



# XV. On the nature of what is commonly termed a "vacuum"

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$$r = 1.500 \text{ centim.},$$

$$R = 3.000 \text{ centims.},$$

$$d = 2.250 \quad ,,$$

$$\text{and} \quad a = 0.125 \text{ centim.}$$

$$\text{Hence} \quad F = 396 \times 10^3 \text{ grammes per square centimetre,}$$

$$\left. \begin{array}{l} 14Q = 50586.5 \\ V = 722.7 \end{array} \right\} \text{ absolute electrostatic C.G.S. units.}$$

Changing the units to the ordinary ones in practical use, we find

$$14Q = 16.86 \text{ microfarads,}$$

$$V = 216810 \text{ volts.}$$

Assuming the sparking-distance to increase as the square of the potential, it can be calculated from the experimental results obtained by Messrs. Warren De La Rue and Müller (Proc. Roy. Soc. Jan. 1876), namely that 1000 rod-chloride-of-silver cells give a spark 0.009166 inch, that a difference of potentials of 216,810 volts would produce a spark in air between two electrodes at a distance of about 36 feet apart. This is, of course, a relatively very short distance; but it must be remembered that we have only taken into consideration that portion of the energy of the discharge which was employed in breaking the fourteen insulators, and have neglected all that was spent in heat, light, &c.

XV. *On the Nature of what is commonly termed a "Vacuum."*  
By S. TOLVER PRESTON.

1. **I**T may perhaps not be uninteresting to consider what light the researches of Professor Maxwell on molecular distances in connexion with the kinetic theory of gases, and those of Sir William Thomson and others, are capable of throwing upon the physical condition of what is ordinarily termed a "vacuum." This inquiry might have an additional interest at the present time, when experiments with extremely rarefied media in connexion with the radiometer and the discharge of electricity in evacuated tubes are going on, and certain inferences regarding the condition of "vacua" would lead one to infer that a prevalent idea may exist regarding the state of a "vacuum" (so termed) which is not consistent with facts, as indeed I am not aware that any special investigations have been made on this subject. I make no pre-

\* Communicated by the Author.

tence to do more than apply the mathematical results of others to a special case; and I shall be glad if the result obtained is of any service, or may induce others to pursue the subject further.

2. It has been deduced by Professor Maxwell (Phil. Mag. Dec. 1873) that the number of molecules contained in a cubic centimetre of any gas at normal density may be estimated, in round numbers, at 19 million billions. This is carefully given by Professor Maxwell as a *probable* or approximative result. But, on the other hand, it should be kept in view that the result is estimated on the basis of experimental data; and other results predicted by mathematics in connexion with the kinetic theory, and which admit of direct test by experiment, have (as is well known) been confirmed in a striking manner. Also it is needless to add that mathematics is not less certain because the dimensions dealt with are small. Sir William Thomson in a paper on "Atoms," published in 'Nature' (March 31st, 1870), by four distinct lines of argument arrives at accordant results as limiting values for dimensions of molecular structure; and these results agree very well with the above estimate of Professor Maxwell. Sir William Thomson finally remarks that the results may be considered as established with "a very high degree of probability."

3. Taking, therefore, Professor Maxwell's result in reference to a gas, if we take the cube root of the number of molecules contained in a cubic centimetre, or  $\sqrt[3]{19 \times 10^{18}}$ , we have the number of molecules which (placed at their mean distances) would reach the length of a linear centimetre, or we have 2,668,400. The mean distance of the molecules of a gas at normal density is therefore  $\frac{1}{2,668,400}$  of a centimetre, about one seven-millionth of an inch—which, it may be remarked, is about one seventh of the distance capable of being measured by a Whitworth machine. We have now to consider what the effect is on rarefying the gas. To clear the ideas, suppose all the molecules in a given space (such as an air-pump receiver) to be placed regularly; *i. e.*, suppose the given space to be subdivided up into a number of imaginary cubes of such a size that, when molecules are placed at the corners of all these cubes, exactly the whole number of molecules is thus taken up. Then the side of one of these cubes will be one seven-millionth of an inch long, representing the mean distance of the molecules. Rarefying a gas to a given degree is of course equivalent to increasing the space in which the gas is to that same degree. The side of a cube being as the cube root of its volume, it follows that when the gas is

rarefied, which is equivalent to increasing the volume of space occupied by it, the side of any cube (representing the mean distance) will be increased in the ratio of the cube root of the number of times the gas is rarefied. In order to take an extreme case, let us suppose the gas to have been rarefied a million times (*i. e.* to one millionth of its normal density) this corresponding to about  $\frac{1}{\sqrt[3]{33,000}}$  of an inch of mercury, a measure that would be imperceptible on an ordinary barometric gauge. After this degree of rarefaction the mean distance of the molecules will have been increased to a hundred times, or  $\sqrt[3]{1,000,000}$ . The mean distance of the molecules, after rarefying a million times, will therefore be about one seventy-thousandth of an inch, a dimension which, if plotted on a scale, would be invisible to the eye. It follows, therefore, that even with this extreme degree of rarefaction (supposing it could be attained with a good mercurial pump), the molecules of gas are still packed so close that their distance, if marked on a scale, would be invisible to the eye, and still 19 billions (dividing the number originally contained in a cubic centimetre by 1,000,000) of them are enclosed in a cubic centimetre. This may possibly not harmonize with the general idea of what is called a "vacuum." Indeed it may be fairly questioned whether the inconceivable number of 19 billion separate existences accumulated in the narrow limits of a cubic centimetre of space may not be properly regarded as something the very opposite of a "vacuum." The *size* of a molecule may not be of so much influence. Its *presence* may be the main thing. The presence of 19 billion separate portions of matter in a cubic centimetre of space may conceivably produce an effect on an electric discharge or a radiometer very different from a vacuum. One reason why the distance of the molecules of gas increases with such extreme slowness on rarefying is evidently due to the fact that the distance only increases as the cube root of the number of times the gas is rarefied. If it were imagined to be possible to carry the rarefaction a million times as far as the above extreme limit, there would still be 19 million molecules in a cubic centimetre.

