

XVIII.—*On the Colour of Steam under certain circumstances.* By JAMES D. FORBES, Esq., F.R.S.S.L. & Ed., Professor of Natural Philosophy in the University of Edinburgh.

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IN the end of May, or beginning of June last, I happened to stand near a locomotive engine on the Greenwich Railway, which was discharging a vast quantity of high-pressure steam by its safety-valve. I chanced to look at the sun through the ascending column of vapour, and was struck by seeing it of a very deep orange-red colour, exactly similar to that of dense smoke, or the colour imparted to the sun when viewed through a common smoked glass.

I did not pay much attention to the fact at the moment, nor attempt to vary the experiment; but, reflecting on it afterwards, it seemed to me not only as in itself very singular, but as still more extraordinary, because I had never heard of a property of steam which must have been witnessed by thousands of persons. Some months after (in the end of October), being on the Newcastle and Carlisle Railway, I resolved to verify the fact, which I had no difficulty in doing, and I farther discovered a very important modification of it. For some feet or yards from the safety-valve at which the steam blows off, its colour for transmitted light is the deep orange-red I have described.* At a greater distance, however, the steam being more fully condensed, the effect entirely ceases. Even at moderate thicknesses, the steam-cloud is absolutely opaque to the direct solar rays; the shadow it throws being as black as that of a dense body, and when the thickness is very small, it is translucent, but *absolutely* colourless, just like thin clouds passing over the sun, which have, indeed, a perfect analogy of structure. When the steam is in this state, no indication of colour is perceptible in passing from the thickness corresponding to translucency, to that which is absolutely opaque.

Having made these observations, which were all that the circumstances enabled me to accomplish, I was very anxious to verify them under steam of various pressures, and to determine the following, amongst other points. (1.) Whether steam, in its purely gaseous form, is really, as commonly supposed, colourless; (2.) Whether the colour depends on a stage in the process of condensation, and on that alone; (3.) What effect the tension of the steam has upon the phenomena.

But there was another inquiry which interested me much more than all these, which was, to examine how the spectrum was affected by the absorbent action of the steam, which appeared to leave the red and orange rays predominant. Judging

* The same may be observed, during the ordinary progress of the engine, in the steam thrown into the chimney, but the presence of smoke renders the experiment less satisfactory.

from the phenomena of absorption of light by gaseous bodies, and especially the singular action of nitrous acid gas in dividing the spectrum into a vast number of bands, discovered by Sir D. Brewster, I thought it by no means improbable that steam, acting in a similar manner, might exercise its specific action upon the prismatic colours at many points. Should this conjecture be confirmed, I also foresaw an application to the phenomena of the atmosphere and the production of the atmospheric lines of the solar spectrum, also remarked by Sir D. Brewster.

After various ineffectual attempts to obtain the requisite facilities, Mr Edington, of the Phoenix Iron Works at Glasgow, most kindly put at my disposition an excellent high pressure boiler, and farther afforded me every facility for prosecuting my experiments on the optical properties of steam. I first examined the simple phenomena of colour as seen by the naked eye. A lantern* was held behind a jet of steam, issuing from a stopcock in the top of the boiler, having a bore of $\frac{1}{4}$ inch. When the safety-valve (which acted with great promptness) was loaded with 50 lb. on the inch, the steam issued nearly invisible, and, at the small thickness of the jet in that part, perfectly colourless. As the light was raised, the orange colour appeared at a height of a few inches above the cock, and rapidly deepened up to a height of about 20 inches; after which it appeared that the rapid condensation of the steam only rendered it more opaque, without deepening its hue. At that height, therefore, I resolved to transmit the light, and to analyze it by a prism. A theodolite, and good prism in front of the telescope, were placed at a distance of about 25 feet in front of the boiler. Beyond the steam-cock a lantern, with a lens refracting parallel rays, was adjusted, and between the steam-cock and the prism a slit of variable width. The light, reaching the prism through the slit, must first pass through the column of steam at a height of about 20 inches from the orifice. To test the adjustment of the apparatus, and also for the purpose of contrast, I had provided a bottle, about five inches diameter, full of remarkably dense nitrous acid gas, which Mr Kemp was so good as to prepare. When this was placed where the steam was to issue, the appearance of the nitrous acid spectrum was magnificently displayed. I then removed the bottle, and opened the steam-cock gradually (the pressure on the safety-valve being 55 lb. above the atmosphere, or the tension of the steam $4\frac{2}{3}$ atmospheres.) The violet end of the spectrum was almost instantly absorbed, then the whole blue, and part of the green, just as in the nitrous acid spectrum, but *no lines were visible in the remaining part*. When the cock was fully opened, the spectrum exhibited a singular appearance. The bright red was the only part which seemed natural. The extreme red was slightly invaded by the opacity of the steam. Most of the orange, the yellow, and as much of the green as was not absorbed, had a dirty and disagreeable hue, which I described in a memorandum at the time

