ter, gigging is alternated a number of times with shearing, for the purpose of giving a thick or dense nap. Shearing at this stage of manufacture is called "cropping," a process of clipping off the nap to allow the teasels to get more into the goods so as to produce a thick bottom to the nap. The lustrous appearance of what are termed "faced goods," such as doeskins, broadcloths, etc., though not a little attributable to gigging, is due more particularly to boiling the fabrics in water for many hours. The accomplishment of this process is to tightly roll the fabrics on wooden rolls and place them in a large wooden kettle filled with water which is brought to a boiling point, and so sustained for a period of hours. After gigging, the cloth is dried, either on a machine where the heat is derived from steam, or on "tenter-bars" located out of doors and exposed to the rays of the sun.

Tenter-bars are of a framework construction so contrived as to stretch the cloth to the proper width by means of tenter-hooks, right-angled hooks, like this one, and there held till it is fully dried. Next, the cloth is brushed by means of one or two rotary brushes, or it passes at once to the "finishing" shear, a machine which cuts the nap to its proper length. The shearing machine requires the most careful handling of any machine in the finishing department. All its adjustments should be very exact. The best discerning judgment of the department has to be employed on it. The principal parts of the machine are the "cylinder," which consists of a helicoidal arrangement of a number of blades, and the "ledger-blade," which is a flat piece of steel brought to a very keen edge. The ledger-blade is brought in contact with the cylinder almost at a tangent. The former is stationary, while the latter is made to revolve at the great speed of about one thousand turns a minute. These two together do the cutting. This process is followed by light brushing, with perhaps a gentle steaming, on the same principle as that resorted to in the laundry before ironing, for after brushing, the cloth is put through an operation of hot pressing which has the same effect as ironing in the laundry. From the press the cloth is either rolled or folded ready for packing preparatory for the market.—*Bulletin Wool Manufacturers' Association.*

AUTOMATIC TROUGH FLUSHING CLOSET.

THE necessity for an efficient automatic flushing closet has long been felt, and we believe that in the form introduced by Messrs. M. J. & S. H. Adams, of Leeds, this want is met.

The trough is made of the best fireclay, or is supplied in iron, to which a specially high glaze is given, both internally and externally.

It is readily fixed by any workman. It is so constructed that the full length is utilized for seats, none being wasted by the valve-chamber as in the ordinary trough flushing closet.

When waste water from yard sinks, slop water, etc., is led into the trough, only a very limited amount (if any) of other water is required for use in the after-flushing; where no such connections are made, the closet works with the amount of water usually allowed for such purposes by water companies (this being regulated by a plain ball-tap, unless otherwise ordered). The trough, when ready, discharges its contents by means of the patent siphon, which is fully charged on the instant. The siphon is equal to a four inch pipe, and will therefore carry off all matter without the fear of choking. The closet will work without attention for an unlimited time. It may be built to any length. The cross section given herewith shows the construction.—*Building News.*

THE TIDES AND THE LENGTHENING DAY.*

By Professor ROBERT S. BALL, LL.D., F.R.S.

THE cause of the ebb and flow of the tides has long ceased to be a mystery. In the earliest times it was noticed that the tides were connected with the moon. Pliny and Aristotle both refer to the alliance between the tides and the age of the moon. For many centuries, perhaps, indeed, for thousands of years, observant men might have known that the moon and the tides were connected. But they did not know any reason why this connection should exist. I dare say they did not even know whether the moon was the cause of the tides or the tides the cause of the moon.

Nor is it easy to explain the tides. We were all taught that the moon makes the tides. Yet I can imagine an objector to say: "If the moon makes the tides, why does it give Bristol a splendid tide of forty feet, while London is put off with only eighteen?" The true answer is that the height of the tide is largely affected by local circumstances, by the outline of the coasts, by estuaries and channels. It is even affected to some extent by the wind. Into such details, however, I do not now enter; all I require is that you shall admit that the moon causes the tides, and that the tides cause currents.

