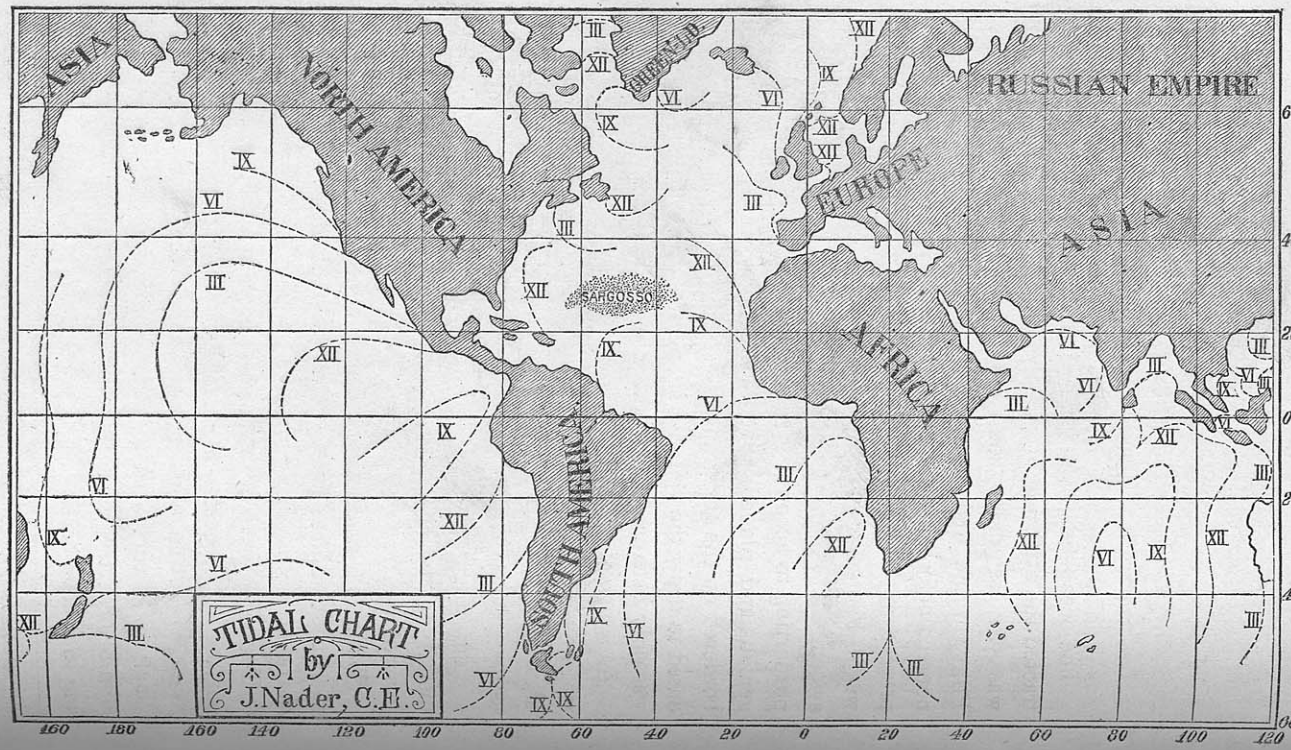
TIDAL CHART
by
J.Nader, C.E.
ASIA
NORTH AMERICA
SOUTH AMERICA
EUROPE
AFRICA
ASIA
RUSSIAN EMPIRE
SARGOSSO
160
180
160
140
120
100
80
60
40
20
0
20
40
60
80
100
120
60
40
20
0
20
40
60

# THE TIDES.

By John Nader, Civil Engineer.

The ocean tide, this mysterious breathing of the sea, has attracted the attention of man from the earliest ages, and the cause was often assigned to some mysterious, if not supernatural agency. Pliny, in the first century, must have been studying the phenomena before he exclaimed, "Causa in Sole Lunâque;" as we proceed in this investimation we will see how nearly correct Pliny was in his remark. Since the announcement of the Copernican[1] system of the universe, many theories have been advanced, all purporting to account for the tides. Some of these were very ingenious and plausible, while others, as we will subsequently see, bordered on the absurd. "Descartes,"[2] as Guillemin says, "first dared to draw the veil and sound the mystery, and if he failed, it was only because of his preconceived ideas of the solar system."

As we shall endeavor to deduce the cause from the effect, we will first investigate the various phases and features of the phenomenon as they actually occur, and then endeavor to assign the cause. Considerable observation and study are required to obtain a clear understanding of the varied features of the tide, of the disturbing influences arising from various sources, and of the form of the true and distorted waves.

The first feature observed, is the periodic rising and falling of the surface of the ocean and the movement of the consequent currents.

The tidal wave in its simplest form is a long undulation of the surface of the ocean, the length of which is the distance between two consecutive high or low waters; the vertical range is very small when compared with the length, but increases as the length diminishes; the time, however, is and remains the same excepting in special cases.

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[1] Nicolaus Copernicus. Born Feb. 9, 1473, Prussia. Died May 24, 1543. System de Mundi, 1507–1530–1543.

[2] Descartes. Born, 1596; died, 1650; 54 years.

The attending currents are the motion of the water on the slopes of the waves in obedience to gravitation. The excursions of these currents, at any particular point, are of short duration; the motion of the wave is so rapid compared with the current that a point in moving down one side is elevated by the advancing wave and left on the reverse slope to return and repeat the journey. It is not uncommon during still weather, to observe objects floating to and fro with the currents during several successive tides.

The figure of a normal or undistorted wave is nearly equal to a curve of sines of a circle whose diameter extends from high to low water with the center at mean level; if the semicircle and the half wave are divided into an equal number of parts, the sines and distances are the co-ordinates of the curve. As a rule the advance slope of the wave is the steeper of the two, for the axis is always inclined forward, owing to the resistance of friction. By comparing a diagram of an observed tide with the theoretical one, the distortion, if there is any, is at once recognized.

In the deep water of the ocean the volume necessary to form the wave in proportion to the force meets with little resistance, whereas in shallow water the resistance of friction from the bottom becomes considerable, and the wave which is thereby retarded in its progress is modified and the horizontal force is transformed into a vertical one; the water in front of the wave is drawn down to form the wave, thereby making the previous low water lower while the momentum of the wave heaps the water upon the obstructed portion, making the high water higher; and while the range is thus increased the length is proportionally diminished.

