VIII. *On the Electrical phenomena exhibited in vacuo.* By Sir Humphry Davy, *Bart. P. R. S.*

Read December 20, 1821.

The production of heat and light by electrical discharges: the manner in which chemical attractions are produced, destroyed, or modified by changes in the electrical states of bodies: and the late important discovery of the connection of magnetism with electricity, have opened an extensive field of enquiry in physical science, and have rendered investigations concerning the nature of electricity and the laws by which it is governed, and the properties that it communicates to bodies, much more interesting than at any former period of the history of philosophy.

Is electricity a subtile elastic fluid? or are electrical effects merely the exhibition of the attractive powers of the particles of bodies? Are heat and light elements of electricity, or merely the effects of its action? Is magnetism identical with electricity, or an independent agent, put into motion or activity by electricity?—Queries of this kind might be considerably multiplied, and stated in more precise and various forms: the solution of them, it must be allowed, is of the highest importance; and though some persons have undertaken to answer them in the most positive manner, yet there are, I believe, few sagacious reasoners, who think that our present data are sufficient to enable us to decide on such very abstruse and difficult parts of corpuscular philosophy.

It appeared to me an object of considerable moment, and one intimately connected with all these queries, *the relations of electricity to space, as nearly void of matter as it can be made on the surface of the earth;* and, in consequence, I undertook some experiments on the subject.

It is well known to the Fellows of this Society who have considered the subject of electricity, that Mr. WALSH believed that the electrical light was not producible in a perfect torricellian vacuum; and that Mr. MORGAN drew the same inference from his researches; and likewise concluded that such a vacuum prevented the charging of coated glass.—Now it is well known, that in the most perfect vacuum that can be made in the torricellian tube, vapour of mercury, though of extremely small density, exists; I could not help, therefore, entertaining a doubt as to the perfect accuracy of these results, and I resolved not only to examine them experimentally, but likewise, by using a comparatively fixed metal in fusion for making the vacuum, to exclude, as far as was possible, the presence of any volatile matter.

The apparatus that I employed was extremely simple, [Pl. V.] and consisted of a curved glass tube with one leg closed, and longer than the other. In this closed leg a wire of platinum was hermetically cemented, for the purpose of transmitting the electricity: or to ascertain the power of the vacuum to receive a charge, it was coated with foil of tin or platinum. The open end, when the closed leg had been filled with mercury or any other metal, was exhausted either by being placed under the receiver, or connected with the stopcock of an excellent air pump; and in some cases, to ensure

greater accuracy, the exhaustion was made after the tube and apparatus had been filled with hydrogene.*

Operating in this way, it was easy to procure a vacuum either of a large or small size, for the rarefied air or gas could be made to balance a column of fluid metal of any length, from 20 inches to the 20th of an inch, and by using only a small quantity of metal, it could be more easily purged of air.

I shall first mention the results I obtained with quicksilver. I found that by using recently distilled quicksilver in the tubes, and boiling it in vacuo six or seven times from the top to the bottom, and from the bottom to the top, making it vibrate repeatedly by striking it with a small piece of wood, a column was obtained in the tube free from the smallest particle of air; but a phenomenon occurred, in discovering the cause of which I had a great deal of trouble. When I used a short tube of four or five inches long only, I found, that after continued boiling and much agitation of the mercury, though there was no appearance of elastic matter, when the mercury adhered strongly in the upper part of the tube, yet that, after electrization, or even on suffering the mercury to pass slowly back into the closed part, a minute globular space sometimes appeared: I thought at first that this was air, which, though so highly rarefied, as it must have been by the exhaustion, adhered to the mercury; and I endeavoured by long boiling the mercury in an exhausted *double* syphon, and making the vacuum in one of the curves, to prevent entirely the presence of air: but the phenomenon always occurred when there was no strong adhesion of the mercury

* The figure will best explain the form of the apparatus.