Though we have not yet put the tides into harness, yet tides are not idle. Work they will do, whether useful or not. In some places the tidal currents are scouring out the river channels; in others they are moving sand banks. From a scientific point of view the work done by the tides is of unspeakable importance. To realize the importance, let us ask the question, Whence is this energy derived with which the tides do their work? The tidal wave produced by the moon is the means whereby a part of the energy stored in the earth is compelled to expend itself in work. I do not say this is an obvious result. Indeed it depends upon a refined dynamical theorem, which it would be impossible to enter into here.

* Abstract of a lecture delivered at the Midland Institute, Birmingham, England.

But what do we mean by taking energy from the earth? Let me illustrate this by a comparison between the earth rotating on its axis and the fly-wheel of an engine. The fly-wheel is a sort of reservoir, into which the engine pours its power at each stroke of the piston. The various machines in the mill merely draw off the power from the store accumulated in the fly-wheel. The earth is like a gigantic fly-wheel detached from the engine, though still connected with the machines in the mill. In that mighty fly-wheel a stupendous quantity of energy is stored up, and a stupendous quantity of energy would be given out before that fly-wheel would come to rest. The earth's rotation is the reservoir from whence the tides draw the energy they require for doing work. Hence it is that though the tides are caused by the moon, yet whenever they require energy they draw on the supply ready to hand in the rotation of the earth.

The earth differs from the fly-wheel of the engine in a very important point. As the energy is withdrawn from the fly-wheel by the machines in the mill, so it is restored thereto by the power of the steam engine, and the fly runs uniformly. But the earth is merely the fly-wheel without the engine. When the work done by the tides withdraws energy from the earth, that energy is never restored. It therefore follows that the energy of the earth's rotation must be decreasing. This leads to a consequence of the most wonderful importance. It tells us that the speed with which the earth rotates on its axis is diminishing. We can state the result in a manner which has the merits of simplicity and brevity.

"The tides are increasing the length of the day."

This statement is the text of the discourse which I am to give you this evening. From this simple fact the new and wondrous theory of tidal evolution is deduced.

At present no doubt the effect of the tides in changing the length of the day is very small. A day now is not appreciably longer than a day a hundred years ago. Even in a thousand years the change in the length of the day is only a fraction of a second. But the importance arises from the fact that the change, slow though it is, lies always in one direction. The day is continually increasing. In millions of years the accumulated effect becomes not only appreciable but even of startling magnitude.

The change in the length of the day must involve a corresponding change in the motion of the moon. This is by no means obvious. It depends upon an elaborate mathematical theorem. I cannot attempt to prove this for you, but I think I can state the result so that it can be understood without the proof. If the moon acts on the earth and retards the rotation of the earth, so, conversely, does the earth react upon the moon. The earth is tormented by the moon, so it strives to drive away its persecutor. At present the moon revolves round the earth at a distance of about 240,000 miles. The reaction of the earth tends to increase that distance, and to force the moon to revolve in an orbit which is continually getting larger and larger.

Here then we have two remarkable consequences of the tides which are inseparably connected. Remember also that we are not enunciating any mere speculative doctrine. These results are the inevitable consequences of the tides. If the earth had no seas or oceans, no lakes or rivers; if it were an absolutely rigid solid throughout its entire mass, then these changes could not take place. The length of the day would never alter, and the distance of the moon would only fluctuate between narrow limits.

As thousands of years roll on, the length of the day increases second by second, and the distance of the moon increases mile by mile. These changes are never reversed. It is the old story of the perpetual dropping. As the perpetual dropping wears away the stone, so the perpetual action of the tides has sculptured out the earth and moon. Still the action of the tides continues. To-day is longer than yesterday; yesterday is longer than the day before. A million years ago the day probably contained some minutes less than our present day of twenty-four hours. Our retrospect does not halt here; we at once project our view back to an incredibly remote epoch which was a crisis in the history of our system.

Let me say at once that there is great uncertainty about the date of that crisis. It must have been at least 50,000,000 years ago. It may have been very much earlier. This crisis was the interesting occasion when the moon was born. I wish I could chronicle the event with perfect accuracy, but I cannot be sure of anything except that it was more than 50,000,000 years ago.

