The Electrification of a Steam-jet

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Dr. Walmsley asked for what value of the magnetizing force the permeability of the iron mentioned in the beginning of the paper was determined; to which Mr. Tomlinson replied that they were much smaller than the earth's horizontal component.

XLII. *The Electrification of a Steam-jet.*

By SHELFORD BIDWELL, M.A., F.R.S.*

THE boiler used in these experiments consists of a small tin bottle capable of holding about fifteen fluid ounces, which is supported upon a tripod above a Bunsen burner. Its neck is fitted with a cork, through which passes a glass tube $\frac{5}{16}$ in. in diameter, terminating in a nozzle with an opening of about $\frac{1}{16}$ in. At a point four inches above the cork, the tube is bent to an angle of 100 or 110 degrees, and the nozzle may be formed at a distance of five or six inches from the bend. In this case its direction will, of course, be nearly horizontal. When it is desired to have a vertical nozzle, the tube is again bent in an upright direction at a distance of not less than five inches from the first angle, the nozzle terminating two or three inches above the second bend. The nozzle is made by simply drawing out the tube to a point in a flame, and cutting off its end at the proper place.

I have given these dimensions in detail, not, of course, because they are absolutely the best possible, but in order that anyone who wishes to repeat the experiment may be enabled to obtain good results without trouble. The object aimed at is to keep the tube as free as possible from water, whether arising from ebullition or from condensation, so that the jet of steam may be regular and uniform; at the same time, it is essential that the end of the nozzle from which the steam issues should not be directly above the gas-burner, or the experiment cannot succeed.

The tin bottle is charged with four ounces of water, and when it boils the burner is adjusted until the steam-jet is as

* Read December 6, 1889.

vigorous as is possible consistently with steadiness ; if the ebullition is too violent, the water thrown up into the tube will produce jerks, masking the effect to be looked for.

The jet is most conveniently observed by means of its shadow projected upon a white screen. For this purpose a lime-light is desirable, but any good source of light may be employed. The shadow of the jet will be seen to be of feeble intensity and of a neutral tint ; the jet is, in fact, nearly transparent, and does not appear to exercise any selective absorption upon the light. If now a sharp point, or, better, a small bundle of points, in connexion with one of the terminals of an influence-machine (such as a Voss), is brought near the base of the jet, the machine being worked slowly, a startling change instantly comes over the shadow. It becomes dark and dense, at the same time assuming a marked orange-brown tint. By removing the point, or simply connecting it to earth, the shadow can be immediately caused to resume its original appearance, again becoming almost invisible. This operation may be repeated as often as desired, one of the most remarkable things about it being the extreme rapidity with which the changes are produced.

The point need not necessarily be directed to the origin of the jet ; it is nearly as effective when placed in the steam at a distance of a foot or more from the nozzle ; and in such a case the *whole* of the steam-jet is equally acted upon from its origin onwards, even when the direction of the point is the same as that of the jet. A ball may be used instead of a point, but it operates only when actually within the jet, whereas a point may be outside it. The effect may also be produced by directing the jet upon an electrified metal disk, supported at a considerable distance from the nozzle.

I have examined the absorption-spectrum of the steam-jet. When the jet is not electrified, its action upon the spectrum is small, the intensity of the whole being slightly diminished in an apparently equal degree throughout. Possibly the violet is dimmed in a somewhat greater proportion than the other colours. Electrification of the jet causes the violet to disappear completely, while the luminosity of the blue and the more refrangible part of the green is materially decreased. The orange and red are, I believe, quite unaffected.

From these facts it may be concluded that electrification causes an increase in the size of the water particles contained in the steam-jet. In the unelectrified condition the majority of these particles are small in relation to a wave-length of light; under the influence of electrification they become larger, and attain a diameter of something like a fifty-thousandth part of an inch.