to the glass. This, and another circumstance, namely, that when the leg in which the torricellian vacuum was made was 15 or 16 inches long, the phenomenon was very rarely perceptible, and always disappeared when the tube was inverted, and the mercury made to strike the top with some force, led me to conclude that the minute space was really filled with the vapour of mercury; the attraction of the particles of the fluid mercury for each other preventing their actual contact with the glass, except when this contact was forcibly made by mechanical means; and I soon proved that this was the case: for by causing the mercury, when its column was short, to descend into the more perfect from the less perfect vacuum, with more or less velocity, I could make the space more or less, or cause its disappearance altogether, in which last case the cohesion between the mercury and the glass was always extremely strong.

I found that in all cases when the mercurial vacuum was perfect, it was permeable to electricity, and was rendered luminous by either the common spark, or the shock from a Leyden jar, and the coated glass surrounding it became charged; but the degree of intensity of these phenomena depended upon the temperature: when the tube was very hot, the electric light appeared in the vapour of a bright green colour, and of great density; as the temperature diminished, it lost its vividness; and when it was artificially cooled to 20° below zero of FAHRENHEIT, it was so faint as to require considerable darkness to be perceptible.

The charge likewise communicated to the tin or platinum foil was higher the higher the temperature; which, like the other phenomenon, must depend upon the different density of

the vapour of mercury; and at 0° FAHRENHEIT it was very feeble indeed.

A very beautiful phenomenon occurred in boiling the mercury in the exhausted tube, which showed the great brilliancy of the electrical light in pure dense vapour of mercury. In the formation and condensation of the globules of mercurial vapour, the electricity produced by the friction of the mercury against the glass, was discharged through the vapour with sparks so bright as to be visible in day light.

In all cases when the minutest quantity of rare air was introduced into the mercurial vacuum, the colour of the light produced by the passage of the electricity changed from green to sea green; and, by increasing the quantity, to blue and purple; and when the temperature was low, the vacuum became a much better conductor.

I tried to get rid of a portion of the mercurial vapour, by using a difficultly fusible amalgam of mercury and tin, which was made to crystallize by cooling in the tube; but the results were precisely the same as when pure mercury was used.

I tried to make a vacuum above the fusible alloy of bismuth; but I found it so liable to oxidate and dirt the tube, that I soon renounced farther attempts of this kind.

On a vacuum above fused tin I made a number of experiments; and by using freshly cut pieces of grain tin, and fusing them in a tube made void after being filled with hydrogene, and by long continued heat and agitation, I had a column of fused tin which appeared entirely free from gas: yet the vacuum made above this, exhibited the same phenomena as the mercurial vacuum. At temperatures below 0°, the light was yellow, and of the palest phosphorescent kind,

requiring almost absolute darkness to be perceived; and it was not perceptibly increased by heat.

I made two experiments on electrical and magnetic repulsions and attractions in the mercurial vacuum, by attaching to the platinum wire two fine wires in one case of platinum, in the other of steel, terminated by minute spherules of the same metals: I found that they repelled each other when the wire was electrified in the most perfect mercurial vacuum, as they would have done in usual cases; and the steel globules were as obedient to the magnet as in the air; which last result it was easy to anticipate.

In some of the first of these experiments, I used a wire for connecting the metal with the stop-cock; but latterly, the rarefied air or gas was the only chain of communication; and this circumstance enabled me to ascertain that the feebleness of the light in the more perfect vacuum was not owing merely to a smaller quantity of electricity passing through it, for the same discharge which produced a faint green light in the upper part of the tube, produced a bright purple light in the lower part, and a strong spark in the atmosphere.

The boiling point of pure olive oil is not much below that of mercury; and the butter or chloride of antimony (antimonane) boils at about 388° FAHRENHEIT. I tried both these substances in the vacuum, and found, as might be expected, that the light produced by the electricity passing through the vapour of the chloride was much more brilliant than that produced by it in passing through the vapour of the oil; and in the last it was more brilliant than in the vapour of mercury at common temperatures: the lights were of different colours, being of a pure white in the vapour of the chloride,

and of a red, inclined to purple, in that of the oil; and in both cases permanent elastic fluid was produced by its transmission.

