to pass a continuous current through the film from its first formation. The measuring current was small and intermittent.

No. of cells.		Apparent thickness of black film, measured electrically, in $\mu\mu$.			
0	...	150	171	148	150
14	...	155	145	142	
28	...	150	157	179	

The conclusion to be drawn from this table was confirmed by experiments in which transient currents from a Ruhmkorff induction coil were employed; they leave no doubt that the passage through a film of such electrical currents as we have used has no appreciable influence on the phenomenon under discussion.

To determine the possible influence of carbonic acid, or of oxygen, absorbed from the surrounding space comparative experiments were made. The apparatus not being air-tight, the plan was adopted of allowing a stream of air carefully freed from CO_2, or of pure oxygen, as the case might be, to flow through the film-box. The results obtained under these conditions, though in some respects not quite satisfactory, justify the assertion that neither the total (or almost total) absence of CO_2 nor a large increase in the quantity of oxygen in the neighbourhood of the film produces any appreciable change in the specific resistance.

It thus appears that a number of possible causes, to which the increase in the conductivity of a thin film might be due, prove on examination to have little or no influence. Although a satisfactory explanation is not at present possible, it will probably be found to depend upon the connection which subsists between the chemical constitution of a film and the surface forces which are brought into play, or are modified by its tenuity. Prof. J. J. Thomson ("Applications of Dynamics to Physics and Chemistry," p. 234) has drawn attention to this connection, and has shown that under certain conditions the chemical action in a thin film throughout which the forces producing capillary phenomena are active, may be totally different from the chemical action in the same substance in bulk. The experiment of Liebreich (*Berlin, Sitzungsberichte*, 1886) is often cited as illustrating this point. When solutions of chloral-hydrate and sodium carbonate are mixed in suitable proportions in a glass tube, chloroform is slowly precipitated as an opaque cloud. Close to the surface, however, and from 1 to 3 mm. below the surface, there is a space perfectly clear and free from chloroform. It is supposed that in this space either the chemical action does not go on, or that if it does chloroform is not deposited. The explanation is not very satisfactory, and in any case the "dead space" is too large to justify us in referring it solely to the action of surface forces. Again, there is no doubt that the surface of a film becomes altered by the action upon it of the surrounding medium, so that the outer layers have different properties from the rest of the liquid. Lord Rayleigh has shown that the surface tension of a soap solution when the surface is new is nearly the same as that of pure water, but diminishes rapidly by exposure to the air. Reinold and Rücker have proved that the surface tension of a cylindrical film is increased by giving the film a new surface (letting fresh liquid flow over it) and that from ten to fifteen minutes elapse before the old value is regained. Other properties of the surface-layer besides its tension may be modified where it is very thin, and the electrical conductivity may be very different from that of the interior liquid. Although the peculiarities of the surface-layer certainly are in some way connected with the main facts here considered, we have shown that they cannot all of them be explained by the simple theory of the formation of a pellicle of different conductivity from the rest of the film.

It is difficult to assign a reason why the addition of salt to the liquid should produce so great a change in the results. In part, the better conducting salt probably masks effects which, when soap alone is used, become predominant; but it is likely that, in part at all events, it actually prevents the changes to which the change in conductivity is due.

The optical method of investigation illustrates the controlling influence of the metallic salt when present in the solution. As we saw above, a small variation in the proportion of dissolved soap has a large effect upon the thickness of the black when no salt is present; but the quantity of soap may be doubled without influencing the thickness, provided the solution contain 3 per cent. of salt. A. W. REINOLD.

SPONTANEOUS COMBUSTION.[1]

WHEN an inflammable substance ignites or becomes incandescent without the application of fire or other apparent cause, it has been customary to speak of it as spontaneous combustion, a term which I think I shall be able to show you presently does not correctly express the actions which lead to this apparently mysterious result.

Early in the eighteenth century a woman was found burnt to death under circumstances which gave no clue as to the cause of the accident, and in order to satisfactorily explain her death, the theory of spontaneous combustion was devised by the experts of the day, and was generally accepted at a time when little or nothing was known of what takes place during the process which we know as combustion; but as the years rolled on, men's views upon this important subject became wider and more exact, until, in the latter part of the last century, the great French philosopher Lavoisier, partly by his own experiments, and partly by the teachings of the work done by others, gave us a true knowledge of combustion and the changes which take place when a body is burnt, whilst the commencement of this century marked still further the advance of our knowledge in this direction, and also as to the conditions necessary for continuing the combustion or burning of any inflammable substance.

We now know that from the nature of combustion it is impossible for the human body to undergo spontaneous ignition or combustion in the way in which the novelists and scientific experts of the last century believed possible, but there are few amongst us who have not heard of, and even come across, cases in which large masses of coal, small quantities of oily rags, or waste, and hayricks which have been made from grass stacked before it was thoroughly dried, have ignited without any apparent cause, and have kept alive in our minds and on our tongues the term "spontaneous combustion"; and you must pardon me if I commence my lecture this evening by reviewing the teachings of Lavoisier's classical work, and then apply the conclusions we arrive at to those cases of spontaneous combustion which we meet with in our daily work.

The theory of combustion which was generally accepted during the last century, was that every combustible body contained within itself the products of combustion combined with a "something" called phlogiston, and when the substance was burnt, this phlogiston escaped, giving the flame or incandescence of combustion, whilst the products were set free. This theory could not, however, for long stand the test of exact experiment, and as soon as Black introduced the balance into scientific research, it was found that when any substance underwent combustion, the products weighed more than the body before it had been burnt, the reverse of what one would have expected had the phlogistic theory been correct.

