time will not only be devoted to teaching but also to the advancement of research in tropical medicine. PAUL C. FREER,

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SOME ASTRONOMICAL CONSEQUENCES OF THE PRESSURE OF LIGHT[1]

THE experiments of Lebedew and Nichols and Hull have proved conclusively that light presses against any surface upon which it falls, and the extraordinarily accurate experiments of Nichols and Hull have fully confirmed Maxwell's calculation that the pressure per square centimeter is equal to the energy in the beam per cubic centimeter.

A clearer idea of the effect of light or radiation pressure is obtained by thinking of a beam of light as a carrier of momentum. We then see that not only does it press against a receiving surface, but also against the surface from which it started.

Some experiments by Dr. Barlow and myself appear to bring to the front this conception of light as a momentum carrier. If a beam falls on a black surface at an angle to the normal, there should be a tangential stress along the surface. An experiment was described in which light fell on a blackened disc at the end of a torsion arm, the disc being at right angles to the arm.[2] The disc was pushed round by the tangential stress. The experiment was carried out in a partially exhausted vessel, but the residual air was a source of disturbance by convection and radiometer effects. A better experiment was made by suspending a disc of mica blackened beneath, about two inches in diameter by a quartz fiber, the disc being horizontal and suspended from its center. When a beam of light fell at 45° on a part of the disc, the horizontal component of the beam being at right angles to the radius to the part where it fell, the disc moved round through the combined effects of convection, radiometer action and the tangential stress, When the beam was allowed to fall on the same place at 45° on the other side of the vertical, convection and radiometer action were very nearly as before, but the tangential stress was reversed. The difference in torsion in the two cases was twice that due to the tangential stress. An experiment with prisms[3] was also described.

Regarding a beam of light as a momentum carrier, it is easily seen that if the receiving surface has velocity u towards the source and the velocity of light is U, the pressure is increased by the motion by the fraction u/U. If the velocity is reversed, the pressure is decreased by this fraction. This is the "Doppler reception effect."

If the source is moving, and we assume that the amplitude of the emitted waves depends on the temperature and nature of the source alone, it can be shown that the pressure on the source is $U/(U \mp u)$ of its value when the source is at rest. This is the "Doppler emission effect."

In considering the consequence of light pressure, it is necessary to know the temperature of a body exposed to the sun's radiation. It can be shown that a small black particle, at the distance of the earth from the sun, has about the mean temperature of the earth's surface, say 300° Abs., and that the temperature of the sun is about twenty times as high, say 6000° Abs. The temperature of the particle varies inversely as the square root of its distance from the sun.

The direct pressure of sunlight is virtually a lessening of the sun's gravitation pull. On bodies of large size this is negligible. On the earth it is only about a forty-billionth of the sun's pull, but the ratio increases as the diameter decreases, and a particle one forty-billionth of the earth's diameter, and of the same density, would be pushed back as much as it is pulled in, if the law held good down to such a size. If the radiating body is diminished, the ratio of gravitation pull to light push is similarly diminished, and it can be shown that two bodies of the temperature of the earth's surface and of the earth's mean density would neither attract nor repel each other, if their diameter was about one inch. The consequence of this on a swarm of me-

[1] Abstract of an address before the Royal Institution of Great Britain.

[2] *Phil. Mag.*, IX. (1905), p. 169.

[3] *Ibid.*, p. 404.

teorites is obvious. It is probable that this balancing of gravitation and light pressure must be taken into account in the motion of the particles supposed to constitute Saturn's rings.

When we consider the motion of a small particle round the sun, we have, first, the direct pressure lessening gravitation. If it has density equal to that of the earth and diameter one one-thousandth of an inch, the lessened pull at the distance of the earth will imply a lengthening of the year by nearly two days. Secondly, the Doppler emission effect comes into play, for the particle crowds forward on its own waves emitted in front, and draws away from those emitted behind, so that there is increase of pressure in front and a decrease behind. Thus there is a force resisting the motion. The particle will then tend to fall inwards in its orbit, and in the case considered, about 800 miles in the first year. It would probably move in a spiral into the sun, and reach it in less than 100,000 years. A particle one inch in diameter would reach the sun from the earth in less than a hundred million years.

The Doppler reception effect will not come into play in a circular orbit, but in an elliptic orbit it acts as if it were a force resisting change of distance, and therefore it tends to make an elliptic orbit even more circular.

Applying these considerations to a comet regarded as a swarm of small particles coming into our system, a sorting action will at once begin. The smaller particles will have their period of revolution lengthened out more than the larger ones, and they will tend to trail behind. The Doppler emission effect will damp down the motion, and again, more markedly with the smaller particles, and all will tend to spiral into the sun. The Doppler reception effect will tend to destroy the ellipticity of the orbit, more especially with the smaller particles, and ultimately the particles of different sizes may move in orbits so different that they may not appear to belong to the same system. In course of time they should all end in the sun. Perhaps the zodiacal light is due to the dust of long dead comets.

It appears just possible that Saturn's rings may be cometary matter which the planet has captured, and on which these actions have been at play for so long that the orbits have become circular.

J. H. POYNTING

SCIENTIFIC APPOINTMENTS AT THE UNIVERSITY OF WISCONSIN

A NUMBER of changes have been made at Wisconsin in the several scientific departments. The board of regents have named Dr. Charles R. Bardeen, at present professor of anatomy, dean of the new college of medicine. The faculty of the new medical college includes, besides Dean Bardeen as professor of anatomy, Dr. Joseph Erlanger, professor of physiology; Dr. H. L. Russell, professor of bacteriology; Dr. M. P. Ravenel, professor of bacteriology; Dr. W. D. Frost, associate professor of bacteriology; E. G. Hastings, assistant professor of bacteriology; Dr. C. A. Fuller, instructor in bacteriology and assistant in the hygienic laboratory; Dr. Harold C. Bradley, assistant professor of physiological chemistry; Dr. J. R. Blackman, assistant in physiology; Dr. Richard Fischer, assistant professor of pharmacy; Dr. Edward Kremers, professor of pharmaceutical chemistry; Dr. Louis Kahlenberg, professor of physical chemistry; Dr. Victor Lenher, associate professor of chemistry; Dean E. A. Birge, Associate Professor W. S. Marshall, and Assistant Professor S. J. Holmes in the department of zoology; Professor R. A. Harper, Associate Professor C. E. Allen and Assistant Professor R. H. Denniston of the department of botany; and Professor B. W. Snow, Professor C. E. Mendenhall, and Assistant Professor A. H. Taylor of the department of physics.

Professor Mazyck Porcher Ravenel takes charge of the Department of Bacteriology, succeeding Dr. Harry L. Russell, who was appointed dean of the College of Agriculture, vice W. A. Henry, resigned. Dr. Ravenel has been assistant medical director of the Henry Phipps Institute for the Study of Tuberculosis in Philadelphia, and was formerly bacteriologist for the State Sanitary Live Stock Board of Pennsylvania, where he carried on research work in connection with treatment of tuberculosis and rabies.