The law of the diminution of the density of vapours by diminution of temperature, has not been accurately ascertained; but I have no doubt, from the experiments of Mr. DALTON, and some I have made myself, that it is represented by a geometrical progression; the decrements of temperature being in arithmetical progression; and in three pure fluids that I operated upon,* the ratio seemed nearly uniform for the same number of degrees below the boiling point; and (taking intervals of 20 degrees of temperature) .369416. Upon this datum, and considering the boiling points of mercury to be 600°, that of oil 540°, that of the chloride of antimony 340°, and that of tin 5000° all above 52°, and the elastic force of vapour of water at this temperature to be equal to raise by its pressure about .45 parts of an inch of mercury; the relative strengths of vapour will be, for mercury 000015615, for oil 0016819, for chloride of antimony 01692, and for tin 37015, preceded by 48 zeros.†

It is not known whether the vapour from solids follows a similar law of progression as that from fluids, and these numbers are only given to show how minute the quantity of matter must be in vapours where its effects are distinct upon electrical phenomena; and how much more minute it must be in the case of mercury artificially cooled; and almost beyond imagination so in vapours from substances requiring very elevated temperatures for their ebullition.

* Water, chloride of phosphorus, and alcohol or carburet of sulphur.

† I am obliged to CHARLES BABBAGE, Esq. F. R. S. for these calculations.

I made some comparative experiments to ascertain whether below the freezing point of water, the diminution of the temperature of the torricellian vacuum diminished its power of transmitting electricity, or of being rendered luminous by it. To about 20° this appeared to be the case; but between 20° above and 20° degrees below zero, the lowest temperature I could produce by pounded ice and muriate of lime, it seemed stationary; and as well as I could determine, the electrical phenomena were nearly of the same intensity as those produced in the vacuum above tin.

Unless the electrical machine was very active, no light was visible during the transmission of the electricity; but that this transmission took place, was evident from the luminous appearance of the rarefied air in the other parts of the syphon, and from the diminution of the repulsion of the ball of the quadrant electrometer attached to the prime conductor. When the machine was in great activity, there was a pale phosphorescent light above, and a spark on the mercury below, and brilliant light in the common vacuum. A Leyden jar *weakly* charged could not be made to transmit its electricity by explosion through the cooled torricellian vacuum, but this electricity was slowly dissipated through it; and when *strongly* charged, the spark passed through nearly as much space as in common air, and with a light visible in the shade. At all temperatures below 200°, the mercurial vacuum was a much worse conductor than highly rarefied air: and when the tube containing it was included in the exhausted receiver, its temperature being about 50°, the spark passed through a distance six times greater in the Boylean than in the mercurial vacuum.

It is evident from these general results that the light (and

probably the heat) generated in electrical discharges depends *principally* on some properties or substances belonging to the ponderable matter through which it passes; but they prove likewise that space, where there is no appreciable quantity of *this matter, is capable of exhibiting* electrical phenomena: and, under this point of view, they are favourable to the idea of the phænomena of electricity being produced by a highly subtile fluid or fluids, of which the particles are repulsive, with respect to each other, and attractive of the particles of other matter. On such an abstruse question, however, there can be no demonstrative evidence. It may be assumed, as in the hypothesis of HOOKE, HUYGENS, and EULER, that an ethereal matter, susceptible of electrical affections, fills all space; or that the positive and negative electrical states, may increase the force of vapour from the substances in which they exist; and there is a fact in favour of this last idea which I have often witnessed—when the voltaic discharge is made in the Boylean vacuum, either from platinum or charcoal, in contact with mercury, the discharging surfaces require to be brought very near in the first instance; but the electricity may be afterwards made to pass to considerable distances through the vapour generated from the mercury or charcoal by its agency;—and when two surfaces of highly fixed metal, such as platinum or iron are used, the discharge will pass only through a very small distance, and cannot be permanently kept up.