The idea naturally suggests itself that the phenomenon may be of the same nature as that observed by Lord Rayleigh in the case of water-jets*. A stream of water issuing in a nearly vertical jet from a small orifice is found to break up into separate drops at a certain distance above the orifice. Under ordinary conditions these drops collide with one another, and, again rebounding, become scattered over a considerable space. But when subjected to the influence of an electrified body, as a rubbed stick of sealing-wax, brought near the point of resolution, the colliding drops no longer rebound but coalesce, and the entire stream of water, both ascending and descending, appears to become coherent. Now it seems to me certain that the innumerable minute particles of water generated in the steam-jet, each consisting perhaps of only a few molecules, must necessarily come into frequent collision with one another; for we cannot suppose that they all travel with equal velocities and in exactly the same direction; and there is no reason why they should not behave just in the same manner as the larger drops of the water-jet, rebounding when they are not electrified, coalescing into larger drops when they are. It is true that the degree of electrification required to produce the phenomenon in the case of the steam-jet is apparently much greater than in the other, a rubbed stick of sealing-wax being altogether inoperative. Perhaps this is a consequence of the different sizes of the drops in the two cases. That the actual electrification of the particles in the steam-jet is really very small indeed, is proved by the fact that if two electrified steam clouds are generated in close proximity to each other, they exhibit little, if any, evidence of mutual repulsion when they are similarly electrified, or of attraction when their electrifications are of the opposite kind.

* Proc. Roy. Soc. 1879.

Lord Rayleigh shows cause for believing that if the electrifications of the drops in the water-jet were strictly equal, the phenomenon in question would not occur; and the reasons why they are not, in fact, equal would just as well apply to the case of the steam-jet. How unequal charges of electricity of the same name are operative in bringing about coalescence Lord Rayleigh does not explain, nor am I prepared to hazard a conjecture on the point.

Lord Rayleigh concludes his paper by referring to the importance of the investigation from a meteorological point of view. I may do the same. It seems certain that the steam-jet experiments go far towards explaining the cause of the intense darkness which is characteristic of thunder-clouds, as well as of the lurid yellow light by which that darkness is frequently tempered.

I had made the above described experiments and drawn the above stated conclusions concerning them, and had just requested the Secretary of the Physical Society to accept the present communication, when Prof. Silvanus Thompson, whose knowledge of scientific history is proverbially encyclopædic, was good enough to bring to my notice the fact that experiments upon the electrification of a steam-jet had been recently made in Germany by the late Robert Helmholtz. An account of these experiments, which are of the greatest interest, is given in Wiedemann's *Annalen*, vol. xxxii. p. 1. The author appears never to have examined his jets by transmitted light, and makes no mention of the marvellous increase of opacity under electrification, to which I have called attention. His observations were all made against a *dark* background, the illuminating beam of light coming obliquely from the front, but shaded from the eyes. When the jet is electrified, he says, it is at once seen more clearly and sharply against the background; it also assumes diffraction colours, like those seen in strata of fog. Very strong electrification produces a deep blue colour, indicating the formation of very small mist drops. On slowly diminishing the electrification the blue tint at first becomes gradually paler, which points to the formation of larger drops; and it is then succeeded by tints of purple, red, yellow, green, and finally, when the discharge is very feeble, by pale blue tones again. Under

certain circumstances all these several tints may be seen at once in different portions of the jet.

I, too, had observed these diffraction colours, which were sometimes very beautiful; but having convinced myself that they undoubtedly occurred at times when no electrical influence (that I knew of) was operating, I did not follow up the observation.

Helmholtz found that these condensation phenomena could be just as well produced by some other causes as by electrification, and especially by the agency of flame. All the exciting causes in question involve some continuous chemical action inside the steam-jet. He conjectures, therefore, that the sudden condensation may be due to molecular tremors or shocks, which upset the unstable equilibrium of the super-saturated vapour, just as a small disturbance will sometimes cause the sudden crystallization of a supersaturated saline solution; and after showing that chemical reactions may occur freely even outside the visible portion of a flame, he states his opinion that similar dissociations and recombinations take place among the molecules of the air affected by an electric discharge, as evidenced, for instance, by the formation of ozone.