At the critical epoch to which our retrospect extends, the length of the day was only a very few hours. I cannot tell you exactly how many hours. It seems, however, to have been more than two and less than four. If we call it three hours we shall not be far from the truth. Perhaps you may think that if we looked back to a still earlier epoch, the day would become still less and finally disappear altogether! This is, however, not the case. The day can never have been much less than three hours in the present order of things. Everybody knows that the earth is not a sphere, but that there is a protuberance at the equator, so that, as our school books tell us, the earth is shaped like an orange. It is well known that this protuberance is due to the rotation of the earth on its axis, by which the equatorial parts bulge out by centrifugal force. The quicker the earth rotates the greater is the protuberance. If, however, the rate of rotation exceeds a certain limit the equatorial portions of the earth could no longer cling together. The attraction which unites them would be overcome by centrifugal force and a general break up would occur. It can be shown that the rotation of the earth when on the point of rupture corresponds to a length of the day somewhere about the critical value of three hours, which we have already adopted. It is therefore impossible for us to suppose a day much shorter than three hours. What occurred prior to this I do not here discuss.

Let us leave the earth for a few minutes, and examine the past history of the moon. We have seen the moon revolves around the earth in an ever-widening orbit, and consequently the moon must in ancient times have been nearer the earth than it is now. No doubt the change is slow. There is not much difference between the orbit of the moon a thousand years ago and the orbit in which the moon is now moving.

But when we rise to millions of years the difference becomes very appreciable. Thirty or forty millions of years ago the moon was much closer to the earth than it is at present; very possibly the moon was then only half its present distance. We must, however, look still earlier, to a certain epoch not less than fifty millions of years ago. At that epoch the moon must have been so close to the earth that the two bodies were almost touching.

Everybody knows that the moon revolves now around the earth in a period of twenty-seven days. The period depends upon the distance between the earth and the moon. The time and the distance are connected together by one of Kep-

ler's celebrated laws, so that, as the distance shortens, so must the time of revolution shorten. In earlier times the month must have been shorter than our present month. Some millions of years ago the moon completed its journey in a week instead of taking twenty-eight days, as at present. Looking back earlier still, we find the month has dwindled down to a day, then down to a few hours, until at that wondrous epoch when the moon was almost touching the earth, the moon spun round the earth once every three hours.

We have hitherto been guided by the unerring light of dynamics, but at this momentous epoch dynamics deserts us, and we have only probability to guide our faltering steps. One hint, however, dynamics does give. It reminds us that a rotation once in three hours is very close to the quickest rotation which the earth could have without falling to pieces. As the earth was thus predisposed to rupture, it is of extreme interest to observe that a cause tending to precipitate such a rupture was then ready to hand. It seems not unlikely that we are indebted to the sun as the occasion by which the moon was fractured off from the earth and assumed the dignity of an independent body. It must be remembered that the sun produces tides in the earth as well as the moon, but the solar tides are so small compared with the lunar tides, that we have hitherto been enabled to neglect them. There could, however, have been no lunar tides before the moon existed, and consequently in the early ages before the moon was detached, the earth was disturbed by the solar tides, and by the solar tides alone.

The primeval earth thus rose and fell under the tidal action of the sun. Probably there were no oceans then on the earth; but tides do not require oceans or even water for their operation. The primitive tides were manifested as throbs in the actual body of the earth itself, which was then in a more or less fluid condition. Even at this moment, bodily tides are disturbing the solid earth beneath our feet; but these tides are now so small as to be imperceptible when compared with the oceanic tides.

At the remote epoch of which we are speaking the solar tides were very small, as they are at present. Yet, small as they are, there was a particular circumstance which may have enormously increased their importance. The point to which I refer can be illustrated very simply. We have here a weight of fourteen pounds freely suspended, and here I have a small wooden mallet which barely weighs half an ounce, yet, small as this mallet is, I can make the heavy weight swing by merely giving it blows with the mallet. Let me try. I give the weight blow after blow. I hit it as hard as I can, yet the weight hardly swings. I have not yet been successful. The art of succeeding is merely to time the blows properly; this I am now doing, and you see the weight swings in an arc which is steadily augmenting.

