BALL ROBERT STAWELL

TIME AND TIDE: A ROMANCE OF THE MOON

Robert Ball

Time and Tide: A Romance of the Moon

Ball R.

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Содержание

Robert S. Ball
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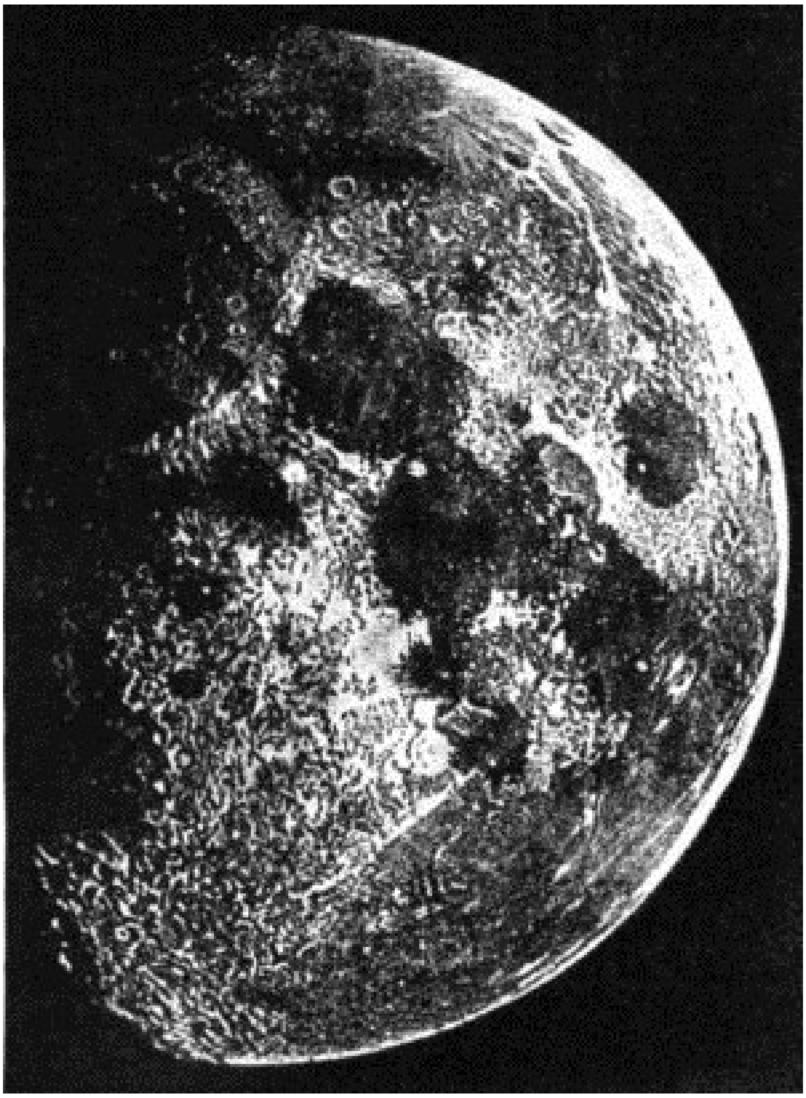

View of the Moon two days after first quarter.
From a photograph by Mr. Lewis M. Rutherford.
Frontispiece.

TO

The Members of the London Institution

I DEDICATE

THIS LITTLE BOOK

PREFACE

Having been honoured once again with a request that I should lecture before the London Institution, I chose for my subject the Theory of Tidal Evolution. The kind reception which these lectures received has led to their publication in the present volume. I have taken the opportunity to supplement the lectures as actually delivered by the insertion of some additional matter. I am indebted to my friends Mr. Close and Mr. Rambaut for their kindness in reading the proofs.

Robert S. Ball.

Observatory, Co. Dublin,
April 26, 1889.

LECTURE I

It is my privilege to address you this afternoon on a subject in which science and poetry are blended in a happy conjunction. If there be a peculiar fascination about the earlier chapters of any branch of history, how great must be the interest which attaches to that most primeval of all terrestrial histories which relates to the actual beginnings of this globe on which we stand.

In our efforts to grope into the dim recesses of this awful past, we want the aid of some steadfast light which shall illumine the dark places without the treachery of the will-o'-the-wisp. In the absence of that steadfast light, vague conjectures as to the beginning of things could never be entitled to any more respect than was due to mere matters of speculation.

Of late, however, the required light has been to some considerable extent forthcoming, and the attempt has been made, with no little success, to elucidate a most interesting and wonderful chapter of an exceedingly remote history. To chronicle this history is the object of the present lectures before this Institution.

First, let us be fully aware of the extraordinary remoteness of that period of which our history treats. To attempt to define that period chronologically would be utterly futile. When we have stated that it is more ancient than almost any other period which we can discuss, we have expressed all that we are really entitled to say. Yet this conveys not a little. It directs us to look back through all the ages of modern human history, through the great days of ancient Greece and Rome, back through the times when Egypt and Assyria were names of renown, through the days when Nineveh and Babylon were mighty and populous cities in the zenith of their glory. Back earlier still to those more ancient nations of which we know hardly anything, and still earlier to the prehistoric man, of whom we know less; back, finally, to the days when man first trod on this planet, untold ages ago. Here is indeed a portentous retrospect from most points of view, but it is only the commencement of that which our subject suggests.