The tide is often much distorted by storms, so much in fact at times, as to almost lose its identity. A remarkable case occurred in New York Bay in the summer of 1869; it indicated that a vere storm was raging somewhere on the Atlantic ocean which arrested for a time the progress of a portion of the wave; the entire volume arrived in due time, but in a distorted form.

The force of the wind has also a great effect upon the tides in bays and rivers where at times every feature is disturbed beyond recognition. In the Delaware river in the winter of 1851 and

1852 the tide at Fort Delaware fell continuously for 36 hours in consequence of the wind blowing down stream, and instead of six feet the fall was actually fourteen.

The tides have their origin in the oceans and thence proceed to our shores, part of the time as forced and part of the time as free waves, that is to say, they are moving part of the time under the action of the tide-making force and when by the earth's rotation they are removed from this influence they continue under their own *vis-viva* until again brought within the influence of the same cause. After investigating some of the peculiarities of the tides on the coasts, we will return to the ocean wave. After reaching the coast the tide enters every bay and river within its scope, and, while doing so, undergoes many modifications. The range is subject to change with every change in the cross-section, so that observations along a river will vary considerable even at short distances. In extensive bays the fact is more marked than in rivers, the range, which is increased by the contraction of the inlet, is at once diminished when the wave enters and spreads in the basin, but, while the influx is retarded, the main wave passes by, the ocean falls and efflux begins before the bay is filled to the ocean level, so that the bay never rises to a level with the ocean and for the same reason also, never becomes as low. The Delaware and Chesapeake bays are cases of this kind; the Mexican gulf is one of the most extreme and will receive special notice further on.

The time card of steamers carrying on small tidal rivers is a curiosity to those not familiar with such rivers, some of which have scarce one foot of water at their entrance at low tide, so that the boats are obliged to enter and leave the river on the tide wave and their time must vary from day to day as we find the tides do vary. On large tidal rivers the case is different. Vessels will meet several tides during one trip, as, for instance, on the Hudson river, New York. The tide which passes New York city at 8:13 A. M., reaches Albany at 3:30 P. M., with a mean velocity of about 17 miles an hour so that the length of the half wave, from high to low water, is about 100 miles.

A boat leaving Albany at high water, at say 15 miles an hour,

on the *ebb*, reaches low water in a little over three hours; then at the rate of twelve miles an hour on the *flood*, reaches high water in 3½ hours more 40 miles above New York, which point (New York) it makes in 2½ hours more and is then within 20 miles of the next low water. On the upstream trip the conditions would be different. Here it would only be a question of speed between the boat and the wave, and if the boat left at low water on the first of the *flood* current, it would meet the contrary current about 20 miles below Albany. The fact is that the trip upstream is made in less time than that downstream.

The tide of Long Island Sound and the East river, is remarkable in several respects. That portion of the tide which enters at Sandy Hook moves slowly up the narrow channel of the East river and a few miles above New York encounters another portion of the same ocean tide which entered the Sound at Montauk Point and flowed back through the Sound over 100 miles in the meantime.

With a reasonably fair idea of the tides, the most remarkable feature may appear to be their regularity, but by the time the novelty has worn off there may also arise some doubts upon that point in the mind of the observer.

If the observations should begin at a particular time, there will be two precisely similar waves, in something less than 25 hours. In the course of a few days, during which the tides will appear later each day, the two tides will become unequal in range, at the same time both may be higher or lower than when first observed, the evening tide may be the greater yet it is just as possible that the morning tide will be the greater of the two, depending entirely upon the time when the observations commenced.

Before progressing any further we will be obliged to assume some means of comparison to enable us to pursue the subject intelligently. Now, if we find that the phases of any two or more distinct phenomena run parallel, or in other words coincide, we may conclude that one is either the cause or companion of the other.

The phases of the tide compare in point of time exactly with those of the moon so that the moon is either the cause of the tides or their companion subject to the same laws.

The two equal tides take place when the moon has no declination, i. e., when in the plane of the earth's equator no matter what its position otherwise may chance to be. When the moon moves north or south of the equator the tides become unequal. In most localities the highest of the two will be the one following the upper transit during north declinations and lower transits during south declinations; when the tides observed do not succeed the transit which attends their formation, the exact reverse of this is true. Leaving aside the semi-diurnal inequalities, the highest tides occur at new and full moon and are known as *spring tides*, the least tides occur when the moon is in her quadratures and are known as *neap tides*. The highest of the high tides occur when the full or change takes place during maximum declinations, then one of the waves is much larger than the other, in some localities the inequality is so great as to compound the two waves to such a degree that only one distorted wave is apparent in 24 hours.

The mean time from the moon's upper transit to the succeeding high water, during a lunation, is called the "Corrected Establishment" or the "Establishment of the Port." The establishment is used by mariners and others for calculating the time of the tide from the position of the moon.

In the Gulf of Mexico the tides are more complicated; in Galveston Bay two very small irregular tides are observable in 24 hours when the declination of the moon is small, when this increases either way, the two become unequal until only one high water is recognizable in 24 hours; this continues several days before and after maximum declination.

By careful obseavations the two compounded waves are observable unless affected by local disturbances which latter often exceed the range of the tide which is from one-half to two feet.

The foregoing facts illustrate the general features of the tides and warrant the assumption that the moon is in some manner connected with the same.

If we examine the coast lines of continents we will observe a general similarity in some while in others we may even compare their details and in either case find remarkable resemblance which

has suggested the idea, to some of our geographers, of joining the continents and assuming lines of cleavage.

South America, Africa and Oceanica have a strong resemblance; the locations of such detached portions as the Falkland Islands, Madagascar, New Zealand, Ceylon and Formosa are notable; the Fjords of Norway and Patagonia and the Firths of Scotland resemble each other closely, while the serrated S. W. coast of Ireland is the duplicate of the to coast of Maine. In these localities the tide impinges upon the coast in the same manner, in each case, both as to direction and impulse.

