

perimented with; as this form of electricity was the key to the other different forms, the latter would never have been discovered.

When rarefied by the air pump to a quarter of the normal pressure, the insulting qualities of air are not so good, and when reduced to a pressure of 10 or 20 millimetres it is a good conductor and exhibits the phenomena referred to before. As this is about the limit attainable by an ordinary air pump, it is very natural that experimenters became possessed of the idea stated above, that the conductivity of the air would keep on increasing as the exhaustion proceeded, but after the Sprengel mercurial air pump was invented, by which the air can be exhausted to a thousandth of a millimetre of mercurial pressure (which is about equivalent to one-millionth part of ordinary atmospheric pressure), it was found that the capacity of the air to show the auroral phenomena in the usual way ceased.

The electric current then behaves in a very different manner, as it radiates in straight lines and cannot turn corners, so that when the tubes are bent it gives occasion to very striking and novel phenomena, which were first brought forward by Prof. Crookes in the tubes which are known by his name.

The difference between the Geissler tubes and the Crookes tubes is, that in the first the vacuum is very imperfect. In the Crookes tubes it is about a thousand times better, while if we succeed in making the vacuum a million times better, the conductivity of the air ceases absolutely. To accomplish this we must aid the function of the Sprengel air pump by some chemical device which will remove the last remnant of air. It then becomes an absolute non-conductor, which ordinary atmospheric air is not, because it is possible to pass currents of high tension in the form of an electric spark through the densest and driest air. In the absolute vacuum, however, it is impossible to pass, over the space of a quarter inch, a spark which, when leaping through the air, will be six or more inches long.

I exhibit here such a tube, in which the two platinum wires are brought together within a distance of scarcely a quarter inch. In this tube a vacuum did exist so perfect that it was impossible to pass a spark through, which through air would leap over a distance of more than six inches. I found that the spark would rather pass over the outside of the tube for that distance than go through the interior. In order to satisfy myself that no trace of electricity passed through the interior space of an quarter inch, I connected one of the platinum wires with a Leyden jar, wound a brass chain half way around the middle part of the tube, and connected this brass chain with the ground, in order to prevent any electricity from reaching the Leyden jar through the air along the outside, but I was not able to obtain the least trace of a charge in the Leyden jar. Later I increased the strength of the current more and more, until at last something happened in the tube which destroyed the vacuum; something volatilised, covering the sides of the glass interior with a blackish deposit, which may perhaps be platinum black, a thing which may not be impossible, if we consider that the electric discharge furnishes us the highest temperature which we can possibly produce by any means.

For more than 20 years I have preached this non-conductibility of a perfect vacuum, as it was proved by experiments with the Ruhmkorff coil, by de la Rive and Du Moucel. The latter describes the experiments in his book "Sur l'appareil d'induction de Ruhmkorff," published in Paris about 25 years ago.

It has not a little surprised me that the priority of this discovery is so remote as I found it to be, and that so important a fact as that of the non-conducting power of a perfect vacuum has been overlooked and ignored for nearly a century after it

was proved by experiment. I found in the *Philosophical Transactions* for 1785, page 272, vol. 75, the extract of a paper read by Morgan before the Royal Society, and which I published eight years ago in the *Practical American*, which I edited at the time. The paper referred to states that a mercurial gauge 15 inches long, filled with pure mercury which was boiled in the glass until all air was expelled, was coated with tin-foil 5 inches down from its sealed end, and was inverted into the mercury in a little trough, through a perforation in its brass cap; the air over the mercury in the trough was then exhausted when the mercury in the gauge fell down more or less in proportion to this exhaustion, but had always a perfect vacuum over it. If then the tin-foil coating the upper end of the tube was connected with the conductor of an electric machine, not the smallest ray of light nor the slightest charge could be produced in this exhausted gauge; but if the mercury had been imperfectly boiled, coloured luminous phenomena were seen. The same was the case when the sealed end of a perfectly exhausted tube became cracked so that a little air had access. At first the electric charge passed with a yellow or green light; more air made the colour a beautiful green, then blue, from blue to indigo; more air still, violet and purple, until the medium became so dense as to no longer conduct electricity. The writer closes with the observation:—"I think there can be little doubt, from the above experiments, of the non-conductive power of a perfect vacuum. This seems to prove that there is a limit even in the rarefaction of air, which sets bounds to its conducting power; or, in other words, that the particles of air may be so far separated from each other as no longer to be able to transmit electricity; that if they are brought to within a certain distance of each other, their conducting power begins, and continually increases, till their approach also arrives at the limit."

It is also a fact, known for more than a century by expert barometer makers, that the luminosity which shows itself in the dark in its vacuum, when a barometer is moved up or down in order to cause the mercurial column to oscillate in the same way, is only seen when the mercury has been boiled in the tube to a moderate degree; when the vacuum is made too perfect it shows itself feebly, or not at all, the same as is the case when the vacuum is contaminated with watery vapours.

So much for facts; now for the theory which explains them, and for which we are indebted to Prof. Crookes. It gives us an inside view of the nature of matter in the conditions in which it presents itself to us, and is based on the theory of Dalton, that all matter consists of an immense number of infinitesimal particles, called atoms, which are indestructible, and in continual motion, which latter is also indestructible.

Astronomy teaches that in the planetary system we find a condition of things which is far beyond our ordinary conception based on our experience about things falling under the daily, immediate observation of our senses. First, the distances at which the celestial objects are placed are immense in proportion to their size, stupendous as it appears to us. Secondly, they are in a continuous motion, which is indestructible. Every planetary system is to us a perfect "perpetuum mobile."

Modern chemistry teaches the same doctrine in regard to ultimate atoms, which constitute that which we call matter. First, the distances of these atoms are also very large, in proportion to their size, which is infinitesimally small beyond our conception; secondly, these small particles or atoms are also in a continuous everlasting motion, as indestructible as is the motion of the planetary bodies.