During the last century lived Joseph Priestley, one of the most remarkable men this country has ever claimed as her own—a man so varied in his attainments, and so energetic in his life and labour, that he published over one hundred different works dealing with every conceivable subject, from theology to science; but it was in the latter field that he especially shone, and the greatest achievement of his life was the discovery of the gas which we now call oxygen, a discovery which he communicated to his friend Lavoisier.

Lavoisier at once saw the importance of the discovery which Priestley had made, and then conceived and carried out an experiment which has become historical as proving for the first time beyond doubt the fact that the air was not a simple elementary substance, but contained two perfectly distinct gases—oxygen and nitrogen.

Lavoisier placed in a long-necked retort about four ounces of mercury, and so arranged the apparatus that the air above the mercury in the retort should freely communicate with the air in a measured receiver, all contact with the outer air being prevented by standing the receiver in a vessel of mercury. He now heated the four ounces of mercury in the retort nearly to its boiling-point, and kept it at this temperature for twelve days and twelve nights. At first no change took place, some of the mercury merely distilling into the upper part of the apparatus and falling back again; but presently some little red specks began to appear on the surface of the metal, and increased in amount for several days, but at length ceased to form; and after continuing the heating for a day or two longer,

in order to make sure that the action was completed, he allowed the whole apparatus to gradually cool down again to its original temperature.

Before starting the experiment he had carefully measured the air in the apparatus, which amounted to fifty cubic inches, and the first thing which he now noticed was that of this forty-two cubic inches only remained, and that this residual gas had lost all the most characteristic properties of air; a taper plunged into it was at once extinguished, a mouse placed in it died after a few moments; it would, in fact, neither support life nor combustion, and he recognised it as a gas discovered some three years before by Rutherford, and now called nitrogen.

He then collected the red film formed on the surface of the mercury, which weighed forty-five grains, and heated the powder in a hard glass tube to a higher temperature than that at which it had been formed, when it again broke up, leaving behind metallic mercury, and yielding eight cubic inches of a gas which had to an exaggerated extent all the properties which the air had lost—a gas which he at once recognised as being the oxygen or "vital" air which Priestley had discovered in 1774.

It was in this way that the air was shown to consist of the two gases, oxygen and nitrogen, and we know from experience that air is necessary for carrying on those cases of combustion which we ordinarily meet with, and the quickest way to extinguish a fire is to cut off the supply of air from it.

Having reached this point, the next question which suggests itself is, which of the constituents of the atmosphere is it which supports and carries on combustion, and how does it act in doing so? And the answer to these points can most readily be given in Nature's own words, by carefully translating the result of a few simple experiments.

Here are two gas jars, the one containing oxygen, the other nitrogen, and, taking a small ball of tow soaked with turpentine which is burning vigorously, I plunge it into the atmosphere of nitrogen, when it is at once extinguished, but on now relighting it, and plunging it into the oxygen, it burns far more fiercely than before, and emits a most brilliant light. If we continued experimenting in this way, we should find that everything tends to confirm the impression gained from our first experiment, and we soon learn, as Lavoisier did, that anything which will burn in air will burn with still greater vigour in oxygen, whilst nitrogen alone instantly stops the combustion of those bodies which require air to enable them to burn; indeed, we might go a step beyond Lavoisier's experiments, and find that many bodies not looked upon as combustibles, such as iron and zinc, burn with considerable brilliancy in pure oxygen; and it is from these facts that we came to look upon oxygen as our great supporter of combustion.

The enunciation of these truths by the great French philosopher was one of the most important steps in the history of science, but with increase of knowledge we find that we must still further widen our views with regard to combustion, and must take care not to fall into the error of looking upon those substances which will burn in air or oxygen as the only combustibles, and oxygen as the only supporter of combustion; we find, indeed, that these terms are purely relative, and a substance which we look upon as a combustible may, under altered conditions, become a supporter of combustion. Indeed, a body like coal gas, which burns in air or oxygen, will support in turn the combustion of air, and we can experimentally show that it is just as easy to have a flame of air burning in coal gas, as under ordinary conditions to have a flame of coal gas burning in air.

Again, we find that many cases of combustion will take place without the presence of oxygen or those substances generally looked upon as combustibles, and we can take a metal like antimony, and cause it to undergo brilliant combustion by throwing it in a powdered condition into an atmosphere of a gas called chlorine, although neither the metal nor the gas answer to our general ideas as to combustible or supporter of combustion.

If we examine carefully all cases of combustion, we find that in them we have a body with certain definite properties of its own, uniting itself with something else to form what we call the products of combustion, which are equal in weight to the sum of the weights of the two bodies uniting, and which have characteristic properties differing from those of the original substances, an action which we term one of chemical combination; and extended experiments show us that in order to obtain a true con-

ception of combustion, we must look upon it as "the evolution of heat during chemical combination."

