primeval planet such as that above described, a system would necessarily be developed which would bear a strong resemblance to our own. A theory, reposing on *verae causae* which brings into quantitative correlation the lengths of the present day and month, the obliquity of the ecliptic, and the inclination and eccentricity of the lunar orbit should have claims to acceptance.

§ 38. *The Influence of Tidal Friction on the Evolution of the Solar System and of the Planetary Subsystems.@@1*—According to the nebular hypothesis of Kant and Laplace the planets and satellites are portions detached from contracting nebulous masses, and other theories have been advanced subsequently in explanation of the present configuration of the solar system. We shall here only examine what changes are called for by the present theory of tidal friction. It may be shown that the reaction of the tides raised in the sun by the planets must have had a very small influence in changing the dimensions of the planetary orbits round the sun, and it appears improbable that the planetary orbits have been sensibly enlarged by tidal friction since the origin of the several planets.

Similarly it appears unlikely that the satellites of Mars, Jupiter and Saturn originated very much nearer the present surfaces of the planets that we now observe them. But, the data being insufficient, we cannot feel sure that the alteration in the dimensions of the orbits of these satellites has not been considerable. It remains, however, nearly certain that they cannot have first originated almost in contact with the present surfaces of the planets, in the same way as in the pre­ceding sketch has been shown to be probable with regard to the moon and earth. Numerical data concerning the distribution of moment of momentum in the several planetary sub-systems exhibit so striking a difference between the terrestrial system and those of the other planets that we should from this alone have grounds for believing that the modes of evolution have been considerably different. The difference appears to lie in the genesis of the moon close to the pre­sent surface of the planet, and we shall see below that solar tidal friction may be assigned as a reason to explain how it has happened that the terrestrial planet had contracted to nearly its present dimensions before the genesis of a satellite, but that this was not the case with the exterior planets. The efficiency of solar tidal friction is very much greater in its action on the nearer planets than on the farther ones. The time, however, during which solar tidal friction has been operating on the external planets is probably much longer than the period of its efficiency for the interior ones, and a series of numbers proportional to the total amount of rotation destroyed in the several planets would present a far less rapid decrease as we recede from the sun than numbers simply expressive of the efficiency of tidal friction at the several planets. Nevertheless it must be admitted that the effect produced by solar tidal friction on Jupiter and Saturn has not been nearly so great as on the interior planets. And, as already stated, it is very improbable that so large an amount of momentum should have been destroyed as materially to affect the orbits of the planets round the sun.

We will now examine how the difference of distances from the sun may have affected the histories of the several planets. According to the nebula hypothesis, as a planetary nebula contracts, the increasing rapidity of the rotation causes it to become unstable, and an equatorial portion of matter detaches itself. The separation of that part of the mass which before the change had the greatest angular momen­tum permits the central portion to resume a planetary shape. The contraction and the increase of rotation proceed continually until another portion is detached, and so on. There thus recur at intervals epochs of instability, and something of the same kind must have occurred according to other rival theories. Now tidal friction must diminish the rate of increase of rotation due to contraction, and therefore if tidal friction and contraction are at work together the epochs of instability must recur more rarely than if con­traction alone acted. If the tidal retardation is sufficiently great, the increase of rotation due to contraction will be so far counteracted as never to permit an epoch of instability to occur. Since the rate of retardation due to solar tidal friction decreases rapidly as we recede from the sun, these considerations accord with what we observe in the solar system. For Mercury and Venus have no satellites, and there is progressive increase in the number of satellites as we recede from the sun. Whether this be the true cause of the observed distribu­tion of satellites amongst the planets or not, it is remarkable that the same cause also affords an explanation, as we shall now show, of that difference between the earth with the moon and the other planets with their satellites which has caused tidal friction to be the principal agent of change with the former, but not with the latter. In the case of the contracting terrestrial mass we may suppose that there was for a long time nearly a balance between the retardation due to solar tidal friction and the acceleration due to contraction, and that it was not until the planetary mass had contracted to nearly its present dimensions that an epoch of instability could occur. It may also be noted that if there be two equal planetary masses which generate satellites, but under very different conditions as to the degree of condensation of the masses, the