We therefore see that a succession of impulses, in themselves small, can yet produce a great effect when they are properly timed. In the present case the impulses should succeed each other at the same interval as this pendulum requires for one to-and-fro oscillation. The time therefore depends on the body struck, and not at all on the body which gives the impulses.

Just as this pendulum swings with a definite period, so the vibrations of the primeval earth had a certain period appropriate to them. Suppose that the liquid primeval globe were pressed in on two quadrants and drawn out on the two others, and that the pressures were then released. The globe would attempt to regain its original form, but this it could not do at once, any more than the pendulum can at once regain its vertical position; the protruded portions would go in, but they would overshoot the mark, and the globe would thus oscillate to and fro. Now it has been shown that the period of such oscillations in our primitive globe is about an hour and a half, or very close to half the supposed length of the day at that time. The solar tides, however, also have a period half the length of the day. Here then we have a case precisely analogous to the fourteen-pound weight I have just experimented on. We have a succession of small impulses given which are timed to harmonize with the natural vibrations. Just as the small timed impulses raised a large vibration in the weight, so the small solar tides on the earth threw the earth into a large vibration. At first these vibrations were small, but at each succeeding impulse the amplitude was augmented, until at length the cohesion of the molten matter could no longer resist; a separation took place; one portion consolidated to form our present earth; the other portion consolidated to form the moon.

There is no doubt whatever that the moon was once quite close to the earth; but we have to speculate as to what brought the moon into that position. I have given you what I believe to be the most reasonable explanation, and I commend it to your attention. There are difficulties about it, no doubt; let me glance at one of them.

I can easily imagine an objector to say: "If the moon were merely a fragment torn off, how can we conceive that it should have that beautiful globular form which we now see? Ought not the moon to have rugged corners and an irregular shape? and ought not the earth to show a frightful scar at the spot where so large a portion of its mass was rent off?"

You must remember that in those early times the earth was not the rigid solid mass on which we now stand. The earth was then so hot as to be partially soft, if not actually molten. If then a fragment were detached from the earth, that fragment would be a soft yielding mass. Not for long would that fragment retain an irregular form; the mutual attraction of the particles would draw the mass together. By the same gentle ministrations the wound on the earth would soon be healed. In the lapse of time the earth would become as whole as ever, and at last it would not retain even a scar to testify to the mighty catastrophe.

I am quite sure that in so large and so cultivated an audience as that which I am now addressing, there are many persons who take a deep interest in the great science of geology. I believe, however, that the geologist who had studied all the text books in existence might still be unacquainted with the very modern researches which I am attempting to set forth. Yet it seems to me that the geologists must quickly take heed of these researches. They have the most startling and important bearing on the prevailing creeds in geology. One of the principal creeds they absolutely demolish.

I suppose the most read book that has ever been written on geology is Sir Charles Lyell's "Principles." The feature which characterizes Lyell's work is expressed in the title of the book, "Modern Changes of the Earth and its Inhabitants Considered as Illustrative of Geology." Lyell shows how the changes now going on in the earth have in course of time produced great effects. He points out triumphantly that there is no need of supposing mighty deluges and frightful earthquakes to account for the main facts of geology.

Lyell attempts to show that the present action of winds

and storms, of rains and rivers, of ice and snow, of waves and tides, will account for the formation of strata, and that the gentle oscillations of the earth's crust will explain the varying distribution of land and water. In this we can to a great extent follow him. I am quite satisfied with the oscillations in the land. If the land rises an inch or two every century in one place and falls to the same extent elsewhere, all that is required has been explained. Nor do I feel at present disposed to question his views as to rivers or to glaciers, to rains or to winds. There is, however, one great natural agent of which Lyell does not take adequate account. He does not attach enough importance to the tides. No doubt he admits that the tides do some geological work. He even thinks they can do a great deal of work. The sea batters the cliffs on the coasts, and wears them into sand and pebbles. The glaciers grind down the mountains, the rains and frosts wear the land into mud, and rivers carry that mud into the sea. In the calm depths of ocean this mud subsides to the bottom; it becomes consolidated into rocks; in the course of time these rocks again become raised to form the dry land with which we are acquainted.

