VIII. "On the Heat which is developed at the Poles of a Voltaic Battery during the passage of Luminous Discharges in Air and in Vacuo." By JOHN P. GASSIOT, F.R.S. Received June 12, 1861.

1. When the wires attached to the terminal plates of an extended series of a voltaic battery are brought into contact with each other, the circuit of the battery is completed; and if in this state the ends of the wires are separated from each other, the usual luminous or arc-discharge is produced, the length of the arc depending on the number of the cells of which the battery consists. If this luminous discharge is continued for a few seconds, the metallic positive pole or anode becomes red-hot, and will ultimately be fused, while the negative remains comparatively cool. This experiment was originally described by me in the 'Philosophical Magazine' of December 1838, p. 436. In the same periodical of June 1840, p. 478, Mr. Grove suggested as an explanation, that this effect "might be due to the interposed medium, and that, were there any analogy between the state assumed by voltaic electrodes in elastic media and that which they assumed in electrolytes, it would follow that the chemical action in the positive electrode in atmospheric air would be more violent than at the negative, and that, if the chemical action were more violent, the heat would necessarily be more intense."

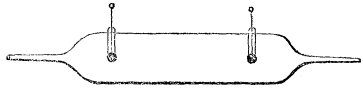
2. Since that time I am not aware that any other explanation relative to the heating of the positive pole of the voltaic battery has been published. Mr. Grove merely gives it as a suggestion; but as it is immaterial whether either or both poles are of copper, aluminium, platinum, or any other metal, or of coke, as in either case it is the positive that is heated, the phenomenon cannot arise from any effect of oxidation, but must be due to some action in the battery circuit hitherto unexplained.

3. In the Bakerian Lecture for 1858, I have stated that, "when the discharge from an induction coil is taken in air or in vacuo with thin platinum wires, the negative terminal becomes red-hot, and if the discharges are continued the wire will be fused." This heating of the negative terminal, provided the wires are thin, always takes place whatever may be the length of the discharge or the medium through which it passes.

4. That this heating of the negative terminal in the discharge from an induction coil had some intimate relation to the heating of the positive pole of the voltaic battery was very probable; but why in the one case the heat should be evolved at the negative, and in the other at the positive terminal, appeared extraordinary and well worth further investigation. The result of the experiments I have made with this object forms the subject of the present communication.

5. After verifying the fact that the heating of the negative terminal of an induction coil is always obtained either in a carbonic acid vacuum, in rarefied gases, or in air, provided the terminal wire is thin, but not if thick, I proceeded to examine with greater precision than formerly the nature and character of the luminous discharges in vacuo as obtained from my water-battery, as well as from the 400 insulated cells of the nitric-acid battery (Proceedings, March 15, 1860); and for this object I had several small vacuum-tubes constructed, about 3 inches long and 1 inch diameter; in each of these, two metallic or carbon balls, about $\frac{1}{8}$ of an inch in diameter, were attached to the platinum wires, hermetically sealed in the tube about one inch apart.

Fig. 1.

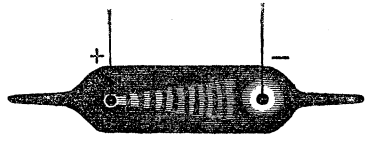


Each wire is protected by a glass tube as far as the ball; the vacuum is obtained by means of carbonic acid absorbed by caustic potassa, as described in my former communications.

6. The discharges in these tubes from an induction coil or from my water-battery present nearly the same appearance, viz. a brilliant luminosity surrounding the negative ball, generally without (fig. 2), but sometimes with (fig. 3) a minute stratified discharge from the positive.

Fig. 2.

Fig. 3.



7. When the vacuum-tube is introduced into the circuit of 400 insulated cells of the nitric-acid battery, the discharge at first always

assumes the form represented in fig. 2. This discharge, as well as those from the induction coil and the water-battery, when examined, is found to be very perceptibly intermittent, and will generally continue for some time after the circuit has been completed. As the action of the battery improves, *the luminous glow round the negative metallic ball gradually increases in size*, and in a few seconds the ball becomes red-hot. This result I repeatedly obtained; and in two instances with tubes in which balls of aluminium, $\frac{1}{4}$ inch diameter, had been inserted, the negative dropped from the wire into the tube in a molten state, but leaving the positive ball with its original metallic lustre.

Fig. 4.

8. The preceding experiments, so far from assisting me in explaining the cause of the heating of the positive pole of the voltaic battery, rather tended to complicate the inquiry; for experiment now showed that in carbonic acid vacua the heating effect was elicited at the negative pole, whether the discharge was made from a voltaic battery or form an induction coil; but as experiment also showed that heat is always evolved from the latter at the negative, whether in air or in vacuo, and that from the battery it always in air appears at the positive, it was evident the media through which discharges were made afforded no explanation for the elucidation of a phenomenon of which hitherto the more it was examined by experiment the more difficult appeared the solution.

9. My next experiments were made in vacuum-tubes in which balls of carbon were inserted in lieu of metal. With these I at first obtained the usual heating of the negative, but in one instance I observed that both balls were at the same time exhibiting red heat; in this instance, either from some alteration having taken place in the vacuum, or from some other cause which I had not time to examine, the discharge from the carbon balls became so uncertain as to afford me little information worth recording, except as to the fact I have stated of both balls being heated: the cause of this I was subsequently enabled to determine.

