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581st ORDINARY GENERAL MEETING.

HELD IN COMMITTEE ROOM B, THE CENTRAL HALL, WESTMINSTER, ON MONDAY, JUNE 5th, 1916, AT 4.30 P.M.

COLONEL CHAS. EDWARD YATE, C.S.I., C.M.G., M.P. FOR THE MELTON DIVISION OF LEICESTERSHIRE, TOOK THE CHAIR.

The Minutes of the preceding Meeting were read and confirmed.

The SECRETARY announced the election of Miss Caroline J. Crawford and of Mrs. Marston as Associates of the Institute.

The SECRETARY read the following letter* from the Rt. Hon. the Secretary of State for War:—

"War Office, Whitehall, S.W.
3rd June, 1916.

"Lord Kitchener desires to thank Professor Hull for the card of invitation which he was so good as to send him, but regrets that his engagements will not permit of his being present at the Central Hall, Westminster, on Monday, the 5th instant, on the occasion of his lecture on 'The Tides.'

"Professor Edward Hull, M.A., LL.D., F.R.S."

The CHAIRMAN said that it gave him great pleasure to preside at a Meeting of the Victoria Institute, of which he had been at one time an Associate, until the pressure of other duties obliged him to retire. And it was an especial pleasure to preside on the occasion of a lecture by his old and valued friend, Professor Hull, whom he would now ask to address them on the subject of "The Tides."

THE TIDAL WAVE ON THE OFF SIDE OF THE EARTH FROM THE MOON. By Prof. EDWARD HULL, LL.D., F.R.S.

IT is remarkable that one of the most generally recognized of the physical phenomena belonging to our globe—that of the double tides—is still a subject under discussion, and that we may say of it "*tot homines quot sententiae.*" It is universally recognized that the tidal wave which visits our coasts twice in

* At the moment when this letter was read, Lord Kitchener had already started on his last voyage.

the twenty-four hours, is due to the attraction of the moon, augmented, under certain conditions, by that of the sun, by which the ocean waters are raised to a small extent above the normal level in the form of a wave which, owing to the rotation of the earth, moves along from east to west till, obstructed by some barrier of land thrown across its path, such as that of Africa or America, its course is deflected or destroyed. This elevatory force is applied within the plane of the Ecliptic, and has its maximum effect along a line drawn from the centre of the moon to that of the globe, but diminishes towards the great circle which has the moon at its pole where the force ultimately becomes tangential. Of the several great oceans on the Earth's surface, only one, the Pacific—as it covers nearly half the globe at the equator—offers sufficient expanse for the formation of a full tidal wave. The other oceans, such as the Atlantic and Indian, present insufficient surfaces towards the moon for the full development of the tidal wave; and still less does the Mediterranean, though both are influenced to some small extent.

Existing Theories.—The solution of the problem for the existence of a tidal wave on opposite sides of the globe has been often attempted, but with unsuccessful results, as admitted by writers themselves. The favourite theory, and one generally adopted, may thus be stated: "The attraction of the moon is strongest on the earth's surface next the moon, less at the centre, and less again on the parts beyond; so that the solid body of the earth, which is attracted as though it was condensed into its own centre, is more powerfully attracted than the ocean water on the off side from the moon, and is drawn away from the water."

A recent writer on this subject, Mr. J. A. Hardcastle, rejects the theory that "on the side towards the moon the water is drawn away from the earth, while on the other side the earth is drawn away from the water."*

The latest writer I have met with is Mr. Arthur R. Hinks, recently Chief Astronomical Assistant at Cambridge Observatory,† but he skips rather lightly over the subject of the double tides, and apparently does not accept any of the accepted theories, or give one by himself. He merely remarks that "the subject is

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* *Journ. Brit. Astron. Assoc.*, Dec., 1912, p. 141. Mr. Hardcastle's letter is misleading; for, although headed "Tide on the other side," it deals with "tide on this side," as the last paragraph of it shows.

† "Astronomy," *Home University Library*, p. 58.

complex and difficult; and that the well-known figure of high water under the moon, where the moon drags the water away from the earth, and another high water on the opposite side where the moon drags the earth away from the water, is responsible for not a little misconception." I entirely agree.

The last work to which I shall refer is by Sir George H. Darwin on *The Tides.** I had hoped that I should have here a clear and intelligible theory of the origin of the second tidal wave on the side opposite from the moon, but in this I have been disappointed. The cause of this may, I admit, lie with myself, but from the statement made on this subject by Mr. A. R. Hinks—who cannot have been ignorant of Darwin's investigations—I gather that he also was unable to accept his reasoning, otherwise he would have quoted him with approval. Darwin's reasoning is certainly obscure, and I venture to say incorrect, as he makes the moon's attraction to act in opposite directions on opposite sides of the earth at the same time. This I cannot admit.† Further references are unnecessary; and as there seems to be no generally recognized explanation available, this is my apology for offering one. Before proceeding further, I may here state explicitly that I do not consider the *direct* attraction of the moon to have any appreciable influence on the formation of the antipodal tide wave. This will appear in the sequel.