For man is but the final product of the long anterior ages during which the development of life seems to have undergone an exceedingly gradual elevation. Our retrospect now takes its way along the vistas opened up by the geologists. We look through the protracted tertiary ages, when mighty animals, now generally extinct, roamed over the continents. Back still earlier through those wondrous secondary periods, where swamps or oceans often covered what is now dry land, and where mighty reptiles of uncouth forms stalked and crawled and swam through the old world and the new. Back still earlier through those vitally significant ages when the sunbeams were being garnered and laid aside for man's use in the great forests, which were afterwards preserved by being transformed into seams of coal. Back still earlier through endless thousands of years, when lustrous fishes abounded in the oceans; back again to those periods characterized by the lower types of life; and still earlier to that incredibly remote epoch when life itself began to dawn on our awakening globe. Even here the epoch of our present history can hardly be said to have been reached. We have to look through a long succession of ages still antecedent. The geologist, who has hitherto guided our view, cannot render us much further assistance; but the physicist is at hand—he teaches us that the warm globe on which life is beginning has passed in its previous stages through every phase of warmth, of fervour, of glowing heat, of incandescence, and of actual fusion; and thus at last our retrospect reaches to that particular period of our earth's past history which is specially illustrated by the modern doctrine of Time and Tide.

The present is the clue to the past. It is the steady application of this principle which has led to such epoch-making labours as those by which Lyell disclosed the origin of the earth's crust, Darwin the origin of species, Max Müller the origin of language. In our present subject the course is equally clear. Study exactly what is going on at present, and then have the courage to apply consistently and rigorously what we have learned from the present to the interpretation of the past.

Thus we begin with the ripple of the tide on the sea-beach which we see to-day. The ebb and the flow of the tide are the present manifestations of an agent which has been constantly at work. Let that present teach us what tides must have done in the indefinite past.

It has been known from the very earliest times that the moon and the tides were connected together—connected, I say, for a great advance had to be made in human knowledge before it would have been possible to understand the true relation between the tides and the moon. Indeed, that relation is so far from being of an obvious character, that I think I have read of a race who felt some doubt as to whether the moon was the cause of the tides, or the tides the cause of the moon. I should, however, say that the moon is not the sole agent engaged in producing this periodic movement of our waters. The sun also arouses a tide, but the solar tide is so small in comparison with that produced by the moon, that for our present purpose we may leave it out of consideration. We must, however, refer to the solar tide at a later period of our discourses, for it will be found to have played a very splendid part at the initial stage of the Earth-Moon History, while in the remote future it will again rise into prominence.

It will be well to set forth a few preliminary figures which shall explain how it comes to pass that the efficiency of the sun as a tide-producing agent is so greatly inferior to that of the moon. Indeed, considering that the sun has a mass so stupendous, that it controls the entire planetary system, how is it that a body so insignificant as the moon can raise a bigger tide on the ocean than can the sun, of which the mass is 26,000,000 times as great as that of our satellite?

This apparent paradox will disappear when we enunciate the law according to which the efficiency of a tide-producing agent is to be estimated. This law is somewhat different from the familiar form in which the law of gravitation is expressed. The gravitation between two distant masses is to be measured by multiplying these masses together, and dividing the product by the *square* of the distance. The law for expressing the efficiency of a tide-producing agent varies not according to the inverse square, but according to the inverse *cube* of the distance. This difference in the expression of the law will suffice to account for the superiority of the moon as a tide-producer over the sun. The moon's distance on an average is about one 386th part of that of the sun, and thus it is easy to show that so far as the mere attraction of gravitation is concerned, the efficiency of the sun's force on the earth is about one hundred and seventy-five times as great as the force with which the moon attracts the earth. That is of course calculated under the law of the inverse square. To determine the tidal efficiency we have to divide this by three hundred and eighty-six, and thus we see that the tidal efficiency of the sun is less than half that of the moon.

When the solar tide and the lunar tide are acting in unison, they conspire to produce very high tides and very low tides, or, as we call them, spring tides. On the other hand, when the sun is so placed as to give us a low tide while the moon is producing a high tide, the net result that we actually experience is merely the excess of the lunar tide over the solar tide; these are what we call neap tides. In fact, by very careful and long-continued observations of the rise and fall of the tides at a particular port, it becomes possible to determine with accuracy the relative ranges of spring tides and neap tides; and as the spring tides are produced by moon plus sun, while the neap tides are produced by moon minus sun, we obtain a means of actually weighing the relative masses of the sun and moon. This is one of the remarkable facts which can be deduced from a prolonged study of the tides.

The demonstration of the law of the tide-producing force is of a mathematical character, and I do not intend in these lectures to enter into mathematical calculations. There is, however, a simple line of reasoning which, though it falls far short of actual demonstration, may yet suffice to give a plausible reason for the law.

