important of these conditions I take to be the equatorial position of the Aruwhimi basin; the second that it is situated in the heart of the continent. Both of these, but more particularly the former, determine it as the seat of ascending air-currents, and therefore of their dynamic cooling on a gigantic scale, and it is to this dynamic cooling that the high rainfall of the region is to be ascribed.

Very probably a considerable portion of the precipitated moisture is locally re-evaporated, so that, as suggested long ago by Sir John Herschel in the case of the Brazilian forest rainfall, the same water is precipitated again and again. There are not, I believe, in the lower atmosphere, any steady winds blowing outwards to carry away the evaporation of the damp forest tract, and the main loss of water to be supplied by easterly or other winds is that carried off by the river drainage, probably less than half of the rainfall. The air which has ascended to the higher regions of the atmosphere as a part of the main circulation of the globe, parts with nearly the whole of its vapour in the act of ascending.

We have a case in some respects analogous to that of the Upper Aruwhimi in the very damp and equally forest-clad province of Upper Assam. This too is characterized by a very calm atmosphere, being girt with lofty mountains on the north and east, and also shut off on the south and south-west from the Bay of Bengal by hills of considerable elevation. Such gentle winds as blow in the valley are chiefly from the east or down valley. Yet the rainfall is over 100 inches in the year, and the whole tract is one of marsh and dense forest. It is indeed not situated under the equator, and herein it is less favourably conditioned as a region of excessive rainfall than the basin of the Aruwhimi.

As the result of a long study of the rainfall of India, and perhaps no country affords greater advantages for the purpose, I have become convinced that dynamic cooling, if not the sole cause of rain, is at all events the only cause of any importance, and that all the other causes so frequently appealed to in popular literature on the subject, such as the intermingling of warm and cold air, contact with cold mountain slopes, &c., are either inoperative or relatively insignificant.

Folkestone, April 11.

HENRY F. BLANFORD.

"Les Tremblements de Terre."

M. FOUQUÉ's letter (*NATURE*, March 28, p. 510) does not meet the main points of my criticism of his book. He thinks that a pendulum swinging in synchronism with the ground's motion is the right thing to use as an absolute seismometer. M. Poincaré's mathematical note, to which he refers as supporting his view, does not support it, but shows why such a pendulum is unsuitable. It is necessary to emphasize this, for it relates to a fundamental matter in the dynamics of earthquake measurement—a matter on which the work done of late years in Japan seems to me to be so intimately based that a misunderstanding about it must be fatal to a proper appreciation of that work. And, in point of fact, I did not find that M. Fouqué gave an appreciative account of what any of the Japanese observers had done. As to his mention of Prof. Ewing's seismograph, in particular, I criticized it not so much because it was meagre as because it was incorrect,—so incorrect as to justify the inference that the author was not acquainted with that instrument.

THE REVIEWER.

Hertz's Equations.

MR. WATSON's criticism, that Hertz's equations are only true for places at some distance from the oscillator, is no doubt perfectly valid. [There is, by the way, an insignificant and obvious misprint of λ for ρ about the middle of his letter.] But this was entirely recognized by Hertz himself; he treated the oscillator as infinitesimal, knowing that it was nothing of the kind when you got near it, and refrained from drawing his diagram-curves into its neighbourhood, for this very reason.

The fact is surely that, to work out completely the case of electric oscillators in a compound body formed of a couple of spheres joined by a cylinder, would tax the resources of a strong mathematician; and it is impossible that the vibration can be, in any sense, a pure one; all manner of sub-vibrations must be superposed upon the main.

From the physical point of view, some general notion of what was happening at a distance of a wave-length or more from the oscillator was desirable, and this Hertz satisfactorily obtained.

But, to work out what is happening in the immediate neighbourhood of a dumb-bell oscillator must be left, I imagine, to the time when some pure mathematician may devote his attention to this particular shape of conductor, if the case appears to him of sufficient interest. At present I see no special reason why it should be so regarded, but of that Mr. Watson is a better judge. I hope he may see fit to attack the problem.

Grasmere, April 13.

OLIVER J. LONGE.

THE COMPRESSIBILITY OF HYDROGEN.

AS stated in the obituary notice that appeared in *NATURE* (vol. xxxviii. p. 593) at the time of the melancholy accident which caused his death, Wroblewski was engaged in an investigation of the behaviour of hydrogen on compression. The results of this investigation, as far as it had then advanced, have now been made public (*Monatsh. für Chem.*, 1888, p. 1067 *et seq.*). They are of a most important and interesting nature, and form a fitting memorial of the patience and skill of the observer, who most unhappily was not spared to bring this, the last and most complete of a long series of similar investigations, to a close.

