seemed particularly appropriate for the 18-inch telescope of the Flower Observatory. It was believed that it should be possible to re-measure each of the pairs, and thus to make the present series of observations a complete one.

Work was systematically begun on these stars in 1901, and in the course of two years the list was nearly completed. But there were many stars with which the results of my measures differed from the first obtained, and a number of others which, because they were so difficult that they could only be observed on unusually good nights, were not finished. To obtain later measures of these, the present publication has therefore been delayed until now. Nearly all stars showing decided change have been re-measured since 1904, and no pair remains which is not either measured, or of which I am not reasonably certain that it is single in this telescope at this time."

The arrangement and completeness of the work is above all criticism. No pair is measured on less than three nights and most of them on five or six. The care and thoroughness with which every part of the work has been done is obvious on every page. No better evidence could be offered of the optical excellence of the 18-inch telescope made by Mr. Brashear than its use in so successfully carrying out this long series of difficult observations.

This work was a much needed one, and a proper tribute to the reputation and memory of one who has perhaps been longer in astronomical work than any other in the country. In bringing together these discoveries, scattered in many volumes of the periodical in which they were originally printed, Mr. Doolittle has done for Hough what Hussey has done for Otto Struve stars, Lewis for the Struve stars, and the writer for the Burnham lists. Future observers of any of these stars will appreciate these several compilations as well as the new measures which bring the history of these systems down to the present time.

SOME ASTRONOMICAL CONSEQUENCES OF THE PRESSURE OF LIGHT.

J.H.POYNTING.

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 disk at the end of a torsion arm, the disk being at right angles to the arm*. The disk 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 disk of mica blackened beneath, about two inches in diameter by a quartz fiber, the disk being horizontal and suspended from its center. When a beam of light fell at 45° on a part of the disk, the horizontal component of the beam being at right angles to the radius to the part where it fell, the disk 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† 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 velociey 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

* *Phil. Mag.*, IX (1905), p. 169.

† *Ibid.* p. 404.

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 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 meteorites 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-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 particles 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.