interesting account of the manner in which he was led to attack the problem. We shall give below the investigation of the tides of an ocean covering the whole earth; the theory is substantially Laplace’s, although presented in a dif­ferent form, and embodying an important extension of Laplace’s work by S. S. Hough. This theory, although very wide, is far from representing the tides of our ports. Observation shows, in fact, that the irregular distribution of land and water and the various depths of the ocean in various places produce irregu­larities in the oscillations of the sea of such complexity that the rigorous solution of the problem is altogether beyond the power of analysis. Laplace, however, rested his discussion of tidal observation on this principle—*The state of oscillation of a system of bodies in which the primitive conditions of movement have disappeared through friction is coperiodic with the forces acting on the system.* Hence if the sea is acted on by forces which vary periodically according to the law of simple oscilla­tions (a simple time-harmonic), the oscillation of the sea will have exactly the same period, but the moment at which high-water will occur at any place and the amplitude of the oscillation can only be de­rived from observation. Now the tidal forces due to the moon and sun may be analysed into a number of constituent periodic parts of accurately determinable periods, and each of these will generate a corresponding oscillation of the sea of unknown amplitude and phase. These amplitudes and phases may be found from observation. But Laplace also used another prin­ciple, by which he was enabled to effect a synthesis of the various oscillations, so that he does not discuss a very large number of these constituent oscillations. As, however, it is impossible to give a full account of Laplace’s methods without recourse to technical language, it must suffice to state here that this procedure enabled him to discuss the tides at any port by means of a combination of theory with observation. After the time of Laplace down to 1S70, the most important workers in this field were Sir John Lubbock (senior), William Whewell and Sir G. B. Airy. The work of Lubbock and Whewell (see § 33 below) is chiefly remarkable for the co-ordination and analysis of enormous masses of data at various ports, and the construction of trustworthy tide-tables and the attempt to construct cotidal maps. Airy contributed an important review of the whole tidal theory. He also studied profoundly the theory of waves in canals, and explained the effects of frictional resistance on the progress of tidal and other waves.

The comparison between tidal theory and tidal observations has been carried out in two ways which we may describe as the synthetic and the analytic methods. Nature is herself synthetic, since at any one time and place we only observe one single tide-wave. All the great investigators from Newton down to Airy have also been synthetic in their treatment, for they have sought to represent the oscillation of the sea by a single mathematical expression, as will appear more fully in chapter V. below. It is true that a presupposed analysis lay behind and afforded the basis of the synthesis. But when at length tide-gauges, giving continuous records, were set up in many places the amount of data to be co-ordinated was enor­mously increased, and it was found that the simple formulae previously in use had to be overloaded with a multitude of corrections, so that the simplicity became altogether fictitious. This state of matters at length led Lord Kelvin (then Sir William Thomson) to suggest, about 1870, the analytic method, in which the attempt at mathematical synthesis is frankly abandoned and the complex whole is re­presented as the sum of a large number of separate parts, each being a perfectly simple wave or harmonic oscillation. All the best modern tidal work is carried on by the analytic method, of which we give an account below in chapter IV.

Lord Kelvin’s other contributions to tidal theory are also of profound importance; in particular we may mention that he established the correctness of Laplace’s procedure in discussing the dynamical theory of the tides of an ocean covering the w hole earth, which had been impugned by Airy and by William Ferrel. We shall have frequent occasion to refer to his name hereafter in the technical part of this article.

Amongst all the grand work which has been bestowed on the theory of this difficult subject, Newton, notwithstanding his errors, stands out first, and next to him we must rank Laplace. However original any future contribution to the science of the tides may be, it would seem as though it must perforce be based on the work of these two.

§ 8. *The Tide-Predicting Instrument.—*In the field of the practical application of theory Lord Kelvin also made another contribution of the greatest interest, when in 1872 he suggested that the laborious task of constructing a tide-table might be effected mechanically. Edward Roberts bore a very important part in the first practical realization of such a machine, and a tide-predictor now in regular use at the National Physical Laboratory for the Indian government was constructed by Légé under his direction. We refer the reader to Sir William Thomson’s (Lord Kelvin’s) paper on “Tidal Instruments” in *Inst*. *C.E.,* vol. lxv., and to the sub­sequent discussion, for a full account and for details of the share borne by the various persons concerned in the realization of the idea.

Fig. 4 illustrates diagrammatically the nature of the'instrument. A cord passes over and under a succession of pulleys, every other pulley being fixed or rather balanced and the alternate ones being movable; the cord is fixed at one end and carries a pen or pencil at the other end. In the diagram there are two balanced pulleys and one movable one; a second unit would require one more movable pulley and one more balanced one. If, in our diagram, the lowest or movable pulley were made to oscillate up and down (with a simple har­monic motion), the pencil would execute the same motion on half the linear scale. If the instru­ment possessed two units and the second movable pulley also rocked up and down, the pencil would add to its previous motion that of this second oscillation, again on half scale. So also if there were any number of additional units, each consisting of one movable and one balanced pulley, the pencil would add together all the separate simple oscillations, and would draw a curve upon a drum, which is supposed to be kept revolving uniformly at an appropriate rate.

The rocking motion is communicated to each movable pulley by means of a pin attached to a wheel C sliding in a slot attached to the pulley frame. All the wheels C and the drum are geared together so that, as the drum turns, all the movable pulleys rock up and down. The gearing is of such a nature that if one revolution of the drum represents a single day, the rocking motion of each movable pulley corresponds to one of the simple constituent oscilla­tions or tides into which the aggregate tide-wave is analysed. The nature of the gearing is determined by theoretical considerations derived from the motions of the sun and moon and earth, but the throw of each crank, and the angle at which it has to be set at the start are derived from observation at the particular port for which the tide-curve is required. When the tide-predictor has been set appropriately, it will run off a complete tide-curve for a whole year; the curve is subsequently measured and the heights and times of high and low-water arc tabulated and published for a year or two in advance.

The Indian instrument possesses about 20 units, so that the tide­curve is regarded as being the sum of 20 different simple tides; and tide-tables are published for 40 Indian and Oriental ports. A tide­predictor has been constructed for the French government under the supervision of Lord Kelvin and is in use at Paris; another has been made by the United States Coast Survey at Washington; in 1910 one was under construction for the Brazilian government. These instruments, although differing considerably in detail from the Indian predictor, are essentially the same in principle.

§ 9. *Tidal Friction.—*All solid bodies yield more or less to stress; if they are perfectly elastic they regain their shapes after the stresses are removed, if imperfectly elastic or viscous they yield to the stresses. We may thus feel certain that the earth yields to tide-generating force, either with perfect or imperfect elasticity. Chapter VIII. will contain some discussion of this