water up into the interior of the hanger—thus keeping the bolt dry—and "neither rust nor electrolysis can corrupt."

(*b*) A different form of hanger—simply a metallic link between the ear and span wire, and insulated by two or three independent external insulators.

(*c*) The hanger to be composed of glazed porcelain with a plain metal bolt passing through, but the porcelain must be kept dry and sheltered from rain.

Several other points of interest are touched upon by the authors, and the discussion which followed the reading of the paper by Mr. Tweedy proved that the opinions on the points raised by the paper were very varied, and led to a keen criticism. The idea of a shield was generally welcomed, and a suggestion was made that it should be manufactured in such a form as to be readily adjusted to existing hangers, without having to dismantle the same.

On the subject of the strength of poles, however, the majority was against any reduction in size, and the question of the Standard Committee's "standard pole" provoked an animated discussion.

The subject of the paper is one which for a long time has needed discussion, and the interest in it was shown by the fact that, after the paper was read and discussed at the Birmingham local section's meeting, it was rediscussed in London later in the session, and we may hope that the many points and facts brought forward will help to mitigate the present existing difficulties of the overhead system, and at the same time help to reduce the capital expenditure on tramway schemes that may be undertaken by local authorities.

SOME ASTRONOMICAL CONSEQUENCES OF THE PRESSURE OF LIGHT.[1]

JUST a year ago Prof. Nichols gave here an account of the beautiful experiment carried out by himself and Prof. Hull which, with the similar experiment of Lebedew, proved conclusively that a beam of light presses against any surface upon which it falls. Not only did Nichols and Hull detect the pressure, which is difficult enough, so minute is it, but they measured it with extraordinary accuracy, and confirmed fully Maxwell's calculation that the pressure on 1 sq. cm. is equal to the energy in 1 cubic centimetre of the beam.

Thus we have a new force to be reckoned with. It is apparently of negligible account in terrestrial affairs, partly in that it never has free and uninterrupted play. But out in the solar system, where there is no disturbing atmosphere, and where it may act without interruption for ages, it may produce very considerable results. Even here, so minute is the force that it need only be taken into account with minute bodies. Prof. Nichols in his discourse told how it may possibly account for the formation of comets' tails if these tails are outbursts of finest dust. To-night I shall try to show how it may be of importance with bodies which, though still minute, are yet far larger than the particles dealt with by Prof. Nichols. Such small bodies appear to abound in our system, and to reveal their existence on any starlight night when perishing as shooting stars.

We are to examine, then, how the pressure of light, or more generally the pressure of radiation, from one end of the infra-red to the other end of the ultra-violet spectrum will affect the motion of these small bodies.

I think we get a clearer idea of the effects of light or radiation pressure if we realise from the beginning that a beam of light is a carrier of momentum, that it bears with it a forward push ready to be imparted to any surface which it meets.

Thus, let a source A (Fig. 1) send out a beam to a surface B, and to bring out this idea of carriage of momentum let A only send out light for a short time, so that the beam does not fill the whole space from A to B, but only the length CD. While the beam is between A and B, B feels nothing. But as soon as D reaches B, B begins to be pushed, or it receives momentum in the direction AB, and will continue to feel the push or receive momentum until C has reached B, when the push will cease. The existence of this push on B is definitely proved by the experiments of Lebedew and Nichols and Hull. Now, unless we are prepared to abandon the conservation of momentum, this momentum must have existed in the beam CD and have been carried with it, and it must have been put into the beam by A while it was sending forth the waves. A, then, was pouring out forward momentum, and was feeling a back push while it was radiating. This back push against the source has not, I think, been proved to exist by direct experiment, though an indirect proof may perhaps be afforded by the case of reflection. When a beam is totally reflected, the push measured in light-pressure experiments is double that when it is absorbed, that is, there is a push by the incident beam and an equal push by the reflected beam, and we may perhaps regard the reflected beam as starting from the reflector as source, and then we have a push back against the source. But whether this be proof or not, I do not see how there can be the slightest doubt that the pressure against the source exists, and that for the same intensity of beam it is equal to that against a receiving surface.

FIG. 1.

