OWENS COLLEGE, MANCHESTER.

THE RECENT DEVELOPMENTS

OF

COSMICAL PHYSICS:

A LECTURE

INTRODUCTORY TO THE SESSION, 1870–71.

BY

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THE RECENT DEVELOPMENTS OF COSMICAL PHYSICS.

The privilege of addressing you at the commencement of this session is one which involves peculiar difficulty, preceded as the occasion has so recently been by one of the most important events in the history of Owens College.

This event may be regarded as the local indication of a wave of educational progress, which promises soon to flood and fertilize our country; but I should do the inhabitants of this city, and the authorities of this college less than justice, were I merely to say that they have been influenced by this wave. Their function is to lead rather than to follow, to create and stimulate the national thought, and to direct it when created into its proper channel, rather than to be borne along by a current which they cannot resist.

There are two conflicting theories with regard to education. The extreme partisans of one of these would have us believe that the great object of education is not so much to inform as to discipline the mind—the subject taught in a seminary may not in itself increase the student's real knowledge, yet if it tend to discipline his mind it has proved its value in their eyes as a branch of education.

According to the upholders of this theory our object in going to school is to leave it with a mind enlarged in its capacity for acquiring knowledge rather than stored with knowledge itself—having trained the soldier well they would send him without scruple into the enemy's country not only to fight his own way but to find his own weapons.

But there is another and opposite class of theorists who regard education not as an agent for training the mind so much as a means of storing it with knowledge. The extreme partisans of this theory would teach the student nothing but what is of apparent and immediate use; above all things they would teach him the sciences both in their principles and also in the various details of their applications to the industrial arts of life.

The mind of the student who has undergone a training of this kind carried to its extreme resembles the inmate of a house which is not so much well furnished as filled full of furniture. In the accumulation of mere material anything like plan or principle has been forgotten. It ought to be remembered that the value of a fact lies not in its existence somewhere in the mental storehouse, but in the readiness with which the mind can find it when required.

Now between these two extreme theories it is surely possible to steer a middle course—it is possible to avoid grounding on Scylla without being swallowed up in the vortex of Charybdis. In the material world what would be said to a man who insisted upon developing bodily strength by a course of gymnastics without reference to food, or of another who insisted upon doing the same by a course of diet without reference to exercise? But is the separation more natural in the mental world? Is not that mind most perfectly disciplined which is at the same time most perfectly informed? The student who has been disciplined by only one branch of knowledge is, I venture to think, the possessor of a mind only partially disciplined, as it is only partially informed. He may not easily perceive his deficient discipline, but in after life he must often have cause to regret his deficient information. Nor is he whose mind is inordinately stored with scientific details one whit better off. Facts in education ought to be strictly subordinated to principles. A sound principle of science clearly understood will embrace a great multitude of facts just as a simple rule of arithmetic will enable us to obtain a thousand products, each of which we should have to remember were it not for the rule. And in other branches of science if the triumph of principle be not so apparent, it is only because we have a less accurate knowledge of its fundamental laws. It would be difficult indeed to say how many of the failures in the various walks of life are due to the neglect or ignorance of some principle which has been either omitted or dismissed from our calculations. From our leaders downwards we are a nation systematically ignoring principles, and in the minds of many a high esteem for fact is held to be quite consistent with a contempt for theory. A theory is not regarded as the very sap and life-blood of the tree of knowledge, but rather as the mildew that blights its leaves or the worm that gnaws its root. Facts and theories are esteemed by this class of men to be sworn foes to each other, and the philosopher is supposed to live in a world of his own, rather hostile than otherwise to the world around him.

The existence of the two extreme educational theories to which I have alluded would thus seem to indicate the wisdom of a middle course. We ought to start from a platform as comprehensive as possible. Literature and science ought to go hand in hand in producing the well-trained and well-informed disciple. And while there ought to be a broad basis of instruction common to all, there should be raised upon this common basis several distinct departments, so that the student may have the opportunity of attaining proficiency in that of his choice. I need not remind you that this plan has been adopted in Owens College, and that based upon an educational ground-work common to all there are three separate departments branching out from the common basis. It is of that which embraces more especially experimental science that I would now speak.

While the technical applications of the various sciences can only be taught to advantage in the workshops of the world, it is yet eminently desirable that the student should have an intimate, ready, and comprehensive knowledge of scientific principles.

Such principles are like weapons, and they should not only be placed in the hands of the scientific recruit, but he should be taught how to wield them to advantage.

