ELEMENTARY THEORY OF THE TIDES: THE FUNDAMENTAL THEOREMS DEMONSTRATED WITHOUT MATHEMATICS, AND THE INFLUENCE ON THE LENGTH OF THE DAY DISCUSSED

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T. K. ABBOTT

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INFLUENCE ON THE LENGTH OF THE DAY DISCUSSED.

BY

T. K. ABBOTT, B.D.,

FELLOW AND TUTOR, TRINITY COLLEGE, DUBLIN.

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PREFACE.

The substance of the following pages has already appeared, partly in the *Philosophical Magazine*, 1871, 1872, and the *Quarterly Journal of Mathematics*, 1872, and partly in *Hermathena*, 1882. Hitherto correct statements about the Tides have been confined to treatises which employ the resources of the higher mathematics. Other works almost without exception* repeat such erroneous statements as that the place of high water without friction would be under the moon, and that high water is retarded by friction. No apology then is needed for the publication in a more accessible form of the present Essay, in which the fundamental theorems are deduced from elementary physical principles without the use of mathematics, except for quantitative calculations. The problem of the influence of the Tides on the length of the day is discussed in a similar method.

* The only exception with which I am acquainted is Stubbs' edition of Brinkley's Astronomy, in which the reasoning of this Essay is adopted.

For the benefit of readers who may wish to see the latter problem analytically treated, I have given in an Appendix the substance of Sir George Airy's investigation.

ELEMENTARY THEORY OF THE TIDES.

THE tide-producing force is the difference between the attraction of the moon (or sun) on the solid body of the earth, which is the same as if it were all concentrated at the centre E, and that on the particles of the ocean at x, z.

Confining ourselves to the moon :—

The direction of the tide-producing force is always tangential, and towards the line joining the centres of the earth and moon.

First, the vertical component being in the same line as gravity (either in the same or an opposite direction) cannot directly produce any motion. In fact, it could not do so unless it actually exceeded the force of gravity. And it is too minute to produce any indirect effect.

Secondly, the tangential component is the difference between the tangential components of the moon's force at the centre and at the surface. Now (see figure), at a point x in the hemisphere nearer the moon, the force is greater than at E, and, moreover, makes a less angle with the tangent; therefore the effective difference is in the direction of its tangential component, *i.e.* towards C. At a point z in the further hemisphere the force is less than at E, and also makes a greater angle with the tangent;

therefore the effective difference is in the direction opposite to its tangential component, *i.e.* it acts towards A. The tide-producing force then always acts towards EM (in the direction of the arrows). From this we can deduce theorems relating to the place of high and low water, &c., without requiring to determine the magnitude of the force which will be hereafter taken into account. At present we need only observe that it is very small compared with gravity.

First, then, let us consider the case of water limited to an equatorial canal. The moon being supposed in the equator, we shall establish the following theorems:—

I. If there were no friction it would be low water under the moon, and high water in quadratures.

II. Friction accelerates the times of high and low water.

III. In addition to the oscillatory motion of the water there is a constant current produced by the action of the moon.

IV. The effect of friction on this is to increase the length of the day.

I.—*Without friction it would be low water under the moon, and high water in quadratures.*

I suppose the moon to be fixed, and the earth rotating in the direction $ABCD$, carrying the ocean with it.

Now, in the course of one lunar day every particle of the ocean is subjected to precisely the same forces, acting in the same order of succession and for the same periods, being accelerated for about one quarter of a day, viz.

while passing from *B* to *C*; then retarded for a quarter, from *C* to *D*, and so on. The variation in the amount of the force does not concern us, being the same for every particle.

This being so, it is obvious that those particles will be moving faster which have been for a longer time acted on by an accelerating force, and the velocity will be a maximum when the accelerating force has acted during its full period, viz. through one quadrant. On the other hand, those particles will be moving slower which have been longer acted on by a retarding force, and the absolute velocity will be a minimum when the retarding

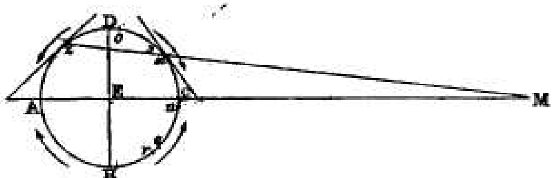

Fig 1.

force has acted during its full period, or through one quadrant. The maximum velocity is therefore at *A* and *C*, the minimum at *B* and *D*.

Secondly, it is clear that the tide will be rising where each portion of water is moving faster than that just in advance of it; or, in other words, where water is flowing in faster than it flows out. Where this process has gone on for the maximum time the tide will be highest. On the other hand, the tide will be falling where the water is moving slower than that in advance of it—or, in other words, is flowing out faster than it flows in. Where this has continued for the maximum time the tide is lowest.