Some experiments which have been made by Dr. Barlow and myself appear to bring to the front this conception of light as a momentum carrier. When a beam falls on a black surface it is absorbed—extinguished—and its momentum is given up to the surface. In a beam of light AB (Fig. 2) the momentum is a push forward in the direction AB, and if it falls on a black surface S it gives up this momentum to S. The total push which is in the direction AB may be resolved into a normal push N and a tangential push T. If S can move freely in its own plane, and only in that plane, T alone comes into play, and S will slide towards *s*.

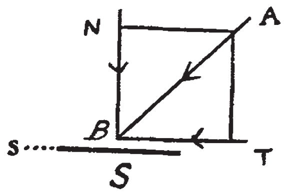

FIG. 2.

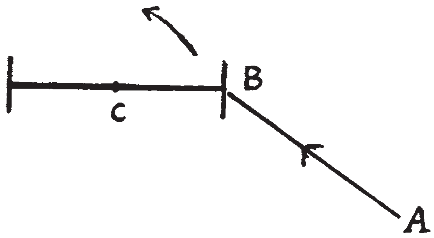

FIG. 3.

To show this effect we fixed two glass discs at the end of a short torsion rod hung by a fine quartz fibre the discs being perpendicular to the rod, and the face of one of them being blackened. Fig. 3 shows a plan of the arrangement. The apparatus was enclosed in a glazed case, which was exhausted to about 2 cm. pressure of mercury. On directing a horizontal beam AB at 45° on to the black surface B, the normal force merely pressed B back, but the tangential force turned B round the point of suspension C away from AB. It is difficult to make the disc quite symmetrical and the beam quite uniform, and

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[1] Discourse delivered at the Royal Institution on May 11, by Prof. J. H. Poynting, F.R.S.

unless these conditions are fulfilled the disturbing forces due to heating of the surface, convection currents and radiometer effects may easily have a large moment either way round C. But these disturbing forces take time to develop, as Nichols and Hull showed, while the tangential push of the light acts instantly. Always when the beam is first directed on to B the motion in the first second or two is away from AB.

It has been urged that this experiment is not conclusive in that the lampblack is granular, and the force observed may be due to normal pressure against the sides of the grains. But if the back surface of the disc is blackened, so that the surface is much smoother, the action is as great.

Another form of the experiment which we have lately made is perhaps better. A horizontal disc of mica, about 2 inches in diameter, is suspended in the case by a quartz fibre (Fig. 4). The disc is blackened on its under face. If a beam of light AB is incident at 45° at B, it tends to push the disc one way round. The gas action due to heating may possibly, and sometimes does, act against this push. But if an equal beam CB is sent from the other side instead of AB, the heating, and therefore the gas action, is the same, while the tangential push is in the opposite direction, and the deflection now is always less in the direction of the arrow than it was before, and the difference gives twice the effect due to the tangential push of either.

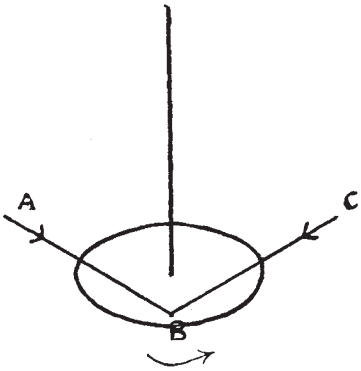

FIG. 4.

Another experiment, rather different in kind, even more clearly shows that light carries a stream of momentum. Two glass prisms BD (Fig. 5) were fixed at the end of a torsion arm and suspended by a fibre from C. A beam of light AB was directed horizontally so as to pass through the two prisms and emerge parallel to its original direction along DE. Always the torsion arm turned as indicated by the arrow, just as a pipe would tend to turn if it were bent as the beam of light is bent and carried a stream of water—a stream of forward momentum.

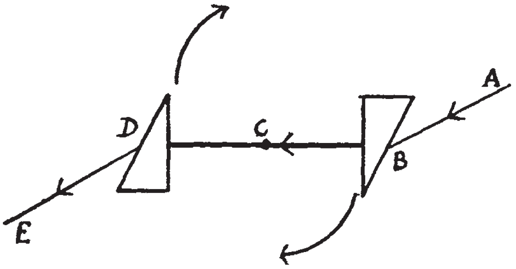

FIG. 5.

