power of producing nuclei when cold, while others, as aluminum, had little effect. Experiments with ordinary air and with the pure air found in the neighborhood of Loch Awe both showed that whereas large nuclei were present, small nuclei requiring more than a 6 per cent expansion to produce condensation were generally absent. This did not support the theory that nuclei are aggregations of ions, since in this case nuclei of all sizes from that of a single ion upward would be expected. Some tests were made with air ionized by means of radium salts, but even after long intervals extending up to a day no tendency was observed for the ions to combine and produce large nuclei. It is therefore considered as proved that the "large ions of the atmosphere" are in reality nuclei to which an ion has become attached and given up its charge. The paper contains much detail information which can not be summarized in an abstract.—*J. S. Di[nes]*.

RELATION BETWEEN SUNLIGHT AND MOONLIGHT.[1]

By J. S. Dow.

[*Reprinted from* Science Abstracts, Sect. A, Sept. 29, 1917, §931.]

Taking sunslight to be equivalent to 10,000 candle-feet (for perpendicular incidence from an unclouded sky), the corresponding illumination from the full moon is calculated to be 0.02 candle-foot. The author finds this to be very near the value he obtained by actual measurement. The range of illumination between sunlight and moonlight is thus of the order of 1 to 500,000.—*C. P. B[utler]*.

[See this REVIEW for June, 1914, p. 347 for another estimate of the moon's brightness.]

551.510.5 (048)

MINUTE STRUCTURE OF THE SOLAR ATMOSPHERE.[2]

By G. E. HALE & F. ELLERMAN.

[*Reprinted from* Science Abstracts, Sect. A, Sept. 29, 1917, §873.]

A short summary is given of the result of an extensive investigation of spectroheliograms showing the structure of the solar atmosphere at various levels in comparison with that of the low-lying photosphere and sunspots. For the photosphere Langley's "rice grains" and "granules" are still the best standards for denoting the minute structure, the granules being about 0.3 second in diameter (say about 130 miles). Photographs taken with the spectroheliograph in calcium light can be made to show details at different levels according to the slit setting. The smallest calcium flocculi observed are less than 1 second in diameter. In the case of the highest levels shown by the dark hydrogen flocculi in Hα-light, the smallest flocculi are about 2 seconds in diameter. This seems to support the view that the photosphere and gaseous atmosphere above it are formed of columns of hot gases, rising by convection from the interior of the sun. To illustrates these difference of level a stereoscopic picture is given of a dark hydrogen flocculus floating over the region of a large spot group on 1915, August 7, the vortex action of the spots is also well shown by the bending of the hydrogen flocculus near the spot umbræ. It is concluded that the minute structure of the quiescent solar atmosphere resembles that of the photosphere. In disturbed regions, the small granular regions are replaced by slender filaments, lying side by side, resembling the structure of penumbræ of sunspots.—*C. P. B[utler]*.

The present editor reprints below the last paragraph of the original proceedings of the National Academy of Sciences, February, 1916, **2**:108:

> We have shown in this paper that the minute structure of the quiescent solar atmosphere resembles that of the photosphere. In disturbed regions, the small granular elements (minute flocculi) are replaced by numerous slender filaments, lying side by side, and recalling the structure of the penumbra in sun spots. While these results appear to support the hypothesis that the solar atmosphere consists of parallel columns of ascending and expanding gases, which are drawn out horizontally in spot penumbræ and in disturbed regions of the chromosphere, such questions as the dimensions of the columns and the direction of motion and velocity of the vapor in sun spots and in the atmosphere about them are reserved for subsequent discussion.

523.4 (048)

WHY THE AXES OF THE PLANETS ARE INCLINED.

By Prof. WILLIAM H. PICKERING

(Harvard College Observatory, Mandeville, Jamaica, B. W. I.).

[*Reprinted from* Popular Astronomy, October, 1917, 25.]

[The intimate relation existing between the climates and meteorology of a planet and the inclination of its axis to the plane of the ecliptic, seems sufficient justification for introducing this astronomical discussion here—C. A., jr.]

This question is constantly asked by students of astronomy, and the answer generally given is either that it "just happened so," or else that "nobody knows." In point of fact the answer is not very far to seek. Imagine a large revolving gaseous mass condensed toward the center. Recent observations seem to show that at least one of the nebulæ revolves as one piece, as if it were a solid body, but in general there is no question but that in a loosely formed gaseous mass the outer portions will travel at a lower linear rate than the inner ones. Let figure 1 represent such a condensing gaseous mass, with a huge condensation at *a* and a relatively small one beginning to form at *b*. The shape of the latter is of no consequence, whether it is spherical from the beginning, or merely the portion of an arm of a spiral. In either case its outer portion revolves about *a* more slowly than its inner, as is indicated by the arrows, and if it finally condenses sufficiently to form an independent body, revolving about *a* in a positive direction, its rotation on its own axis will be *negative*, or as we usually describe it *retrograde*.

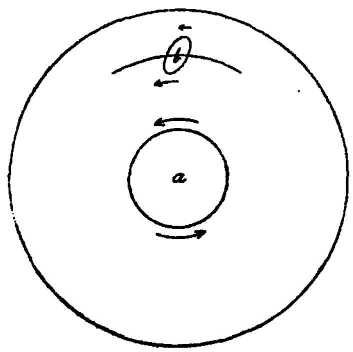

FIG. 1.—Illustrating the origin of the initially retrograde rotation of a satellite or a planet, *b*.