Now to bring this about the lecture room is not enough, but it must be supplemented by the laboratory, whether chemical or physical, in which the student desiring proficiency may be brought into intimate contact with nature herself.

In the laboratory he may see with his own eyes, and handle with his own hands, as well as hear with his own ears.

If he be determined to cross-question nature after a fashion of his own, he will have the opportunity of doing so. If he thinks he has found out a new truth, he will have the opportunity of making good his conjecture.

But, besides its use in supplementing class instruction, an experimental laboratory has an important, though indirect, influence upon the training of the mind.

Above all things the student is taught caution in his deductions. The laboratory is a place where a certain class of speculations may be brought at once to the test of experience.

An hypothesis is put as it were without delay into the crucible and conveyed into the furnace, and it is soon seen how much of it is dross and how much pure gold.

But again, while the experimentalist is taught caution in arriving at a conclusion, he is at the same time taught promptness and candour in modifying his views.

We sometimes find that a man who hastily propounds a false theory is very reluctant to withdraw from his position, even after it has been proved untenable. He advanced prematurely, and at length when he is compelled to withdraw, his retreat is undignified, if not disastrous.

All along it was evident that he thought too much of himself and too little of his cause, and had he displayed more caution in seizing an advanced position, and less pertinacity in retaining it, knowledge would have advanced more and he himself would have suffered less.

Another important lesson which the laboratory student may learn, is "not to despise the day of small things." An unexpected result always means something, it may mean some experimental error which the student is thus taught to avoid, but it may also mean some new truth.

The progress of our race in truth has been an onward one, a progress from less to greater light; and the dim outline seen in the early dawn may, perhaps, be a morning cloud, but it may also be the more distant and grander features of the landscape just beginning to appear.

We read in the Eastern legend how a fisherman caught with his net a small vase, the lid of which had been sealed down "in the name of God." When it was opened a smoke immediately arose and spread to a great height, until at last it became consolidated into the features and form of a mighty genius.

Now the experimental philosopher who in his laboratory discovers a new truth resembles this fisherman. The whole history of science is full of instances where the greatest results have flowed from the most trivial experiments; and you have already been reminded by my predecessor in the chair of Natural Philosophy, how the mighty genius electricity rose up from an experiment of Galvani, who noticed a convulsion in the limbs of a frog which he had suspended by two metals.

I shall now briefly allude to the present position and prospects of physical science, but as this field is too large to be embraced in one address, I shall dwell in preference on Cosmical Physics.

We have lately made very great progress in our knowledge of the laws of nature, and have arrived at very important generalizations. The grandest of these is without doubt the great law of the conservation of energy. Like the giant oak of the forest, a principle of this magnitude is from its nature a plant of slow growth. It was dimly perceived by Galileo, and more clearly by Newton and Leibnitz; it received development from Rumford and Davy, but it has only revealed itself as a great principle in the present age.

This result is pre-eminently due to a citizen of Manchester—to the illustrious Dr. Joule, who so grappled with the principle as to bring it within the domain of ascertained truths. Other philosophers have hardly been behind. Thomson and Rankine in this country—Mayer, Helmholz and Clausius abroad—have lent their powerful aid to its development.

Let me now endeavour to explain what is meant by the conservation of energy.

We are kept down in this world by a force called gravity, and we are kept together by a force called cohesion.

If it were not for gravity the earth would leave the sun and we should leave the earth, and if it were not for cohesion we ourselves and everything around us would fall to powder.

There is no doubt about the utility of these two forces, nevertheless when we ascend a mountain we are sometimes tempted to wish there were no gravity, and when we cut down a tree we are tempted to wish there were no cohesion.

The mountaineer who strives to reach the summit, and the woodman who plies his axe, are both conscious of being resisted in their efforts by the forces of nature. And when the summit has been gained, when the tree has fallen, the worker is conscious of being in many respects a different man from what he was at the beginning of his labour. He has lost or spent something, and that something is energy, which means the power of doing work; his strength is exhausted, and he is incapable of any further effort.

Which of us in some moment of weakness has not felt a desire to escape from this primeval curse of labour—if it be a curse—into the milder economy of some land of perpetual ease, echoing the plaint of the poet,

> Why should we only toil, the roof and crown of things?

Now, in the imaginative Eastern mind this happy release was to be obtained by invoking some genius subservient to man, while the less imaginative European invoked a machine—a machine that without feeding or fuel of any kind would accomplish an endless amount of work. This formed the dream of the Western enthusiast—the perpetual motion of the scientific visionary. But the true man of science always denied the possibility of such a creation.

