this point in his description in the *Bot. Mag.*, and it was for the further investigation of the case that I raised a plant in my garden.

The flowers grow on long peduncles, which generally have a horizontal position, projecting some five or six inches from the mass of the foliage. When the calyx opens, the filaments as well as the style are irregularly twisted; but in about two or three days all become straight. The style hangs obliquely downwards; the filaments all bend sideways, the bend being inside the tube of the corolla, a little over the hairs at their base. There is often a distance of 15 centimetres between the anthers of either side. About 5 or 6 o'clock p.m. the anthers burst, and soon after the style rises and assumes a central position, so that there is a distance of about 10 centimetres between the stigmata and any of the anthers. *Only then* is nectar being secreted by the glandular disk round the base of the ovary, but so copiously that by means of a small pipette I obtained from each flower a mean quantity of 0·14 cubic centimetres. This nectar is completely transparent, very sweet, and slightly mucilaginous. It contained a kind of gum which is precipitated by absolute alcohol. *The nectar appears therefore when the anthers have done their work;* even an hour before their rupture no trace of it is to be found. The nectar-cavity in the tube of the corolla is completely shut up by the numerous spreading hairs at the base of the filaments, so that an outflow is impossible. The grains of pollen are very large (0·2 millim. in diameter) and of the same structure as in *Cobœa scandens*. They are covered by a glutinous layer, and are heavier than water.

Several weeks passed at first before I witnessed the manner of fertilisation. The stigmata were every morning carefully examined, but no pollen could be discovered on them. The filaments twisted back again and got somewhat frizzled, after one single night's expansion. About noon the corolla drops off, separating from close to the glandular ring, and then slipping down over the style, which, by this time, is again in a relaxed hanging position. There is always some nectar in the tube of the corolla after its separation, but none remains in the calyx round the ovary, nor does its secretion continue.

These facts show clearly that the fertilisation must take place in the same night after the bursting of the anthers, and it was but natural to suppose that it was effected by nocturnal moths. It would appear, furthermore, that *the nectar is not of any direct advantage to the plant*, as Mr. G. Bonnier emphatically affirms (*Annales des Sci. Nat. Bot.*, sér. vi. vol. viii. p. 206), because of its being produced and lost in all flowers, fertilised or not, in the same way.

As soon as the number of flowers increased (on some evenings twenty to twenty-five had their anthers opened), I found every morning most of them with pollen on the stigmata, and keeping a close watch, I discovered that the plant was visited by several large Sphingidæ belonging to the genera *Chaerocampa*, *Diludia*, and *Amphonyx*. I observed altogether four visits of an Amphonyx, three of a Chaerocampa, and one of a Diludia. All of them proceeded in the same manner. Holding the body close over the style, they dipped their spiral tongues into the tube of the corolla, beating all the while the anthers so violently with the tips of the fore-wings that they dangled about with great velocity in every direction. The grains of pollen being covered by a sticky substance, many of them adhered to the wings. I have caught an Amphonyx which, after having visited six flowers consecutively, had the tips of the fore-wings almost yellow with pollen. When leaving a flower for another one, some of this pollen is even lost on the foliage, but by the time the insect takes its central position before the flower the stigmata are likewise touched by the wings, and thus some pollen is left on them. Some flowers remain without being fertilised, especially in places where the moths cannot reach them easily. All flowers fertilised in this manner set fruit very soon; but no flower gave a fruit without having its stigmata pollenised by crossing.

Self-fertilisation is therefore excluded, and this is further proved by the following experiments:—Twelve flowers were artificially fertilised by their own pollen and afterwards protected by muslin bags; only in one case was a fruit obtained; but I am not quite sure whether there did not come some foreign pollen on the stigmata of this flower. Cross-fertilisation was likewise tried in twelve flowers, nine being experimented on in the same evening after the opening of the anthers, and three the next morning. All the former are now with fruit; the latter remained sterile. This fact shows how very short is the period of possible fertilisation.

Flowers visited by nocturnal moths are as a rule either large and of white colour, or have a strong smell; but in our *Cobœa* the former is certainly not the case, and my olfactory nerves at least cannot discover any smell. But it is well known that insects, especially Lepidoptera, are in this respect of a really wonderful keenness, which enables them to track a scent absolutely imperceptible to man.