The tides really owe their origin to the fact that the tide-producing agent operates more powerfully on those parts of the tide-exhibiting body which are near to it, than on the more distant portions of the same. The nearer the two bodies are together, the larger proportionally will be the differences in the distances of its various parts from the tide-producing body; and on this account the leverage, so to speak, of the action by which the tides are produced is increased. For instance, if the two bodies were brought within half their original distance of each other, the relative size of each body, as viewed from the other, will be doubled; and what we have called the leverage of the tide-producing ability will be increased twofold. The gravitation also between the two bodies is increased fourfold when the distance is halved, and consequently, the tide-producing ability is doubled for one reason, and increased fourfold again by another; hence, the tides will be increased eightfold when the distance is reduced to one half. Now, as eight is the cube of two, this illustration may be taken as a verification of the law, that the efficiency of a body as a tide-producer varies inversely as the cube of the distance between it and the body on which the tides are being raised.

For simplicity we may make the assumption that the whole of the earth is buried beneath the ocean, and that the moon is placed in the plane of the equator. We may also entirely neglect for the present the tides produced by the sun, and we shall also make the further assumption that friction is absent. What friction is capable of doing we shall, however, refer to later on. The moon will act on the ocean and deform it, so that there will be high tide along one meridian, and high tide also on the opposite meridian. This is indeed one of the paradoxes by which students are frequently puzzled when they begin to learn about the tides. That the moon should pull the water up in a heap on one side seems plausible enough. High tide will of course be there; and the student might naturally think that the water being drawn in this way into a heap on one side, there will of course be low tide on the opposite side of the earth. A natural assumption, perhaps, but nevertheless a very wrong one. There are at every moment two opposite parts of the earth in a condition of high water; in fact, this will be obvious if we remember that every day, or, to speak a little more accurately, in every twenty-four hours and fifty one minutes, we have on the average two high tides at each locality. Of course this could not be if the moon raised only one heap of high water, because, as the moon only appears to revolve around the earth once a day, or, more accurately, once in that same average period of twenty-four hours and fifty-one minutes, it would be impossible for us to have high tides succeeding each other as they do in periods a little longer than twelve hours, if only one heap were carried round the earth.

The first question then is, as to how these two opposite heaps of water are placed in respect to the position of the moon. The most obvious explanation would seem to be, that the moon should pull the waters up into a heap directly underneath it, and that therefore there should be high water underneath the moon. As to the other side, the presence of a high tide there was, on this theory, to be accounted for by the fact that the moon pulled the earth away from the waters on the more remote side, just as it pulled the waters away from the more remote earth on the side underneath the moon. It is, however, certainly not the case that the high tide is situated in the simple position that this law would indicate, and which we have represented in Fig. 1, where the circular body is the earth, the ocean surrounding which is distorted by the action of the tides.

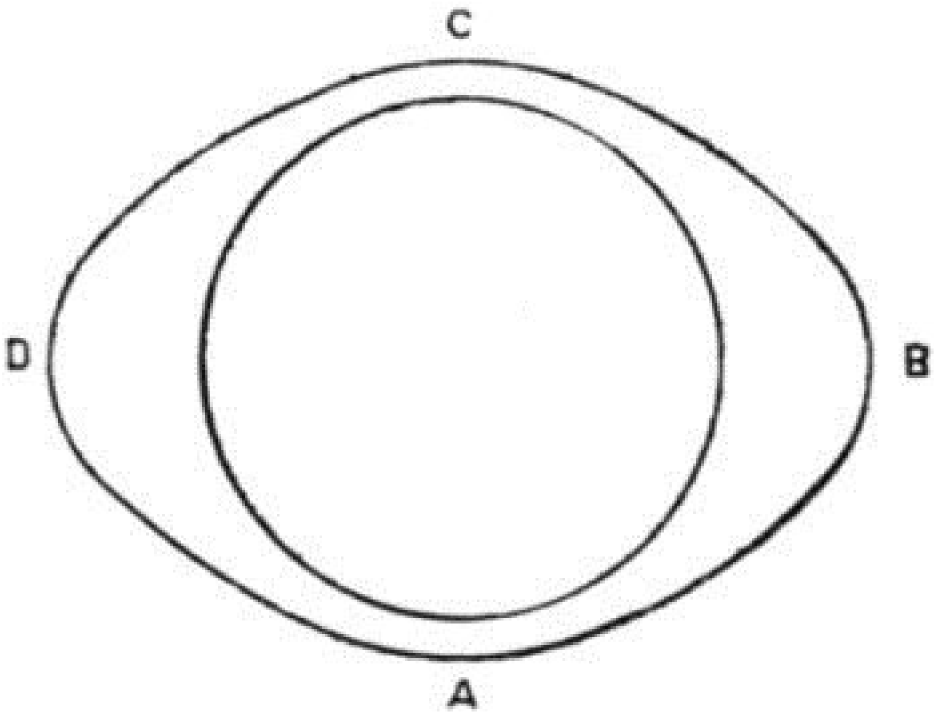

Fig. 1

We have here taken an oval to represent the shape into which the water is supposed to be forced or drawn by the tidal action of the tide-producing body. This may possibly be a correct representation of what would occur on an ideal globe entirely covered with a frictionless ocean. But as our earth is not covered entirely by water, and as the ocean is very far from being frictionless, the ideal tide is not the tide that we actually know; nor is the ideal tide represented by this oval even an approximation to the actual tides to which our oceans are subject. Indeed, the oval does not represent the facts at all, and of this it is only necessary to adduce a single fact in demonstration. I take the fundamental issue so often debated, as to whether in the ocean vibrating with ideal tides the high water or the low water should be under the moon. Or to put the matter otherwise; when we represent the displaced water by an oval, is the long axis of the oval to be turned to the moon, as generally supposed, or is it to be directed at right angles therefrom? If the ideal tides were in any degree representative of the actual tides, so fundamental a question as this could be at once answered by an appeal to the facts of observation. Even if friction in some degree masked the phenomena, surely one would think that the state of the actual tides should still enable us to answer this question.