Galileo was among the first to define with clearness the true functions of a machine. His point of view was very simple. In a system of pulleys, for instance, by applying a weight of one pound we may raise perhaps as much as fifty or a hundred pounds, but when the pound weight has fallen one foot, the fifty pounds weight will not have risen the same distance, it will only have risen the fiftieth part of a foot. All that is done is this—by lowering a small weight through a large space we raise a large weight through a small space, and it will be found that the small weight multiplied into the space through which it is lowered will exactly equal the large weight multiplied into the space through which it is raised. We gain power, but we lose space; we spend one kind of energy upon the machine, and we produce just as much energy and no more, only of a kind which is more convenient.

Thus the world of mechanism is not a manufactory in which energy is created but rather a mart into which we may bring energy of one kind and barter it for some of another kind that suits us better, but if we come with nothing in our hand, with nothing we shall most assuredly return. We thus perceive that a machine does not create but only transmutes, and the same rule applies if we take the whole universe into account, for the energy or power of doing work throughout the universe is as constant and unchangeable as is the quantity of matter which it contains.

Again, there are two kinds of energy in the physical just as there are in the social world; there is actual energy and there is energy due to position. A body in actual motion such as a cannon ball, or a rushing river, or the wind can without doubt do work, whether this work be to demolish a fortress, to turn a wheel, or to propel a vessel—this is actual physical energy or energy due to actual motion.

But there is also a species of energy due to position. A large weight on the top of a house or other elevation has the capacity of doing work owing to its position, for by letting it fall upon the top of a pile we can drive this into the ground. A head of water has the same capacity, and so has a clock wound-up and a cross-bow bent. These are instances of bodies not in visible motion which have yet the capacity of performing work owing to their position, for it is manifestly the elevated position of the head of water and of the clock weight, and it is the bent position of the bow, that create the capacity for doing work which resides in these various contrivances. So much for energy of position.

Now there is very frequently a change of energy of position into actual energy, or of actual energy into that of position, but there is never a creation, for what is gained in the one case is always lost in the other.

Thus if I project a stone upwards with considerable velocity I communicate to it the energy of actual motion, but if at the top of its flight I take it aside and lodge it on the top of a house there is no longer any actual energy in the stone. Has this energy disappeared for ever, without leaving behind it any equivalent? Far from it. The actual energy has been spent in acquiring for the stone an energy due to position, and I may re-convert this energy of position into actual energy by causing the stone to drop from the top of the house, in which case it will reach the ground with the same velocity and therefore with the same energy it had when it was originally projected upwards.

Thus we see that reckoning energy of position along with energy of actual motion there is in this case no annihilation but only a transmutation of energy from one form to another, and we can always in such a case get back our expenditure in some shape or other.

But the case is not so clear if we consider percussion or friction. Suppose for instance the blacksmith strikes the anvil a heavy blow with his hammer. What has become of the energy of this blow after the stroke has been delivered? or suppose we stop a railway train by means of friction at the break-wheel, what has become of the energy of the train? Has this energy disappeared from the universe for ever, or has it merely been transmuted into some other and less apparent form?

Let us answer this question by examining somewhat minutely what really takes place in cases of percussion or friction. It is well known that a piece of metal becomes hot after a violent blow, it is also well known that friction produces heat. We are thus tempted to connect the disappearance of the energy of visible motion with the production of heat. May not heat consist of a peculiar motion of the various particles of a heated body, and may not the energy of the blow or that of the motion stopped by friction have been transformed into heat without becoming annihilated? This was what Rumford and Davy thought, Rumford when he boiled water by means of the heat produced in the process of boring cannon, and Davy when he melted ice by causing two pieces to rub against each other. It was however reserved for Joule to show that there is a precise and definite relation between mechanical energy and heat in virtue of which if a pound of water be allowed to drop from the height of 772 feet, it will be heated one degree Fahrenheit, and if it drop from twice this height it will be heated just twice as much.

There are no less than two changes of energy in the case of this pound of water which is supposed to drop. It starts with energy of position, for it is 772 feet above the surface of the earth, and in virtue of this elevated position it has a certain amount of energy. As it falls this energy of position becomes gradually less, not however without being transformed into something else, until when the stone is just about to strike the ground it has all been converted into the energy of actual motion. The moment it strikes there is a further change; this energy of actual motion is at once changed into that called heat, and the water has become one degree hotter in consequence.