We may further observe the work of erosion of the average tide and of the greater at maximum declinations in the double indented coasts on the west of the continents, the first impulse of the tide being from west to east in nearly all cases.

According to the usually accepted theory of the tides, the moon elevates the water of the ocean by attraction. Now, if we admit of attraction, we must also admit of its laws according to one of which, bodies attract with a force in direct proportion to their masses. The mass of the sun is such that his attraction upon the earth is 170 times greater than the moon's and the tide should be in proportion to the respective attractive powers of the two bodies.

Reclus in "The Ocean" says that, "the solar tides would be 5000-6000 feet high if the true cause of the tides was not to be found in the difference of attraction exercised on the waters of the different parts of the earth." The difference of the moon's attraction on the near and remote sides of the earth is just twice the difference of the sun's, while the sun's attraction is 589 millionths of the earth's gravity and moon's attraction is only 34½ millionths. The centrifugal force at the equator due to the earth's rotation is the 1-289th part of the earth's gravity and hence only six times greater than the sun's attraction, while it is more than 1000 times greater than the moon's.

The moon's assumed affinity for aqueous matter we will not consider since we have as yet no reason to doubt that gravitation is the same throughout the Universe. In space, all matter is attracted alike, that some bodies are heavier than others is that they,

on account of their density, contain a greater mass, and gravity acting upon this mass gives them their preponderance, at the same time one volume will respond to the force of gravity as readily as another, nothwithstanding their different densities.

A tide occurs at opposste sides of the earth at the same time, that is, one tide follows the upper transit of the moon and another the lower one in the same place. The water is said to be drawn away from the earth on one side and the earth away from the water on the remote side.

We know that two forces acting in the same direction are represented by a simple sum of these forces and that attraction acting from one side through a body upon matter on the opposite side will only aid gravity in holding that matter more securely on that side, but, it is admitted that matter is heavier on the earth's surface on the side remote from the sun, which fact recalls the argument, that if anything is affected by foreign attraction it will be affected most by the superior force.

Argumeet aside, the tide is certainly obedient to the moon, but the manner in which this is brought about, is the problem to be solved.

One feature of the phenomena which is used to show that the tide is raised by attraction, is the difference in range of the semi-diurnal tides at different positions of the moon, the higher tide succeeding the superior transit and north declination and the lower transit during south declination, showing that the moon draws the water after it.

Now let us see how true this is.

The Atlantic tide is created in the southern part of the South Atlantic ocean, and moving eastward reaches the African coast shortly after the moon's transit at that place. Thence it moves north and west, reaching the United States coast twelve hours later. The other side of the wave in connection with the Arctic tide moving east and north, reaches Ireland four hours later, and Dover straits twelve hours later still; so that in some places it is the tide after moon's transit, and in others the previous tide which is observed, so that the facts become reversed.

Nearly all authors on this subject — the tides — are satisfied

with nothing less than the great South Pacific ocean, a thousand miles off shore, for sufficient space to create the tidal wave, whence they propagate the same all over the world from east to west. Some think it possible that there is a new impulse given in each ocean, while others think that possibly the origin may be in the Indian ocean.

That these speculations are not all correct is evident from my chart of co-tidal lines, which is based upon a collection of actual facts from undoubted sources. One tide reaches the west coast of Africa at the same moment of absolute time that another reaches the east coast of Madagascar. These can by no means be the same wave in any form, for, after reaching the respective coasts, a portion of each moves southward, these meet near the Cape of Good Hope, unite, and move south as one wave. One tide arrives on the west shore of Patagonia at the same time that another reaches the east shore of the Falkland Islands. These move south and three hours later unite near Cape Horn and go south as one wave. These also are two entirely separate and distinct tides coming from different oceans and from opposite directions. A still more remarkable tide is that which reaches the north end of New Zealand from the northeast. This tide travels south between Austria and New Zealand, is met by a tide from the Indian ocean south of Tasmania, is turned eastward and makes the detour of New Zealand in time to pass the succeeding tide off the north end of the Islands. This wave is an important one, as it returns just in time to reform the Pacific tide. The Society Islands, where there is no perceptible tide, lie in the node between the ascending and descending tides. The solar tide of 5–6 inches reported at Tahiti is occasioned by the shifting of the node of no tide, and the time, three hours before and after noon and midnight, is occasioned by what is termed *priming* and *lagging* of the lunar tides.

The tide of the Indian ocean has its origin near the center of that ocean, first moving decidedly north and east and then spreading in a north and west direction. Owing to the great difference in depth of this ocean and the consequent resistance, this tide is subject to movements peculiar to itself. The Maldive islands are

situate 400 miles west of Ceylon, and occupy 500 miles in a north and south direction by about 40 miles wide. They are divided into numerous groups by navigable channels of various depths. It is estimated that the whole number of islands or Atols is no less than 50,000, of which the largest is not more than eight miles in circumference. These islands present an immense barrier to the tide, so that one portion is retarded, while another portion moves on rapidly, making a large detour returns upon the retarded portion like an eddy. The wave moving westward with a great convex front reaches Madagascar, and, passing around both ends, fills Mozambique Channel with high water in half an hour. One portion then passes southwest and meets the south Atlantic tide, the other advances north to Cape Gardafui, then moves eastward with great velocity to the west coast of Hindoostan, filling the Arabian sea, and moving south reaches the Maldives eight hours after the main wave has passed the same point and entered the Bay of Bengal. It will also be observed that the easterly side of this tide moves both north and south of Australia; that on the north meets the Pacific tide coming through Torres straits with a difference of four hours; that on the south travels beyond Tasmania and joins a portion of the Pacific tide, a portion of both, however, returning from South Victoria along the Antarctic continent to maintain the equilibrium.

The tide in the north Atlantic, which had its origin partly in the Arctic Ocean and partly in the south Atlantic, moves eastward with an extensive convex front and divides on the south end of the British Isles; one portion enters the British Channel and reaches Dover Straits in the time that the other portion makes the entrance to the North Sea. The tide in Dover Straits meets another which entered the North Sea twelve hours before but passes to the east of it and along the coast of France and the Netherlands, and combining with a later tide from the north reaches the Skaw 17 hours after passing Callais, while another portion of this identical tide travels south along the English coast. It will be observed that there is always a whole wave in the North Sea which is necessary to preserve the sequence.