The rapidity with which chemical combination takes place varies to a very great extent with surrounding circumstances, and inasmuch as heat is very rapidly dissipated it often happens that where a chemical combination is slow, the heat produced by it is given off as rapidly as it is generated, so that the temperature of the mass becomes but little raised, and escapes detection by our senses. For instance, if I take a steel watch-spring, and having ignited a small piece of German tinder attached to the end of it, plunge it into a vessel of oxygen gas, the combustion of the tinder ignites the watch-spring, which burns away in the gas with the greatest brilliancy, and the evolution of heat is sufficient to fuse some of the metal, the result being that the watch-spring is converted into a chemical compound of iron and oxygen. If instead of bringing about the combination of the iron and oxygen as we have done in a few seconds, we allowed it to remain in moist air for two or three months, combination with the oxygen of the air would result, and the metal would rust away, and if the weight of metal had been the same in each case, and the same weight of oxygen had been combined with, exactly the same amount of heat would have been generated in each case; but in the rapid combustion of the metal, this heat, being all generated in a few seconds of time, would have made its presence perfectly manifest; whilst when the same action is spread over a long period, as in the rusting of the metal, the heat being dissipated as it is generated, escapes our notice; and there are many amongst us who would smile at the idea that the rusting of their garden railings was giving rise to any increase of temperature.

In this case the heat generated by the combination of the iron with oxygen was made manifest by raising the burning metal to a high temperature in the presence of oxygen free from the diluting action of the inert nitrogen which is mixed with it in the air; but we can do the same thing by taking the iron in a very finely-powdered condition, so that a very large surface shall be exposed to the action of the oxygen of the air. I have here iron in this condition, sealed up in a glass tube, and on opening and shaking out the finely-divided metal into the air, it at once enters into combination with oxygen, and the heat generated is sufficient to make it red-hot. If, however, the same weight of iron in a compact form, such as wire, be taken, a long period of time, extending perhaps over years, would be required for its conversion into oxide by air and moisture, and the heat generated would be spread over such a duration of time that it would be inappreciable, unless the conditions were such that the heat was unable to escape or the surface of metal exposed very large. A case of this kind occurred during the manufacture of the Mediterranean telegraph cable, which was enclosed in a strong casing of iron wire, and tightly coiled in water tanks, one hundred and sixty-three miles of cable being wound in a coil thirty feet in diameter. Owing to a leak in the tank which contained the cable the water ran off, leaving the wire casing exposed to air, and the moist metal oxidised so rapidly that sufficient heat was generated to form considerable quantities of vapour, and to give rise to serious fears as to the softening of the insulating material of the core.

Many cases of chemical combination with the oxygen of the air take place in nature, which are so slow that the heat evolved during the action escapes our senses, and indeed all cases of decay are processes of this kind, and the action is termed one of "slow combustion."

A tree left to rot upon the ground gradually disappears in the course of years, being mainly oxidised into gaseous products such as carbon dioxide and water vapour, and yet scarcely any evolution of heat is observed, although the same amount of heat is generated as if the tree had been cut into logs and burnt.

In all cases slow combustion is accelerated by increase of temperature, and the higher the temperature the more rapid becomes the chemical action, and all combustible bodies, at a certain temperature, undergo what is termed "ignition," that is to say, a temperature is reached at which slow combustion passes into ordinary combustion with manifestation of flame or incandescence, the chemical combination being then so rapid that the heat evolved is manifest to our eyesight, whilst a still greater increase in the rapidity of combustion will in some cases bring about the most rapid form of combustion, which we term "explosion."

Many substances are capable of undergoing all three rates of combustion. For instance, it can readily be proved that when organic substances containing hydrogen undergo decay, some of the hydrogen present unites with the oxygen of the air to form water, and the heat generated by the combination is spread over so long a period that at no one moment of time is it perceptible to the sense. If, however, hydrogen gas be confined under pressure in a gas-holder, and allowed to escape through a jet into the air, on being ignited it burns with an intensely hot flame, the heat energy of which can be converted, by suitable contrivances, into other forms of energy, such as mechanical force. In this case as much hydrogen is converted into water in the course of a minute as would have been formed in some years by the process of slow combustion, and the increase in calorific intensity obtained is solely due to the increased rate of combustion, the total thermal value of the hydrogen being the same, whether it is burnt by a slow process taking years, or a rapid one in a minute. If now the same volume of hydrogen be mixed with sufficient air to supply it with the oxygen required to convert it into water, and if a light be applied to the mixture, the hydrogen being side by side with the oxygen necessary for its conversion into water, combustion takes place with enormous rapidity, and the intense heat generated expands the vapour formed to such an extent that an explosion results.

We have now seen that during the decay or slow oxidation of combustible bodies, heat is generated, and that it is only necessary for this heat to reach a certain point, *i.e.* the point of ignition, for the little noticeable slow combustion to become ordinary combustion with its manifestation of flame and incandescence, and it is this action to which the term spontaneous combustion has been given.

When the combustible substance has a great affinity for oxygen, and at the same time a low point of ignition, spontaneous combustion will take place with great ease. Indeed, in some cases, such as that of phosphorus, we are obliged to prevent the access of air to the body if we wish to prevent ignition taking place, and we also find that the finer the state of division of the substance, the more readily will its spontaneous ignition take place, not because dividing the body up in any way lowers the point of ignition, but because the increase in the size of the surface exposed to the oxidising action of the air is so much increased, that the heat is generated with greater rapidity than it can be dissipated. If we take a piece of phosphorus, and expose it to the action of the air, it almost directly commences to give off white fumes, and if the weather is warm, it will in the course of a short space of time even ignite ; in cold weather, however, it may be left until it has nearly all undergone slow oxidation without ignition. If, however, we dissolve it in the liquid called bisulphide of carbon, and pour some of this solution upon a piece of blotting-paper or linen, the carbon bisulphide, being highly volatile, will all evaporate, and leave the phosphorus in such a fine state of division that it will at once spontaneously ignite.

In practically all of the cases of spontaneous ignition which come under our notice, we have the heat evolved during the slow combustion kept in by the presence of a mass of non-conducting material, and this heat being unable to escape gradually grows higher and higher, the chemical combination becoming more and more rapid as the temperature increases, until we reach the point at which ignition of the mass takes place.