I have said that heat is probably a species of energy of actual motion, that is to say, the various particles of a hot body are in violent agitation. But we may have also a molecular variety of energy due to position. For let us think how we procure this energy of position, say for instance that of a stone lodged on the top of a house? Is it not by violently separating the stone from a body which attracts it, namely the earth? We have, in fact, violently pulled asunder two bodies which have a tendency to rush together, and the result is, energy of position.

Now an atom of carbon and one of oxygen have a strong attraction for each other, and their tendency is to rush together and form carbonic acid, and if we or any other energetic agent separate the particles of carbon from those of oxygen, we produce a kind of energy of position just as truly as if we had separated a stone from the earth. As long, therefore, as we have coal in our mines and oxygen in our atmosphere, we have in a separated state two bodies whose tendency it is to rush together, and we have in consequence a large amount of molecular energy of position. When we burn coal in the fire we allow this union to take place, and the result is much the same as when we allow a substance to fall from a height towards the earth—the energy of position is ultimately changed into heat in both cases. The heat of a coal fire is as much due to the rushing together of the carbon and the oxygen as the heat produced by a pound of water falling from a height is due to the rushing together of that body and the earth.

Having now specified very briefly some of the most important varieties of energy, let me ask you to join with me in looking around us and considering what stores of this all-important thing called energy have been placed at our disposal; and first let us begin with ourselves.

We have all, it is hoped, some physical energy in these frames of ours; we can all do some amount of work if we choose. Whence then do our frames derive this energy which they possess?

To answer this question let us see what really happens after we have done a good stroke of hard work. Do we not feel tired and hungry; do not our frames crave food and rest in order that we may have the opportunity of changing this food into that bodily tissue which we have consumed in work?

Doubtless it is this food that supplies us with energy, and if we reflect a little we shall see that food contains carbon as one of its elements, and thus forms a species of molecular energy of position just as truly as coal.

Food is really a species of energy, and if we assimilate to our own use the tissue of the ox or of the sheep in the shape of beef and mutton, we have only to carry our reasoning one step further back, and ask from what source these animals derive their energy? The reply will be—from the vegetable world. The grass of the meadow and the leaf of the forest must, therefore, represent a large store of energy. Now from what source is all this derived? It is derived without doubt from the sun. A leaf is a laboratory in which the sun's rays are at work separating carbon from oxygen, throwing out the oxygen into the air in order to make up for what we vitiate by breathing and burning, and retaining the carbon in some shape to be worked up into vegetable tissue.

We are thus entitled to say that the energy of the sun's rays is spent in separating the carbon and the oxygen from one another in the leaves of the plants. The plant is eaten by the ox, and the ox by the man, and the man reproduces this energy in every motion of his wonderful frame. But as there were not always oxen to eat up leaves, or men to eat up oxen, must there not have been a great waste, especially in those geological periods when the vegetation was rank and luxuriant? By no means. The carbon decomposed in the leaves of plants by the sun's rays during the geological ages has not been wasted, but has formed those magnificent coal beds upon which we draw so largely, and by the aid of which so much of the world's work is now done.

Thus we see that not only food but fuel, whether in the shape of wood or coal, is of vegetable origin, and represents an energy derived ultimately from the sun's rays. And thus the work which we accomplish ourselves by means of our food, and that which our machines accomplish by virtue of their fuel, are indirectly due to the same source.

Let us now regard the subject from a somewhat different point of view.

If an egg be allowed to rest on its shorter axis, it will remain stationary, and any attempt to alter its position will be resisted by the egg. But the case will be different if we succeed, as perhaps we may, in causing it to stand on its longer axis, for in this position the slightest force will cause it to topple over. In the first case the egg is in stable, but in the second case it is in unstable equilibrium.

If it stand upon its longer axis at the very edge of a table, we cannot tell whether the first slight breath of air will cause it to fall inwards upon the table or outwards over the table, to be dashed to pieces on the floor. It is a case where a very slight cause may determine a very considerable issue as far as energy is concerned. Whether the egg will retain its energy of position by falling on the table, or whether it will convert this into the energy of motion, and ultimately into heat, by falling upon the floor, is an issue that depends upon a cause too minute to come within the scope of our calculations.