The tide passing north to Martha's Vineyard is met at Nan-

tucket by a tide from the north four hours younger, but of greater range, so that it is superposed on the lesser. The origin of the Arctic tide is not traceable for want of data in these waters, but it ascends Baffin's Bay.

These facts go to show that we have not one but a number of primary tides, created in different ocaans, acting in perfect harmony and repeating their phases as regular as the moon.

Observing the different motion of the tides, we find that they obey in a particular manner certain varying impulses. Primarily they move east, then west, with a general tendency to and from the equator, unless interrupted by obstructions; and on the whole they partake of a circular motion in time to repeat.

The original motion is a most decisive one, not as though a stone were thrown into the water, as the comparison is sometimes made, but just the opposite; the greater portion of a whole ocean appears to heave and rise into a wave in the course of a few hours.

In particular cases the impulse and its direction are very marked owing to local interferences, such as the Bay of Fundy, where the tide reaches the coast with great rapidity through a tongue of very deep water, then moves endwise to the east, meets with the obstruction of Nova Scotia, so that the wave is augmented to alarming dimensions. Bristol Channel and a number of other places are subject to similar tides, but of less extent. On the other hand we find some cases of this kind in the other direction, for instance the entrance to Magellan Straits, where the tide attains a range of 40 feet and over.

The foregoing are facts obtained from long observation and careful investigation of the phenomena. More than 4,000 reliable data were collected from tables such as "Bowditch's Navigator," Imray & Son's "Lights and Tides of the World," and various other equally reliable sources. These were all reduced to absolute time (Greenwich time) and platted on charts in their respective places. The true places of the co-tidal lines were thus obtained, and the result shows beyond a doubt that the charts of co-tidal lines now in use are far from being correct.

In Pliny's judgment the cause was the sun and moon. We

will also examine the remarks of others on this subject and see how they agree.

The New Am. Cyc. says: "The close relation which the times of high water bear to the times of the moon's passage shows that the moon's influence in raising the tides must be greater than the sun's. In fact, while the whole attraction of the sun upon the earth far exceeds that of the moon, yet, owing to the greater proximity of the latter, the difference between its attraction at the center of the earth and at the nearest and most remote points of its surface, which produces the tides, is about two and one-half times as great as the sun's attraction at the same points."

The argument might answer if the moon was very near the earth so as to gather the water by tangental motion into a wave beneath it until resisted by gravitation, provided also, that sufficient time was allowed, as we are not dealing with a uniform envelop of water, but with oceans separated by continents, and although the velocity of the tides is great, the translation of the water is very slow, not such as would be required in heaping up the water as the moon overleaps the continents from ocean to ocean, whereas the wave comes up as though impelled by a sudden blow or stroke. An article on tides by repulsion in Vol. 4 of the South. Litt. Mess. says: "When La Place[1] had ascertained the fact, that as the mooon passed over the Atlantic it was low water under her and the swell was on either side of her, north and south, and the further from the moon the greater the swell, is it not a little strange that he should have come to the conclusion that the moon was drawing up the water towards herself," further from the same; "as whenever the moon is vertical to any place, it is invariably low water." These remarks, when properly applied, are correct so far as the position of the wave is concerned. Bowditch in Mech. Celeste says: "By a remarkable singularity, the low water takes place when the two bodies are in the meridian, and the high water when they are in the horizon; so that the tide subsides at the equator, under the body that attracts it." It appears that the origin of the tide is lost sight of, and the time

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[1] La Place. Born, 1748; died, 1827.

required to reach the position of the moon is not considered, there are times, however, when the tide is under the moon, but, if we find the moon over a low water, we will also find the parent wave in deep water on on the same meridian.

The same author, in the Messenger, further says: "And as when the moon approaches the meridian of Babelmandeb the the water will fall there but continues its elevation on each side as at Tonquin and in the Mozambique channel," also, "the tide remaining up so long at Tonquin gave rise to the notion, very strangely indeed, that two tides met at that place."

It is merely necessary to examine the facts in both these cases and we will find that the falling water at Babelmandeb is the tide of the moon's previous transit, while tide in the Mozambique channel is that of the immediate transit which culminates with the moon in the Indian ocean in longitude 80° E, but does not culminate in the Mozambique until the moon has reached longitude 20° W. The tide at Tonquin is a part of the Pacific tide which enters the China sea through the Bashee and Balintang channels between Formosa and Luzon and also a small tide from the Balabec straits, these unite before reaching the Gulf of Tonquin, leaving a regular tide of 4 to six feet. There is, however, a tide from the Indian ocean through Mallacca and Sunda Straits which causes interferance in the Gulf of Siam, a body of water similar to the Gulf of Tonquin but ten degrees of latitude nearer the equator; the spring tides are only two feet at the entrance but increase at the head of the gulf, so that the tide at Cape Liant is seven feet, the time, however, is disturbed, so that the tide rises three hours and falls nine.

The irregularities of the tide in the Straits of Magellan are drawn upon to favor the theory by repulsion. These tides are such as would serve any desirable purpose. When the moon is over the Atlantic the tide of the previous transit begins to rise at Cape Virgins, so also the tide at Cape Pillar on the Pacific side and in Cockburn Channel.

During three hours when the moon is over the Atlantic the tide at Cape Pillar does three hours of its rising phase, at Cockburn Channel the last two of falling and the first of rising and at Cape

Virgins the last of rising and first two hours of falling of the previous tide. Now when the moon is over the Pacific, say at 8 hours absolute time longitude 120° W., then it is two hours after high water at Cape Pillar, just high water at Cockburn Channel and seven hours after high water at Cape Virgins or five hours before the high water succeeding the present moon. These conflicting phases make the problem a very complicated one and the more so when we consider the difference in range of these irregular tides. The tide at Cape Pillar at the sixth hour rises scarce five feet; in the Cockburn Channel at the eight hour about five (this tide divides into two branches on Clarence Island), while the tide at Cape Virgins at the thirteenth hour has a range of from 38 to 42 feet. Reclus says that Fitzroy has measured tides here as high as 62 feet. When we further consider the variable width of the Straits with two narrows one of which is described as being like the passage of the Bosphorus from the Black Sea into the Marmara Sea we may conclude the hopeless task of attributing these irregular fluctuation to any supposed cause whatever.

