The Density of the Matter Composing the Kathode Rays.

IN a note which appeared in NATURE of January 19, I indicated a method by which an approximate limiting value could be deduced for the density of the matter composing the kathode rays. The result arrived at was that this must be small compared with 10^{-15} grams per cubic centimetre. This estimate seems to be confirmed by results recently published by E. Riecke (*Wied. Ann.*, 66, p. 954) on the reaction-pressure exerted on the movable kathode-vanes of an electric radiometer. A theoretical investigation leads the author to the result, that this pressure is equal to mu^2, in the notation of my former note (m, mass per unit volume; u, velocity of the particles). His numerical results give an average of about ·04 dynes per square centimetre for the pressure, and he deduces for u, theoretically, the value $9{\cdot}6 \times 10^8$, or, say, 10^9 roughly. Using these numbers, m comes out about 4×10^{-20}.

Queen's College, Belfast, February 11. W. B. MORTON.

Earthquake Echoes.

AN earthquake disturbance, as recorded at a station far removed from its origin, shows that the main movement has two attendants—one which precedes, and the other which follows. The first of these by its characteristics indicates what is to follow, whilst the latter in a very much more pronounced manner repeats at definite intervals, but with decreasing intensity, the prominent features of what has passed. Inasmuch as these latter rhythmical but decreasing impulses of the dying earthquake are more likely to result from reflection than from interference, I have provisionally called them *Echoes*. Although I see an explanation for the orderly arrangement and features of the precursory vibrations, it is sufficient if I confine my remarks in this note to the reverberations which apparently succeed an earthquake.

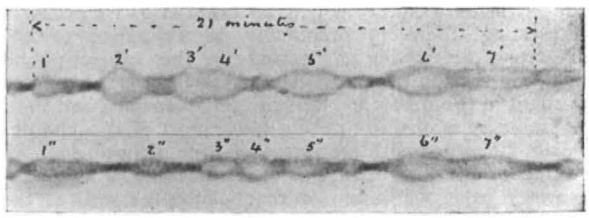
If it can be shown that our world resounds with earthquake echoes, hypotheses at once suggest themselves as starting-points for new investigation.

It is, therefore, of importance that before the idea of earthquake reverberations should be crystallised, the evidence we have of the supposed vibrational repetition should be carefully scrutinised, and that opinions should be expressed respecting the interpretations of observations like the following. When an earthquake is comparatively small, and has originated as a single effort at no great distance (one or two thousand miles) from the observing station, the seismogram shows a single set of preliminary tremors, of short duration, a single set of pronounced vibrations corresponding to an irregularly delivered originating impulse, and finally a series of concluding vibrations which rise and fall in value every three or four minutes. That which appears on a seismogram as a two-blow earthquake terminates with dual reinforcements. As illustrative of this, I may refer to the Isle of Wight seismogram of the South Indian Ocean earthquake of August 31, 1898, copies of which have been sent to the members of the Seismological Investigation Committee of the British Association, and to their various co-operating stations. We have apparently here two large disturbances followed by pairs of echoes. If we closely examine the first pair of these responses (the second pair being too small to exhibit details), we find that its subdivisions roughly agree in character with those observable in the collection of movements which make up the primary impulses. Calling the first maximum 1, and its following echoes 1′, 1″, and 1‴; and the second maximum 2, and its following echoes 2′, 2″, and 2‴, the time intervals expressed in minutes between these various phases are

1 to 1′ = 12. 1′ to 1″ = 8. 1″ to 1‴ = 4.
2 to 2′ = 10. 2′ to 2″ = 7·5. 2″ to 2‴ = 3·5.

In considering these intervals it must be remembered that 1 is greater in amplitude and period than 2, whilst 1′ is similarly greater than 1″, &c. Now, seismological observation appears to point to a result that is difficult to accept, viz. that the smaller the amplitude of a wave, and the shorter is its period, the higher, apparently, is the velocity of its propagation. Should this be so, then it follows, as is indicated by the above series of intervals, that the smaller echoes should return more quickly than those which precede them. A much more certain observation is made when this earthquake is regarded as resulting from a single impulse, and what has been treated as the second maximum is examined as its echo. We then see that the five crests, constituting what has been called the first blow or impulse, are repeated in what has been called the second blow by a five-crest echo, the intensity of each component corresponding with that of its primary. After this we get another five-crest group, followed by two groups each of four crests, beyond which point rhythmical recurrence is lost. A very good illustration of what may be multiple echoes is found in the Isle of Wight seismogram for June 29, 1898. This is a very large earthquake, which probably caused the whole of the earth to pulsate, and its preliminary tremors indicate that it originated at a very great distance. It had a duration exceeding three hours. The main disturbance shows more than fourteen maxima of motion which have a fairly symmetrical arrangement to the right and left of a central dividing line.

Between these first movements and the first set of responses, which commence suddenly, a faint but very uncertain likeness may be seen. When, however, we compare the responses, amongst themselves they apparently show a repetition in form and a uniformity in their time of recurrence that can hardly be the result of accident. To facilitate such a comparison two series of these concluding vibrations are here photographically reproduced, the first series being placed above the second.



It will be noted that the triangularly-headed echo 1′ is not unlike 1″; its spherically-formed successor 2′ is repeated in 2″; and so we may continue through the series until we reach the gourd-formed 6′ and 7′, reflected in corresponding shape by 6″ and 7″. Other points of likeness may be seen between 4 and 5 and between 5 and 6. I may add that if the photogram had been made longer, then three groups of waves would have preceded 1′, which would correspond in form and time with three groups preceding 1″.

The time intervals between these corresponding groups are respectively as follows: from 1′ to 1″, 2′ to 2″, &c.: 30, 31, 30·5, 31, 31, 29 and 28 minutes. We here appear to be dealing with a series of vibrational groups, each of which took almost exactly half an hour to travel to and fro between two reflecting surfaces or districts. If the waves were compressional in character, the distance between these surfaces would be about 8000 kms.; but if they travelled with the velocity of the waves of shock, this distance would be reduced to something under 3000 kms. From their period and amplitude it is probable that the distance lies between these values.

The main point at issue, and the one to be answered before we enter into further speculations, is whether seismograms showing this musical repetition can be interpreted in the manner here suggested. The concluding vibrations of an earthquake have usually been regarded as a disorderly mob of pulsatory movements resulting from spasmodic impulses, which gradually grow feebler as the activity at a seismic centre becomes exhausted. The question before us is whether an earthquake dies by a process analogous to repeated and irregular settlements of disjointed materials, or whether it is simply a blow or blows which come to an end with musical reverberations inside the world. For the present my opinion inclines to the latter, and I see in the earthquake followers the likeness of their parents.

The observational confirmation of the existence or non-existence of these echoes requires a special arrangement of apparatus, installed in a dry, well-ventilated room, having a proper site, and free from tremors. In the dark, damp stable where I work, I regret to say that the frosty nights have brought with them vigorous and persistent tremors, and as a good observing season has now commenced, beautiful seismograms are being spoiled. The last to suffer was that of a magnificent set of waves which arrived from Mexico on the night of January 24. JOHN MILNE.

February 1.