man's mightiest achievements.

Now I purpose this evening taking a single illustration from the rich and wide domain of animal mechanics, but this perhaps the most beautiful, as it is the most complicated, of them all—I mean the flight of a bird. If the phenomenon of flight were a novelty—if we had never seen a bird fly, and were suddenly to see, say, an eagle dart through space from the bosom of the blue empyrean to the level of the green sward, there turn with the rapidity of lightning and soar straight up to the sun again, we should somewhat wonder at the liberties taken with the laws of gravitation, and should try to puzzle out how the thing was done—to find out, in a word, what the animal mechanics were. This is what I hope to find out, with your help, this evening.

Now the first thing we notice about a machine is its shape. Let us then first examine the shape of the bird, and then the nature of the moving power.

The general shape of a bird is something like the shape of a fish; the object being the same in both, namely, to offer as little resistance as possible to the medium—whether it be air or