As I shall have a considerable crop of Cobæa-seeds, I can offer some to any botanists who should wish to grow the plant. A. ERNST

Carácas, April 4

P.S.—As soon as the corolla has fallen off, the peduncle withdraws slowly amongst the dense foliage, where the fruit develops, protected from all kinds of injury.

EXPERIMENTAL RESEARCHES IN ELECTRICITY[1]

Part III.—*Tube-Potential; Potential at a Constant Distance and Various Pressures; Nature and Phenomena of the Electric Arc.*

MESSRS. De La Rue and Müller, in the third part of their researches on the electric discharge, commence by describing a series of experiments to determine the potential necessary to produce a discharge in a tube, exhausted gradually more and more while using a constant number of cells in all the experiments. In consequence of the life of the battery becoming so much exhausted by the method employed the experiments were confined to one gaseous medium, namely, hydrogen. Since the completion, however, of the measurements described in the paper the authors have found two other more convenient methods for determining the tube-potential, which do not exhaust the battery injuriously; these are described in an appendix. The tube, 162, employed was 33 inches long and 2 inches in diameter, the distance between the ring and straight wire terminals being 29·75 inches; the battery consisted of 11,000 cells. The discharge took place when the pressure was reduced to 35·5 mm., 46,710 **M** (millionths of an atmosphere), and the exhaustion was afterwards continued gradually until it fell to 0·0065 mm., 8·6 **M**. In commencing each set of experiments the deflection of a tangent-galvanometer was observed when the battery was short-circuited. By a table previously calculated the value of the deflection in ohms of resistance per cell could be read off; this, multiplied by 11,000, gave the total resistance of the battery; the tube was then connected with the terminals and the galvanometer again observed; this gave a less deflection and indicated a greater resistance, which, multiplied by 11,000, gave the total resistance of the tube and battery: by subtracting the resistance of the battery the resistance of the tube was ascertained. Calling the total resistance R, the tube resistance r, the tube-potential V, $V = \frac{r \times 11{,}000}{R}$. The tube-potential requisite to produce a discharge, with a pressure of 46,710 **M**, was found to be 10,250 cells; this gradually fell until

[1] "Experimental Researches on the Electric Discharge with the Chloride of Silver Battery," by Warren De La Rue, M.A., D.C.L., F.R.S., and Hugo W. Müller, Ph.D., F.R.S. (*Phil. Trans.*, vol. clxxi. p. 65).

a pressure of 0·642 mm., 1,082 M, was reached, the tube-potential being then only 430 cells, after which it rapidly rose, and, at 8·6 M, it required a potential of 8,937 cells to produce a discharge. From the experiments described