A very striking illustration of the effect of combustion is afforded by holding beneath the jet a piece of burning touch-paper, made by soaking blotting-paper in a solution of nitrate of lead. The jet at once becomes quite as opaque as if electrical influence were employed, and the same hissing noise is also heard. The burning touch-paper suggested itself as more convenient than the actual flames used by Helmholtz for the purpose; for these cannot be brought underneath the jet without causing its immediate dissipation; and it is therefore necessary to hold them on one side, and direct their heated gases upon the jet by blowing or fanning.

After reading Helmholtz's paper it naturally occurred to me to try the effect of combustion upon the water-jet. In this case the objection to the use of an actual flame does not, of course, apply. I therefore introduced the flame of a Bunsen burner into the jet, and found that, if the air-holes were stopped up, and the flame thus rendered luminous, a decided effect was produced upon the jet. Often, indeed, it became just as completely coherent throughout its length as if it were electrified, though I have not yet succeeded in

obtaining this result with perfect certainty ; but in every case when the burner was held a little below the point of resolution, a considerable diminution of the scattering was observed. If the air-holes were opened and the flame made non-luminous, it failed to act in any way whatever upon the jet. It is to be remarked that Helmholtz found certain non-luminous flames (of which, however, a gas-flame was not one) to be devoid of influence upon the steam-jet.

Can the effect here also be due to electrification? It can hardly be attributable to heating, because the flame of a Bunsen burner is certainly hotter when it is non-luminous than when it is luminous. On the other hand, it is known from many experiments that flame is electrified. If, for example, we place a luminous flame between the positive and negative ball-terminals of a Voss machine in action (the terminals being too far apart for sparks to pass), we find that the flame, or at least the upper part of it, is repelled by the positive and attracted by the negative ball. This seems to denote positive electrification of the flame.

In conclusion, it should be mentioned that Helmholtz suggests another hypothesis as an alternative to that of molecular shock, though he does not appear to attach much importance to it. It is that the electrical discharge, the flame or other exciting agent, whatever it may be, acts by introducing into the steam-jet minute particles of solid matter which serve as nuclei upon which the water-vapour may condense, as in Aitken's experiments on the formation of fog.

It is possible that several different causes may be competent to produce the condensation phenomena.

Prof. Rücker said Mr. Bidwell had no doubt considered the question, but he should like to ask him whether he thought the behaviour of the jet when the burning paper was held under it might not be due to a lowering of its surface-tension. Though the length at which a liquid cylinder becomes unstable is independent of the tension, the rate at which the transformation into drops takes place depends on it, and thus the distance from the orifice at which discontinuity is established would vary with the state of the surface.

Mr. Richardson inquired whether a red-hot iron had any effect.

Dr. Fison said he had made experiments on the electrification of flame, and found that potentials varying from + 2 volts to $-1\frac{1}{2}$ volt could be obtained in the region within and surrounding a Bunsen-flame.

Prof. S. P. Thompson commented on the contrast between Mr. Bidwell's experiments and those of Dr. Lodge on the dissipation of fogs by electricity, and also asked whether the colour of the jet depended on the length of spark produced by the machine.

Prof. Forbes thought a crucial test between the two hypotheses of Helmholtz could be obtained by trying the experiment in a germless globe.

The President said he had recently noticed that gas-flames were electrified.

Mr. Bidwell, in reply, said that since writing the paper it had occurred to him that the effect of flame upon the water-jet might possibly be due rather to the introduction of dirt into the stream than to electrification, Lord Rayleigh having observed that scattering did not occur if a little soap or milk were added to the water. He thought that the colour assumed by the electrified steam-jet appeared generally to be independent of the sparking-distance. He had not tried whether a red-hot iron produced any effect.

XLIII. *On the Behaviour of Steel under Mechanical Stress.* By C. A. CARUS-WILSON, B.A., A.M.I.C.E., Demonstrator in the Mechanical Laboratory at the Royal Indian Engineering College, Coopers Hill*.

[Plates IX.-XI.]

THE effect of uniform longitudinal stress on a steel bar is threefold :—

- (i.) The molecules are strained.
- (ii.) The elements are strained.
- (iii.) In virtue of the straining of the elements "flow" is produced.

The strain usually observed is the elongation due to flow, which may be recoverable or irrecoverable. The strains of an element can be shown to be a uniform dilatation combined

* Read December 6, 1889.