The tides, says Lyell, help in this work. Tidal currents aid in carrying the mud out to sea; they aid to a considerable extent in the actual work of degradation, and thus contribute their quota to the manufacture of stratified rocks. Such is the modest *role* which Lyell has assigned to the tides, and no doubt the majority of geologists have acquiesced in this doctrine. Nor can there be any doubt that this is a just view of tidal action at present. That it is a just view of tidal action in past times is what I now deny. Lyell did not know—Lyell could not have known—that our tides are but the feeble surviving ripples of mighty tides with which our oceans once pulsed. Introduce these mighty tides among our geological agents, and see how waves and storms, rivers and glaciers, will hide their diminished heads.

I must attempt to illustrate this view of tidal importance in ancient geological times. Let me try by the aid of the tides to explain the great difficulty which every one must have felt in regard to Lyell's theory. I allude to the stupendous thickness of the Paleozoic rocks.

Look back through the corridors of time in the manner in which they are presented to us in the successive epochs of geology. We pass rapidly over the brief career of prehistoric man; then through the long ages of tertiary rocks, when the great mammals were developed; back again to the much earlier period when colossal reptiles and birds were the chief inhabitants of the earth; back again to those still earlier ages when the luxuriant forests flourished that have given birth to the coal fields; back once more to the age of fishes; back finally to those earliest periods when the lowest forms of life began to dawn in the paleozoic era.

As we date remote ages astronomically by the distance of the moon, so we date remote ages geologically by the prevailing organic life. It is a great desideratum to harmonize these two chronological systems, and to find out, if possible, what lunar distance corresponds to each geological epoch. In the whole field of natural science there is no more noble problem. Take, for example, that earliest and most interesting epoch when life perhaps commenced on the earth, and when stratified rocks were deposited five or ten miles thick, which seem to have contained no living forms higher than the humble eozone, if even that were an organized being. Let us ask what the distance of the moon was at the time when those stupendous beds of sediment were deposited in the primeval ocean. We have in this comparison every element of uncertainty except one. The exception is, however, all important. We know that the moon must have been nearer to the earth than it is at present. There are many very weighty reasons for supposing that the moon must have been very much nearer than it is now. It is not at all unlikely that the moon may then have been situated at only a small fraction of its present distance. My argument is only modified, but not destroyed, whatever fraction we may take. We must take some estimate for the purpose of illustration. I have had considerable doubts what estimate to adopt. I am desirous of making my argument strong enough, but I do not want to make it seem exaggerated. At present the moon is two hundred and forty thousand miles away; but there was a time when the moon was only one-sixth part of this, or say forty thousand miles away. That time must have corresponded to some geological epoch. It may have been earlier than the time when the eozone lived. It is more likely to have been later. I want to point out that when the moon was only forty thousand miles away, we had in it a geological engine of transcendent power.

On the primitive oceans the moon raised tides as it does at present; but the forty-thousand-mile moon was a far more efficient tide producer than our two-hundred-and-forty-thousand-mile moon. The nearer the moon the greater the tide. To express the relation accurately, we say that the efficiency of the moon in producing tides varies inversely as the cube of its distance. Here then we have the means of calculating the tidal efficiency for any moon distance. The forty-thousand-mile moon being at a distance of only one-sixth of our present moon's distance, its tidal efficiency would be increased $6 \times 6 \times 6$ fold. In other words, when our moon was only forty thousand miles away, it was two hundred and sixteen times as good a tide producer as it is at present.