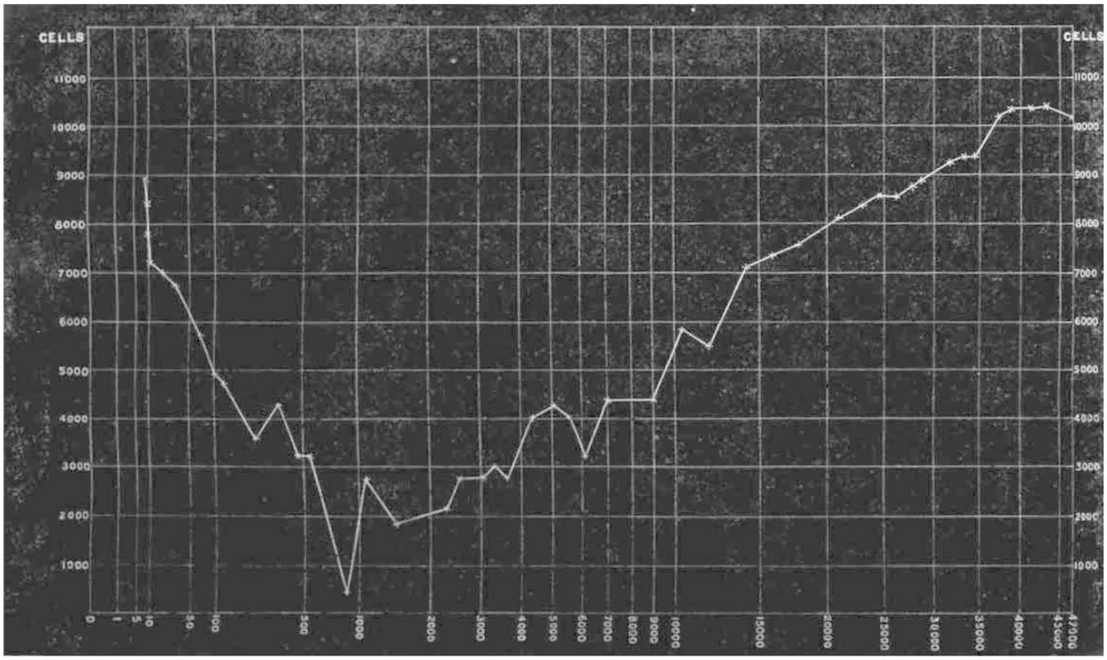

DIAGRAM I.

in a previous paper it was found that, in another tube, it required the full potential of 11,000 cells to produce a discharge at 3 M, and that, at 18 M, this potential was insufficient. The obstruction to the discharge in tube

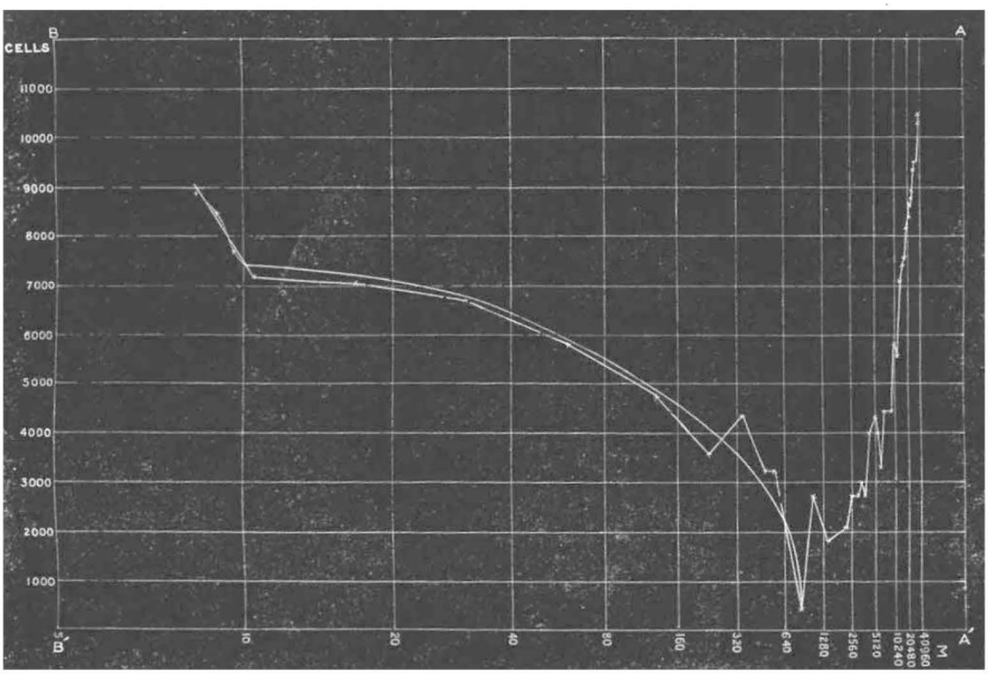

DIAGRAM II.

A—B represents an assumed mean distance of the molecules at a pressure of 5 millionths of an atmosphere. A' to 10, A' to 20, ... A' to 40960, the corresponding distances at pressures 10, 20, 40960 millionths.

162 was as great at 8·6 M as at 28,553 M pressure, and required 8,950 cells in each case.

The diagram (No. I.) laid down from the results when the ring was made positive, shows the curve of the observations as actually obtained without being smoothed. The figure is a reduction to $\frac{1}{35}$ of the original; the abscissæ are as the cube-roots of the various pressures in millionths of an atmosphere, and show relatively the number of molecules in a given linear space; the ordinates are as the number of cells.