An article in Vol. 34 of the *American Journal of Science* says: "That the attraction of the moon regulates the times of the tides caused by the gulf stream, is evident." Further: "Why does the ocean always run swiftly into the Mediterranean Sea? No doubt to keep up the subterranean stream which passes out of the Bay of Mexico, called the Gulf stream."

Here, in the first place is a confounding of cause and effect, the motion of the tidal wave gives a slow progressive motion to a large volume of water.

The waters of the Atlantic set in motion by the tide reflect from the African shore and move in a north west direction; after passing Cape St. Rogue the waters tarry six months under a tropical sun before discharging from the Straits of Florida a volume of water equal to 3,000 Mississippi rivers.

The constant current into the Mediterranean, which until recently was considered to be the consequence of the evaporation of the Sea, is only a surface current, and quite recently a strong counter-current has been discovered at the bottom of Gibraltar Straits setting into the Atlantic and accounting for the greater

part of the influx at the surface. This strait is large enough to give freedom to tides and currents, its length from Cape Trafalgar to Europa point, in Sprin, is 36 miles and its width from 15 to 24 miles, its depth is as much as 5,000 feet. The spring tides at Lissa Island in the Adriatic are 2½ feet and at Tripoli, Syria, at the extreme east end of the Mediterranean, they have still a range ot two feet.

The New American Cycopedia speaking of the age of the tide, says: "This delay, which even at the Cape of Good Hope amounts to fourteen hours, is still the subject of investigation and is probably mainly due to friction."

If the co-tidal charts by Whewell and others were correct, then the delay would be much greater than that here mentioned, these charts give the origin of the tide in the Pactfic, thence they bring the tide across the Pacific and Indian ocean and into the Atlantic by way of the Cape of Good Hope. The fact is, that this tide is created in the Atlantic ocean exactly on time with moon's transit, so that there is no delay at this point, but from here the tide is twelve hours in reaching the United States coast, 14 in reaching Spain and 24 hours readhing Dover by way of the British Channel.

From the same source we have the following:

"If the tides arrive at the same place by two different channels and one of them is retarded behind the other by six hours, in consequence of traveling a longer route or in shallow water, the semidiurnal tides will be destroyed by an interference of the waves, that is, by the high water of one being superimposed on the low water of the other."

This phenomenon is common, two waves unite and one is the result, but, this does not prevent a recurrence after 12 lunar hours, the semidiurnal phase is not affected whatever in any case. If the tide divides on, and passes around an island, the two parts unite and reform the wave, or, if the tides meet in a long channel the result is a commotion which stops both until drawn down by the succeeding tides, or they may, as at the Isle of Wight, cross each other both ways causing double high tides. In this case the tide from the west enters the "Solent" at ten hours with a range

of 7–8 feet, and, the main wave having reached Spithead, another tide enters here a little over one hour later with a range of 12 to 13 feet so that there is a second highwater 2¼ hours after the first at Southampton; the second tide passes also to the west from "Cowes," after the first has passed making a second highwater at Lymington. The two parts of the tide wave remain distinct. The point of meeting or crossing at Cowes is such as to leave the general direction of the tides at rightangles and it can be practically demonstrated that two sets of waves may travel in this manner without any serious interference.

When, however, two tides meet in the ocean, they will form one wave which will progress in a direction which will be the resultant of the previous direction and velocity of the separate tides. We must also bear in mind that in all, excepting rare cases, the tide in questiou supplants a wave which occupied the same location twelve hours before.

The semi-diurnal tides may differ to such an extent that the high water of one corresponds with the low water of the other, and may leave the impression of but one or a *diurnal* tide, the appellation however is a misnomer, there being really no diurnal tide; the distortion can be recognized in every case so that there is no question of there being two tides. This compounding is not due to a meeting of tides but to the location and time of the originating impulse as we will see further on.

It happens at times that one of the semi-diurnal tides is entirely lost and this is, when the wave is small and travels free by its own *vis viva* after the force is removed, being constantly retarded in its movement and at length unable any longer to overcome the resistance of friction the wave finally stops and is lost. This is the case in the gulf tides when the moon's declination is maximum, one of the waves is so small that it is scarcely distinguishable and is at times lost before reaching the coast.

Where two tides of the same type but of nifferent origin meet as at Cape Horn and the Cape of Good Hope, they unite and become one wave. The meeting of the tide off the capes will account for the turbulent condition of the sea in these localities.

Only a few of many tidal theories are noticed tn the foregoing

remarks and it appears that in every instance the authors had a very indifferent knowledge of tidal phenomena.

Reclus was not far from correct when he said: "Cotidals according Whewell are accepted, but it is not certain that things occur in this way, in fact, it is ascertained that in each oceanic basin the tide seems to start from the centre and be propagated in all directions parallel to the general direction of the coasts."

This remark was a welcome discovery when the accompanying chart began to develop into its present form, so also a statement from an unknown author, that the tide possibly had its origin in the middle of the Indian Ocean: also the report of a British naval commander who stated "that instead of a constant current westward around the Cape of Good Hope he had known vessels to remain stationary for days and even to drift to the east." Now it is safe to say that had the tide been constantly in one direction around the cape, as it was supposed to be, then the current would also have been constant in the same direction.

The tides of the British Channel and North Sea have already been mentioned but owing to so singular phenomena a special investigation will be interesting. The accompanying chart shows every feature of these remarkable tides.

The cotidal lines represent the progress at each hour of absolute time; the age of the tide is reckoned from its origin in the South Atlantic when the moon transits the meridian of Greenwich at 12 o'clock noon or midnight (this is at full and change).