Now we have two types of machines, and in one of these we take advantage of the principle of stability, while in the other we use the principle of instability. A clock is a very good instance of a machine of the first kind. When a good clock has been wound up, we are perfectly sure that at noon to-morrow both its hands will stand at twelve, and that its weight will have fallen through a distance which we can calculate with the utmost exactness, if we take the trouble, all its movements being capable of the most rigorous calculation. On the other hand, a mine that is about to be fired by means of an electric battery is a machine or combination in which advantage is taken of nature's unstable arrangements. The powder which is about to explode represents chemical instability, just as the egg on its longer axis represents mechanical instability. The slightest percussion, the smallest spark will rouse the imprisoned giant which it contains into volcanic energy. This spark has to be sent from a distance by the galvanic battery, and to do this we must complete the circuit. We cause the two wires to approach each other until they are only a very small fraction of an inch apart, but the contact is not yet complete—another touch, so slight as to be imperceptible, and the current passes, the powder is ignited, the mine explodes, and the fortress is hurled into the air. In such machines, great results, great transmutations of energy, are due to the most trivial disposing causes. It depends at last upon the smallest conceivable movement of the wires conveying the current whether or not the fortress is to perish.

Nature also employs these two varieties of mechanism. In the solar system we have a clock on a large scale, only very much more accurate than any timepiece we can produce. The movements of every planet in the solar system are susceptible of the most rigorous calculation, and we have only to point our telescope properly in order to tell to the fraction of a second when a given planet will cross the field of view.

But in the living forms with which this world is so plentifully endowed we have machines, which viewed in their relation to matter, belong to the second order we have described. The object here is not regularity but rather freedom of action. The motion of an animal is not like that of a planet—the latter yields to calculation but the former defies it. Now it is probably somewhere in the mysterious brain chamber that the delicate directive touch is given which determines our movements, just as the slightest possible touch to the wire in the battery chamber explodes the distant mine. That mysterious thing we call life is not a bully who swaggers out into the open universe upsetting the laws of energy in all directions, but rather a consummate strategist, who sitting in his chamber before his wires directs the movements of a great army.

While we are thus led to confine the directive action of life to the very boundary of the universe of energy it must not however be supposed that we have solved the problem as to the nature of life. We have only driven the difficulty into a border land of thick darkness, into which the light of knowledge has not yet been able to penetrate.

If there be truth in these statements, and if we see in a living being a machine in which great results are produced by an exceedingly small primeval impulse, are we not led to expect that the unstable forms of nature will here be largely made use of? We must not therefore be surprised that the materials of our bodily frames are eminently liable to decay, or that the very intensity of our life is to be measured by the rate of change taking place in the tissues of our bodies, so that possibly those parts which have during life the noblest and most delicate offices to perform are the very first to perish when life is extinct.

But this unstable matter, which is so wonderfully worked into our frames, is derived from the food we eat. This food does two things for us: it gives us energy in the first place, and in the second it furnishes our frames with a quantity of delicately organized tissue. But food is ultimately derived from the vegetable kingdom, and that kingdom derives it from the sun, so that we are led to regard our luminary as the ultimate material source not only of our energy but also of our delicacy of construction.

Before dismissing this subject, let me say a few words regarding the dissipation of energy. It has been shown by Sir W. Thomson that as far as concerns human convenience all forms of energy do not stand upon the same footing. One of the most perfect forms is mechanical energy, while the very worst is universally diffused heat. Now it is exceedingly easy to convert mechanical energy into heat, the chief difficulty being to prevent such a conversion, and in all cases of friction, percussion, and atmospheric resistance, the nobler form of mechanical energy is converted into the more degraded form of heat. But it is not so easy to convert heat back into mechanical energy. We do this very imperfectly in our steam engines, in which the heat produced by the fuel is converted into useful work, but it is only a small portion of this heat-energy that can be so converted. A large part is dissipated, and lost as far as any useful outcome is concerned. We thus see that the process by which mechanical energy is converted into heat is not a strictly reversible one, for while all mechanical energy may easily be converted into heat, only a small portion of heat is convertible into mechanical energy. It follows that day by day the mechanical energy of the universe is growing less, while the diffused heat of the universe is growing greater. A process of degradation is at work which apparently has no limit, and which will only end when the universe, or at least our part of it, has become entirely unfit as a residence for organized beings.