The observations were again plotted down as in Diagram No. II., making the abscissæ in the inverse ratio of the cube-roots of the various pressures in millionths, so as to represent relatively the mean distance of the molecules at the various pressures in millionths of an atmosphere; this has the effect of extending the scale for decreasing pressures beyond the minimum resistance of the tube, and of compressing it on the opposite side for increasing pressures.

The following tables show the number of cells necessary to produce a discharge for various pressures in millionths of an atmosphere:—

Pressure.	V. Cells.	V. Increase per 1,000 M.
M		cells.
845	430	
1,000	1,000	
1,500	1,780	1,190
2,000	2,190	
		590
3,000	2,780	
		475
4,000	3,230	
		430
5,000	3,660	
		370
6,000	4,030	
		350
7,000	4,380	
		370
8,000	4,750	
		320
9,000	5,070	
		310
10,000	5,380	
		330
11,000	5,710	
		320
12,000	6,030	
		320
13,000	6,350	
		280
14,000	6,630	
		270
15,000	6,900	
		260
16,000	7,160	
		240
17,000	7,430	
		230
18,000	7,630	
		210
19,000	7,840	
		180
20,000	8,000	
		180
21,000	8,180	
		160
22,000	8,340	
		150
23,000	8,490	

Pressure.	V. Cells.	V. Increase per 1,000 M.
M		cells.
23,000	8,490	
		140
24,000	8,630	
		170
25,000	8,800	
		160
26,000	8,960	
		140
27,000	9,100	
		150
28,000	9,250	
		140
29,000	9,390	
		140
30,000	9,530	
		120
31,000	9,650	
		120
32,000	9,770	
		110
33,000	9,880	
		100
34,000	9,980	
		90
35,000	10,070	
		80
36,000	10,150	
		80
37,000	10,230	
		70
38,000	10,300	
		60
39,000	10,360	
		60
40,000	10,420	
		55
41,000	10,475	
		45
42,000	10,520	
		30
43,000	10,550	
		30
44,000	10,580	
		10
45,000	10,590	
		10
46,000	10,600	
		0
47,000	10,600	

Pressure.	V. Cells.	V. Decrease per 10 M increase.
M		cells.
8	9,600	
		11,400
9	8,460	
		9,600
10	7,500	
		420
20	7,080	
		358
30	6,722	
		332
40	6,390	
		300
50	6,090	
		270
60	5,820	
		195
70	5,625	
		180
80	5 445	
		165
90	5,280	

Pressure	V. Cells.	V. Decrease per 10 M increase.
M		cells.
90	5,280	
		135
100	5,145	
		94·5
200	4,200	
		60
300	3,600	
		48
400	3,120	
		45
500	2,670	
		39
600	2,280	
		45
700	1,830	
		51
800	1,320	} 16
900		
1,000	1,000	

An experiment was made in order to ascertain whether there was either any condensation or dilatation of the gas in contiguity with the terminals before the actual passage of the discharge. In order to do this an apparatus was constructed, as shown in Fig. 1.

It consists of a glass cylinder, 4·35 inside diameter, the depth of which is accurately the same in every part, 1·6 inch, so as to insure the parallelism of two glass disks which close its ends. Its cubical contents exclusive of the terminals was found to be 385 cub. centims.

These are held in contact with the ends of the cylinder by means of screw-clamps made of ebonite, and the whole apparatus is supported on a tripod ebonite stand, which is fastened to a square wooden foot. Attached parallel to the top and bottom glass disks, by means of flanged-screw rods, are two brass disks with rounded edges, 3·1 inches in diameter; these are maintained at a distance of 0·13 inch, 3·3 mm. at which the discharge of 11,000 cells would only just take place.

The ends which project through the glass disks are furnished with binding-screws for attaching wires from the battery.

On the side of the cylinder is a tubulure in which is fitted a gauge containing strong sulphuric acid, so as to dry the inside of the apparatus, and to indicate whether any condensation or dilatation of the gas contained in the cylinder occurs on connecting the metallic disks with the battery by means of the contact-key. The edges of the cylinder were rubbed with grease, and care was taken to prove that the apparatus was perfectly tight by causing the fluid in the limb of the gauge to stand for some time higher than that in the bulb. When connection was made with a battery of 9,800 cells, there was not the slightest indication of any alteration of volume of the contained air, so that there was neither condensation about the disks which would have caused a contraction, nor repulsion from the disks which would have caused an expansion of volume. The fluid in the stem was observed with a lens, but not the slightest motion of it took place. The same result was noticed even when water was substituted for sulphuric acid. So far, then, as this apparatus would indicate it, the result is entirely negative.