The height to which the tides rise and fall is so profoundly modified by the coasts and by the depth of the sea, that at present we find at different localities tides of only a few inches and tides of sixty or seventy feet. In ancient times there were no doubt also great varieties in the tidal heights owing to local circumstances. To continue our calculation, we must take some present tide. Let us discard the extremes just indicated and take a moderate tide of three feet rise and three feet fall as a type of our present tides. On this supposition what is to be a typical example of a tide raised by the forty-thousand-mile moon? If the present tides be three feet, and if the early tides be two hundred and sixteen times their present amount, then it is plain that the ancient tides must have been six hundred and forty-eight feet.

There can be no doubt that in ancient times tides of this amount and even tides very much larger must have occurred. I ask the geologists to take account of these facts, and to consider the effect—a tidal rise and fall of 648 feet twice every day.

These mighty tides are the gift which astronomers have now made to the working machinery of the geologist. They constitute an engine of terrific power to aid in the great work of geology. What would the puny efforts of water in other ways accomplish when compared with these majestic tides and the great currents they produce?

In the great primeval tides will probably be found the explanation of what has long been a reproach to geology. The early paleozoic rocks form a stupendous mass of ocean-made beds which, according to Professor Williamson, are twenty miles thick up to the top of the silurian beds. It

has long been a difficulty to conceive how such a gigantic quantity of material could have been ground up and deposited at the bottom of the sea. The geologists said: "The rivers and other agents of the present day will do it if you give them time enough." But unfortunately the mathematicians and the natural philosophers would not give them time enough, and they ordered the geologists to "hurry up their phenomena." The mathematicians had other reasons for believing that the earth could not have been so old as the geologists demanded. Now, however, the mathematicians have discovered the new and stupendous tidal grinding-engine. With this powerful aid the geologists can get through their work in a reasonable period of time, and the geologists and the mathematicians may be reconciled.

I have here a large globe to represent the earth, and a small globe suspended by a string to represent the moon. At the commencement of the history the two globes were quite close; they were revolving rapidly, and the moon was constantly over the same locality on the primeval earth. I do not know where that locality was; it was probably the part of the earth from which the moon had been detached. No doubt it was somewhere near the equator, but the distinction of land and water had not then arisen. Around the primeval earth the moon revolved in three hours; the earth also revolved in three hours, so that the moon constantly remained over the red region. This I can illustrate by holding the small globe which represents the moon in one hand, and making the large globe, which represents the earth, revolve by the other.

This state of things formed what is known as unstable dynamical equilibrium. It could not last. Either the moon must fall back again on the earth, and be reabsorbed into its mass, or the moon must commence to move away from the earth. Which of these two courses was the moon to take? The case is analogous to that of a needle balanced on its point. The needle must fall some way, but what is to decide whether it shall fall to the right or to the left? I do not know what decided the moon, but what the decision was is perfectly plain. The fact that the moon exists shows that it did not return to the earth, but that the moon adopted the other course, and commenced its outward journey.

As the moon recedes, the period which it requires for a journey round the earth increases also. Initially that period was but three hours, and it has increased up until our present month of 656 hours.

The rotation of the earth has been modified by the retreat of the moon. Directly the moon began to retreat the earth was no longer under an obligation to keep the same face thereto. When the moon was at a certain distance the earth made two rotations for every revolution that the moon made. Thus as I carry the small globe round the large globe the latter makes two revolutions for one revolution of the small globe. Still the moon gets further and further away, until the earth performs three, four, or more rotations for each of the moon's revolutions. Do not infer that the rate of the earth's rotation is increasing; the contrary is the fact. The earth's rotation is getting slower, and so is that of the moon; but the retardation of the moon is much greater than that of the earth. Even though the rotation of the earth is much more than the primitive three hours, yet that of the moon has increased to several times the rotation of the earth.

The moon recedes still further and further, and at length a noticeable epoch is reached, to which I must call attention. At that epoch the moon is so far out that its revolution takes twenty-nine times as long as the rotation of the earth. The month was then twenty-nine times the day. The duration of the day was less than the present twenty-four hours, but I do not believe it was very much less. The time we are speaking of is not very remote, perhaps only a very few million years ago. The month was then in the zenith of its glory. The month was never twenty-nine times as long as the day before. It has never been twenty-nine times as long as the day since. It will never be twenty-nine times as long as the day again.