We have seen that the sun is the great source of our material well-being, and that it prepares the food which supplies our frames with energy, as well as with that delicately constructed tissue which is essential to animated existence; but the sun is only a great fire, and it is apparently a fire that has long since ceased to be fed. It is imagined that in the earlier days of our universe the matter of our luminary existed in a diffused and nebulous state, endowed only with the force of gravitation. Now, just as the rushing of a stone to the earth generates heat, so the rushing together of all these nebulous particles into a a compact mass, like the sun, must have generated an enormous amount of heat. This process of condensation is, however, now almost at an end, and the sun with all his energy yet resembles a man whose expenditure exceeds his income.

There is only one issue unless we can see an end to this process of waste. But we fail with our present knowledge to see any prospect of such a change, and we are thus led to contemplate the degradation of the universe, or at least of our own part of it, ending in a total absence of all useful energy and of all life. These are issues upon which the man of science may speculate with advantage, but it should always be borne in mind that our present intellectual stand-point is very low and our knowledge of nature's laws very incomplete.

I have thus endeavoured to give a brief account of a great advance which has been recently made in our knowledge of the laws of nature. Let me now very briefly describe a scarcely less important advance still more recently made in our knowledge of the great bodies of the universe. Ten years since we were hardly conscious of any relationship between this earth and the outlying portions of the Cosmos. A few feeble rays made their way from the stars to us through a bleak and dreary medium called ether, but this was the only known connection between our own system and the universe beyond. The light was only enough to make visible the darkness. The stars for all we knew might have been made of strange elements grouped together by strange laws. They seemed almost to form another universe—to be the domain of another Lord.

But it has been recently discovered that a ray of light gives us much more information than we had hitherto dreamed of. It informs us not only of the position, the distance, and the magnitude of the luminous body, but it tells us also of its composition, of its temperature, of the rate at which it is moving from or towards us—

something even of the very changes which are taking place on its surface. We have lately perfected an instrument called the spectroscope, which enables us to analyze the quality and composition of a ray of light much more easily and accurately than we can perform a chemical analysis. In order to explain the construction of this instrument let me recall for a moment the ordinary photographic camera. By means of the camera lens the image of an exterior object is imprinted on a plate. This image is of course a miniature copy of the object so that the image of a luminous line or slit outside of the camera would be a luminous line or slit imprinted on the camera plate. But if we interpose a glass prism between the luminous slit and its image, the rays of light in passing through this prism will be all bent. They will not all, however, be equally bent.

If there be different kinds of rays coming from the slit, these various rays will be bent in different degrees, and hence the image of the slit due to one ray will be thrown upon one part of the screen or plate while the image due to another ray will be thrown upon another part. The image of the slit will thus be no longer one slit but a great number of slits placed side by side, forming a band or ribbon of light, and this ribbon will be differently colored throughout, because the red rays coming from the slit will be less bent by the prism than the yellow rays, the yellow rays less than the green, the green less than the blue, and the blue less than the violet. Therefore if all these rays are present in the light of the slit, the image will become a many-colored ribbon of light having red at at one of its extremities and violet at the other. This ribbon is called a spectrum, and if the light which illumines the slit be that of the sun we shall receive on the screen the solar spectrum.

The appearance of the spectrum varies greatly with the nature of the substance which emits the light. If this substance be a liquid or solid body at a high temperature we shall then have for our spectrum a continuous ribbon of light going from red at the one extremity through the colors orange, yellow, green, blue, and indigo, to violet at the other. But if the luminous body be an incandescent gas not of great pressure, we have quite a different spectrum. It is no longer a continuous ribbon of light; but we have bright lines standing apart from one another on a dark back-ground. In other words, light from incandescent solids and liquids contains all varieties of rays, while light from incandescent gases contains only a few.

It is another important fact that bodies when cold absorb the very same rays that they give out when heated. Thus the vapour of the metal sodium when incandescent emits a bright yellow line known as the double line D, and when comparatively cold the same vapour will stop this very ray of yellow light coming from another source. Now let us take a luminous solid or liquid body at a high temperature giving out all the rays of the spectrum, and place between it and the eye some comparatively cold sodium vapour. If we examine this combination through a spectroscope, the sodium vapour which gives out the double line D on its own account when hot will be found to absorb the same when cold, so that we shall have an otherwise complete spectrum deficient only in the double line D.

An illustrious German philosopher, Kirchhoff, not only discovered these principles independently, but was the first to apply them to the light of the sun and stars. Thus in the solar spectrum the double line D is dark, and we argue from this that there must be comparatively cold sodium vapour somewhere between the source of light in the sun and our eye. But since there is clearly no incandescent sodium vapour in the atmosphere of our earth, this vapour must therefore be present in that of our luminary. By this means it has been ascertained that the vapours of sodium, iron, nickel, calcium, magnesium, barium, copper, and zinc, exist in the atmosphere of our luminary, while similar elements have been detected by Messrs. Huggins and Miller in many of the stars.