Potential necessary to produce a discharge between disks 1·5 inch diameter at a constant distance and at various pressures

The experiments were made by placing the micrometer-discharger, shown in Fig. 2, under the bell-jar of an air pump to which was attached a gauge about 36 inches long in order to indicate the pressure of the contained gas. In the first instance the disks were adjusted to the striking-distance at atmospheric pressure for the battery of 11,000 cells. Afterwards a less number of cells was connected with the disks and the bell-jar gradually exhausted until the discharge occurred; the height of the mercury in the gauge was then read off. Then a less and less number of cells was connected with the disks and the operation was repeated.

In air the discharge took place at ordinary atmospheric pressure with 11,000 cells when the disks were 0·13 inch, 3·3 mm. distant, and with 600 cells at an average pressure of 10 mm.

In hydrogen it took place at atmospheric pressure with 11,000 cells when the disks were 0·22 inch, 5·59 mm. distant; and with 600 cells at an average of 14 mm. pressure.

In carbonic acid, at atmospheric pressure with 11,000 cells, when the disks were 0·122 inch, 3·096 mm. distant; and with 600 cells at an average pressure of 5·2 mm.

The numbers obtained for air, hydrogen, and carbonic acid respectively were plotted down on millimetre scale paper, the abscissæ being 1 mm. = 2,500 **M**, the ordinates 1 mm. = 25 cells, and curves drawn to give a mean of the several observations. These appeared to resemble hyperbolic curves so closely that true hyperbolic curves were found partly by a geometric construction, partly by computation, which would intersect the mean experimental curves in two points. The results of experiment were again laid down on these new curves, and it was found that they did not differ more from them than they did from each other.

The ratio of the transverse axis (pressure) to the conjugate axis (potential) of the hyperbolas set out on the above-mentioned scale was—

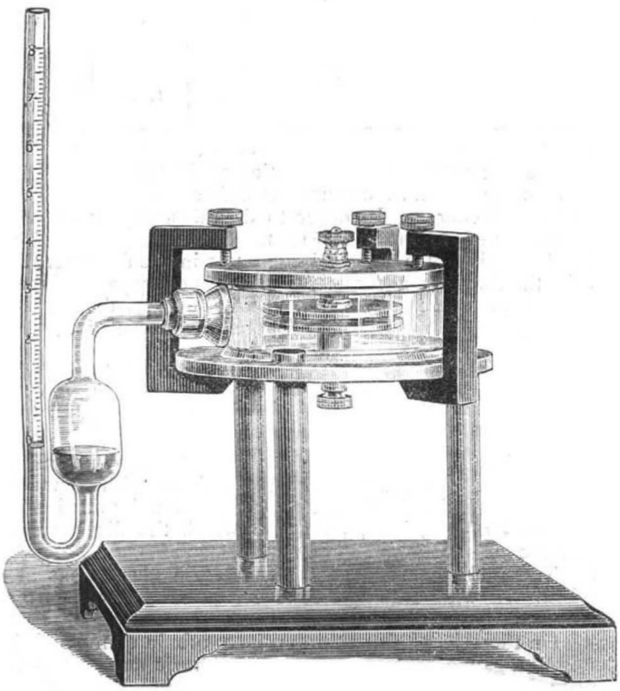

FIG. 1.

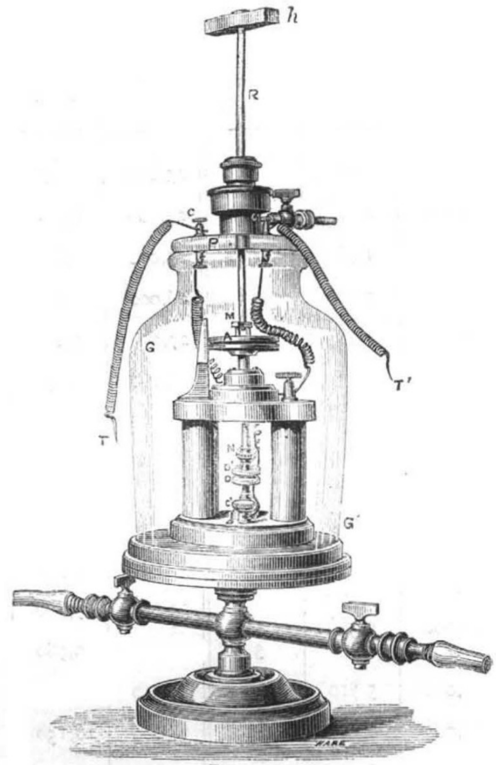

FIG. 2.