Sometimes, also, the increase in temperature necessary to bring about spontaneous ignition is partly due to physical actions. If a gas be suddenly compressed heat is always evolved, a fact prettily shown by the so-called fire syringe, in which the heat evolved by the compression of air is sufficient to ignite a piece of German tinder.

Certain bodies have the power of absorbing many times their own volume of gases, and in doing this they not only give rise to a certain increase in temperature, due to the compression of the absorbed gas upon their surfaces or in their pores, but they also increase the chemical activity of the gas so compressed.

Carbon is one of those substances which possess to an extraordinary degree the power of attracting and condensing gases upon their surface, this power varying with the state of division of the particular form of carbon used. The charcoal obtained from dense forms of wood, such as box, exhibits this property to a high degree, one cubic inch of such charcoal absorbing—according to Saussure—

Ammonia gas ...	90	cubic inches
Sulphuretted hydrogen	55	,, ,,
Carbon monoxide	35	,, ,,
Ethylene—olefiant gas	35	,, ,,
Oxygen	9·25	,, ,,
Nitrogen	6·5	,, ,,

This absorption is very rapid at first, but gradually decreases, and is, moreover, influenced very much by temperature. It is at first purely mechanical, and itself causes a rise of temperature, which in the case of charcoal formed in closed retorts, as in preparing alder, willow, and dogwood charcoal for powder making, would produce spontaneous ignition if it were not placed in sealed cooling vessels for some days before exposure to air. The rate of absorption varies with the amount of surface exposed, and is, therefore, able to take part in this condensing action, so that when charcoal is finely powdered, the exposed surface being much greater, absorption becomes more rapid, and rise of temperature at once takes place. If, after it has been made charcoal, it is kept for a day out of contact with air, and is then ground down into a powder, it will frequently fire after exposure to the air for thirty-six hours, whilst a heap of charcoal powder of one hundred bushels or more will always ignite. It is for this reason that in making the charcoal for powder it is always kept, after burning, for three or four days in air-tight cylinders before picking over, and ten days to a fortnight before it is ground.

There are several very interesting points with regard to the spontaneous combustion of charcoal, which call for more attention than has yet been devoted to it. It is self-evident that the more porous a body is, the greater amount of exposed surface will be available for the condensation of gases, and the great power that charcoal has of absorption is undoubtedly due to its great porosity. Now the temperature at which wood can be carbonised varies very considerably, and wood will begin to char ; that is to say, will begin to be converted into charcoal at temperatures very little above that of boiling water, and in the manufacture of some of the newer kinds of gunpowder the charcoal is formed by heating with superheated steam.

Charcoal formed at this low temperature, however, still contains large quantities of hydrogen and hydrocarbons, and is not nearly so porous as charcoal made at a high temperature ; and although the diminution in porosity reduces the quantity of oxygen absorbed, yet another cause which tends still more to dangerous rise of temperature comes into play.

When a substance condenses oxygen upon its surface from the atmosphere, the gas is in a very chemically active condition, and will bring about chemical combination with considerable rapidity. For instance, if a piece of platinum foil be heated to redness, so as to drive off all gases from its surface, and be then allowed to cool until it ceases to be visibly red, and is held in a stream of mixed air and coal gas, or air and hydrogen, it again becomes red-hot, owing to the chemical combination of these substances upon its surface ; that is to say, it has been able to condense these gases together and set up combustion.

If now charcoal be burnt at a high temperature, the carbon is in a dense condition, and resists to a considerable extent the setting-up of chemical action by the oxygen condensed and absorbed in its pores, but if it has been formed at a low temperature, this condensed oxygen will rapidly act upon the hydrocarbons and hydrogen still remaining in the mass, and will raise in this way the temperature to a dangerous point ; and it is more than probable that very many unexplained fires have been brought about by beams and woodwork becoming charred in contact with flues and heating pipes.

It has been experimentally determined that when wood has been charred at 500° it will take fire spontaneously when the temperature is raised in the presence of air to 680°, and that when wood has been carbonised at 260° a temperature of 340° only is required for its spontaneous ignition.

If a beam is in contact during the winter months with a heated flue, or even steam-pipes, it becomes carbonised upon its surface, and during the summer, when the flue or pipe is probably not at work, it absorbs air and moisture, and during the next winter it again becomes heated and further carbonised, whilst the moisture and air are driven out, leaving the pores in a condition eminently adapted for the absorption of more air as soon as the temperature is allowed to fall, and in many cases sufficient heat is generated to cause the charred mass to smoulder and, when air is freely admitted to it, to burst into flame.

In the case of charcoal burnt at a higher temperature, it may be taken that the cause of heating is to a great extent physical, whilst in the low-burnt charcoal it becomes chemical as well as physical, and it is this chemical action which is the most dangerous, and acts in most cases of spontaneous combustion.

The spontaneous ignition of coal has been the cause of an enormous number of serious accidents, and the earliest theory as to its cause was that it was due to the heat given out during the oxidation of the pyrites or "coal brasses," which are compounds of sulphur and iron, and are present in varying quantities in nearly all coal. This idea has held its ground nearly up to the present time, in spite of the researches of Dr. Richters, who twenty years ago showed the explanation was an erroneous one, and even earlier, in 1864, Dr. Percy pointed out that the cause of spontaneous ignition was probably the oxidation of the coal, and that the pyrites had but little to do with it. Pyrites is found in coal in several different forms, sometimes as a dark powder closely resembling coal itself, and in larger quantities in thin golden-looking layers in the cleavage of the coal, whilst sometimes again it is found in masses and veins of considerable size; these masses, however, are very heavy and are carefully picked out from the coal, and utilised in various manufactures. The yellow pyrites, and even the dark varieties, when in the crystalline form, remain practically unaltered, even after long exposure to moist air, but the amorphous and finely divided portions will oxidise and effloresce with great rapidity, and it is during this oxidation that the heat is supposed to be generated.