Proposed Solution of the Problem.—Let us take the simplest of possible representations of our globe—an orange. This fruit consists of an enclosing rind formed of a solid but flexible material resting on a semi-fluid interior. Squeeze the orange between the finger and thumb, with the result that the fruit will bulge outward at both the intermediate sides between the points of pressure. To compare small things with great is a favourite expression, and may be used in the present case if it can be shown that the lateral pressure on the orange has its counterpart in the lateral pressure exercised by the moon in the case of the globe, of which we must now consider the structure.

The Structure of the Globe.—The globe consists of a solid, but flexible, envelope called "the crust," of variable and unknown

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* Third edition (1911). The substance of lectures delivered in 1897, at the Lowell Institute, Boston.

† The reader is referred to chapter 5, p. 94, on "The tide generating force," and figs. 22 and 23, pp. 103 and 108. Darwin's views are repeated in the *Encyclopædia Britannica*, 11th edition, article "Tides," with great elaboration.

thickness, ultimately resting on a semi-fluid interior of lava, rock in a molten condition due to heat, such as is erupted from volcanoes in action. That this is the condition of the interior immediately under the crust may be inferred from experiments carried out over large portions of the land areas, which go to show that the temperature increases with the depth at an average rate of about 1° Fahr. for every 60 feet of depth. These experiments only reach to about 3,500 feet from the "invariable stratum," only a short distance downwards.* There is no indication that the temperature tends to decrease as the depth increases, and the molten condition of liquid lava extruded from great depths by volcanic action indicates the contrary. We may feel confident that the mass of matter enveloping the centre of the globe nearly retains the temperature of its original condition owing to the exceedingly slow radiation of heat from the surface.

With a continuance of this increasing heat a depth must be eventually reached at which there will be a temperature equal to that of rock fusion at the surface: though the pressure at those depths may affect the conditions of fluidity tending to the solidity of the crust. Taking the rate of increase at 1° Fahr. for every 60 feet below the invariable stratum, the following will be the heat at various depths :—†

Depth.		*Temperature.*	
50 feet	...	50° Fahr.	
1,000 „	...	63° „	
4,000 „	...	116° „	
7,826 „	...	212° „	Boiling point of water.
34,752 „	...	773° „	Critical point of water.
150,000 „	...	3,174° „	Approximate fusion point of rocks.

the last case, about 28 miles, being the minimum thickness of the crust.

Assuming this to be the composition of the globe, it is clear that it can give way to lateral pressure exerted at opposite

* The invariable stratum is the depth of the annual mean temperature of the locality—a few feet from the surface.

† Prestwich, *Geology, Chemical, Physical and Stratigraphical*, vol. ii, p. 537. The question of a solid mobile crust resting on a viscous interior of molten matter due to heat, is ably dealt with, and is one I myself hold strongly in opposition to the theory of a solid interior.

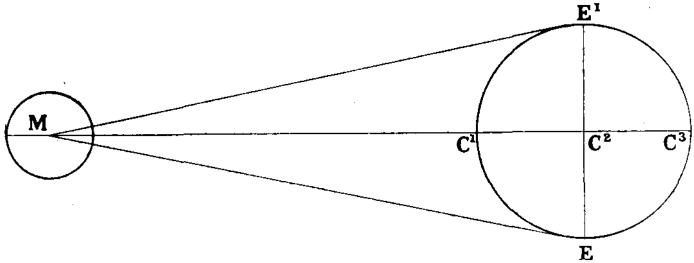
points of the surface where it will yield, while causing the intermediate areas to bulge out from the normal form; and that this is the case can be shown from a consideration of the moon's action on the side of the earth immediately opposed to it.

If we draw a line from the centre of the moon to that of the earth we have the position of maximum attraction between the two bodies; but the attraction of the moon extends over the whole of the side of the globe presented to it.

Proposed Solution of the Problem.—Assuming the earth to consist of a solid, but flexible, envelope of a minimum thickness of 28 miles, but which owing to gravitation may be twice this amount, enclosing a molten or viscous mass of matter due to primeval heat, and revolving on an axis with a velocity of a thousand miles an hour at the equator.

The effect of attraction of the moon on the globe will be greatest in a line joining the centre of the former with that of the latter—a distance of 240,000 miles—and whatever may be its force at the surface of the earth directly opposite to it along this line it will be less at the centre of the globe, according to the Newtonian law of "inversely as the square of the distance." Both the moon and the globe are mutually attracting each other; but as the latter is much larger than the former the centre of gravity of the joint system will not be the centre of the globe, but in a position between the centre and edge of the globe itself. This is of little consequence to my argument. According to the Newtonian law, the attractive force of the moon will be decreased at the off side of the globe as compared with that at the centre, and the attraction at the centre again will be less than at the surface immediately under the moon. But, beside the force of the moon's attraction on that part of the globe directly opposite to itself, its force is spread over the entire hemisphere, decreasing with the distance from the central axis in all directions towards the great circle which has the moon at its pole. At that circle a portion of the moon's attraction acts as a lateral pressure directed from opposite sides towards the centre of the earth. It is this lateral pressure which (as I contend) produces the second (or antipodal) bulging, resulting in the tidal wave on the off side of the globe from the moon.