For air	0·9665
,, hydrogen	1·0170
,, carbonic acid	1·0690

The striking distances at atmospheric pressure for spherical surfaces 3 inches radius and 1·5 inch diameter, with various potentials, as given in Part I. page 68, curve VIII. and at page 118, also those for nearly flat surfaces in pages 73 and 118, were reduced to millimetres distance and plotted down in the same way, but not on precisely the same scale as the preceding curves for constant distance and various pressures. Hyperbolic curves were also found which intersected the experimental curves in two points.

It was seen in the case of spherical surfaces, the result having been obtained as the average of a great number of experiments, that the hyperbola coincided closely with the observations, while for plane surfaces, for which only a few experiments were made, the coincidences were not quite so perfect. Nevertheless, it would appear that the law of the hyperbola holds equally well for a constant pressure and varying distance as it does for a constant distance and varying pressure; the obstacle in the way of a discharge being up to a certain point as the number of molecules intervening between the terminals.[1]

In the two cases of spherical and plane surfaces the ratio between the transverse (distance) and conjugate (potential) axes of the respective hyperbolas was—

For spherical surfaces	1·240
,, disks	1·285

With the data already published in Part I., the authors have laid down a fresh curve for the striking distance

[1] Dr. Alexander Macfarlane has published in the *Transactions* of the Royal Society of Edinburgh, 1878, vol. xxvii., an elaborate and careful research of the "Disruptive Discharge of Electricity" in air and different gases, and between terminals of various forms. An abstract of this paper will be found in NATURE, vol. xix. pp. 184, 185. Dr. Macfarlane used a Holtz machine and employed higher potentials than those we used: he found that the results for the discharge between two disks 4 inches in diameter at various distances up to 1·2 centims. and with various pressures were satisfactorily represented by the hyperbola.

between flat disks on a scale of 10 centims. for a millimetre and 5 centims. to 1,000 cells.

From the curve thus laid down the following numbers were deduced :—

EMF in volts.	Striking distance in centimetres.	Difference of potential per centimetre.	Intensity of force.	
			Electro-magnetic.	Electro-static.
		volts.		
1,000	0·0205	48,770	$4\cdot88 \times 10^{12}$	163
2,000	0·0430	46,500	4·65 ,,	155
3,000	0·0660	45,450	4·55 ,,	152
4,000	0·0914	43,770	4·38 ,,	146
5,000	0·1176	42,510	4·25 ,,	142
6,000	0·1473	40,740	4·07 ,,	136
7,000	0·1800	38,890	3·89 ,,	130
8,000	0·2146	37,280	3·73 ,,	124
9,000	0·2495	36,070	3·61 ,,	120
10,000	0·2863	34,920	3·49 ,,	116
11,000	0·3245	33,900	3·39 ,,	113
11,309	0·3378	33,460	3·35 ,,	112

The remainder of the paper is chiefly occupied with the study of the phenomena of the electric arc under various conditions of distance, pressure, and potential; the results obtained support the view that the arc and the stratified discharge are merely modifications of the same phenomenon.

(*To be continued.*)

A FOURTH STATE OF MATTER [1]

IN introducing the discussion on Mr. Spottiswoode and Mr. Moulton's paper on the "Sensitive State of Vacuum Discharges," at the meeting of the Royal Society on April 15, Dr. De La Rue, who occupied the chair, good-naturedly challenged me to substantiate my statement that there is such a thing as a fourth or ultra-gaseous state of matter.

I had no time then to enter fully into the subject; nor was I prepared, on the spur of the moment, to marshal all the facts and reasons which have led me to this conclusion. But as I find that many other scientific men besides Dr. De La Rue are in doubt as to whether matter has been shown to exist in a state beyond that of gas, I will now endeavour to substantiate my position.