A very surprising result was obtained by Huggins when he directed his spectroscope to certain nebulæ. Their light was found to differ essentially from that of the sun, and to resolve itself into a few bright lines on a dark background, in other words it had the characteristics of light coming from incandescent gas. The spectral position of the lines observed led to the conclusion that these bodies consist of a mixture of hydrogen and nitrogen, but about this there was some uncertainty.

Donati was the first to direct the spectroscope to the light of a comet, and his observations seemed to show that these strange bodies are composed like the nebulæ of incandescent gas. More recently a comet has been observed by Huggins, in which the nature of the light would appear to indicate that the nucleus consisted of ignited gas, while on the other hand the coma gave a continuous spectrum.

To come now to our own luminary—very remarkable strides have lately been made in our knowledge of its physical constitution. It is difficult to say when and by whom the existence of sun spots was first remarked. Galileo however was the first to use them as the means of determining the elements of the sun's rotation. Besides these black spots on the sun's surface, equally mysterious forms have been seen to surround the sun on the various occasions of a total eclipse—these generally went by the name of red flames or red protuberances. Mr. Warren De La Rue was the first to prove that these phenomena were attached to the sun himself, and that the only office of the moon during an eclipse was to subdue the general light sufficiently to render them visible to the eye. While the red flames thus became objects of cosmical interest, Schwabe in Germany and Carrington in this country had both done much to increase our knowledge of sun spots. Schwabe, by a patient course of forty years' observations, had proved the existence of a well-marked periodical fluctuation in the amount and frequency of sun spots, the period of which was about eleven years. Carrington, again, had shown that the region of spots was a somewhat limited one, extending to about 20 or 30 degrees on either side of the solar equator, so that a spot never appears at the sun's pole, and he had also detected a proper motion of spots. Schwabe and Carrington had however confined themselves to mapping down accurately what they saw; but De La Rue, by the introduction of celestial photography, was enabled to obtain autographs of the sun which might be studied at leisure with an absolute certainty of their being correct. A large number of such pictures has been already obtained, and they are in the process of examination by Mr. De La Rue, and those associated with him in this research.

Some of the preliminary results of this examination have already been published, and they seem to point to a connection between the behaviour and frequency of sun spots and the positions of the chief planets of the system.

Our acquaintance with the red flames has extended as rapidly as our knowledge of sun spots. It was discovered independently by Janssen and Lockyer, that these strange protuberances yield to the spectroscope under ordinary conditions of the sun, and without the necessity of waiting for a total eclipse. They exist, in fact always round the sun, but their brightness is quenched in the diffused light which surrounds the sun's border. When, however, we apply a sufficiently powerful spectroscope the diffused light—consisting of ordinary sun light, and therefore containing a great variety of rays—is drawn out into a long spectral ribbon, and has its brightness scattered or diffused over the various parts of this ribbon, while on the other hand the light from the red flames, consisting only of one or two kinds, appears in the spectroscope as one or two bright lines not having their intensity weakened by the scattering action of the spectroscope. They, therefore, stand out in the field of view, while the ordinary light disappears. Lockyer has found, by this means, that there is an envelope of incandescent hydrogen surrounding the glowing surface of the the sun, into which there are frequent injections of heated matter from beneath, and in which there are violent hurricanes often moving at the rate of 100 miles a second. By the laboratory labours of Frankland and Lockyer, taken in connection with the solar observations of the latter, there is, I think, a fair probability of our ultimately ascertaining the pressure and the temperature as well as the chemical composition of the atmosphere of our luminary.

Descending now from the celestial bodies to our own earth, there is some reason to suppose that we are knit to our luminary, and possibly through him to the other members of our system by some other bond, besides that usually recognised. General Sir E. Sabine appears to have proved that disturbances of the earth's magnetism take place most frequently in those years in which there are most sun spots. This is confirmed by the experience of the present year, during which we have had a great number of sun spots, and frequent and large disturbances of the earth's magnetism.

I have already alluded to a possible connection between the behaviour of sun spots, and the positions of the planets; to which we may add, that Schwabe and other observers imagine that they have discovered traces of a periodical variation in the appearance of the planet Jupiter. All these observations would appear to indicate the existence of some unknown bond between the different members of the solar system.