This lateral pressure affects the whole mass of the globe, and necessarily produces a bulging of the surface over the region intermediate between the regions of pressure. As the whole of the interior mass which I infer, on grounds already stated, to be in a fluid or viscous condition, is in continuous contact, there is no other way in which the displaced lateral matter can remain in a state of equilibrium. Where water occupies the surface, the effect is to produce, on both sides, a wave following the course of the moon, owing to the rotation of the earth once every 24 hours, which has its fullest development when the great Pacific is the scene of operations. But the bulging due to compression also necessarily adds to the magnitude of the tidal wave directly opposite the moon. These conditions may be illustrated by the annexed figure. (*See* diagram.)



Let M be the centre of the Moon and C^2 the centre of the Earth. By joining these the line MC^2 traverses the surface of the Earth at C^1, and, if prolonged, the antipodal surface at C^3. The attraction of the Moon is greatest along this line, and least at E and E^1, where the tangents to the Earth's surface from M meet it. The triangle MEE^1, which represents the forces of attraction to the Moon's centre, may be resolved into two triangles MC^2E and MC^2E^1. In MC^2E the line EC^2 represents the component of the Moon's attraction that acts towards the centre of the Earth ; and similarly E^1C^2 in the triangle MC^2E^1. The action of the Moon's attraction at E and E^1 has in part, therefore, a compressing effect upon the surface of the Earth, producing bulging at C^1 and C^3, as already explained. These bulgings produce on oceanic waters a tidal wave at C^3 and augment the direct tidal wave at C^1.

Now, I wish to protest most sincerely that I have no intention of contesting the theories of professed astronomers, who may naturally hesitate to accept my views. On the contrary, I hold that this problem of the antitidal wave may not be inconsistent with theirs. You will observe that my own branch of science, Geology, is here specially called into service, and I venture to call this paper "A Geological Theory of the Tidal Wave on the Off Side of the Moon," and I may add that outside the "astronomic group" of scientists I have found supporters for my views.

The LECTURER here asked for a few minutes' indulgence, as his voice was far from strong. His son, Dr. E. G. HULL, read some notes on the same subject during the interval, and Colonel YATE having been called away by his Parliamentary duties, Lieut.-Colonel G. MACKINLAY succeeded him in the Chair.

The LECTURER then exhibited a number of slides illustrating the form of the cotidal lines round the British Isles.

DISCUSSION.

Colonel MACKINLAY (as Chairman) said that he had not been quite able to follow the first part of Professor Hull's lecture, and saw no reason for giving up the usual explanation of the antipodal tide; namely, that the moon, acting upon the waters of the ocean, attracted those on the nearer side somewhat more strongly than it attracted the earth as a whole, so that the waters on that side were heaped up towards the moon; while its attraction on the waters on the far side being less than on the earth, those waters were, in effect, left behind. He found the second part of Professor Hull's lecture very interesting, and especially his description of the troubled state of the waters where the co-tidal waves round the British Isles meet each other.

Mr. MAUNDER said that the subject with which Professor Hull had dealt was interesting to all. But he could not agree with the Lecturer that there were many divergent theories as to the cause of the tides. The Newtonian law of gravitation held good, and the main cause of the tides was the attraction of the moon. But the working out of the details of tidal movements was very complex, as those who had seen Lord Kelvin's tide machine would quite appreciate. The differences between various writers upon the subject had been differences as to the method that should be adopted in order to give the young student or general reader an idea of the actual effect upon the waters of the moon's attraction that should be at one and the same time readily intelligible and sufficiently full and sound.

Professor Hull, if he had correctly followed him, had taken up a point which had sometimes been omitted from these popular explanations. Referring to the diagram, Professor Hull had shown that the action of the moon at the point E might be resolved into two forces, EC^2 and C^2M, of which EC^2 was directed towards the centre of the earth, and C^2M towards the centre of the moon. Similarly with E^1. It was clear, therefore, that part of the effect of the moon's attraction at E and at E^1 must tend to produce a low tide at those points, and therefore a high tide at the intermediate points; not only at C^1 but also at C^3. The problem, however, might be considered, as Mr. J. A. Hardcastle had done in his papers read before the British Astronomical Association, as one of water moving forward in response to the moon's attraction, rather than as one of water directly raised or depressed by it.

The Rev. JOHN TUCKWELL said that Lord Kelvin had stated that unless the earth were more rigid than a cannon ball, it would bulge more at the equator than was found to be actually the case. He regarded the earth as a body that had been rendered solid by the immense pressure.

After some questions and remarks from Colonel ALVES, Professor LANGHORNE ORCHARD and others, a vote of thanks was passed by the Meeting to the Lecturer, who in acknowledging it again pointed out that the moon would cause a lateral pressure on the earth at the points lettered E and E^1 on the diagram.

The Meeting adjourned at 6.15 p.m.