But a study of the tides at different ports fails to realize this expectation. At some ports, no doubt, the tide is high when the moon is on the meridian. In that case, of course, the high water is under the moon, as apparently ought to be the case invariably, on a superficial view. But, on the other hand, there are ports where there is often low water when the moon is crossing the meridian. Yet other ports might be cited in which every intermediate phase could be observed. If the theory of the tides was to be the simple one so often described, then at every port noon should be the hour of high water on the day of the new moon or of the full moon, because then both tide-exciting bodies are on the meridian at the same time. Even if the friction retarded the great tidal wave uniformly, the high tide on the days of full or change should always occur at fixed hours; but, unfortunately, there is no such delightful theory of the tides as this would imply. At Greenock no doubt there is high water at or about noon on the day of full or change; and if it could be similarly said that on the day of full or change there was high water everywhere at local noon, then the equilibrium theory of the tides, as it is called, would be beautifully simple. But this is not the case. Even around our own coasts the discrepancies are such as to utterly discredit the theory as offering any practical guide. At Aberdeen the high tide does not appear till an hour later than the doctrine would suggest. It is two hours late at London, three at Tynemouth, four at Tralee, five at Sligo, and six at Hull. This last port would be indeed the haven of refuge for those who believe that the low tide ought to be under the moon. At Hull this is no doubt the case; and if at all other places the water behaved as it does at Hull, why then, of course, it would follow that the law of low water under the moon was generally true. But then this would not tally with the condition of affairs at the other places I have named; and to complete the cycle I shall add a few more. At Bristol the high water does not get up until seven hours after the moon has passed the meridian, at Arklow the delay is eight hours, at Yarmouth it is nine, at the Needles it is ten hours, while lastly, the moon has nearly got back to the meridian again ere it has succeeded in dragging up the tide on which Liverpool's great commerce so largely depends.

Nor does the result of studying the tides along other coasts beside our own decide more conclusively on the mooted point. Even ports in the vast ocean give a very uncertain response. Kerguelen Island and Santa Cruz might seem to prove that the high tide occurs under the moon, but unfortunately both Fiji and Ascension seem to present us with an equally satisfactory demonstration, that beneath the moon is the invariable home of low water.

I do not mean to say that the study of the tides is in other respects such a confused subject as the facts I have stated would seem to indicate. It becomes rather puzzling, no doubt, when we compare the tides at one port with the tides elsewhere. The law and order are, then, by no means conspicuous, they are often hardly discernible. But when we confine our attention to the tides at a single port, the problem becomes at once a very intelligible one. Indeed, the investigation of the tides is an easy subject, if we are contented with a reasonably approximate solution; should, however, it be necessary to discuss fully the tides at any port, the theory of the method necessary for doing so is available, and a most interesting and beautiful theory it certainly is.

Let us then speak for a few moments about the methods by which we can study the tides at a particular port. The principle on which it is based is a very simple one.

It is the month of August, the 18th, we shall suppose, and we are going to enjoy a delicious swim in the sea. We desire, of course, to secure a high tide for the purpose of doing so, and we call an almanac to help us. I refer to the Thom's Dublin Directory, where I find the tide to be high at 10h. 14m. on the morning of the 18th of August. That will then be the time to go down to the baths at Howth or Kingstown.

But what I am now going to discourse to you about is not the delights of sea-bathing, it is rather a different inquiry. I want to ask, How did the people who prepared that almanac know years beforehand, that on that particular day the tide would be high at that particular hour? How do they predict for every day the hour of high water? and how comes it to pass that these predictions are invariably correct?

We first refer to that wonderful book, the *Nautical Almanac*. In that volume the movements of the moon are set forth with full detail; and among other particulars we can learn on page iv of every month the mean time of the moon's meridian passage. It appears that on the day in question the moon crossed the meridian at 11h. 23m. Thus we see there was high water at Dublin at 10h. 14m., and 1h. 9m. later, that is, at 11h. 23m., the moon crossed the meridian.

Let us take another instance. There is a high tide at 3.40 P.M. on the 25th August, and again the infallible *Nautical Almanac* tells us that the moon crossed the meridian at 5h. 44m., that is, at 2h. 4m. after the high water.

In the first case the moon followed the tide in about an hour, and in the second case the moon followed in about two hours. Now if we are to be satisfied with a very rough tide rule for Dublin, we may say generally that there is always a high tide an hour and a half before the moon crosses the meridian. This would not be a very accurate rule, but I can assure you of this, that if you go by it you will never fail of finding a good tide to enable you to enjoy your swim. I do not say this rule would enable you to construct a respectable tide-table. A ship-owner who has to creep up the river, and to whom often the inches of water are material, will require far more accurate tables than this simple rule could give. But we enter into rather complicated matters when we attempt to give any really accurate methods of computation. On these we shall say a few words presently. What I first want to do, is to impress upon you in a simple way the fact of the relation between the tide and the moon.

