

Renandot affirms that the two ultra-violet lines are produced by an unknown element of an atomic weight which agrees very closely with the theoretical value of the atomic weight of nebulium as given by Nicholson. The strong green line (which is so marked a feature of this nebula) is, however, due to an element whose atomic weight is considerably less. The temperature of the nebula could not be less than fifteen thousand degrees centigrade.

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## The Effects of Tidal Friction upon the Evolution of the Earth-Moon System

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THE raising of the tides by the Moon is the result of small differences of attraction upon different parts of the Earth. But this differential force not only affects the waters of the oceans, but the solid earth as well, though to a much smaller extent. The ocean tides would be half as great again as they actually are, did not the solid earth yield somewhat to tidal strain. Again, were the solid earth to yield to the same extent as the oceans, there would be no perceptible tides at all. Owing to friction between the Earth and the oceans, the Earth tends to carry the tidal wave ahead of the Moon, whilst the Moon tends to draw the water back. Hence a couple is formed which diminishes the Earth's angular velocity, and tends to lengthen the day. But tidal friction does not merely diminish the Earth's rotational velocity. For on the principle of the conservation of moment of momentum, there must be reaction somewhere else. The Moon's orbital velocity is accelerated, and hence her areal velocity, and hence her distance (since the distance varies as the square of the area) and hence her periodic time. Thus the month is lengthened. It must be noted that the Earth-Moon system occupies a critical situation in the solar system. It alone is truly binary. For the interior planets possess no satellites, and the exterior possess several. And further, the Moon relatively to the size of its primary is by far the largest satellite. Tidal friction has been a powerful force in the assignment of satellites to the various planets. In the case of the interior planets, tidal friction caused by the Sun has been sufficiently

great to prevent their axial rotation ever attaining sufficient velocity for the formation of satellites. In the case of the exterior planets the exact opposite holds good on account of the very slight influence upon them of tidal friction. The Earth, between the two extremes, was subjected to sufficient tidal friction to prevent her for many ages from delivering herself of her large satellite. But at length the critical moment arrived when the increase of velocity due to her contraction overcame the opposite tendency due to tidal friction on the part of the Sun, and equilibrium was destroyed, and the spheroid was torn asunder in twain. And a much larger portion relatively was detached than in the case of the moons of Jupiter or Saturn, because the primary was in a much more advanced and therefore condensed stage when the separation occurred. Whilst the mass of Saturn is nearly 5,000 times greater than its largest Moon, and Jupiter is over 11,000 times more massive than its largest satellite Ganymede, the Earth is only 81 times the mass of the Moon. And again the Moon, unlike the satellites of the giant planets, has only gradually attained its present distance from its primary. The Moon has, therefore, exerted far more influence over its primary by way of tidal friction than has any other satellite in the solar system. Tidal friction has been a very important factor in the development of the Earth-Moon pair. Moreover, the Earth-Moon is probably the only instance in the solar system of the parting asunder of a body which by increasing axial velocity had already become apicoidal in shape. The other satellites have doubtless been formed by their primaries throwing off equatorial rings of semi-nebulous matter. When the Moon first detached itself from its parent Earth, its orbital velocity was equal to the Earth's axial velocity, the day and the month being equal, a period of only 2 to 4 hours. When the mighty disruption took place it must have been at least 60 million years ago. Since then tidal friction has been gradually pushing the Moon further and further away from the Earth. Again tidal friction powerfully operates to cause the relative orbit of a pair of bodies to become more and more eccentric. Hence we find the orbit of the Moon far more eccentric than those of the other satellites which are less affected by tidal friction. Such also is the case with double stars, where tidal friction is at its maximum. In the history of the Earth-Moon system, tide-raising force has been continuously diminishing, whilst the friction caused by relative motion of Earth and Moon relatively to the diminishing tide-raising force has been increasing. 56·81 million years ago, according to Professor Darwin, the tidal protuberances produce upon both Moon and Earth were very great, but owing to the angular velocity of the Earth and the orbital velocity of the Moon being nearly isochronous, friction from this cause was

very slight, less indeed than that caused by the Sun's comparatively minute tidal wave. The Moon now bulges towards the Earth as a result of the tidal-strain upon its once viscous mass. And still both Moon and Earth are mutually trying to make the other rotate synchronously with the period of revolution of the pair. The Earth has already succeeded and the Moon will doubtless ultimately succeed in regard to the Earth too. But the brake the Moon can now exert upon the Earth's rotation is now very small, being indeed unappreciable within historic times. For the last 46 million years the lengthening of the day has only attained 8 and  $1\frac{1}{2}$  hours, from  $15\frac{1}{2}$  to 24 hours period. When the Moon was just flung off from the Earth, about 60 millions of years ago, her distance was but  $1\frac{1}{2}$  radii, and the Earth was but very slightly larger than it is now. The table of dates and measurements is given by Professor Darwin as follows:—57 millions of years ago, the sidereal day in M. S. hours was 5·60, the Moon's sidereal period was 0·23 days, number of days in month was one, Moon's distance from Earth was 1·5 Earth's mean radii. 58·81 million years ago, the day was 6·75 hours, the month was 1·58 days, the number of days in month was 5·62, and the Moon's distance was 9 radii. 46·30 million of years ago, the day was 15·50 hours, the month was 18·17 M. S. days, the number of days in the month was 29·77, the Moon's distance was 47 radii. At present the day is 23·93 hours, the month is 27·32 M. S. days, the number of days in the month is 27·4, and the Moon's distance is 60·27 Earth's radii.

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## A Mathematical Calculation showing that the Duration of the Sun's Ra- diating Energy is sufficient to meet the demands of Geology

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If the gaseous mass of the Sun is in isothermal equilibrium,  
and subject to the law of behaviour of perfect gases, then the  
accumulated energy in the Sun is equal to

$$\frac{M^2}{R}$$