The circumstance, that the intensity of the electrical light in the mercurial vacuum diminishes as it is cooled to a certain point, when the vapour must be of almost infinitely small density, and is then stationary, seems strongly opposed to the idea, that it is owing to any *permanent* vapour emitted

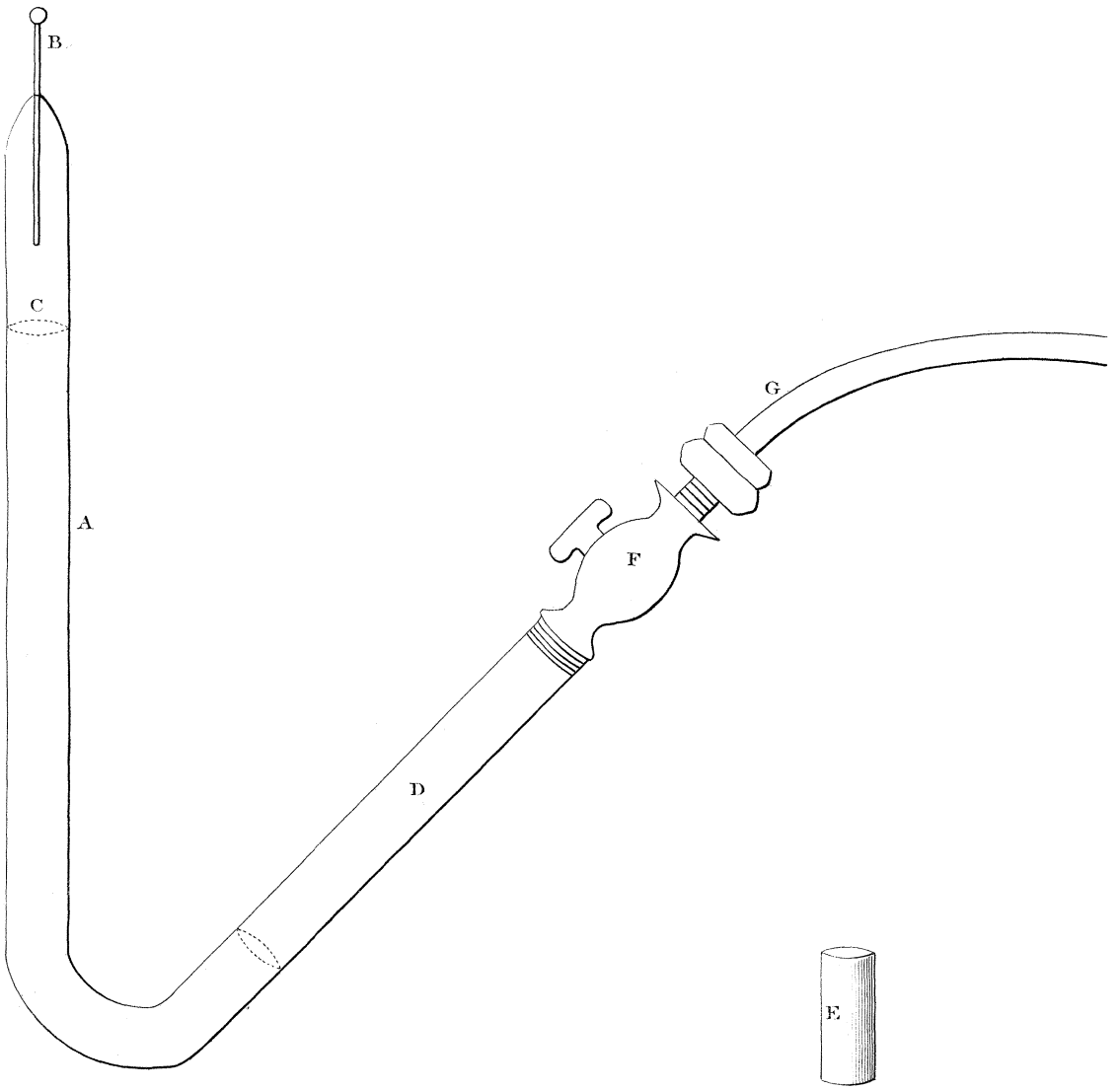
constantly by the mercury. The results with tin must be regarded as more equivocal; because as this substance cannot be boiled in vacuo, it may be always suspected to have emitted a small quantity of the rare air or gas to which it has been exposed; yet, supposing this circumstance, such gas must be at least as highly expanded as the vapour from cooled mercury, and can hardly be supposed capable of affording the dense light, which the passage of the electricity of the charged Leyden phial through the vacuum produces.