To give another illustration, let us see how the tides at London Bridge are related to the moon. On Jan. 1st, 1887, it appeared that the tide was high at 6h. 26m. P.M., and that the moon had crossed the meridian 56m. previously; on the 8th Jan. the tide was high at 0h. 43m. P.M., and the moon had crossed the meridian 2h. 1m. previously. Therefore we would have at London Bridge high water following the moon's transit in somewhere about an hour and a half.

I choose a day at random, for example—the 12th April. The moon crosses the upper meridian at 3h. 39m. A.M., and the lower meridian at 4h 6m. P.M. Adding an hour and a half to each would give the high tides at 5h 9m. A.M. and 5h. 36m. P.M.; as a matter of fact, they are 4h. 58m. A.M. and 5h. 20m. P.M.

But these illustrations are sufficient. We find that at London, in a general way, high water appears at London Bridge about an hour and a half after the moon has passed the meridian of London. It so happens that the interval at Dublin is about the same, *i.e.* an hour and a half; only that in the latter case the high water precedes the moon by that interval instead of following it. We may employ the same simple process at other places. Choose two days about a week distant; find on each occasion the interval between the transit of the moon and the time of high water, then the mean of these two differences will always give some notion of the interval between high water and the moon's transit. If then we take from the *Nautical Almanac* the time of the moon's transit, and apply to it the correction proper for the port, we shall always have a sufficiently good tide-table to guide us in choosing a suitable time for taking our swim or our walk by the sea-side; though if you be the captain of a vessel, you will not be so imprudent as to enter port without taking counsel of the accurate tide-tables, for which we are indebted to the Admiralty.

Every one who visits the sea-side, or who lives at a sea-port, should know this constant for the tides, which affect him and his movements so materially. If he will discover it from his own experience, so much the better.

The first point to be ascertained is the time of high water. Do not take this from any local table; you ought to observe it for yourself. You will go to the pier head, or, better still, to some place where the rise and fall of the mere waves of the sea will not embarrass you in your work. You must note by your watch the time when the tide is highest. An accurate way of doing this will be to have a scale on which you can measure the height at intervals of five minutes about the time of high water. You will then be able to conclude the time at which the tide was actually at its highest point; but even if no great accuracy be obtainable, you can still get much interesting information, for you will without much difficulty be right within ten minutes or a quarter of an hour.

The correction for the port is properly called the "establishment," this being the average time of high water on the days of full and change of the moon at the particular port in question.

We can considerably amend the elementary notion of the tides which the former method has given us, if we adopt the plan described by Dr. Whewell in the first four editions of the *Admiralty Manual of Scientific Inquiry*. We speak of the interval between the transit of the moon and the time of high water as the luni-tidal interval. Of course at full and change this is the same thing as the establishment, but for other phases of the moon the establishment must receive a correction before being used as the luni-tidal interval. The correction is given by the following table—

Hour of Moon's transit after Sun:											
0	1	2	3	4	5	6	7	8	9	10	11
0	-20m	-30m	-50m	-60m	-60m	-60m	-40m	-10m	+10m	+20m	+10m
Correction of establishment to find luni-tidal interval:											

Thus at a port where the establishment was 3h. 25m., let us suppose that the transit of the moon took place at 6 P.M.; then we correct the establishment by -60m., and find the luni-tidal interval to be 2h. 25m., and accordingly the high water takes place at 8h. 25m. P.M.

But even this method is only an approximation. The study of the tides is based on accurate observation of their rise and fall on different places round the earth. To show how these observations are to be made, and how they are to be discussed and reduced when they have been made, I may refer to the last edition of the *Admiralty Manual of Scientific Inquiry*, 1886. For a complete study of the tides at any port a self-registering tide-gauge should be erected, on which not alone the heights and times of high and low water should be depicted, but also the continuous curve which shows at any time the height of the water. In fact, the whole subject of the practical observation and discussion and prediction of tides is full of valuable instruction, and may be cited as one of the most complete examples of the modern scientific methods.

In the first place, the tide-gauge itself is a delicate instrument; it is actuated by a float which rises and falls with the water, due provision being made that the mere influence of waves shall not make it to oscillate inconveniently. The motion of the float when suitably reduced by mechanism serves to guide a pencil, which, acting on the paper round a revolving drum, gives a faithful and unintermitting record of the height of the water.

Thus what the tide-gauge does is to present to us a long curved line of which the summits correspond to the heights of high water, while the depressions are the corresponding points of low water. The long undulations of this curve are, however, very irregular. At spring tides, when the sun and the moon conspire, the elevations rise much higher and the depressions sink much lower than they do at neap tides, when the high water raised by the moon is reduced by the action of the sun. There are also many minor irregularities which show the tides to be not nearly such simple phenomena as might be at first supposed. But what we might hastily think of as irregularities are, in truth, the most interesting parts of the whole phenomena. Just as in the observations of the planets the study of the perturbations has led us to results of the widest interest and instruction, so it is these minor phenomena of the tides which seem most pregnant with scientific interest.

The tide-gauge gives us an elaborate curve. How are we to interpret that curve? Here indeed a most beautiful mathematical theorem comes to our aid. Just as ordinary sounds consist of a number of undulations blended together, so the tidal wave consists of a number of distinct undulations superposed. Of these the ordinary lunar tide and the ordinary solar tide are the two principal; but there are also minor undulations, harmonics, so to speak, some originating from the moon, some originating from the sun, and some from both bodies acting in concert.