I will not now dwell on the interesting modification of the third law of motion which we must make to reconcile with it these experiments on light. It is enough to say that we must admit the luminiferous medium into momentum transactions just as long ago we admitted it into transactions with energy.

Let us now see how this way of regarding a beam of light leads us to expect a modification of the pressure when the receiving or the emitting surface is moving.

First, let us suppose that the receiving surface is moving towards the source. Let A (Fig. 6*a*) be the source. Let B be the receiving surface, moving towards A with velocity u. If B were at rest at C it would receive in one second the radiation and the momentum in length $CD=U$, the velocity of light. But when a given wave starts from D, let the surface start from B, and let them meet at the end of a second. Then B has evidently absorbed the momentum in length $BD=U+u$, and it has received more than it would have done if at rest in the ratio $U+u : U$. The pressure, therefore, is increased, and by the fraction u/U. It is easy to see from Fig. 6*b* that if B is moving away from the source it receives less momentum, has less pressure than if it were at rest, and the decrease is again by the fraction u/U. We may call this the "Doppler reception effect," "Doppler" since he was the first to point out the effect of motion on radiation.

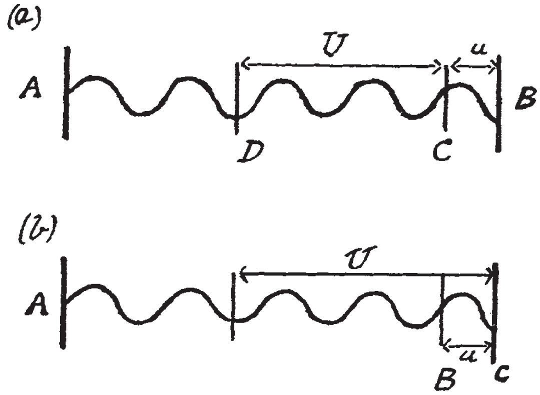

FIG. 6.

If the source is moving there is a nearly equal effect upon it. The pressure is increased if it advances and is decreased if it retreats, but the effect arises in a different way. It is now due to alteration of wave-length. The source crowds up and shortens the waves it sends forward, putting into them more energy and more momentum, and so suffering an increase in pressure, while it draws away from and lengthens the waves it sends backward, putting into them less energy and momentum, and so suffering a decrease in pressure. The alteration of pitch produced in sound by motion of the source is familiar to all.

We can easily deduce the alteration in pressure if we make the reasonable assumption that the amplitude, the height or depth of the waves sent out from the source, depends on its temperature alone, and not on its motion.

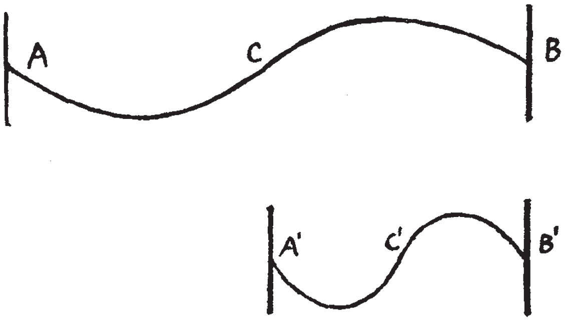

FIG. 7.

Let us imagine, by way of illustration, that the source moves with half the velocity of light, so that a wave which would be ACB (Fig. 7) is packed into half the space A'C'B'. With waves of the same height, the energy in a given length is inversely as the square of the wave-length, so that A′C′B′ has four times the energy and momentum that ACB has *in the same length*, or the wave A′C′B′ has twice the energy and twice the momentum of the wave ACB sent out in the same time, and the pressure against A′ is twice that against A.

When the speed of the source u is small compared with that of light, the increase of pressure in forward motion, or decrease in backward motion, is practically the fraction u/U (more exactly it is altered to $U/U \pm U$ of the value when at rest). We may call this the Doppler emission effect.

Coming back to the pressure on a source at rest, that pressure depends on the rate at which the source is pouring out radiant energy, and that rate depends on the temperature of the source. If the body is a black body or a full radiator, the rate of radiation is as the fourth power of the absolute temperature, a law no longer depending on precarious hypotheses, but the result of direct experiment. Here is a table showing the energy radiated and the pressure back against the radiating surface at three important temperatures:—

Radiation from and Back Pressure against a Radiating Surface.