Hydrogen has long occupied an exceptional and isolated position among gases. This is due to the fact that, as Regnault first pointed out, hydrogen forms the sole exception to the law that the product of the pressure into the volume, $p\nu$, of any gas decreases with increasing pressure, the exact converse being true in the case of hydrogen, this product showing a regular increase. It is true that, as since shown by Amagat and others, this behaviour of hydrogen becomes general for all gases when the pressure is increased beyond a certain limit, but before reaching this limit the product $p\nu$ invariably decreases until a minimum is reached for all gases with the exception of hydrogen. For hydrogen neither the decrease nor the minimum have yet been observed, the gas as hitherto examined showing an invariable increase of $p\nu$ with increasing pressure. The natural inference was, however, that the exception was only apparent, and that the minimum above noted would be found to occur also with hydrogen if the gas were examined at lower pressures than those hitherto investigated—that is to say, at pressures below one atmosphere. But a difficulty in the way of this hypothesis arises from the fact that the critical pressures of all gases are found to be *below* the pressure at which the minimum value for the product of pressure into volume occurs, and therefore on the above reasoning the critical pressure of hydrogen would have to be phenomenally low and considerably beneath one atmosphere.

To gain a further insight into the relation of volume to pressure in the case of hydrogen, Wroblewski decided to investigate this relation through a wide range of temperature. For this purpose he selected as temperatures sufficiently apart, the boiling-point of water, 100° C., the melting-point of ice, 0° C., the boiling-point of liquid ethylene, -103°·5 C., and the boiling-point of liquid oxygen, -183° C. The pressures employed varied from one to seventy atmospheres.

The method of experimenting was exceedingly simple. The gas at a known pressure was forced into a bulb of known capacity having a capillary neck, and kept at one of the above four temperatures. A sufficient length of time was allowed for the gas to attain the fixed temperature; it was then transferred to a eudiometer, and its volume measured. It is needless to add that every precaution was taken both in purifying the gas and in applying the necessary corrections.

The results with the three first of the above temperatures agree with the behaviour of hydrogen already observed, the product of volume into pressure constantly increasing with the pressure. It was found that for the range of pressures under investigation (one to seventy

atmospheres) the relation between these two quantities may be expressed in all three cases by the general equation $pv = a + bp + cp^2$. The curves which this equation represents have their concave side towards the axis of p . Between the temperatures $-103^{\circ}5$ and 100° , then, nothing is observed that contradicts former experience with regard to hydrogen on compression.

But at the temperature of boiling oxygen, -183° , the behaviour of hydrogen is very different. Up to a pressure of about fourteen atmospheres the product pv decreases with rising pressure, and the above equation no longer holds good. At about fourteen atmospheres, however,

this decrease has reached a minimum, and from this point the gas behaves in the ordinary way, and the product pv increases with the pressure in accordance with the equation given above. Not the least sign of liquefaction occurs at this temperature at any of the pressures employed.

This is an observation of great importance. It shows that at sufficiently low temperatures hydrogen behaves on compression like all other gases, and has a minimum value of pv occurring, not at some exceptionally low pressure, but at a pressure of fourteen atmospheres.

For the general representation of the four isothermals

In the sketch given of the apparatus used when the gas was cooled by means of liquid oxygen, a is the bulb in which the compression of the hydrogen takes place. The vessel containing this is filled with oxygen under pressure and surrounded by ethylene under evaporation, liquid ethylene being obtained by passing the gas already cooled by a mixture of ice and salt through a worm tube immersed in r in a mixture of solid carbon dioxide and ether. By suddenly diminishing the pressure on the oxygen by opening the tap V communicating with the outside air, the gas is partially liquefied and the desired temperature is reached. The volume of the gas in a is afterwards measured by allowing it to escape into the eudiometer E .

thus obtained, Wroblewski employs an empirical formula that differs but slightly from one given by Clausius—

$$p = \frac{RT}{v - a} - \frac{K}{\epsilon^{1/2} v^2}$$

the values of the constants being in the present case $R = \frac{1}{27.3}$, $a = 0.00111665$, $K = 0.00051017$, and $\epsilon = 1.003892$. This equation serves for the calculation of the critical temperature, pressure, and volume of hydrogen, for which the values are found to be—

$$\theta\epsilon^3 = \frac{8K}{27Ra}, \pi = \frac{RT}{8a}, \text{ and } \phi = 3a,$$

or, substituting the values for the constants, we get—

$$\begin{aligned} \text{Critical temperature } \theta &= 32.6 \text{ or } -240^{\circ}4 \text{ C.,} \\ \text{,, pressure } \pi &= 13.3 \text{ atmospheres,} \\ \text{,, volume } \phi &= 0.00335, \end{aligned}$$

from which

$$\text{Critical density} = 0.027.$$

Similar results were obtained by employing other formulæ than the one given above, but this was retained as being in best agreement with the experimental results.