In the study of sound we can employ an acoustic apparatus for the purpose of decomposing any proposed note, and finding not only the main undulation itself, but the several superposed harmonics which give to the note its timbre. So also we can analyze the undulation of the tide, and show the component parts. The decomposition is effected by the process known as harmonic analysis. The principle of the method may be very simply described. Let us fix our attention on any particular "tide," for so the various elements are denoted. We can always determine beforehand, with as much accuracy as we may require, what the period of that tide will be. For instance, the period of the lunar semi-diurnal tide will of course be half the average time occupied by the moon to travel round from the meridian of any place until it regains the same meridian; the period of the lunar diurnal tide will be double as great; and there are fortnightly tides, and others of periods still greater. The essential point to notice is, that the periods of these tides are given by purely astronomical considerations from the periods of the motions theory, and do not depend upon the actual observations.

We measure off on the curve the height of the tide at intervals of an hour. The larger the number of such measures that are available the better; but even if there be only three hundred and sixty or seven hundred and twenty consecutive hours, then, as shown by Professor G. H. Darwin in the *Admiralty Manual* already referred to, it will still be possible to obtain a very competent knowledge of the tides in the particular port where the gauge has been placed.

The art (for such indeed it may be described) of harmonic analysis consists in deducing from the hourly observations the facts with regard to each of the constituent tides. This art has been carried to such perfection, that it has been reduced to a very simple series of arithmetical operations. Indeed it has now been found possible to call in the aid of ingenious mechanism, by which the labours of computation are entirely superseded. The pointer of the harmonic analyzer has merely to be traced over the curve which the tide-gauge has drawn, and it is the function of the machine to decompose the composite undulation into its parts, and to exhibit the several constituent tides whose confluence gives the total result.

As if nothing should be left to complete the perfection of a process which, both from its theoretical and its practical sides, is of such importance, a machine for predicting tides has been designed, constructed, and is now in ordinary use. When by the aid of the harmonic analysis the effectiveness of the several constituent tides affecting a port have become fully determined, it is of course possible to predict the tides for that port. Each "tide" is a simple periodic rise and fall, and we can compute for any future time the height of each were it acting alone. These heights can all be added together, and thus the height of the water is obtained. In this way a tide-table is formed, and such a table when complete will express not alone the hours and heights of high water on every day, but the height of the water at any intervening hour.

The computations necessary for this purpose are no doubt simple, so far as their principle is concerned; but they are exceedingly tedious, and any process must be welcomed which affords mitigation of a task so laborious. The entire theory of the tides owes much to Sir William Thomson in the methods of observation and in the methods of reduction. He has now completed the practical parts of the subject by inventing and constructing the famous tide-predicting engine.

The principle of this engine is comparatively simple. There is a chain which at one end is fixed, and at the other end carries the pencil which is pressed against the revolving drum on which the prediction is to be inscribed. Between its two ends the chain passes up and down over pulleys. Each pulley corresponds to one of the "tides," and there are about a dozen altogether, some of which exercise but little effect. Of course if the centres of the pulleys were all fixed the pen could not move, but the centre of each pulley describes a circle with a radius proportional to the amplitude of the corresponding tide, and in a time proportional to the period of that tide. When these pulleys are all set so as to start at the proper phases, the motion is produced by turning round a handle which makes the drum rotate, and sets all the pulleys in motion. The tide curve is thus rapidly drawn out; and so expeditious is the machine, that the tides of a port for an entire year can be completely worked out in a couple of hours.

While the student or the philosopher who seeks to render any account of the tide on dynamical grounds is greatly embarrassed by the difficulties introduced by friction, we, for our present purpose in the study of the great romance of modern science opened up to us by the theory of the tides, have to welcome friction as the agent which gives to the tides their significance from our point of view.

There is the greatest difference between the height of the rise and fall of the tide at different localities. Out in mid-ocean, for instance, an island like St. Helena is washed by a tide only about three feet in range; an enclosed sea like the Caspian is subject to no appreciable tides whatever, while the Mediterranean, notwithstanding its connection with the Atlantic, is still only subject to very inconsiderable tides, varying from one foot to a few feet. The statement that water always finds its own level must be received, like many another proposition in nature, with a considerable degree of qualification. Long ere one tide could have found its way through the Straits of Gibraltar in sufficient volume to have appreciably affected the level of the great inland sea, its effects would have been obliterated by succeeding tides. On the other hand, there are certain localities which expose a funnel-shape opening to the sea; into these the great tidal wave rushes, and as it passes onwards towards the narrow part, the waters become piled up so as to produce tidal phenomena of abnormal proportions. Thus, in our own islands, we have in the Bristol Channel a wide mouth into which a great tide enters, and as it hurries up the Severn it produces the extraordinary phenomenon of the Bore. The Bristol Channel also concentrates the great wave which gives Chepstow and Cardiff a tidal range of thirty-seven or thirty-eight feet at springs, and forces the sea up the river Avon so as to give Bristol a wonderful tide. There is hardly any more interesting spot in our islands for the observation of tides than is found on Clifton Suspension Bridge. From that beautiful structure you look down on a poor and not very attractive stream, which two hours later becomes transformed into a river of ample volume, down which great ships are navigated. But of all places in the world, the most colossal tidal phenomena are those in the Bay of Fundy. Here the Atlantic passes into a long channel whose sides gradually converge. When the great pulse of the tide rushes up this channel, it is gradually accumulated into a mighty volume at the upper end, the ebb and flow of which at spring tides extends through the astonishing range of not less than fifty feet.