Absolute temperature	Energy emitted in ergs per second per sq. cm.	Back pressure in dynes per sq. cm.
0°	0	0
300° (Earth)	$4 \cdot 3 \times 10^4$	$9 \cdot 6 \times 10^{-6}$
6000° (Sun)	$6 \cdot 9 \times 10^9$	1·5

A black surface on the earth, then, is pushed back with a force of 1/100,000 mgm. per sq. cm. by its own radiation, while the surface of the sun is pushed back with a force of a milligram and a half on the square centimetre. This table helps us to realise the exceeding minuteness of the forces with which we have to deal.

While we are considering the connection between radiation and temperature, it will be useful to see how the temperature of an absorbing particle depends on its distance from the sun. Take first such a particle, at the distance of the earth from the sun. If the sky were completely filled with suns it would be at the temperature of the sun, and give out the corresponding radiation. But the sun only fills 1/200,000 of its sky, so that the particle only receives and gives out 1/200,000 of that radiation. Its temperature is therefore $\sqrt[4]{200,000}$, say about twenty times less than that of the sun. We can form a tolerably good estimate of the temperature of the particle, since the rotation of the earth and its circulating atmosphere make its mean temperature, which is nearly 300° absolute, the same as that of the particle. So that the temperature of the sun is probably about 6000° absolute, or at any rate gives out as much radiation as a full radiator at that temperature.

If we move the particle in to, say, one-quarter the distance, a little within the nearest approach of Mercury, the heat from the sun is sixteen times as great, so that the temperature of the particle is twice as great, say 600° absolute, about the temperature of boiling quicksilver. Out near Jupiter it will be half as great, say 150° absolute, the temperature varying inversely as the square root of the distance.

Now we have the data from which we can trace some of the consequences of light pressure in the solar system.

The direct pressure of sunlight is virtually a lessening of the sun's gravitation, for, like it, it varies as the inverse square of the distance. As we can by direct measurement find, or at any rate form an estimate of, the energy per c.c. in sunlight, we can calculate the pressure which sunlight exerts on a square centimetre exposed directly to it at the earth's distance, and it works out to about 0·6 mgm. per square metre. On the whole earth it is only about 75,000 tons, a mere nothing compared with the sun's pull, which is forty billion times greater.

But if we halved the radius of the earth we should have one-eighth the gravitation, while we should only reduce the light pressure to one-quarter, or one would be only twenty billion times the other. With another halving it would be only ten billion times as great, and so on until, if we made a particle a forty-billionth of the radius of the earth, its gravitation would be balanced by the light pressure if the law held good so far.

This effect of diminution of size applies to the radiating body as well. If we halved the radius of both earth and sun, the gravitative pull would be one sixty-fourth, while the light pressure would be one-sixteenth, or we should in each halving reduce the ratio of pull to push twice as much, and should much sooner reach the balance between the two, and, of course, the balance would be reached sooner the hotter the bodies. Thus two bodies of the temperature and density of the sun, and about 40 metres in diameter, would neither attract nor repel each other. Two bodies of the temperature and density of the earth would neither attract nor repel each other if a little more than 2 cm., or just under an inch, in diameter.

Suppose, then, a swarm of scattered meteorites 1 inch in diameter and of the earth's density approaching the sun. Out in space their gravitation pull would be greater than their mutual radiation push, and there would be a slight tendency to draw together. When they came within 100 million miles of the sun radiation would about balance gravitation, and they would no longer tend to draw together. As they moved still nearer repulsion would exceed gravitation; and there would be a tendency—slight, no doubt—to scatter.

It appears possible that this effect should be taken into account in the motion of Saturn's rings if these consist of small particles. Let us suppose that Saturn is still giving off heat of his own in sensible quantity, and, merely for illustration, let us say that his temperature is about that of boiling mercury, 600° absolute. Imagine one of a thinly scattered cloud of particles near the division of the rings. At such a distance from the sun the particle will be receiving nearly all its heat from the planet, which will occupy about one-sixteenth of its sky. If the planet filled the whole sky the particle would be at 600°, and give out corresponding radiation. But filling only one-sixteenth of the sky it gives to the particle, and the particle gives out again, only one-sixteenth of the 600° radiation. It is therefore at $\sqrt[4]{1/16}$, or half the temperature, 300° absolute, the temperature of the earth. Particles in the ring, then, about 1 inch in diameter would neither attract nor repel each other, and each would circle round the planet as if the rest were absent.