Some coals that are very liable to spontaneous ignition only contain 0·8 per cent. of pyrites, and if we imagine this to be concentrated in one spot instead of being spread over the whole mass, and to be oxidised in a few hours, the temperature would rise only a few degrees, and under ordinary circumstances this rise in temperature would be practically inappreciable.

The oxidisation of masses of pyrites under certain conditions gives rise to the formation of ferrous sulphate and sulphur dioxide, with liberation of sulphur, and one might easily imagine that this free sulphur, which has an igniting point of 250° C., would play an important part in the action by lowering the point of ignition. This, however, could only happen with large masses of pyrites undergoing oxidation, and with the small amount of pyrites present in coal, supposing air were present in sufficient quantity to oxidise it, the sulphur formed would be converted into sulphur dioxide at temperatures as low as 60° C. This oxidation of sulphur at low temperatures is an action not generally known, but in my experiments I have found it takes place with considerable rapidity. The only way in which pyrites can assist the spontaneous ignition of coal is that when it oxidises, it swells and splits up the coal, thus exposing fresh surfaces to the action of the atmospheric oxygen.

I have carefully determined the igniting points of several kinds of coal, and find that

Cannel coal	ignites at	698° F.	= 370° C.
Hartlepool coal	,, ,,	766° F.	= 408° C.
Lignite coal	,, ,,	842° F.	= 450° C.
Welsh steam coal	,, ,,	870° F.	= 477° C.

So that it is impossible for the small trace of pyrites scattered through a large mass of coal, and slowly undergoing oxidation, to raise the temperature to the necessary degree.

When coal is heating, a distinctive and penetrating odour is evolved, which is the same as that noticed when wood is scorched, and the gases produced consist of nitrogen, water vapour, carbon dioxide, carbon monoxide, hydrocarbons of the paraffin series, and sulphuretted hydrogen, the presence of the latter gas showing beyond doubt that oxidation of the sulphur has nothing to do with the action.

Ever since coal has been generally adopted as a fuel, it has been recognised that great care was necessary in the storing and shipment of masses exceeding 1000 tons, and if the coal has been stored wet or in a broken state, firing or heating of the mass has frequently taken place. Much inconvenience and loss has been caused by this on shore, but the real danger has occurred during shipment, and owing to this many a vessel has been lost with all hands, without any record of the calamity reaching shore.

Owing to the greater facility for treating the coal when it becomes heated on shore in coal stores and gas works, absolute ignition only rarely takes place, and it is mainly from evidence obtained in the case of coal cargoes that we learn most as to the causes which lead to it.

Coal is a substance of purely vegetable origin, formed out of contact with air, by long exposure to heat and pressure, from the woody fibre and resinous constituents of a monster vegetation which flourished long before the earth was inhabited by man. Coal therefore may be looked upon as a form of charcoal, which having been formed at a temperature lower than that of the charcoal-burner's heap, and under great pressure, is very dense, and still contains a quantity of these constituents which, in the ordinary burning, are driven off as wood naphtha, tar, &c., and these bodies consist of compounds containing essentially carbon and hydrogen, together with a little oxygen and nitrogen, and form the volatile matter and hydrocarbons of the coal. Coal also contains, besides these, certain mineral bodies, which were present in the fibre and sap of the original wood, and these form the ash which is left behind on the coal being burnt. These mineral substances consist almost entirely of gypsum or sulphate of lime, silica, and alumina, together with some oxide of iron, which gives the colour to the reddish-brown ash of many coals, and which has been formed by the decomposition of the pyrites in the original coal.

The mineral constituents of coal are the only ones, with the exception of the pyrites, that play no part in the phenomena attending the heating and spontaneous ignition of coal, and we need therefore only regard the actions which take place when the carbon, hydrocarbons, and pyrites in freshly-won coal come in contact with air and moisture.

Certain kinds of coal exhibit the same power of absorbing gases which charcoal has, although to a less degree. The absorptive power of new coal due to this surface attraction varies, but the least absorbent will take up one and a-quarter times its own volume of oxygen, whilst in some coal more than three times their volume of the gas is absorbed, which gives rise to an increase in temperature, and tends to increase the rate of the action which is going on, but is rarely sufficient to bring about spontaneous ignition, as only about one-third the amount of oxygen being absorbed by coal that is taken up by charcoal, and the action being much slower, tends to prevent the temperature reaching the high ignition point of the coal.

All coal contains a certain proportion of hydrogen, with which some of the carbon is combined, together with the nitrogen and oxygen, forming the volatile matter in the coal. The amount of this volatile matter varies greatly, anthracite containing the smallest quantity, and cannel and shale the largest. When the carbon of the coal absorbs oxygen, the compressed gas becomes chemically very active, and soon commences to combine with the carbon and hydrogen of the bituminous portions, converting them into carbon dioxide and water vapour. As the temperature rises so this chemical activity increases, so that the heat generated by the absorption of the oxygen causes it to rapidly enter into chemical combination. This kind of chemical combination—oxidation—is always accompanied by heat, and this further rise of temperature helps the rapidity of oxidation, so that the temperature rises steadily; and this taking place in a large mass of coal, which from physical causes is an admirable non-conductor, will often cause such heating of the mass that if sufficient air can pass into the heap in order to continue the action the igniting point of the coal will be reached.

