of the lunar equator, causes her always to show the same face to the earth.

All this must have taken place early in the history of the earth, to which we now return. As the month increases in length the lunar orbit becomes eccentric, and the eccentricity reaches a maxi­mum when the month occupies about a rotation and a half of the earth. The maximum of eccentricity is probably not large. After this the eccentricity diminishes. The plane of the lunar orbit is at first practically identical with the earth’s equator, but as the moon recedes from the earth the sun’s attraction begins to make itself felt. We must therefore introduce the conception of two ideal planes (here called the proper planes), to which the motion of the earth and moon must be referred. The lunar proper plane is at first inclined at a very small angle to the earth’s proper plane, and the orbit and equator coincide with their respective proper planes. As soon as the earth rotates with twice the angular velocity with which the moon revolves in her orbit, a new instability sets in. The month is then about twelve of our present hours, and the day about six such hours in length. The inclinations of the lunar orbit and of the equator to their respective proper planes increase. That of the lunar orbit to its proper plane increases to a maximum of 6o or 7°, and ever after diminishes, that of the equator to its proper plane increases to a maximum of about 2? 45', and ever after diminishes. The maximum inclination of the lunar orbit to its proper plane takes place when the day is a little less than nine of our present hours, and the month a little less than six of our present days. The maximum inclination of the equator to its proper plane takes place earlier than this. Whilst these changes have been going on the proper planes have been themselves changing in their positions relatively to one another and to the ecliptic. At first they were nearly coincident with one another and with the earth’s equator, but they then open out, and the inclination of the lunar proper plane to the ecliptic continually diminishes, whilst that of the terrestrial proper plane continually increases. At some stage the earth became more rigid, and oceans were formed, so that oceanic tidal friction probably came to play a more important part than bodily tidal friction. If this be the case, the eccentricity of the orbit, after passing through a stationary phase, begins to increase again. We have now traced the system to a state in which the day and month are increasing, but at unequal rates, the inclination of the lunar proper plane to the ecliptic and of the orbit to the proper plane are diminishing, the inclination of the terrestrial proper plane to the ecliptic is increasing and of the equator to its proper plane is diminishing, and the eccentricity of the orbit is increasing. No new phase now supervenes and at length we have the system in its present configuration. The minimum time in which the changes from first to last can have taken place is 54,000,000 years.

There are other collateral results which must arise from a sup­posed primitive viscosity or plasticity of the earth’s mass. For during this course of evolution the earth’s mass must have suffered a screwing motion, so that the polar regions have travelled a little from west to east relatively to the equator. This affords a possible explanation of the north and south trend of our great continents. Also a large amount of heat has been generated by friction deep down in the earth ; and some very small part of the observed in­crease of temperature in underground borings may be attributable to this cause. The preceding history might vary a little in detail according to the degree of viscosity which we attribute to the earth’s mass, and according as oceanic tidal friction is or is not, now and in the more recent past, a more powerful cause of change than bodily tidal friction. The argument reposes on the imperfect rigidity of solids and on the internal friction of semi-solids and fluids ; these are veræ causæ. Thus changes of the kind here dis­cussed must be going on, and must have gone on in the past. And for this history of the earth and moon to be true throughout, it is only necessary to postulate a sufficient lapse of time, and that there is not enough matter diffused through space to materially resist the motions of the moon and earth in perhaps 200,000,000 years. It seems hardly too much to say that, granting these two postu­lates, and the existence of a 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 veræ causæ, 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.

§ 51. The Other Planetary Subsystems.

If this has been the evolution of the earth and moon, a similar process must have been going on elsewhere. So far we have only considered a single satellite and the sun, but the theory may of course be extended, with modifications, to planets attended by several satellites. We will now, therefore, consider some of the other members of the solar system. A large planet has much more energy of rotation to be destroyed, and moment of momentum to be redistributed, than a small one, and therefore a large planet ought to proceed in its evolution more slowly than a small one. Therefore we ought to find the larger planets less advanced than the smaller ones. The masses of such of the planets as have satel­lites are, in terms of the earth’s mass, as follows:—Mars=1/7 ; Jupiter=340 ; Saturn = 100; Uranus = 17; Neptune = 20.