* The experiments were performed at night.

as "dingy, alternating between yellow and purple, with shades of green. When the steam had its highest pressure, there was a decidedly purple tinge." The appearance to the naked eye of the slit was now identically the colour of the nitrous acid gas, through which I from time to time viewed a distant gas flame, and compared it with the colour of the slit. The experiment was performed under 50 and 55 lb. many times over. The light examined was then caused to pass through the steam only 10 inches above the orifice of the stop-cock, under the idea that though the colour there was fainter, possibly there might be a tendency to develope lines in the spectrum. But the experiment being made under the same pressure as before, the effect was similar, only much less intense: the slit had now but a faint tawny colour, and prismatic analysis shewed the violet alone absorbed.

Steam blowing off at 25 lb. The lantern and slit 20 inches above orifice, as at first. To the eye the light appears as red as under 55lb. Mr Edington observed, that the colour is deeper than that of the nitrous acid gas bottle. Neither he nor his assistants ever observed the colour of steam before. Prismatic phenomena as before, only the obscuration not quite so great.

Steam blowing off at 15 lb. "Evidently redder than the gas bottle. Same phenomena of spectrum, but green remains pure throughout, and verges on (bounds immediately with) orange. During the absorption of violet before vanishing (the steam-cock being gradually opened), it assumes a dirty white colour, verging on yellow and purple." A common lamp was viewed through different parts of the column of steam of this pressure, from the orifice up to a height of five or six feet, and wherever it was not entirely obscured, it appeared of different shades of smoke colour, up to an intense tawny orange.

With 7 lb. on the inch, still visibly red to the eye: prismatic phenomena similar, but slighter.

With 4 lb., no longer visibly red to the eye, when arranged as above; and even with the prism the violet appears but little affected. When let off in large quantity from the safety-valve, and a lamp viewed through it, there is a faint redness close to the orifice, but every where above, the transition is from colourless translucency to complete opacity. At about 2 and 1 lb., no colour can be detected.

From these experiments I would deduce the following conclusions:

(1.) Steam in its purely gaseous form, is, as commonly supposed, colourless, at least at small thicknesses.

(2.) The orange-red colour of steam, by transmitted light, appears to be due to a particular stage of the condensing process. In the incipient state of condensation, steam is colourless and transparent; it is next transparent and smoke-coloured; finally it becomes colourless at small thicknesses, absolutely opaque at greater.

(3.) The state of tension of the steam seems only to affect the phenomenon in so far as it renders the critical colorific stage of condensation more or less completely observable.

(4.) The absorptive action of steam on the spectrum is not exerted in the same way as that of other gaseous coloured bodies, such as nitric acid gas and iodine vapour. It cuts off, however, totally the same part of the spectrum as nitrous acid does. Its phenomena perhaps have a greater analogy to those of opalescence than any other.

The effect of mere change of mechanical structure in altering the optical properties of bodies, is a phenomenon likely to give important information, both as to the constitution of matter, and the constitution of light; and the present observation may perhaps be one day received as a contribution towards a mechanical theory of vapour, including that most singular stage which intervenes between the gaseous and completely liquid form, and which is probably connected with the mechanical suspension of clouds. It is at all events very important to know that a portion of watery vapour confined in a close vessel, and subjected to change of temperature alone, without chemical change, is capable of undergoing the alterations of colour and transparency which have been adverted to. The singular fact noticed by Sir D. BREWSTER in the case of nitrous acid gas, whose colour deepens to an intense orange-red by the simple application of heat, seems to be a fact of the same kind.

I cannot doubt that the colour of watery vapour under certain conditions, is the principal or only cause of the red colour observed in clouds. The very fact that that colour only appears in the presence of clouds, is a sufficient refutation of the only explanation of the phenomena of sunset and sunrise having the least plausibility, given by optical writers. If the red light of the horizontal sky were simply complementary to the blue of a pure atmosphere, the sun ought to set red in the clearest weather, and then most of all. But experience shews that a lurid sunrise or sunset is *always* accompanied by clouds, and in a great majority of cases, when the changing state of previously transparent and colourless vapour may be inferred from the succeeding rain. In like manner terrestrial lights seen at a distance grow red and dim, when the atmosphere is filled with vapour soon to be precipitated. Analogy applied to the preceding observations would certainly conduct to a solution of such appearances; for I have remarked that the existence of vapour of high tension is by no means essential to the production of colour, though of course a proportionably greater thickness of the medium must be employed to produce a similar effect when the elasticity is small.

GLASGOW, 29th December 1838.