It has been suggested that very bituminous coal, such as cannel and shale, are liable to spontaneous ignition from the fact that heavy oils would exude from them on a rise of temperature, and that these, by oxidising, might produce rapid heating. Experiment, however, shows that this is not the case, and that the heavy mineral oils have a decided effect in retarding heating.

We can now trace the actions which culminate in ignition. As soon as the coal is brought to bank, absorption of oxygen commences, but except under rare conditions the coal does not heat to any great extent, as the exposed surface is comparatively small, and the largeness of the masses allows of the air having free access to all parts, so keeping down the temperature. After the coal has been screened and the large pieces of pyrites picked out, it is put in trucks. Here it begins to get broken up, owing to the many joltings and shuntings, and so offers a larger surface to the action of the air. When it has arrived at the ship, it is further broken up by being shot down the tips or shoots, and more harm is done at this than at any other period, for the coal is broken by reason of the distance it has to fall, and it has to bear the impact of every succeeding load falling upon it, and it rapidly becomes slack, so that the under part of the ship-load is a dense mass of small coal, which soon rises in temperature by reason of the large surface exposed to the air and the con-

sequent absorption of oxygen. This sets up chemical combination between the oxygen absorbed by the coal and the hydrocarbons, and in some cases culminates in combustion.

It is found that the mass of coal exercises a most important action in the liability to spontaneous combustion, as although with 500 tons of coal to the cargo the cases of spontaneous combustion amount to only about $\frac{1}{4}$ per cent. when the bulk is increased to 2000 tons, cases of spontaneous combustion rise to 9 per cent., this being due to the fact that the larger the cargo the more non-conducting material will there be to keep in the heat, and also to the fact that the breaking-up of the coal and the exposing fresh surfaces will of course increase with increase in mass ; and it is also found that coal cargoes sent to European ports rarely undergo spontaneous combustion, whilst the number of cases rise to a startling extent in shipments made to Asia, Africa, and America. The result is party due to the length of time the cargo is in the vessel, the absorption and oxidation being a comparatively slow process, but the main cause is the increase of heat in the tropics, which causes the action to become more rapid ; and if statistics had been taken, most of the ships would have been found to have developed active combustion somewhere about the neighbourhood of the Cape, the action fostered in the tropics having raised the temperature to the igniting point by that time.

Moisture has a most remarkable effect upon the spontaneous ignition of coal. The absorption of oxygen is at first retarded by external wetting, but after a time the presence of moisture accelerates the action of the absorbed oxygen upon the coal, and so causes a serious increase of heat. The researches of Cowper, Baker, Dixon, and others, have of late years so fully shown the important part which moisture plays in actions of this kind, that it is now recognised as a most important factor. A very marked case of the influence of moisture came under my notice a few months ago. A ship took in a cargo of coal at a South Welsh port, the weather being fine and dry whilst she was loading at the main hatch, but wet whilst she was taking in the coal at the after-hatch, the result being that the temperature in a few days was uniformly about 10° higher in the coal that had been loaded wet, than in the dry portion of the cargo, spontaneous ignition being the final result at the after-hatch.

In order to prevent the spontaneous ignition of large masses of coal, it is manifest that every precaution should be taken during loading or storing to prevent crushing of the coal, and on no account must a large accumulation of small coal be allowed. Where possible the depth of coal in the store should not exceed 6 to 8 feet, and under no conditions must steam-pipes or flues be allowed so near the mass of coal as to give rise to any increase of temperature. These precautions would amply suffice to prevent spontaneous ignition in stored coal on land, whilst special precautions would have to be taken in the case of coal for shipment.

Perhaps he commonest case of spontaneous combustion is the ignition of oily waste or greasy cotton rags. Nearly all vegetable and animal oils have the power of slowly absorbing oxygen, and in some of them this goes on with considerable rapidity, with conversion of the oil into a resin, a property which gives them the power of drying, and causes a considerable rise of temperature. A mass of oil, however, only exposes a very small surface to the oxidising influence of the air, but when such oil comes to be spread upon any non-conducting fabric, the oxidisation is very rapid, and the non-conducting power of the fibre of the fabric prevents the rapid dispersion of the heat, with the result that even a small quantity of such oily substance will readily inflame.

There are plenty of well-authenticated cases in which even a handful of oily cotton waste, which has been used for polishing furniture, has ignited when thrown on one side, and caused most disastrous fires. Just twenty years ago Mr. Galletly read a most valuable paper before the Chemical Section of the British Association, in which he showed that the liability of oils to produce spontaneous combustion was in proportion to their tendency to dry. If a substance like cotton-waste be rendered oily with anything except the mineral oils, it acquires the power of taking up oxygen from the air, and this gives rise to heat. The oxidation is slow at ordinary temperatures, and accordingly it may be some time before the increase of temperature becomes manifest ; but when this point is reached, the action proceeds with great rapidity, and the point of ignition is reached in a very short time, and then the mass bursts into flame. If the oily matter be placed in a warm position at first, spontaneous

ignition may take place within a few hours, or even minutes. Galletly found that oily cotton at ordinary temperatures took some days to heat and ignite, whilst if placed in a chamber warmed to 130° to 170° F. (54° to 76° C.) the cotton greasy with boiled linseed ignited in 1 hour 15 minutes, and olive oil on cotton in 5 hours ; and in a chamber heated to 180° to 200° F. (82° to 93° C.) olive oil on cotton ignited in two hours.