I will commence by explaining what seems to me to be the constitution of matter in its three states of solid, liquid, and gas.

I. First as to Solids:—These are composed of discontinuous molecules, separated from each other by a space which is relatively large—possibly enormous—in comparison with the diameter of the central nucleus we call *molecule*. These molecules, themselves built up of *atoms*, are governed by certain forces. Two of these forces I will here refer to—attraction and motion. Attraction when exerted at sensible distances is known as *gravitation*, but when the distances are molecular it is called *adhesion* and *cohesion*. Attraction appears to be independent of absolute temperature; it increases as the distance between the molecules diminishes; and were there no other counteracting force the result would be a mass of molecules in actual contact, with no molecular movement whatever—a state of things beyond our conception—a state, too, which would probably result in the creation of something that, according to our present views, would not be *matter*.

This force of cohesion is counterbalanced by the movements of the individual molecules themselves, movements varying directly with the temperature, increasing and diminishing in amplitude as the temperature rises and falls. The molecules in solids do not travel from one part to another, but possess adhesion and retain fixity of position about their centres of oscillation. Matter, as we know it, has so high an absolute temperature that the movements of the molecules are large in comparison with their diameter, for the mass must be able to bear a reduction of temperature of nearly 300° C. before the amplitude of the molecular excursions would vanish.

The state of solidity, therefore—the state which we are in the habit of considering *par excellence* as that of *matter* —is merely the effect on our senses of the motion of the discrete molecules among themselves.

Solids exist of all consistences, from the hardest metal, the most elastic crystal, down to thinnest jelly. A perfect solid would have no viscosity, *i.e.*, when rendered discontinuous or divided by the forcible passage of a harder solid, it would not close up behind and again become continuous.

In solid bodies the cohesion varies according to some unknown factor which we call chemical constitution; hence each kind of solid matter requires raising to a different temperature before the oscillating molecules lose their fixed position with reference to one another. At this point, varying in different bodies through a very wide range of temperature, the solid becomes liquid.

II. In liquids the force of cohesion is very much reduced, and the adhesion or the fixity of position of the centres of oscillation of the molecules is destroyed. When artificially heated, the inter-molecular movements increase in proportion as the temperature rises, until at last cohesion is broken down, and the molecules fly off into space with enormous velocities.

Liquids possess the property of viscosity—that is to say, they offer a certain opposition to the passage of solid bodies; at the same time they cannot permanently resist such opposition, however slight, if continuously applied. Liquids vary in consistency from the hard, brittle, apparently solid pitch to the lightest and most ethereal liquid capable of existing at any particular temperature.

The state of liquidity, therefore, is due to inter-molecular motions of a larger and more tumultuous character than those which characterise the solid state.

III. In gases the molecules fly about in every conceivable direction, with constant collisions and enormous and constantly varying velocities, and their mean free path is sufficiently great to release them from the force of adhesion. Being free to move, the molecules exert pressure in all directions, and were it not for gravitation they would fly off into space. The gaseous state remains so long as the collisions continue to be almost infinite in number, and of inconceivable irregularity. The state of gaseity, therefore, is pre-eminently a state dependent on collisions. A given space contains millions of millions of molecules in rapid movement in all directions, each molecule having millions of encounters in a second. In such a case the length of the mean free path of the molecules is exceedingly small compared with the dimensions of the containing vessel, and the properties which constitute the ordinary gaseous state of matter, which depend upon constant collisions, are observed.

What, then, are these molecules? Take a single lone molecule in space. Is it solid, liquid, or gas? Solid it cannot be, because the idea of solidity involves certain properties which are absent in the isolated molecule. In fact, an isolated molecule is an inconceivable entity, whether we try, like Newton, to visualise it as a little hard spherical body, or, with Boscovich and Faraday, to regard it as a centre of force, or accept Sir William Thomson's vortex atom. But if the individual molecule is not solid, *à fortiori* it cannot be regarded as a liquid or gas, for these states are even more due to inter-molecular collisions than is the solid state. The individual mole-

[1] "On a Fourth State of Matter," in a letter to the Secretary of the Royal Society. By W. Crookes, F.R.S.