These numbers afford at once an explanation of the ordinary behaviour of hydrogen on compression and the

absence of the minimum of p_v at ordinary temperatures, this being due to the fact that hydrogen possesses a very low critical temperature combined with a low critical pressure. For if, instead of taking temperature and pressure in the ordinary units, we take temperature in terms of the critical temperature, and pressure in terms of the critical pressure as units, and then with temperatures as abscissæ and pressures as ordinates construct the curve for the observed minimum points of p_v , this curve will be found to be one and the same for all gases. As Wroblewski has shown, it is a continuation of the curve for the vapour pressures at different temperatures of the liquefied gases, pressure and temperature being expressed in terms of the critical. Drawing this curve by the aid of the observations that have already been made with ethylene, carbon dioxide, methane, and other gases, it is found that the pressure for the minimum point rapidly rises with rising temperature, and reaches a maximum of about 3π for a temperature of 1.4θ . From this point, however, the pressures decrease as the temperature rises, so that, when the temperature is about 3θ , the pressure at which the minimum p_v occurs is π , or the critical pressure; and if the temperature be further increased beyond this point the pressure of minimum p_v is reduced below the critical, and continues still further to fall as the temperature rises.

Applying this to hydrogen at a temperature of about 3θ , the pressure of minimum p_v should be π , the critical pressure, and this as a matter of fact agrees with the result of the above experiments. For 3θ is approximately -176°C ., at which point the required pressure should be the critical or 13.3 atmospheres, and observation shows that at -183°C . this pressure is fourteen

atmospheres, and as, the temperature being lower, we should expect the pressure to be somewhat higher, this is a very close approximation indeed. At higher temperatures the pressure falls below the critical, and this evidently takes place so rapidly that at -103°C ., or for about 5θ , the pressure of minimum p_v is so small a fraction of the critical as to be removed outside the range of observation. The critical pressure itself being low of course assists this process.

This, then, explains the behaviour of hydrogen on compression, and why this behaviour differs from that of the other gases. For a gas must be raised to a temperature of over 3θ before it will act like hydrogen, whereas gases have up to the present only been examined at temperatures not far removed from the critical.

The very low critical temperature of hydrogen is remarkable. It confirms the saying of Regnault, that hydrogen at ordinary temperatures is a gas *plus que parfait*. At the same time it shows that no reliance can be put on Pictet's statement that hydrogen was liquefied at about -140°C . under a pressure of 360 atmospheres; and whether the temperature attained in Cailletet's experiments was low enough to actually liquefy the gas must be looked upon as extremely doubtful. At the time of his death Wroblewski was planning experiments for the liquefaction of hydrogen, the only thing necessary to make his work complete.

By cooling hydrogen under a pressure of 110 atmospheres to -213.8°C . by the evaporation of liquid nitrogen, and then suddenly diminishing the pressure, as low a temperature as -223°C . was obtained, but the hydrogen still remained in the gaseous state and refused to liquefy.

H. CROMPTON.

THE MANATEE.

THE Zoological Society have added to their living collection in the Regent's Park a young specimen of the Manatee (*Manatus americanus*), which those who wish to have an opportunity of inspecting an extremely curious form of Mammalian life should take an early opportunity of visiting. The Manatees belong to the order *Sirenia* of naturalists, and are sometimes called

"herbivorous Cetaceans," although it is, to say the least, very doubtful whether they have any near relationship whatever to the true Whales or order Cetacea. These creatures were abundant in former geological epochs, but since the extermination of the *Rhytina*, or Steller's Sea-cow, at the latter part of the last century, have only two representatives still living on the earth's surface, viz. the Manatee of America and Africa, and the Dugong of the Indian Ocean.

As will be seen by our outline sketch, taken from the Zoological Society's Proceedings, the Manatee is shaped more like a fish than an ordinary mammal. It is formed exclusively for aquatic life, and inhabits the estuaries and rivers of the American and African continents, where it passes its time browsing on the plants beneath the surface and adjacent to the banks. It remains mostly under the water, and only raises its head above the surface to breathe.

The present specimen, which arrived at the Gardens from Liverpool on March 2, is the second example of this singular form that has been received alive by the Society. The first specimen was acquired in August 1875, and lived about a month in the Regent's Park, where it

attracted many visitors. When dead, however, it was by no means wasted, as it formed the subject of an excellent article on its anatomy read before the Zoological Society by the late Prof. Garrod, and subsequently published in the tenth volume of the Society's Transactions.¹

In 1879, a pair of Manatees, received from the Island of Trinidad, lived for several months in the Brighton Aqua-

¹ A complete account of the anatomy of the Manatee was prepared by Dr. Murie in 1872, from the examination of a specimen of this animal imported from Surinam for the Zoological Society, which unfortunately only lived just long enough to reach England. This will be found in the eighth volume of the Zoological Transactions. The attention of residents on the Amazons should be called to the existence in that river of a second species of Manatee (*Manatus inunguis*), discovered by the great Austrian naturalist, Johann Natterer, in 1830, but as yet little known in Europe.