A tongue of deep water, over 2,500 fathoms deep, extends far into the Bay of Biscay, and when the tide arrives off this point it makes a decided lateral move into the bay with great velocity, from the 14th to the 15th hour, at the same time approaching the shores of Ireland and England, dividing on Cape Clear at the 16th and Lands End a little before the 17th hour; the southeast portion passes through the British channel and Dover straits in a northeast direction at the 24th hour, and it here passes a tide on its west 12 hours older. Meeting as they do, these tides reflect and preserve their individuality on opposite shores in opposite directions. The tide from the channel keeps along the east shore and meets a tide off the coast of Jutland 12 hours younger than

the one we have followed thus far. But where is our associate? While we were lingering in the channel, and the straits, he went around the longer way with great strides and met our predecessor at the point where we now are, just as we were tasting of the Dutch Rhine, and combining with him made the passage of the Skagger Rack and washed the shores of Gotheborg Sweden at 30 hours as we shall when 42 hours old. From Cape Clear the tide moves along the west shore of Ireland, the Western Isles and coast of Scotland, reaching the Orkney and Shetland Isles at the 21st hour. Here it divides, never to meet again; one part passes between the Islands and moves south along the coast of Scotland and England and at the mouth of the Thames at the 36th hour passes a Channel tide 24 hours old, its own associate is already approaching Jutland. The tide between the Shetlands and Norway moves rapidly southeastward through a belt of water over 100 fathoms deep, and at the 26th hour meets a channel tide 12 hours older, as we have before observed. When this Norway tide departs eastward a portion breaks to the westward and follows the main wave along the coast of Scotland, but, being delayed by several hours, causes a second high water, thus making apparent four highwaters as far as Peter Head. These four tides were attributed to the channel tides, but it is evident that if this was the case, the tides would be observed along the English rather than the Scottish coast. The middle of the North Sea has no tide, which is corroborated by careful soundings made by the British navy over a shoal where no oscillation was observed. From this it will be observed that there can be not less than two tidal waves in the North Sea at any time, and as many as four at one time during each phase, the resulting confusion of currents can easier be imagined than described.

A portion of the tide which we have been considering enters St. George's and Bristol channels, also the North channel into the Irish sea. The waves by St. George's and North channels meet near the the Isle of Man about the 23d hour, their range along the Irish coast was moderate, but the meeting produces a range of 20 feet and over.

The tide in the Bristol channel, charging straight from the sea

into a nearly uniformly contracting channel, increases rapidly in range as it ascends the Severn. Entering with range of 20 feet it increases to 27 at Ilfracombe, to 35 at Bridgewater Bay, to 37 at Cardiff, 38 at Chepstow and to 40 feet at Bristol. Above Bristol the entire rise occurs in about two hours, and the fall in about ten. Here the resistance of friction is such that the axis of the wave is much inclined by the dragging of the front, and the impulse from the momentum of the volume. The front of the wave becomes steeper and the rear slope much longer, the latter being drawn to supply the next wave.

The *Mascarret Eager* or *Barre* is an exaggerated distortion due to excessive contraction either lateral or vertical. The immediate cause of this phenomenon is, that a sufficient quantity of water to preserve the form of the wave is unable to rise in front before it is overwhelmed by the heaped up water of the wave whose axis is inclined so far from the vertical that it breaks over and rolls along upon the surface. When occasioned by excessive lateral contraction, the *eager* forms at and follows along the shores of the stream, but when caused by shoals in the middle grounds it forms and follows up the middle of the stream, preserving its identity for a considerable time after passing the cause of the abnormity. A few short waves generally follow the *eager*, leaving high water immediately behind them.

While investigating the various phases of the tidal phenomena, it must be noticed that there always has been a determination to have the tide move with the moon from east to west, and owing to this desire many aspects have remained unnoticed, or have been disregarded because they happened to conflict with some theory under construction. In nearly all articles on tides the common remark is, that "in tidal rivers the tide always moves up-stream, even when this is in the opposite direction to that in which the moon appears to move." This would imply that tide should remain under the moon while the earth revolved to the east, and that the tides on the east shores are produced by the advance of the solid earth against the suspended mobile waters. It is true, the tide moves south along the east shores of Scotland and England, but, as we have seen, it is also true that at the same time

there is a tide on the west shore of the Netherlands in the same latitude. The course of the Severn, before noticed, is eastward from the sea, so also the direction of the Bay of Fundy, with 70 feet tide. These facts are sufficient to show that the tide does not follow the moon in her apparent course from east to west, while the earth is revolving on its axis from west to east.

For the purpose of attracting attention to coincidences, a few of the principal mountain chains are given on the chart of which the tides and the conformation of the coasts are, however, the principal features. It will be observed that after forming in the deepest part of the oceans, the first point of impact of the tides is against the foot of a chain of mountains. The indentations of the coasts are not wholly the effect of tidal abrasion, as is indicated by the parallel position of the mountains, but indicate that the tide producing force now operative was active in contributing towards the formation of continents in a fluid much denser than that which it now propels.

By observing the beginning and progress of a storm at sea, we may form some idea of how nature has grown into equilibrium. When the storm begins the waves are varied in form and size and their motions are tumultuous, but when at length sufficient matter is set in motion to satisfy the conditions between the force acting and the surface under action, then the waves become perfect in form and their regularity will bear comparison with the tides.

The tide producing force necessarily acts upon all bodies of water, either great or small, but its effect is very different in lakes and inland seas from what it is in the oceans. In the former there is a constant and ineffectual effort to produce regularity, in the latter the oscillation is established.

The mass and extent of surface must be proportioned to the force. In inland lakes and seas there are continued fluctuations, but small, and the intervals are short, the duration being from a few minutes to several hours.

These oscillations are the result of the tide producing force and the irregularity is the effect of interference and reaction, the surface, mass and force not being in correct proportion.

The lake and also ocean tides may be illustrated by a simple

experiment and the various phases and interferences may be produced just as they occur in nature.

If we take a basin of water and agitate the same, we may produce one or more waves; if now we regulate the impulse while we observe the motion, we may time the same so as to produce regular oscillations which will continue until a change of force takes place; whenever such change takes place either in amount or duration, interferences will appear which after a time will cause the wave or waves to come to a state of rest, but if the same impulse continues, the oscillations begin again, increase to maximum, diminish and again cease.

This will be the case whether the impulse be greater or less or the time faster or slower than that necessary to produce regularity. This is practically true of the great lakes, the oscillations observed are the effect of the tide producing force which is entirely disproportioned to the extent of the volume acted upon, the resulting irregularities recur in periods from which the tide may be determined by elimination.