Mars should therefore be furthest advanced in its evolution, and it is here alone in the whole system that we find a satellite moving orbitally faster than the planet rotates. This will also be the ultimate fate of our moon, because, after its orbital motion has been reduced to identity with that of the earth’s rotation, solar tidal friction will further reduce the earth’s angular velocity; the tidal reaction on the moon will then be reversed, and the moon’s orbital velocity will increase and her distance from the earth diminish. But, since the moon’s mass is very large, she must recede to an enormous distance from the earth before this reversal takes place. Now the satellites of Mars are very small, and therefore they need only recede a very short distance from the planet before the reversal of tidal reaction. The periodic time of the satellite Deimos is 30h 18m, and, as the period of rotation of Mars is 24h 37m, Deimos must be still receding from Mars, but very slowly. The periodic time of the satellite Phobos is 7h 39m ; therefore it must be approaching Mars. It does not seem likely that it has ever been remote from the planet.@@1 The eccentricities of the orbits of both satellites are small : that of Deimos is ⋅0057 and that of Phobos ∙0066. If the viscosity of the planet be small, or if oceanic tidal friction be the principal cause of change, both eccentricities are diminishing ; but, if the viscosity be large, both are increasing. As we have no means of knowing whether the eccentricities are increasing or diminishing, the larger eccentricity of the orbit of Phobos cannot be a fact of much importance either for or against the present views. But it must be admitted that it is a slightly unfavourable indication. The position of the proper plane of a satellite is determined by the periodic time of the satellite, the oblateness of the planet, and the sun’s distance. The inclination of the orbit of a satellite to the proper plane is not determined by anything in the system. Hence it is only the inclination of the orbit which can afford any argument for or against the theory. The proper planes of both satellites are necessarily nearly coincident with the equator of the planet ; but it is in accordance with the theory that the inclinations of the orbits to their respective proper planes should be small. Any change in the obliquity of the equator of Mars to the plane of his orbit must be entirely due to solar tides. The present obliquity is about 30°, and this points also to an advanced stage of evolution, at least if the axis of the planet was primitively at all nearly per­pendicular to the ecliptic.

We now come to the system of Jupiter. This enormous planet is still rotating in about ten hours ; its axis is nearly perpendicular to the ecliptic ; and three of its satellites revolve in seven days or less, whilst the fourth has a period of 16d 16h. This system is obviously far less advanced than our own. The inclinations of the proper planes to Jupiter’s equator are necessarily small, but the inclinations of the orbits to the proper planes appear to be very interesting from a theoretical point of view. They are in the case of the first satellite 0° 0' 0", in the case of the second 0o 27' 50", in that of the third 0° 12' 20", and in that of the fourth 0° 14' 58". We have shown above that the orbit of a satellite is first coincident with its proper plane, and that the inclination afterwards rises to a maximum and finally declines. If then we may assume, as seems reasonable, that the satellites are in stages of evolution corresponding to their distances from the planet, these inclinations accord well with the theory. The eccentricities of the orbits of the two inner satellites are insensible, those of the outer two small. This does not tell strongly either for or against the theory, because the history of the eccentricity depends considerably on the nature of the friction to which the tides are subject. Yet it on the whole agrees with the theory that the eccentricity should be greater in the more remote satellites. It appears that the satel­lites of Jupiter always present the same face to the planet, just as does our moon. This was to be expected.

The case of Saturn is not altogether so favourable to the theory. The extremely rapid rotation, the ring, and the short periodic time of the inner satellites point to an early stage of development ; whilst the longer periodic time of the three outer satellites and the high obliquity of the equator indicate a later stage. Perhaps both views may be more or less correct, for successive shedding of satellites would impart a modern appearance to the system. It has probably been previously remarked that the Saturnian system bears a strong analogy to the solar system, Titan being analogous to Jupiter, Hyperion and Iapetus to Uranus and Neptune, and. the inner satel­lites to the inner planets. Thus anything which aids us in forming a theory of the one system will throw light on the other. The details of the Saturnian system seem to be more or less favourable to the theory. The proper planes of the orbits (except that of Iapetus) are nearly in the plane of the ring, and the inclinations of all the orbits thereto appear not to be large. As the result of

@@@1 Mr Nolan considers the theory inapplicable to the case of Mars ; see Nature, 29th July 1886.