These discrepancies between the tides at different places are chiefly due to the local formations of the coasts and the sea-beds. Indeed, it seems that if the whole earth were covered with an uniform and deep ocean of water, the tides would be excessively feeble. On no other supposition can we reasonably account for the fact that our barometric records fail to afford us any very distinct evidence as to the existence of tides in the atmosphere. For you will, of course, remember that our atmosphere may be regarded as a deep and vast ocean of air, which embraces the whole earth, extending far above the loftiest summits of the mountains.

It is one of the profoundest of nature's laws that wherever friction takes place, energy has to be consumed. Perhaps I ought rather to say transformed, for of course it is now well known that consumption of energy in the sense of absolute loss is impossible. Thus, when energy is expended in moving a body in opposition to the force of friction, or in agitating a liquid, the energy which disappears in its mechanical form reappears in the form of heat. The agitation of water by paddles moving through it warms the water, and the accession of heat thus acquired measures the energy which has been expended in making the paddles rotate. The motion of a liquid of which the particles move among each other with friction, can only be sustained by the incessant degradation of energy from the mechanical form into the lower form of diffused heat. Thus the very fact that the tides are ebbing and flowing, and that there is consequently incessant friction going on among all the particles of water in the ocean, shows us that there must be some great store of energy constantly available to supply the incessant draughts made upon it by the daily oscillation of the tides. In addition to the mere friction between the particles of water, there are also many other ways in which the tides proclaim to us that there is some great hoard of energy which is continually accessible to their wants. Stand on the bank of an estuary or river up and down which a great tidal current ebbs and flows; you will see the water copiously charged with sediment which the tide is bearing along. Engineers are well aware of the potency of the tide as a vehicle for transporting stupendous quantities of sand or mud. A sand-bank impedes the navigation of a river; the removal of that sand-bank would be a task, perhaps, conceivably possible by the use of steam dredges and other appliances, whereby vast quantities of sand could be raised and transported to another locality where they would be innocuous. It is sometimes possible to effect the desired end by applying the power of the tide. A sea-wall judiciously thrown out will sometimes concentrate the tide into a much narrower channel. Its daily oscillations will be accomplished with greater vehemence, and as the tide rushes furiously backwards and forwards over the obstacle, the incessant action will gradually remove it, and the impediment to navigation may be cleared away. Here we actually see the tides performing a piece of definite and very laborious work, to accomplish which by the more ordinary agents would be a stupendous task.

In some places the tides are actually harnessed so as to accomplish useful work. I have read that underneath old London Bridge there used formerly to be great water-wheels, which were turned by the tide as it rushed up the river, and turned again, though in the opposite way, by the ebbing tide. These wheels were, I believe, employed to pump up water, though it does not seem obvious for what purposes the water would have been suitable. Indeed in the ebb and flow all round our coasts there is a potential source of energy which has hitherto been allowed to run to waste. The tide could be utilized in various ways. Many of you will remember the floating mills on the Rhine. They are vessels like paddle steamers anchored in the rapid current. The flow of the river makes the paddles rotate, and thus the machinery in the interior is worked. Such craft moored in a rapid tide-way could also be made to convey the power of the tides into the mechanism of the mill. Or there is still another method which has been employed, and which will perhaps have a future before it in those approaching times when the coal-cellars of England shall be exhausted. Imagine on the sea-coast a large flat extent which is inundated twice every day by the tide. Let us build a stout wall round this area, and provide it with a sluice-gate. Open the gate as the tide rises, and the great pond will be filled; then at the moment of high water close the sluice, and the pond-full will be impounded. If at low tide the sluice be opened the water will rush tumultuously out. Now suppose that a water-wheel be provided, so that the rapid rush of water from the exit shall fall upon its blades; then a source of power is obviously the result.

At present, however, such a contrivance would naturally find no advocates, for of course the commercial aspect of the question is that which will decide whether the scheme is practicable and economical. The issue indeed can be very simply stated. Suppose that a given quantity of power be required—let us say that of one hundred horse. Then we have to consider the conditions under which a contrivance of the kind we have sketched shall yield a power of this amount. Sir William Thomson, in a very interesting address to the British Association at York in 1881, discussed this question, and I shall here make use of the facts he brought forward on that occasion. He showed that to obtain as much power as could be produced by a steam-engine of one hundred horse power, a very large reservoir would be required. It is doubtful indeed whether there would be many localities on the earth which would be suitable for the purpose. Suppose, however, an estuary could be found which had an area of forty acres; then if a wall were thrown across the mouth so that the tide could be impounded, the total amount of power that could be yielded by a water-wheel worked by the incessant influx and efflux of the tide would be equal to that yielded by the one hundred horse engine, running continuously from one end of the year to the other.