There are many peculiarities attending the tides as they meet with the varied obstructions of the coast, prominent among these is that the range of tide is less at the most advanced portions of a continent than at either side. The advancing tide in these cases meets with the resistance of the submerged portion of the Cape long before reaching the coast and departs to either hand, thereby diminishing the tide at the cape, which, having reached the coast, divides, and by its momentum crowds upon that part of the tide already making in the bays or indentations of the coast on either side.

We have thus far followed the tidal phenomena through all their principal phases with the moon as the cause or companion of the same.

In order to deduce the cause of the tides we will refer to first principles and then compare facts with the laws of nature. According to Keppler's[1] two first laws, based upon the observations

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[1] Johan Keppler, Wurtemburg. Born 1570, died 1630. 1st and 2d, 1609; 3rd, 1618, May 15.

of Tycho Brahé[1] and published in 1609, the planets revolve around the sun in elliptical orbits and their radii vectores describe equal areas in equal times. The moon is supposed to revolve about the earth in this manner, the orbit being elliptical with the earth occupying one of the foci. Now, Keppler's laws are strictly true when only one planet and the sun are considered, but in a system, they are subject to complicated pertutbations. Newton's[2] Principle, based upon Keppler's laws half a century later, is consequently subject to equally complicated modifications.

According to the laws of gravitation, all bodies attract each other in proportion to their mass and inversely as the squares of the distance, also, bodies which mutually attract each other revolve around their common centers of gravity. These apply to our whole system, and we may say, to the whole universe. Between the earth and moon there will be a point which will describe an orbit around the sun while the earth's center will describe a circle around this common center of revolution. There will appear some complication, for while the two bodies revolve about a common center, the moon is describing an elliptical orbit whose excentricity varies between 1-18 and 1-15 and whose major axis makes a complete revolution in about nine years in direct motion, and although both conditions cannot be entirely true at the same time, yet this will not alter the law while it modifies the results. When the moon is in quadratures both bodies are affected alike by the sun, as the common center lies in their mutual orbit. At this instant either law will apply as the respective orbits of the moon due to either law coincide at this point, and although it may be said that the earth has actual control, its force being at right angles to that of the sun at this point, the moon is actually performing a planetary orbit about the sun.

As soon however as the moon moves out of quadratures in the ellipse, the earth yields to the law of mutual attraction, on account of the dominant force of the sun, its center describes an undu-

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[1] Tycho Brahé, a Dane. Born 1546, died 1601. Rejected Corernicus.

[2] Newton, born 1642, died 1727. Principia, 1627.

lating course about the sun and the common center or point of revolution between the earth and moon describes the orbit.

The ultimate result of these antagonistic efforts is, that the point of revolution between the earth and moon fluctuates between the earth's center and the common center of gravity of the two bodies.

The earth revolves about the common center of revolution, which lies within its own volume, with the same regular velocity that the moon revolves in her orbit. This motion produces a centrifugal force, which, owing to eccentricity, is tangent to the earth only in the plane of the moon and the axis of rotation; the constant change of the axis causes this force to fluctuate between nil and maximum twice in a lunation, that is, nil at quadratures and maximum at syzygies.

The force thus produced, which I will call centrifugal preponderance, varies between the 1-900 and 1-500 of the centrifugal force due to the earth's rotary motion. The effect of the earth's rotation was to produce the spheroidal form of the earth and its present office is to maintain it with a flattening at the poles of nearly 26 miles; if this force were to cease, the oceans would retire to the poles.

Now a force equal to 1-900 part of this, acting uniformly and constantly, would, if we simply consider the result proportionate to the force, cause a flattening of 150 feet, but as we shall see, this force does not act uniformly or constantly, neither have we a continuous mobile surface to consider acted upon, so that this change of form is impossible. Should we however assume a uniform surface of water and taking this force as acting in the mean one-half the time on one-tenth of the surface on opposite sides, we would have a tide of seven feet which agrees with the protuberances of the Elipsoid of water produced by some highly scientific investigations.

The eccentricity of the force causes the same to deviate from the centrifugal force due to the earth's rotation everywhere on the surface excepting at two points; these are, the point directly under the moon and the point opposite. At other points in the plane of the moon's orbit it has a tendency of only slightly de-

flecting the earth's force, and in the endeavor to overcome the superior force of gravity the waters are thereby depressed shortly before being presented to the point of activity and hence are prepared to leap forward to meet the moon at its transit as the tides are known to do.

The centrifugal force is greatest in the plane of the moon's orbit and diminishes towards the poles of rotation in proportion to the cosine of the angular distance so that at the distance of 60 degrees it is reduced to one half. The centrifugal force of a rotating sphere is everywhere parallel to the plane of the equator; the components of this force at any point are: a force acting in opposition to gravity and a force at right angles to the same, having a tendency to move matter towards the equator. This is the case with the tides, for no sooner have they formed, in fact during their formation, they depart toward the equator.

To follow the recurring impulse upon the tides as they depart from their origin on their respective journeys must here be omitted for want of time, by comparing the cotidal lines on the chart with the moon's hour at the top and bottom of the chart, the effect can easily be traced.

In order to connect several other features of the tide with this tide-producing force, it will be necessary to define more closely the moon's position and the variable orbit which she pursues.

The moon's orbit is inclined to the plane of the ecliptic about $5\frac{1}{4}$ degrees so that her latitude cannot exceed this quantity, but the earth's equator is inclined 23° 26′ to the ecliptic, thence the moon's declinations will vary from 0 to 28° 40′ north and south of the equator. The maximum declinations also vary by twice the latitude by reason that the nodes of the orbit are not constant but have a retrogade motion so that the moon may occupy every possible position in a zone of 10° 40′. The declinations will be greatest when the line of nodes coincides with the equinoctial line, for here the earth's declination plus the moon's latitude will be the moon's declination. These maximum declinations coincide with the moon's quadratures at the equinoxes and with the syzygies at the solstices, and vary between these points in the interval.