Passing on from these mutual actions, let us see how radiation pressure will affect a spherical absorbing particle moving round the sun. We have already seen that the direct pressure of sunlight acts as a virtual reduction of the sun's pull, and a small particle will not require so great a velocity to keep it in a given orbit as a large body will. A particle 1/1000 inch in diameter, at the distance of the earth from the sun, and of the earth's density, will move so much more slowly than the earth that its year will be nearly two days longer than ours.

In the second place we have the Doppler emission effect. The particle crowds forward on its own waves emitted in the direction of motion, and draws away from those it sends out behind. There is an increased pressure in front, a reduced pressure behind, and a net force always opposing the motion. This force is a very small fraction of the direct sun push, in fact only $\frac{1}{3} \times \frac{\text{velocity of particle}}{\text{velocity of light}}$ of that push.

But, unlike that force, it is always acting against the motion, always dissipating the energy. The result is that the particle, losing some of its energy, falls in a little towards the sun, and moves actually faster in a smaller orbit. The particle we are considering would fall in about 800 miles from the distance of the earth in the first year. Next year it would be hotter, the effect would be greater, and it would move in further. I think it would reach the sun in much less than 100,000 years. As the effect works out to be inversely as the radius, a particle an inch in diameter would reach the sun in much less than a hundred million years.

There is another Doppler emission effect which must be mentioned. If the whole solar system is drifting along relatively to the ether, there is a Doppler resistance to the drift utterly negligible on the sun and planets, but quite appreciable on meteoric dust. I confess that I am utterly unable to tackle the equations of motion when this force is taken into account, but if we make rough approximations it seems possible that it too would lead to a gradual approach to the sun. The most obvious method of approximation in dealing with a small disturbing force is to omit it. Let us adopt this method here, and turn to another effect which can be tackled—a Doppler reception effect, which only comes into play when a particle is changing its distance from the sun.

Imagine a particle moving in an elliptic orbit to be coming towards the sun. The sun pressure against it is slightly increased by the motion, or, virtually, gravitation is lessened. When the particle has swung round the sun and is retreating, the sun pressure is slightly lessened, or, virtually, gravitation is increased. That is, there is always a force tending to resist change of distance from the sun, tending, I take it, to make the orbit less eccentric, more circular.

Now let us see how these forces will act on a comet, supposing a comet to consist of a somewhat thinly scattered cloud of particles of various sizes down to, say, a ten-thousandth of an inch in diameter. Somewhat below that size the particles would be repelled and never tend to approach the sun at all, and would be weeded out of the comet as it first came into our system. Let us suppose that, to begin with, the various sizes are well mixed up. Then at once a sorting action will begin. The direct sun pressure will lengthen out the year of the finer particles more than that of the coarser, and they will gradually trail behind in the orbit.

Then the Doppler emission effect will gradually damp down the motion, again more markedly with the finer particles, and they will tend to spiral in towards the sun and shorten the period of revolution. Then the Doppler reception effect will tend to make the orbit ever less elliptic, and again with the smaller particles the action will be more rapid.

In any single revolution the effect will no doubt be small, even on the smaller particles, but after thousands or millions of revolutions the particles of different sizes may move in orbits so different that they may not appear to have any connection with each other. In course of ages all the smaller particles, and if we have a sufficient balance in the bank of astronomical time even the larger particles, will end their course in the sun itself.

There is one member of our system, Encke's comet, which at first sight looks as if it were manifesting these actions even in the short time, less than a century, that it has been under observation. Its motion is commonly interpreted as a shortening of its period by 2½ hours in each revolution of 3½ years. But Mr. H. C. Plummer has investigated its case, and finds such difficulties, difficulties with which I need not now trouble you, that I fear the obvious explanation that the Doppler resistance is the cause must be abandoned. But though we may not notice the effects in any short time, I see no escape from the conclusion that if comets are clouds of small particles brought into, and made members of, our system, they at once begin to undergo a sorting action, the finer particles drawing inwards more rapidly, and ultimately ending their career in the sun. Possibly the Zodiacal Light is the dust of long dead comets.