Cases of spontaneous combustion, due to this cause, have been more abundant than from any other, and cases are even on record where serious fires have resulted from sparrows using oily waste in the construction of their nests. In all well-regulated workshops the orders against allowing any accumulation of oily waste are very stringent, and the most reasonable precaution to be taken is that all oily material, when done with, should be thrown into a metal vessel containing water, or which, at any rate, can be either emptied of waste or filled with water at night. If a sheet of cotton be hanging in a warm room and is splashed with oil, a hole will often be found charred in the fabric by the next morning, whilst if a few drops of a drying oil be allowed to fall on powdered charcoal or lamp-black, ignition is almost certain to follow in a few hours.

Another common case of spontaneous ignition is that of hay-stacks which have been made up before the grass has been thoroughly dried, this being due to the sap left in the vegetable fibre undergoing fermentation, which being a process of oxidation gives rise to heat. This heat is kept in by the surrounding hay, which is an admirable non-conductor of heat, and gradually increases until the ignition point of the mass is reached, when the stack bursts into flame. In some cases the action does not go as far as this, and we often see the inside of a haystack charred to an almost black colour, showing that the action has stopped but little short of the point required to give active combustion, this being probably due to the stack having been very closely built, and the access of air to the centre being small, and in some cases, when such a rick is cut, the air coming in contact with the central portion causes active ignition. If hay has once been properly dried, and then becomes wetted with rain, spontaneous ignition hardly ever takes place, although the hay becomes mouldy, and it is evident that the action which leads to ignition of the hay is fermentation of the sap.

Having now discussed the more common cases of spontaneous ignition, and seen that in every case it is due to rise of temperature, brought about by chemical action until the igniting point of the substance is reached, we are in a position to understand the impossibility of spontaneous combustion taking place in the human body.

The process of respiration by which the tissues of the body used up in every action, voluntary or involuntary, are got rid of by a process of slow combustion, gives a normal temperature to the living body, and it might seem, at first sight, possible by preventing the escape of such temperature, to increase it to a point at which ignition might be possible ; but we know by experience that the effect of swathing the body in non-conducting materials, so as to prevent the escape of heat from it, results in profuse perspiration, and before the living flesh could undergo combustion it would be necessary to drive from it the whole of the moisture which it contains.

The human body contains from 75 to 80 per cent. of its weight of water, and in order to evaporate this amount, an enormous amount of heat would be required, and life would have been impossible long before the necessary dryness of the mass had been arrived at. In fact, the moisture present in the body may be looked upon as its great safeguard against the effect of heat, and it is perfectly possible for a living man to remain in an oven which would roast a steak or cook an egg ; the evaporation of water from the skin taking up so much heat that the temperature of the living flesh would never rise above a certain point until the moisture was exhausted. It used to be supposed that the cases of spontaneous combustion took place in people whose intemperate habits had caused the body to become saturated with alcohol, and that it was this substance which caused its ready ignition ; but as Liebig pointed out, some forty years ago, the presence of the alcohol could have no effect, as if we take a sponge and soak it in spirits of wine and ignite it, the alcohol burns away and leaves the sponge untouched, and the same thing would undoubtedly happen in the case of the living flesh.

In this lecture I have tried to bring before you the important fact that spontaneous combustion merely means that the heat due

to chemical actions taking place in any substance, heat which has been unable to escape has raised the temperature to the point of ignition, a point at which slow combustion passes into rapid combustion with manifestation of incandescence ; and in speaking of spontaneous combustion, we must clearly remember that it represents merely the acceleration of an action which has been going on slowly and surely, although our senses may have been too deadened to detect it, and that if we wished to be hyper-critical, "Unaided Ignition," or "Natural Ignition," would be a far more correct term to apply to it than "Spontaneous Combustion."

UNIVERSITY AND EDUCATIONAL INTELLIGENCE.

CAMBRIDGE.—The following appointments in connection with the scientific departments are announced :—Mr. Francis Darwin, Reader in Botany, to be Deputy Professor in the place of Prof. Babington, who is still unable to lecture ; Dr. D. MacAlister to be Assessor to the Regius Professor of Physics ; Dr. Hill, Master of Downing, and Dr. H. D. Rolleston to be Examiners in Anatomy ; Dr. A. S. Lea and Prof. Schäfer to be Examiners in Physiology ; Dr. W. J. Sollas and Mr. P. Lake (St. John's) to be Examiners in Geology ; Mr. Skinner (Christ's) to be an Examiner in Chemistry ; Prof. J. J. Thomson and Prof. G. F. Fitzgerald (of Dublin) to be Examiners in Physics ; Mr. A. Sedgwick (Trinity) and Mr. W. Bateson (St. John's) to be Examiners in Zoology ; Prof. Lewis and Mr. H. A. Miers to be Examiners in Mineralogy ; Mr. Seward (St. John's) and Prof. D. E. Oliver to be Examiners in Botany.

Prof. Sir R. S. Ball has been appointed an Elector to the Isaac Newton Astronomy Studentships.

The Moderators and Examiners for the next Mathematical Tripos (Part I.) are Mr. Walsh (Jesus), Mr. Dawson (Christ's), Mr. Burnside (Pembroke), and Mr. Whitehead (Trinity). For the Second Part, Dr. Forsyth, Sir R. S. Ball, Prof. Lamb, and Mr. H. F. Baker (St. John's) are to examine.

