In inland seas, such as the Mediterranean, the tides are nearly insensible except at the ends of long bays. Thus at Malta the tides are not noticed by the ordinary observer, whilst at Venice they are conspicuous.

The effect of a strong wind on the height of tide is generally supposed to be very marked, especially in estu­aries. In the case of an exceptional gale, when the wind veered round appropriately, Airy states@@1 that the water has been known to depart from its predicted height at London by as much as 5 feet. The effect of wind will certainly be different at each port. The discrepancy of opinion on this subject appears to be great,—so much so that we hear of some observers concluding that the effect of the wind is insensible. Variations in barometric pressure also cause departures from the predicted height of water, high barometer corresponding to decrease of height of water. Roughly speaking, an inch of the mercury column will correspond to something less than a foot of water, but the effect seems to vary much at different ports.@@2

§ 3. *General Explanation of the Cause of Tides.*

The moon attracts every particle of the earth and ocean, and by the law of gravitation the force acting on any par­ticle is directed towards the moon’s centre, and is jointly proportional to the masses of the particle and of the moon, and inversely proportional to the square of the distance between the particle and the moon’s centre. If we imagine the earth and ocean subdivided into a number of small portions or particles of equal mass, then the average, both as to direction and intensity, of the forces acting on these particles is equal to the force acting on that particle which is at the earth’s centre. For there is symmetry about the line joining the centres of the two bodies, and, if we divide the earth into two portions by an ideal spherical surface passing through the earth’s centre and having its centre at the moon, the portion remote from the moon is a little larger than the portion towards the moon, but the nearer portion is under the action of forces which are a little stronger than those acting on the further portion, and the resultant of the weaker forces on the larger portion is exactly equal to the resultant of the stronger forces on the smaller. If every particle of the earth and ocean were being urged by equal and parallel forces, there would be no cause for relative motion between the ocean and the earth. Hence it is the departure of the force acting on any particle from the average which constitutes the tide­generating force. Now it is obvious that on the side of the earth towards the moon the departure from the average is a small force directed towards the moon ; and on the side of the earth away from the moon the departure is a small force directed away from the moon. Also these two departures are very nearly equal to one another, that on the near side being so little greater than that on the other that we may neglect the excess. All round the sides of the earth along a great circle perpendicular to the line joining the moon and earth, the departure is a force directed inwards towards the earth’s centre. Thus we see that the tidal forces tend to pull the water towards and away from the moon, and to depress the water at right angles to that direction. If we could neglect the rotations of the bodies, and could consider the system as at rest, we should find that the water was in equilibrium when elongated into a prolate ellipsoid with its long axis directed towards and away from the moon.

But it must not be assumed that this would be the case when there is motion. For, suppose that the ocean con­sisted of a canal round the equator, and that an earthquake or any other cause were to generate a great wave in the canal, this wave would travel along it with a velocity de­

pendent on the depth. If the canal were about 13 miles deep, the velocity of the wave would be about 1000 miles an hour, and with depth about equal to the depth of our seas the velocity of the wave would be about half as great. We may conceive the moon’s tide-generating force as making a wave in the canal and continually outstripping the wave it generates, for the moon travels along the equator at the rate of about 1000 miles an hour, and the sea is less than 13 miles deep. The resultant oscillation of the ocean must therefore be the summation of a series of partial waves generated at each instant by the moon and always falling behind her, and the aggregate wave, being the same at each instant, must travel 1000 miles 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 ; but, 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 make it high water at those times.

If we consider the moon as revolving round the earth, the water assumes nearly the shape of an oblate spheroid with the minor 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. Laplace’s 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 tide­generating forces being about three times their difference)

@@@1 Airy, “Tides and Waves.”

@@@2 Airy, op. cit., §§ 572-573.