instant, must travel 1000 m. an hour so as to keep up with the moon.

Now it is a general law of frictionless oscillation that, if a slowly varying periodic force acts on a system which would oscillate quickly if left to itself, the maximum excursion on one side of the equilibrium position occurs simultaneously with the maximum force in the direction of the excursion; hut, if a quickly varying periodic force acts on a system which would oscillate slowly if left to itself, the maximum excursion on one side of the equilibrium position occurs simultaneously with the maximum force in the direction opposite to that of the excursion. An example of the first is a ball hanging by a short string, which we push slowly to and fro; the ball will never quit contact with the hand, and will agree with its excursions. If, however, the ball is hanging by a long string we can play at battledore and shuttlecock with it, and it always meets our blows. The latter is the analogue of the tides, for a free wave in our shallow canal goes slowly, whilst the moon’s tide-generating action goes quickly. Hence when the system is left to settle into steady oscillation it is low-water under and opposite to the moon, whilst the forces are such as to tend to make high-water at those times.

If in this case we consider the moon as revolving round the earth, the water assumes nearly the shape of an oblate spheroid or orange-shaped body with the shortest axis pointed to the moon. The rotation of the earth in the actual case introduces a complexity which it is not easy to unravel by general reasoning. We can see, however, that if water moves from a lower to a higher latitude it arrives at the higher latitude with more velocity from west to east than is appropriate to its latitude, and it will move accordingly on the earth’s surface. Following out this conception, we see that an oscillation of the water to and fro between south and north must be accompanied by an eddy. The solution of the difficult problem involved in working out this idea will be given below.

The conclusion at which we have arrived about the tides of an equatorial canal is probably more nearly true of the tides of a globe partially covered with land than if we were to suppose the ocean at each moment to assume the prolate figure of equili­brium. In fact, observation shows that it is more nearly low-water than high-water when the moon is on the meridian. If we consider how the oscillation of the water would appear to an observer carried round with the earth, we see that he will have low-water twice in the lunar day, somewhere about the time when the moon is on the meridian, either above or below the horizon, and high-water half-way between the low waters.

If the sun be now introduced we have another similar tide of about half the height, and this depends on solar time, giving low-water somewhere about noon and midnight. The superposition of the two, modified by friction and by the interference of land, gives the actually observed aggregate tide, and it is clear that about new and full moon we must have spring tides and at quarter moons neap tides, and that (the sum of the lunar and solar tide-generating forces being about three times their difference) the range of spring tide will be about three times that of neap tide.

So far we have supposed the luminaries to move on the equator; now let us consider the case where the moon is not on the equator. It is clear in this case that at any place the moon’s zenith distance at the upper transit is different from her nadir distance at the lower transit. But the tide-generating force is greater the smaller the zenith or nadir distance, and therefore the forces are different at successive transits. This was not the case when the moon was deemed to move on the equator. Thus there is a tendency for two successive lunar tides to be of unequal heights, and the resulting inequality of height is called a “ diurnal tide.” This tendency vanishes when the moon is on the equator; and as this occurs each fortnight the lunar diurnal tide is evanescent once a fortnight. Similarly in summer and winter the successive solar tides are generally of unequal height, whilst in spring and autumn this difference is inconspicuous.

One of the most remarkable conclusions of Laplace’s theory of the tides, on a globe covered with ocean to a uniform depth, is that the diurnal tide is everywhere non-existent. But this hypothesis differs much from the reality, and in fact at some ports, as for example Aden, the diurnal tide is so large that during two portions of each lunation there is only one great high-water and one great low-water in each twenty-four hours, whilst in other parts of the lunation the usual semi-diurnal tide is observed.

§ 6. *Progress of the Tide-wave over the Ocean and in the British* Seas.—Sufficient tidal data would give the state of the tide at every part of the world at the same instant of time, and if the tide wave is a progressive one, like such wave as we may observe travelling along a canal, we should be able to picture mentally the motion of the tide-wave over the ocean and the successive changes in the height of water at any one place. But we are not even sure that the wave is progressive, for in some oceans, such as perhaps the Atlantic, the motion may be only a see-saw about some line in mid-ocean—up on one side and down on the other; or it may more probably be partly a progressive wave and partly a see-saw or stationary oscillation. In contracted seas the wave is undoubtedly predominantly progressive in character, but too little is known to enable us to speak with any confidence as to wider seas.

Whewell and Airy, while acknowledging the uncertainty of their data, made the attempt to exhibit graphically the progress of the tide-wave over a large portion of the oceans of the world. In the first edition of this article (*Ency. Brit.,* 9th ed.) we reproduced their chart. But, since doubts as to its correct­ness have gradually accumulated, we think it more prudent to refrain from reproducing it again.@@1

As we have already indicated, the tide in British seas has mainly a progressive character, and the general march of the wave may be exhibited on a chart by what are called cotidal lines. If at the full and change of moon we draw lines on the sea through all the places which have high-water simultaneously, and if we mark such lines successively XII, I, II, &c., being the Greenwich time of high-water along each line, we shall have a succession of lines which show the progress of the wave from hour to hour.

For phases of the moon, other than full and change, the num­bers may be taken to represent the interval in hours after the moon’s transit, either visible or invisible, until the occurrence of high water. But for these other phases of the moon the interval varies by as much as one hour in excess or defect of the number written on any of the lines. Thus when the moon is about five days old, or five days past full, the numbers must all be reduced by about one hour so that I, II, III, &c., will then be replaced by XII, I, II, &c.; and when the moon is about ten days old, or ten days past full, the numbers must all be augmented by about one hour, and will read II, III, IV, &c. However, for a rough comprehension of the tides in these seas it is unnecessary to pay attention to this variation of the intervals.

Airy in his “ Tides and Waves ” gives such a chart for Great Britain and the North Sea, and he attempts to complete the cotidal lines conjecturally across the North Sea to Norway, Denmark and the German coast. In this case, as in the more ambitious attempt referred to above, further knowledge has led to further doubt. We therefore give in fig. 3 Berghaus’s modification of Airy’s Chart,@@2 abandoning the attempt to draw complete cotidal lines. In this chart we can watch, as it were, the tide-wave running in from the Atlantic, passing up the Bristol Channel and Irish Sea, travelling round the north of Scotland and southward along the east coasts of Scotland and England. Another branch comes up the Channel, and meets the wave from the north off the Dutch coast. The Straits of Dover are so narrow, however, that it may be doubted whether

@@@1 Portion of Airy's Chart *(Encycl. Metrop.,* art. “ Tides and Waves") is given in Darwin, *Tides and Kindred Phenomena in the Solar System.*

@@@2 Berghaus’s *Physical Atlas* (1891), pt. ii., “ Hydrography.”