But that department of cosmical physics which is of most immediate interest to ourselves, is undoubtedly the meteorology of our globe; and here it is of great importance to know whether the earth's climate and atmosphere are influenced in any way by the changes taking place in the atmosphere of the sun. Such a connection has not yet been traced, but it has hardly yet been sought for in a proper manner. Recent observations discussed by Baxendell, lead us to think there may be some connection between the daily changes in the earth's magnetism, and the daily motions of the air. Coupling this with the fact that the frequency of terrestrial magnetic disturbances would appear to be connected with that of sun spots, we are led to contemplate at least the possibility of some connection between meteorology and sun spots.

If these remarks are of any value they tend to indicate the probable union of the various branches of observational enquiry into one great cosmical research, and point to the wisdom of a very close union between the workers in the cognate fields of meteorology, terrestrial magnetism, and celestial physics.

At the present moment the prospects of meteorology are more hopeless than those of the other two branches. Our knowledge of the motions of the various components of the earth's atmosphere is extremely limited, and yet without this knowledge it is impossible to connect meteorology with the other branches of cosmical enquiry. If we endeavour to analyze the causes of this backward state of meteorological research, the first and most apparent is the magnitude of the problem.

We are too intimately associated with the earth and its atmosphere to be easily able to tell its motions. Strange to say, the meteorology of the sun is more easily studied than that of the earth, and we know already as much about the strength of solar storms as we do about that of terrestrial hurricanes.

But another cause of the backward state of Physical Meteorology arises from the fact that there are two branches of science each of which may be furthered by meteorological observations. There is first the Physiological branch of meteorology, the object of which is to trace the influence of climate upon animal and vegetable life; and there is next the Physical branch, the object of which is to study the physics of the earth's surface, and more especially the motions of its atmosphere.

It is now high time that a separation should be made in the mind of the observer between these two branches of research. If he would rather pursue the Physiological enquiry, let him say so definitely, but if he wish to pursue Physical meteorology let him clearly keep before his mind the object of all his labours. He should ask himself the question, what is the best system of observation, and what is the best method of reduction, to advance the great object of Physical meteorology—a knowledge of the motions of the earth's atmosphere, and of the causes thereof? He should not fix upon a system of observavations and a method of reduction that may possibly, but upon one that must necessarily, further this great object.

I have thus endeavoured in a few words to bring before you the recent advances in cosmical physics. Besides this, there are two other no less important branches of physical enquiry. We have the physics of organized beings, and we have also molecular physics. But there is this difference between these two branches and that of which I have now spoken:—To forward physiology or molecular physics we chiefly require experiment, but to forward cosmical physics we chiefly require observation. You are all aware that at the present moment a Royal Commission is enquiring as to the relation between science and the State; and, perhaps, therefore you will permit me the opportunity of stating my views as to the manner in which this very necessary assistance may best be given. I think that those branches of science which demand for their extension experiments not requiring very great time, may be furthered with much advantage in institutions such as Owens College. I believe it to be advantageous to bring the highest class of physical teaching into contact with research. If Government be disposed to grant pecuniary aid to such researches, an extension of the allowance made annually to the Government Grant Committee of the Royal Society would appear to be a very legitimate way of accomplishing this object.

The scientific Professors of a College would thus have to state the aim of their research to a Committee of the Royal Society entrusted with the disposal of Government means, and the requisite funds would be forthcoming. No one, I think, can doubt that the small sum of £1000 annually entrusted by Government to the Royal Society for miscellaneous experiments, is administered in a most praiseworthy manner; and if Government would be ready to grant, and the Royal Society willing to undertake, an extension of this trust, it would, I think, be a great point gained for this class of physical experiments. (I speak only of experiments, but the encouragement of experimenters is a point of equal importance.) But when we come to experiments and observations requiring great time, the case is very different. Certain experiments, whether from the great time they require or the great expense they demand, cannot be well performed in a College; while routine and long-continued observations such as those connected with the various branches of cosmical physics are of such a nature as to require a central establishment to superintend their organization and reduction. There is thus I think the necessity for a central establishment of some kind devoted to that class of experiments and observations requiring great time, great space, and great expense for their completion.

Referring more particularly to Cosmical Physics, I feel convinced that meteorology should be pursued in connection with terrestrial magnetism and solar observations; and were a well considered scheme for solving this great problem fairly introduced, I am sure that scientific institutions and individuals throughout the country would do all that they possibly could to promote this most important branch of physical research.

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