10. In two of the vacuum-tubes hollow brass balls had been attached to the platinum wires. In the first of these the negative very

soon became heated by the discharge. As the discharge of the battery continued, a sudden flash of light was visible in the vacuum, and the glass instantly became coated with metal. On examining the tube, I ascertained that one-half of the negative ball was separated from the other, and partly fused: the intense heat had vaporized the silver with which the two hemispheres forming the ball had been soldered, and it was this vaporized metal that was deposited on the sides of the tube. The positive ball remained much tarnished, as if it had also been heated.

11. I then introduced the second tube, having similar hollow brass balls, into the circuit of the battery. In this tube the negative also was at first heated to redness; when in this state, a sudden brilliant stratified discharge took place, as fig. 5.

Fig. 5.

The evolution of nitrous acid fumes in the battery denoted its intense action. This discharge from the battery continued for about two seconds, *the negative ball instantly losing its luminosity, the positive becoming red-hot.*

12. This experiment appeared to offer an explanation as to the cause of the heating of the poles; but on attempting to repeat it, the tube was unfortunately fractured by the heating of the platinum wire, as were also two tubes with coke balls: the result I had obtained was, however, too interesting to me not to repeat the experiment; and I had six vacuum-tubes prepared, each of the same dimensions as already described, two with coke balls, two with iron, and two with copper, all solid: the best and most conclusive results were obtained with the copper. The experiments which I now proceed to describe were made on the 27th of last May, in the presence of the Rev. Dr. Robinson and Professor Stokes.

13. In the first tube the negative ball very soon became red-hot, when suddenly the brilliant, clearly defined, conical stratified discharge as in fig. 5 appeared, continuing for three or four seconds. On breaking the circuit of the battery, we ascertained that the negative ball, or that attached to the zinc terminal of the battery, had, as before, entirely lost its heated appearance, while the positive, or that attached

to the platinum end of the battery, remained at a dull red heat, which it retained for two or three seconds after the circuit of the battery had been broken.

14. A second tube with copper balls was then introduced into the battery circuit; in this I also obtained the usual luminous negative glow discharge surrounding the ball attached to the zinc terminal of the battery; this glow, as before, gradually enlarged, and in a few seconds the ball became red-hot; the circuit of the battery was then instantly broken, the negative ball retaining its red heat for several seconds. In this experiment it will be observed that the circuit of the battery was broken before the sudden brilliant discharge, previously described, had appeared. These results fully confirmed my original experiment (11) of the alternate heating of the positive and negative terminals of the voltaic battery, when the discharge is made in vacuo.

15. The result of my previous experiment (11) having been thus confirmed, the explanation of those that preceded it became easy of solution. When both coke terminals (9) were heated to redness, the continuous or arc discharge had only lasted for an instant, evolving heat at the positive terminal; but the negative during this short interval retained the luminosity it had previously acquired, and consequently at the time of the disruption of the circuit, both coke terminal balls exhibited red heat. Again, in the first experiment with the brass balls (10), the arc discharge was also only momentary, a disruption of the circuit having been caused by the partial fusion of the negative ball; but the duration of this discharge was sufficient to tarnish the positive terminal; while with balls of aluminium (7), a metal that fuses at a very low temperature, the negative was melted by the heat evolved in the intermittent discharge; and we ascertain that under this condition the positive terminal is in no way affected, for the metal retained its original lustre.

16. The voltaic discharge of a battery of 400 insulated cells, charged with nitric and sulphuric acid, when observed in these vacuum-tubes, at first assumes precisely the same appearance as that of one of nearly 4000 cells charged with rain-water, as it is also similar to that of the discharge from an induction coil (fig. 2); but the action of the nitric acid so far differs from that of the water-battery, that while the discharge of the latter will remain for several weeks (or until the water in some of the cells has evaporated) of nearly the same form

and appearance (figs. 2 or 3), the discharge from the nitric-acid battery quickly alters: as the action of the battery improves, the glow round the negative terminal enlarges, heat in that portion of the tube is sensibly developed, as can be ascertained by touching the tube with the hand, and in a few seconds the negative ball becomes red-hot. During this time no apparent sign of chemical action takes place in the cells of the battery; the heating effect appears to be mainly due to the elevation of tension; for if the copper wires attached to the terminals rest on gold-leaf electroscopes, the leaves continue expanded until the arc discharge takes place, when they instantly collapse, and heat is evolved at the positive terminal.

17. In vacuo, as long as the intermittent discharge continues, resistance apparently takes place at the negative terminal; and this is not only evinced by the heat which is evolved, but by the disruption of the metal which is separated from this pole in minute particles, and deposited in a lateral direction on the sides of the vacuum-tube.

18. As soon as the action of the battery becomes sufficiently energetic, so as to cause the continuous or arc discharge to pass, an entirely new effect is developed: the discharge itself becomes intensely vivid, the stratifications assume a conical form with their apex directed towards the negative (fig. 5), and heat is instantly perceptible at the positive terminal, while the negative as instantly cools.

19. It is beautiful and interesting to observe the suddenness with which the red heat of the negative terminal ball disappears, and the equal suddenness with which the heat is at the same instant elicited in the positive, when the brilliant arc discharge takes place.

From the results obtained by these experiments, I infer that the development of heat, either at the positive or the negative pole of a voltaic battery, is entirely due to the amount of resistance which takes place in that part of the battery circuit.

Fig. 2.

Fig. 3.

Fig. 5.