two satellites will be likely to differ in mass; we cannot, of course, tell which of the two planets would generate the larger satellite. Thus, if the genesis of the moon was deferred until a late epoch in the history of the terrestrial mass, the mass of the moon relatively to the earth would be likely to differ from the mass of other satellites relatively to their planets. If the contraction of the planetary mass be almost completed before the genesis of the satellite, tidal friction will thereafter be the great cause of change in the system; and thus the hypothesis that it is the sole cause of change will give an ap­proximately accurate explanation of the motion of the planet and satellite at any subsequent time. We have already seen that the theory that tidal friction has been the rulingpower in the evolution of the earth and moon co-ordinates the present motions of the two bodies and carries us back to an initial state when the moon first had a separate existence as a satellite; and the initial configuration of the two bodies is such that we are led to believe that the moon is a portion of the primitive earth detached by rapid rotation or by other causes.

Let us now turn to the other planetary’ sub-systems. The satellites of the larger planets revolve with short periodic times; for the smallness of their masses would have prevented tidal friction from being a very efficient cause of change in the dimensions of their orbits, and the largeness of the planet's masses would have caused them to proceed slowly in their evolution. The satellites of Mars present one of the most remarkable features in the solar system, for, whereas Mars rotates in 24h. 37m., Deimos has a period of 30h. 18m. and Phobos of only 7h. 39m. The minuteness of these satellites precludes us from supposing that they have had much influence on the rotation of the planet, or that the dimensions of their own orbits have been much changed.

The theory of tidal friction would explain the shortness of the periodic time of Phobos by the solar retardation of the planet’s rotation, which would operate without directly affecting the satellites’ orbital motion. We may see that, given sufficient time, this must be the ultimate fate of all satellites. Numerical comparison shows that the efficiency of solar tidal friction in retarding the terrestrial and martian rotations is of about the same degree of importance, notwithstanding the much greater distance of the planet Mars. In the above discussion it will have been apparent that the earth and moon do actually differ from the other planets to such an extent as to permit tidal friction to have been the most important factor in their history.

By an examination of the probable effects of solar tidal friction on a contracting planetary mass, we have been led to assign a cause for the observed distribution of satellites in the solar system, and this again has itself afforded an explanation of how it happened that the moon so originated that the tidal friction of the lunar tides in the earth should have been able to exercise so large an influence. We have endeavoured not only to set forth the influence which tidal friction may have, and probably has had in the history of the system, if sufficient time be granted, but also to point out what effects it cannot have produced. These investigations afford no grounds for the rejection of theories more or less akin to the nebular hypothesis; but they introduce modifica­tions of considerable importance. Tidal friction is a cause of change of which Laplace’s theory took no account; and, although the activity of that cause may be regarded as mainly belonging to a later period than the events described in the nebular hypothesis, yet it seems that its influence has been of great, and in one instance of even paramount, importance in determining the present condition of the planets and their satellites. Throughout the whole of this discussion it has been supposed that sufficient time is at our disposal. Yet arguments have been adduced which seemed to show that this supposition is not justifiable, for Helmholtz, Lord Kelvin and others have attempted to prove that the history of the solar system must be comprised within a period considerably less than a hundred million years.@@2 But the discovery of radio-activity and the consequent remarkable advances in physics throw grave doubt on all such arguments, and we believe that it is still beyond our powers to assign definite numerical limits to the age of the solar system.

Dr T. J. J. See *(Researches on the Evolution of Stellar Systems;* vol. ii. (1910) *Capture Theory)* rejects the applicability of tidal friction to the cosmogony of the solar system, and argues that the satellites were primitively wandering bodies and were captured by the gravitational attraction of the planets. Such captures are considered by Dr See to be a necessary result of the presence in space of a resisting medium; but the present writer does not feel convinced by the arguments adduced. (G. H. D.)

**TIDORE** or Tidor, an island of the Malay Archipelago, off the W. coast of Halmahera, S. of Ternate. It is nearly circular and has an area of about 30 sq. m. Several quiescent volcanic peaks, reaching 5700 ft., occupy most of the island, and are covered with forests. The capital, Tidore, on the east coast, is a walled town and the seat of a sultan tributary to the Dutch

@@@1 A review of this and of cognate subjects is contained in G. H. Darwin’s presidential address to the Brit. Assoc. in 1905.

@@@2 Thomson and Tait’s *Nat*. *Phil.,* app. E; *Nature* (Jan. 27, 1887); Wolf, *Théories cosmogoniques* (1886).