Resuming our history, we find the moon still continuing to revolve in an ever-widening circle, the length of the month and of the day both increasing. The ratio of the day to the month was still undergoing a change. When the moon was a little further off the earth only revolved twenty-eight times instead of twenty-nine times in one revolution of the moon. Still the velocity of the earth abates until it only makes twenty-seven revolutions in one revolution of the moon. This is an epoch of special interest, for it is the present time. In the present order of things the moon revolves round the earth once while the earth rotates twenty-seven times. This has remained sensibly true for thousands of years, and no doubt will remain sensibly true for thousands of years to come, but it will not remain true indefinitely. Wondrous as are the changes which have occurred in times past, not less wondrous are the changes which are to occur in time to come. The tides have guided our gropings into the past; they will continue to guide our researches to make a forecast of the future.

Further and further will the moon retreat, and more and more slowly will the earth revolve. But we shall not pause at intervening stages; we shall try to sketch the ultimate type to which our system tends. In the dim future, many millions of years distant, the final stage will be approached. As this stage draws nigh, the rotation of the earth will again approach to equality with the revolution of the moon. From the present month of twenty-seven days we shall pass to a month of twenty-six days, of twenty-five days, and so on, until eventually we shall reach a month of two days, and lastly a month of one day. When this state has been attained the earth will constantly turn the same region toward the moon. I do not know what is the locality on the earth which is destined for this distinction.

Here you see that the first state and the last state of the earth-moon history are in one sense identical. In each case the same face of the earth is constantly directed toward the moon. In another way, how different are the first stage and the last! At the beginning the day and the month were both equal, and they were each three hours. At the end the day and the month will be again equal, but they will each be 1,400 hours. The moon will then go round the earth in 1,400 hours, while the earth will rotate on its axis in the same time. In other words, the day is destined in the very remote future to become as long as fifty-seven of our days. This epoch will assuredly come if the universe lasts long enough. When it has come it will endure for countless ages. It would endure for ever if the earth and the moon could be isolated from all external interference.

Our remote posterity will have a night 700 hours long, and when the sun rises in the morning 700 hours more will elapse before he can set. This they will find a most suitable and agreeable arrangement. They will look back on our short periods of rest and short periods of work with mingled curi-

osity and pity. Perhaps they will even have exhibitions of eccentric individuals able to sleep for eight hours, work for eight hours, and play for eight hours. They will look on such curiosities in the same way as we look on the man who undertakes to walk a thousand miles in a thousand hours.

For an overwhelming proof of tidal efficiency I shall summon the heavens themselves to witness, and I shall point to the stupendous task which tides have already accomplished. As the moon has made and is making tides on the earth, so the earth once raised tides on the moon. These tides have ceased for ages; their work is done; but they have raised a monument in the moon to testify to the tidal sufferings which the moon has undergone. To that monument I now confidently appeal. The moon being much smaller than the earth, the tides on the moon produced by the earth must have been many times as great as the tides on our earth produced by the moon. It matters not that the moon now contains no liquid ocean. Nor does it matter whether the moon ever had a liquid ocean. In very ancient days the moon was hot the hard, rigid mass which it now appears. Time was when the volcanoes raged on the moon with a fury which nothing on our earth at present can parallel. The moon was then in a soft or a more or less fluid condition, and in this viscous mass the earth produced great tides.