We have seen how the moon assumes various positions from south to north of the equator in each revolution about the earth, and we will find that the oceans are differently affected during inferior from superior transits. For we will first suppose the moon in the plane of the equator which occurs at new and full moon in the equinox and in the quadratures at solstices. It is evident that the moon holds the same relative position to the sea under her as the lower transit does to the sea on the remote side, and the result is the same; but when we consider the moon in maximum north or south declinations then the conditions are entirely changed; the lower transit of north declination and upper of south decliation affect the sea further south than the upper north and lower south so that the results must be different for each pair. In order to illustrate, several tides of Cape Flattery on the Pacific coast are added to the sketch; these are sketched according to the reported observations of the U. S. coast survey.

The wave A 1 arrives arrives ahead of mean time after transit; B 1 is behind time; A 2 is separated one lunar day from A 1, and so on. These are the tides of max. decs. The tides A 1, A 2, etc., were formed by an upper transit with the moon at U, N. dec., or by a lower transit with the moon at L, S. decl., and the ocean at E will be affected alike by either; but since the line from the moon pierces the ocean north of the equator, the tide will be formed north of the mean origin and will come ahead of mean time. On the other hand, the tides B 1, B 2, etc., are formed by an upper transit with the moon at L, S. decl., or by a lower transit with the moon at U, N. decl., and the ocean at Q will also be affected equally by either; but since the line from the moon pierces the ocean south of the equator the tide will be formed south of the mean origin and will be behind time. The result is obvious; the wave B 1 being behind its proper place and the wave A 2 in advance, an overlapping takes place and the tides assume a mixed type. The tide travels by the rising of the water in front and the falling to the rear of the crest, hence the tide A in raising the rear slope of the tide B draws upon the volume and causes a degradation of the latter, the distance between B 1 and A 2 being greater than the mean interval, the

depression also becomes greater as the water which should belong to one is in part taken up by the other. If these intervals were not oscillating as they are; but continuous in pairs, the result would be the same as in inland lakes.

The highest spring tides should take place during the equinoxes when the oceans are affected alike for both upper and lower transits by the maximum force for several days in succession, but from four years careful observations I have found the mean rise and fall greatest during the five months, August to December inclusive; also the highest and lowest tides and maximum and minimum rise and fall from November to February inclusive.

The tides are known to rise higher as the moon approaches the earth. As the moon approaches, the common centre comes nearer the earth's centre and the centrifugal force increases as the moon's motion increases from its closer proximity, hence the tides increase. The tides on opposite sides, or corresponding to different transits of the moon, are practically alike when the moon is on the equator, now since the impulse on opposite sides is about as 500 to 900 the question will arise why the effect is not in proportion to the cause. As the pendulum will return nearly to the point from which it has fallen so these oscillations would also nearly repeat themselves, but since other waves approach to form the succeeding tide it is only necessary that the impulse should be repeated at the regular intervals necessary for equilibrium. There are those who deny the existence of the force at the side remote from the moon, but the inequality of the semidiurnal tides is sufficient to prove the existence of that force.

It has been stated that the force is nil at the moon's quadratures, then why any tides at these phases? The nil force exists but an instant and as before remarked, these oscillations will nearly repeat themselves even when they are changing with an increasing ratio as they change when approaching quadratures at the equinoxes, in fact Newton said, that when these oscillations were fairly established, the luminaries might be removed, and the tides would continue for an indefinite time. We also find that the effect does not immediately follow the cause, for the inverse order of tides does not take place for several days after change of

declination neither do the highest tides occur at full and change of the moon, nor the least tides in the quadratures.

A singular fact in nature, which is attributable to the tides, is the existence of the Sargossa seas in mid ocean. The tide in mid ocean is very small as has been ascertained at islands along the course of the tide. At the shores however, the tide is retarded and its range increased, so that the surface of the ocean is practically lower than its limits, forming a sort of settling basin whence the singular seas. A current chart by Bowditch shows a current from all directions towards the Sargossa sea in the Atlantic.

There is another question which arises and that is, why, if there is a primary tide in each of the southern oceans, there is not also the same in the northern oceans?

In the first place, the southern oceans are the largest and deepest and the effect produced upon them would preponderate over that produced on the smaller oceans. In the second place, the origin was not a matter of chance or choice but necessity, for as soon as the condensation of aqueous matter was sufficient to fill or to partly fill an oceanic basin, the tides began to move and as the oceans continued to increase, the motion was imparted to the increasing waters, the regularity of the impulse had the effect of producing the regular succession of tides of the oceans as the earth in its diurnal revolutions presented them successively to the tide producing force.

To sum up this investigation we have:

First. A primary tide in each of the southern oceans, and one in the Arctic ocean. These rise twice a day, and their appearance corresponds in time exactly with the moon's apparent motion. The semi-diurnal tides differ in magnitude with the moon's declination from the equator, showing that there is a tide force under the moon and also one on the remote side of the earth giving a tide following the inferior as well as the superior transit of the moon. The tides are greatest at the full and change and least at quadratures, and the range varies perceptibly with the distance of the moon.

Second. The moon revolves about the earth in an eliptical orbit, and by mutual attraction both revolve about a common

center. This common center is the point attracted by the sun and describes the orbit common to both bodies. The earth's center describes an undulating line, being part of the time within and part of the time without the common orbit. The common center is a variable point, on account of the variable attraction of the sun on the two bodies, and varies or fluctuates between the earth's center and the common center of gravity of the two bodies. The earth revolves about the common center with the same angular velocity that the moon revolves in her orbit.

The resulting eccentric motion of the earth begets a centrifugal force which coincides with the centrifugal force of the diurnal revolution only under and opposite to the moon in the plane passing through the moon. At other plates it tends only to deflect the line of gravity. When the common center coincides with the earth's center the force ceases, and is maximum when these points are at their greatest distance. When the moon approaches the earth her velocity increases, also the angular velocity about the common center, hence also the centrifugal force. This force tends also to move matter towards the equator in the plane of its activity.

From the foregoing argument the following is deduced as the cause of the tides:

In the first place it is evident that every phase and feature points direct to the moon as the cause of the phenomena, but in the next place the laws of nature show very clearly that the moon is only the implement by which the superior controlling force operates, the moon's efforts as the satellite of the earth being due to the sun's influence. The sun is therefore the prime cause operating in accordance with the grand principle discovered by the great Newton and announced to the world 193 years ago, the principle of UNIVERSAL GRAVITATION.