Where our ignorance is complete and unbounded hardly any supposition can be ruled out. Let me, then, in conclusion, make one wild suggestion. Suppose that a larger planet, still so hot as to be a small sun, succeeds in capturing a cloud of cometary dust. Just the action I have been describing should go on. The cloud would gradually spread into a long trail, the larger particles leading, the smaller dropping behind and moving in, and ultimately we might have a ring round the planet, a ring tending to become more and more circular as time went on, with the larger particles outside and the finer particles forming an inner fringe. With different grades of dust we might have different rings. Is it possible that Saturn has been wild enough to have adopted this suggestion?

UNIVERSITY AND EDUCATIONAL INTELLIGENCE.

CAMBRIDGE.—The special board for mathematics is now submitting for the approval of the Senate regulations for part i. and part ii. of the mathematical tripos embodying the resolutions which were adopted by Senate on October 25. It has been found necessary to make provision for the transition from the present system to the new one, and some temporary provisions are suggested for this purpose. In other respects all the regulations now submitted have already been published in the draft regulations appended to the report above referred to. It is these detailed regulations that the master of Sidney Sussex College and some other members of the Senate have announced their intention to "non-placet."

The observatory syndicate has been considering the great increase in astrophysical work which has been in the last few years carried on in the University observatory by Mr. H. F. Newall. It considers the time has come when an assistant of university standing should be appointed to assist Mr. Newall, and announces the generous offer of Mr. Newall to find 100*l.* a year for five years toward the stipend of such an assistant. The syndicate recommends (1) that for a period of five years, from January 1, 1907, there be appointed at the observatory an assistant, to be entitled "the assistant in astrophysics," who shall be under the general direction of the Newall observer; (2) that the assistant in astrophysics be appointed by Mr. Newall with the consent of the Vice-Chancellor, and be removable in like manner; (3) that a stipend of 100*l.* per annum, payable from the University chest, be assigned to the assistant in astrophysics, Mr. Newall having undertaken to augment the stipend by an annual sum of 100*l.* for a period of five years from January 1, 1907.

Two largely signed memorials have been presented to the council of the Senate. The first urges (1) that a paper or papers in natural science shall be included amongst the compulsory subjects of any examination which may be substituted for the present previous examination, and (2) that in the classical part of such an examination no separate paper in Greek and Latin grammar shall be set. The second requests the council of the Senate to appoint a syndicate to consider the advisability of instituting a diploma in architecture in view of the great importance of architectural studies, which has already been felt in other universities, where such studies have been successfully organised.

The following have been nominated examiners in the mechanical sciences tripos:—Prof. Hopkinson, Prof. W. E. Dalby, and Mr. C. E. Ingles; in State medicine, Dr. Anningson, Prof. Nuttall, Dr. J. Lane Notter, Dr. R. D. Sweeting, and Dr. A. Newsholme; in the diploma of tropical medicine and hygiene, Prof. Nuttall, Mr. C. W. Danields and Mr. W. B. Leishman.

The board of agricultural studies, in consultation with the president of the Royal Agricultural Society, has appointed Major P. G. Craigie, C.B., to be Gilbey lecturer on the history of the economics of agriculture for three years from January 1.

A syndicate has been nominated to obtain plans and estimates for the extension of the Cavendish Laboratory on the site recently assigned it by a Grace of the Senate. This extension has been rendered possible by the generosity of Lord Rayleigh, who has presented the Nobel prize to the University.

Mr. Aubrey Strahan, St. John's College, has been approved by the general board of studies for the degree of Doctor in Science.

A University lectureship in botany is now vacant by the resignation of Prof. Seward. The general board of studies will shortly proceed to appoint a lecturer to hold office from Christmas, 1906, until Michaelmas, 1911. The annual stipend is 100*l.* Candidates are requested to send their applications, with testimonials if they think fit, to the Vice-Chancellor on or before November 30, 1906.

Mr. R. P. Gregory, of St. John's College, has been appointed senior demonstrator in botany until September 30, 1911.

Mr. A. Hutchinson, of Pembroke College, has been