Great tides in truth they were, for the earth is eighty times as heavy as the moon. On the other hand, the moon is only one-fourth the diameter of the earth; so that the actual height of the tides on the moon would be still many times as great as the tides on the earth. When the moon was nearer to us, as it was in early ages, those tides were still greater. Think for one moment of what a lunar tidal wave of such magnitude would be capable. This wave is perhaps of molten lava; it would tear over the surface with terrific power, and anything that friction could accomplish that great current would do. That tidal current has done its work; even if the moon were fluid at the present day it could no longer be distracted by tides. Remember, it is not the mere presence of the tide which produces friction. It is the action of the tide in rising and in falling which accomplishes the work. If, therefore, the moon moved so that it was always high tide at the same place, the tides could produce no further effect. The spot where the tide is high on the moon is the spot which is toward the earth. It hence follows that the action of the tides will cease when the moon constantly directs the same face to the earth. The moon has thus at length gained a haven of rest from a tidal point of view. No doubt the moon has a high tide and it has a low tide, but those tides no longer ebb and flow: The moon has succumbed to the incessant action of friction, and has assumed the only attitude which can relieve it from incessant disturbance.

For many centuries it had been an enigma to astronomers why the moon should always turn the same face to the earth. It could be shown that there were many million chances to one in favor of this being due to some physical cause. The ordinary theory of gravitation failed to explain the cause. Every one had noticed this phenomenon. Yet the explanation was never given till lately. It was Helmholtz who showed that this was a consequence of ancient tides, and this simple and most satisfactory explanation has been universally accepted. The constant face of the moon is a living testimony to the power of the tides. What tides have accomplished on the moon is an earnest of what tides will accomplish on the earth.

In the great conflict of the tides the earth has already conquered the moon, and forced the moon to render perpetual homage as a token of submission. Remember, however, that the earth is large, and the moon is small. Yet small though the moon is, it gallantly struggles on. "You have forced me," cries the moon to the earth, "to abandon the rotation with which I was originally endowed; you have compelled me to rotate in the manner you have dictated. I will have my revenge. It is true I am weak, but I am unrelenting; day by day I am exhausting you by the tides with which I make you throb. The time will assuredly come, though it may not be for millions of years, when you shall be forced to make a compromise. When that compromise is made, the turmoils of the tides will cease; our mutual movements will be adjusted. With equal dignity we shall each rotate around the other; with equal dignity we shall each constantly bend the same face to the other."

THE CAUSES OF VOLCANIC ACTION.*

By PROFESSOR J. PRESTWICH, University of Oxford.

THE hypothesis generally accepted in this country as to the cause of volcanic action is that of the late Mr. Poulett Scrope, who considered that "the rise of lava in a volcanic vent is occasioned by the expansion of volumes of high-pressure steam, generated in a mass of liquefied and heated matter within or beneath the eruptive orifice," and that the expulsion of the lava is effected solely by high-pressure steam generated at great depths, but at what depths is not mentioned, nor is it explained how the water is introduced, whether from the surface, or whether from water in original combination with the basic magma. The objections to this hypothesis are: 1. That during the most powerful explosions, *i. e.*, when the discharge of steam is at its maximum, the escape of lava is frequently at its minimum. 2. That streams of lava often flow with little disengagement of steam, and are generally greatest after the force of the first violent explosion is expended. 3. That it is not a mere boiling over, in which case, after the escape of the active agent—the water—and the expulsion of such portion of the obstructing medium, the lava, as became entangled with it, the remaining lava would subside in the vent to a depth corresponding to the quantity of lava ejected; but the level of the lava, *ceteris paribus*, remains the same during successive eruptions.

Of the important part played by water in volcanic eruptions there can be no doubt, but instead of considering it as the primary, the author views it as a secondary cause in volcanic eruptions. All agree in describing ordinary volcanic eruptions as generally accompanied or preceded by shocks or earthquakes of a minor or local character, to which succeed paroxysmal explosions, during which vast quantities of stones, scoria, and ashes, together with volumes of steam, are projected from the crater. The first paroxysms are the most violent, and they gradually decrease and then cease altogether. The flow of lava, on the other hand, which commences sooner or later after the first explosions, is continued and prolonged independently. Ultimately the volcano returns to a state of repose, which may last a few months, or many years. Adopting the theory of an original igneous nucleus, the author considers a certain fluidity of the former and mobility of the latter. The one and the other feebly represent conditions of which the phenomena

* From a paper read before the British Association.