Mrs. E. J. Moore, daughter of the late Colonel Fletcher, has presented to the University her father's valuable collection of Silurian fossils, in supplement of the Fletcher collection pur-chased many years ago for the Woodwardian Museum.

The Clerk Maxwell Studentship in Experimental Physics, of the value of about £180 a year, tenable for three years, is vacant by the resignation of Mr. W. Cassie, who has been ap-pointed to a professorship at the Royal Holloway College. Candidates must be members of the University who have been a student for one term or more at the Cavendish Laboratory. The names of applicants are to be sent to Prof. J. J. Thomson before November 18.

A grant of £100 from the Worts Travelling Scholars Fund has been made to F. W. Keeble, Frank Smart student of Caius College, to enable him to pursue botanical research in Ceylon.

An examination for scholarships and exhibitions in Natural Science, of the value of £80 a year and under, will be held at Trinity College on Tuesday, October 31.

AT the annual meeting of the New Decimal Association, on October 18, Mr. Samuel Montagu, M.P., remarked that there was a prospect of the United States adopting the metric system as well as a decimal system of coinage. Efforts had been made to induce Mr. Acland to instruct inspectors to examine in the metric system in those schools where it was taught, and, in a letter received from the Education Department on the subject, it was said : "The Code does not prescribe knowledge of the metric system, but of the principles of that system—*i.e.* of the diminution of quantities by tenths, and their increase by tens, with examples sufficient to illustrate the conveniences of the system. Her Majesty's inspectors are required to satisfy themselves that the principles as thus defined are properly taught. It is proposed to issue a memorandum to inspectors on the point at an early date."

SCIENTIFIC SERIALS.

American Journal of Science, October.—On endothermic reactions effected by mechanical force, by M. Carey Lea. The object of this investigation was to find whether the blackening effects of pressure upon the silver haloids and other salts could be made immediately visible to the eye, instead of after the application of a reducing agent. For this purpose the pressure was increased to about a million pounds per square inch, or about seventy thousand atmospheres. This pressure was obtained by means of a vice actuated by a screw with six turns to the inch and a lever three feet long. The nuts had to be four inches in length to prevent stripping of the thread. The jaws were specially constructed, and faced with steel welded on. The materials experimented upon were wrapped in platinum or silver foil, which remained unaffected by the pressure. Silver sulphite and carbonate were moderately darkened by two days' pressure, and silver salicylate considerably so. Salts of mercury also showed pronounced effects, which prove that mechanical force can bring about endothermic reactions corresponding to those affected by light, heat, and other forms of energy.—Con-ditions of Appalachian faulting, by Bailey Willis and C. Willard Hayes. The authors discuss the antecedent conditions for the development, the mechanics of step-folds and thrust-faults as bearing upon actually observed Appalachian structure, and the direction from which the compressing force acted. They come to the conclusion that the latter was equal in opposite directions, and directed north-westward and south-eastward.—On the separation of copper from cadmium by the iodide method, by Philipp E. Browning. The copper was precipitated from a mixed solution by potassium iodide, and filtered through an asbestos felt, washed, dried at 120° C. and weighed. The fil-trate and washings containing the cadmium were heated to boiling, and sufficient sodium carbonate was added to complete the precipitation. The precipitate was washed with hot water until free from sulphate or iodide. The crucible containing the cadmium carbonate was heated gently at first, then gradually to a higher degree until the white carbonate had changed to the brown oxide. The method, as tested by means of standard solutions, is fairly accurate, and it is simple in manipulation.—Also papers by Messrs. Foerste, Hidden, Wheeler, Eakins, Williams, Penfield, and Marsh.

THE *American Meteorological Journal* for October contains an account, by A. L. Rotch, of the establishment of a meteoro-logical station at Charchani, near Arequipa, at an altitude of 16,650 feet, which is said to be the highest station in the world. A sum of money was left to Harvard College Observatory by U. A. Boyden, for the purpose of establishing an observatory at a high station, and owing to the remarkable clearness of the air at Arequipa, Peru, this situation was selected for the purpose. The establishment is fully equipped with instru-ments and is 8,050 feet above the sea ; to the north east and ten miles distant is the quiescent volcano of the Misti, 19,000 feet in altitude, and twelve miles north rises Charchani, 20,000 feet high. The meteorological station now in question has been established just below the permanent snow line, and is supplied with self-recording aneroid and thermometers. The ascent from the permanent observatory, 8,600 feet below, can be made by mule in about eight hours, and an assistant is en-trusted with the duty of visiting the station periodically to attend to the records. The results of the observations at both stations will be published in the Annals of the Harvard College Observatory, and will furnish a valuable addition to our know-ledge of mountain meteorology.

In the same number, Prof. G. E. Curtis gives an analysis of the causes of rainfall, with especial relations to surface condi-tions. Among these a principal question is whether forestation increases and deforestation decreases the rainfall. The author considers that the influence of forests has been over-estimated, and that if they affect the rainfall, the amount has, in most cases, not been greater than the amount of probable error in the observations themselves, and therefore that the statistics give no assurance that the effect is not an error of observation. If the rainfall is increased it must be due either to an increase of evaporation, and its subsequent precipitation over the same region, or to the diversion of rain to the forest area, which might have fallen elsewhere.

SOCIETIES AND ACADEMIES.

PARIS.

Academy of Sciences, October 16.—M. Lœwy in the chair.—On the stability of equilibrium of the axis of the gyroscopic top, by M. H. Resal.—On the partial differen-tial equation presented in the theory of the vibrations