If this is the method by which the planets were formed, which seems not unlikely, why is it then that their rotation is found to be direct instead of retrograde? In point of fact the rotation of the two outermost *is* retrograde as has been known theoretically, from the direction of revolution of their satellites, for many years. Only recently this direction has been confirmed spectroscopically for Uranus at the Lowell Observatory (Lowell Observatory Bulletin No. 53) and the period of rotation found, $10^h 50^m$. This period has been confirmed,

[1] Illum. engr., London, April, 1917, 10: 113-114.
[2] Proc., Nat. acad. sci., February, 1916, 2: 102-108.

still more recently, by Mr. Campbell at Harvard (Circular 200).

Owing to the rotation of the planets on their axes a daily tide will be produced on each of them by the sun, but this tide can have no influence whatever on the direction of the rotation of the planets. But besides this daily tide an annual tide is also produced, the effect of which in general, although very small, is to slow down the rotation, and finally to make each planet constantly present the same face to the sun. The slowing-down process, however, is peculiar, and not at all what one would naturally expect. The simplest case to explain is that where the axis lies in the plane of the orbit, as is nearly the case at present with the planet Uranus (fig. 2). The effect of this annual tide, which is shown by the two bulging lines, is to tend to cause the planet to rotate about an axis perpendicular to its orbit. This force, or more strictly speaking, couple, acts continuously, and is indicated by the two short arrows. Its direction it will be noted lies at right angles to that of the couple producing precession.

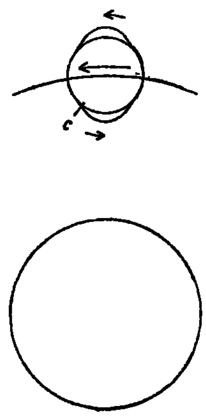

FIG. 2.—Illustrating present retrograde rotation of Uranus, inclination of axis 98°.

Owing to the rapid rotation on its axis, Uranus acts as a gyroscope, and refuses to shift its plane in the direction in which it is pulled, but does gradually yield in a direction at right angles to the pull. That is to say, its axis of rotation cants over, so that instead of revolving as at present in a retrograde direction, its axis will sooner or later lie exactly in the plane of the orbit [=plane of paper]. Instead of pole *c* being above the plane of the paper, it will coincide with it. Its inclination then instead of being 98° will become 90°. When this occurs we can no longer say that its rotation is retrograde any more than that it is direct. In fact it is neither the one nor the other.

But the process does not end here. After being reduced to 90° the inclination of the axis next becomes 89°, and the direction of motion is now positive, i. e., the rotation is direct. It continues to decrease steadily as the centuries pass, and will finally become 0°, which is the stable inclination and beyond which no change can occur. It will then be rotating on an axis exactly perpendicular to the plane of its orbit, and with a direct motion. This is the theoretical result that must necessarily occur, and the shifting of the plane of rotation can readily be illustrated practically by means of a gyroscope mounted within two rings, or a ring and a fork. Under these circumstances a slight pull to one side on the end of the axle, or any friction introduced on the vertical axle of the fork, will correspond to the annual tide.

In the case of the tide itself the pull is relatively very minute at present, but this was not the case when the planets were huge gaseous masses. The inclinations of the outer ones are Neptune 145°, Uranus 98°, Saturn 27°, and Jupiter 3°. The tidal pull increases very rapidly as we approach the sun, which is the chief reason that the inclination of Jupiter has now nearly reached its theoretical limit of 0°. While the original thin flattened solar nebula must have extended far beyond the present orbit of Neptune, the great great swirl that ultimately developed into the planet Jupiter must for a similar reason have been at least thirty million miles in diameter, and its age must be reckoned in thousands of millions of years. The inclinations of the two small terrestrial planets, the Earth and Mars, are both 23° and, doubtless owing to their small mass and consequent rapid cooling, they reached their present solid form before the tidal forces were able to complete their work. The diminution in their inclinations is still going on, but at an almost infinitesimal rate.

But have we any evidence other that Saturn and Jupiter formerly rotated in a retrograde direction? In 1901 it was shown that Saturn's ninth satellite revolved about the planet in a direction opposite to the revolution of all the other satellites, in short was retrograde. The explanation of this is clearly that when this outermost satellite was formed this was the actual direction of rotation of Saturn itself, and that, when by planetary inversion[1] the planet later turned over, as above explained, and assumed a direct rotation, the inner and younger satellites were formed, and therefore revolve as we now see them.[1] An attempt has lately been made to explain this retrograde revolution of the outer satellites of Saturn and Jupiter by accidental capture from outside. This theory seems unnecessary since the case is entirely covered by the tidal theory. The latter is the only one, however, that has ever been offered, as far as the writer is aware, to explain the high inclination of the equator of Uranus to its orbit, and the successively diminishing inclinations of the equators of the four large outer planets of our system. Whatever, therefore, the explanation of the retrograde revolution of their outer satellites may be, it is very certain that at an early date the direction of rotation of the four great planets themselves was retrograde.

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[1] Instead of planetary, this might perhaps more properly be called Polar Inversion since the sun shows its influence as well as the planets. The sun's equator, as is well known, is inclined 5.7° to the invariable plane of the solar system. For a proposed explanation of this phenomenon see Annals, Harvard College Observatory, Cambridge, Mass., 61:363. Even the spiral nebulæ exhibit the same influence. When the main nebula has a companion, as is the case with the Great Nebula in Andromeda (N. G. C. 224), the plane of the latter is nearly always markedly inclined to that of the former. (See also N. G. C. 4485 and 4536.)