When the intense heat produced by electricity is considered, and the strong attractive powers of differently electrified surfaces, and the rapidity of the changes of state, it does not seem at all improbable, that the superficial particles of bodies, which, when detached by the repulsive power of heat, form vapour, may be likewise detached by electrical powers, and that they may produce luminous appearances in a vacuum, free from all other matter by the annihilation of their opposite electrical states.

In common cases of electrical action, the quantity of the heat generated by the annihilation of the different electrical states depends, as I stated in my last communication to the Society, upon the nature of the matter on which it acts; and in cases when electrical sparks are taken in fluids, vapour or gas is always generated; and in elastic fluids, the intensity of the light is always greater, the denser the medium. The luminous appearances therefore, it is evident from all the statements, must be considered as secondary; whilst the uniform exertions of electrical attractions and repulsions, under all circumstances, in rare and dense media and in vacuo, and with respect to solids, fluids, and gases, point them out (whe-

ther they be specific affections of a subtile imponderable fluid, or peculiar properties of matter) as primary and invariable electrical phenomena.

I have mentioned in the last page the suspicion, that melted tin may contain air. I shall conclude this paper by stating the grounds of this suspicion, and noticing a circumstance which appears to be of considerable importance, both in relation to the construction of barometers and thermometers, and to the analysis of gaseous bodies. Recently distilled mercury that has been afterwards boiled and cooled in the atmosphere, and which presents a perfectly smooth surface in a barometer tube, emits air when strongly heated in vacuo, and that in quantities sufficient to cover the whole interior of the tube with globules; and on keeping the stop-cock of one of the tubes used in the experiments on the mercurial vacuum open for some hours, it was found that the lower stratum of mercury had imbibed air, for when heated in vacuo, it emitted it distinctly from a space of a quarter of an inch of the column; smaller quantities were disengaged from the next part of the column; and its production ceased at about an inch high in the tube. There is great reason to believe, that this air exists in mercury in the same invisible state as in water, that is distributed through its pores; and the fact shows the necessity of long boiling the mercury in barometer and thermometer tubes, and the propriety of exposing as small a surface of the mercury as possible to the air. It may explain, likewise, the difference of the heights of the mercury in different barometers; and seems to indicate the propriety of reboiling the mercury in these instruments after a certain lapse of time.


B
C
A
G
F
D
E

EXPLANATION OF THE PLATE.

PLATE V.

A. The tube, of the usual diameter.

B. The wire for communicating electricity.

E. A small cylinder of metallic foil, to place as a cap on tubes not having the wire B, to make a coated surface.

C. The surface of the quicksilver, or fused tin.

D. The part of the tube to be exhausted by the stop-cock F, after being filled by means of the same stop-cock, when necessary, with hydrogene.

G. The moveable tube connected with the air-pump.

It is evident, that by introducing more mercury, the leg D may be filled with mercury, and the stop-cock closed upon it, so as to leave only a torricellian vacuum in the tube, in which the mercury may be boiled. I have found that the experiment tried in this way, offers no difference of result.