There are many drawbacks to a tide-mill of this description. In the first place, its situation would naturally be far removed from other conveniences necessary for manufacturing purposes. Then too there is the great irregularity in the way in which the power is rendered available. At certain periods during the twenty-four hours the mill would stop running, and the hours when this happened would be constantly changing. The inconvenience from the manufacturer's point of view of a deficiency of power during neap tides might not be compensated by the fact that he had an excessive supply of power at spring-tides. Before tide-mills could be suitable for manufacturing purposes, some means must be found for storing away the energy when it is redundant, and applying it when its presence is required. We should want in fact for great sources of energy some contrivance which shall fulfil the same purpose as the accumulators do in an electrical installation.

Even then, however, the financial consideration remains, as to whether the cost of building the dam and maintaining the tide-mill in good order will not on the whole exceed the original price and the charges for the maintenance of a hundred horse power steam-engine. There cannot be a doubt that in this epoch of the earth's history, so long as the price of coal is only a few shillings a ton, the tide-mill, even though we seem to get its power without current expense, is vastly more expensive than a steam-engine. Indeed, Sir William Thomson remarks, that wherever a suitable tidal basin could be found, it would be nearly as easy to reclaim the land altogether from the sea. And if this were in any locality where manufactures were possible, the commercial value of forty acres of reclaimed land would greatly exceed all the expenses attending the steam-engine. But when the time comes, as come it apparently will, that the price of coal shall have risen to several pounds a ton, the economical aspect of steam as compared with other prime movers will be greatly altered; it will then no doubt be found advantageous to utilize great sources of energy, such as Niagara and the tides, which it is now more prudent to let run to waste.

For my argument, however, it matters little that the tides are not constrained to do much useful work. They are always doing work of some kind, whether that be merely heating the particles of water by friction, or vaguely transporting sand from one part of the ocean to the other. Useful work or useless work are alike for the purpose of my argument. We know that work can never be done unless by the consumption or transformation of energy. For each unit of work that is done—whether by any machine or contrivance, by the muscles of man or any other animal, by the winds, the waves, or the tides, or in any other way whatever—a certain equivalent quantity of energy must have been expended. When, therefore, we see any work being performed, we may always look for the source of energy to which the machine owes its efficiency. In fact, it is the old story illustrated, that perpetual motion is impossible. A mechanical device, however ingenious may be the construction, or however accurate the workmanship, can never possess what is called perpetual motion. It is needless to enter into details of any proposed contrivance of wheels, of pumps, of pulleys; it is sufficient to say that nothing in the shape of mechanism can work without friction, that friction produces heat, that heat is a form of energy, and that to replace the energy consumed in producing the heat there must be some source from which the machine is replenished if its motion is to be continued indefinitely.

Hence, as the tides may be regarded as a machine doing work, we have to ascertain the origin of that energy which they are continually expending. It is at this point that we first begin to feel the difficulties inherent in the theory of tidal evolution. I do not mean difficulties in the sense of doubts, for up to the present I have mentioned no doubtful point. When I come to such I shall give due warning. By difficulties I now mean points which it is not easy to understand without a little dynamical theory; but we must face these difficulties, and endeavour to elucidate them as well as we can.

Let us first see what the sources of energy can possibly be on which the tides are permitted to draw. Our course is simplified by the fact that the energy of which we have to speak is of a mechanical description, that is to say, not involving heat or other more obscure forms of energy. A simple type of energy is that possessed by a clock-weight after the clock has been wound. A store of power is thus laid up which is gradually doled out during the week in small quantities, second by second, to sustain the motion of the pendulum. The energy in this case is due to the fact that the weight is attracted by the earth, and is yielded according as the weight sinks downwards. In the separation between two mutually attracting bodies, a store of energy is thus implied. What we learn from an ordinary clock may be extended to the great bodies of the universe. The moon is a gigantic globe separated from our earth by a distance of 240,000 miles. The attraction between these two bodies always tends to bring them together. No doubt the moon is not falling towards the earth as the descending clock-weight is doing. We may, in fact, consider the moon, so far as our present object is concerned, to be revolving almost in a circle, of which the earth is the centre. If the moon, however, were to be stopped, it would at once commence to rush down towards the earth, whither it would arrive with an awful crash in the course of four or five days. It is fortunately true that the moon does not behave thus; but it has the ability of doing so, and thus the mere separation between the earth and the moon involves the existence of a stupendous quantity of energy, capable under certain conditions of undergoing transformation.

There is also another source of mechanical energy besides that we have just referred to. A rapidly moving body possesses, in virtue of its motion, a store of readily available energy, and it is easy to show that energy of this type is capable of transformation into other types. Think of a cannon-ball rushing through the air at a speed of a thousand feet per second; it is capable of wreaking disaster on anything which it meets, simply because its rapid motion is the vehicle by which the energy of the gunpowder is transferred from the gun to where the blow is to be struck. Had the cannon been directed vertically upwards, then the projectile, leaving the muzzle with the same initial velocity as before, would soar up and up, with gradually abating speed, until at last it reached a turning-point, the elevation of which would depend upon the initial velocity. Poised for a moment at the summit, the cannon-ball may then be likened to the clock-weight, for the entire energy which it possessed by its motion has been transformed into the statical energy of a raised weight. Thus we see these two forms of energy are mutually interchangeable. The raised weight if allowed to fall will acquire velocity, or the rapidly moving weight if directed upwards will acquire altitude.

Конец ознакомительного фрагмента.