4. It may therefore be truly said that even the best pump does not increase appreciably the distance of the molecules of gas, inasmuch as the distance moved through by the molecules of gas under the action of the pump, if plotted on a scale, would be inappreciable to the eye; or, in other words, when the most powerful pump has done its work, the molecules of gas are still so close that their distances are too small to be

visible on any scale, and the number of molecules of residual gas contained even in a cubic centimetre of space may be reckoned by billions. In the case of what would be regarded as an ordinary "good vacuum," such as that used in Geissler's vacuum-tubes for electric discharges (say, 0·7 of a millimetre of mercury, or a rarefaction of one thousandth), the distance shifted through by the molecules under the action of the pump in the act of rarefying would be only about  $\frac{1}{778000}$  of an inch, and the number of molecules in a cubic centimetre of the residual gas 19 thousand million millions (a cubic centimetre being about one fourteenth of a cubic inch).

5. It may perhaps be of interest to consider what effect the rarefaction has upon the mean *path* of the molecules of gas, the mean path being the mean or average distance moved through by a molecule before coming into collision with another molecule. The mean path of the molecules of several well-known gases has been calculated by Professor Maxwell from some carefully executed diffusion-experiments by M. Loschmidt. The mean path of a molecule of hydrogen at normal density is given at ·0000965 of a millimetre, or about  $\frac{1}{263200}$  of an inch. Loschmidt has deduced the following proportion:—"As the volume of a gas is to the combined volume of all the molecules contained in it, so is the mean path of a molecule to one eighth of the diameter of a molecule." The mean path of a molecule therefore increases directly as the number of molecules in the unit volume of the gas is diminished. The mean path accordingly increases directly as the number of times the gas is rarefied. The value of the mean path therefore augments, on rarefying, at a disproportionately greater rate than that of the mean distance of the molecules of gas.

6. It appears to have been assumed in certain radiometric experiments that the mean path of the molecules of the residual gas is comparable to the diameter of the bulb of the radiometer itself. In a paper by Mr. Crookes which appeared in the 'Philosophical Magazine' for June last, is the following passage:—"But when the exhaustion is carried to so high a point that the molecules are sufficiently few, and the mean length of path between their successive collisions is comparable with the dimensions of the vessel." This is also assumed in a paper by M. Finkener in Poggendorff's *Annalen* on the subject of the radiometer, where the assumption is made that the gas is rarefied so far that the mean length of path of the molecules is very great compared with

the dimensions of the ball of the radiometer\*. Conceivably these assumptions may naturally arise from the idea that in a "vacuum," so termed, the molecules of gas are few and widely scattered. This, we have shown, is by no means the fact. It may therefore be worth while investigating from the above result of Professor Maxwell what the mean path of the molecules of gas is at the degree of rarefaction at which the rotation of the radiometer was observed to be at a maximum. This maximum is stated in Mr. Crookes's paper to have occurred in the case of hydrogen at a rarefaction of 50 millionths. The mean path being in direct proportion to the rarefaction, its value in this case will be  $\frac{1}{263200} \times \frac{1000000}{50} = \frac{1}{13}$  of an inch about. This is but a small fraction of the diameter of the bulb. It is remarked that the special gauge used could not indicate the pressure of the mercury vapour of the pump, and that therefore the actual values for rarefaction attained might have been somewhat under the estimated values. This would go to make the mean length of path, when the rotation was at its maximum, a still smaller fraction of the diameter of the bulb than above; and it is stated that at higher rarefactions the rotation notably began to fall off. The length of path of the molecules of other gases is also less—about half that of hydrogen. My object here is not in any way to deal with the cause of the rotation of the radiometer, but rather to adduce from the best obtainable data certain facts which may tend to throw a light upon the true physical condition of the rarefied gas enclosed in the instrument; and it is certain that, whatever the true explanation may be, it cannot be otherwise than forwarded by such a course.

London, June 1877.

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XVI. *Ice as an Electrolyte.* By W. E. AYRTON and JOHN PERRY, Professors in the Imperial College of Engineering, Tokio, Japan†.

[Plate II.]

FOR the purpose of measuring the resistance of ice at various temperatures, its power to act as an electrolyte, and its specific inductive capacity, the following piece of apparatus was constructed. A B C D (Plate II. fig. 1) is a copper box 17·4 centims. in diameter, rigidly fixed by means of

\* "Wir verdünnen das Gas so weit, dass der Weg, den ein Molecül zwischen zwei Zusammenstössen mit anderen Molecülen durchschnittlich zurücklegt, sehr gross ist im Verhältniss zu den Dimensionen der Kugel des Radiometers." (Pogg. Ann. July 1876, part 8, p. 579.)

† Communicated by the Physical Society.