CLASSICS OF SCIENCE: Clausius on the Blue Sky

Physics

Scientific curiosity investigates the most commonplace as well as the rarest phenomena. The play of color in reflected light, to which Clausius refers, is seen beautifully in ordinary soap bubbles or in thin soap films made by dipping loops of wire into a strong soap solution. Note the order in which the colors appear as the film becomes thinner.

On the Blue Colour of the Sky and the Morning and Evening Red, by R. Clausius. From Poggendorff's Annalen, Vol. lxxvi, p. 188. *Translated by John Tyndall,* 1853.

BLUE SKY AND WHITE CLOUDS. Note how the color of the sky becomes paler toward the horizon. (*Photograph by A. G. Henry*)

Reflection by Water Particles

It is remarked, in the course of the foregoing paper, that the blue colour of the sky and the morning and evening red stand in close connexion with the reflexion of light in the atmosphere. Among many conjectures on this subject, the assumption that the reflexion takes place on minute bladders of water is often stated to be that which explains these phænomena most completely. For example, Newton says,—"The blue of the first order, though very faint and little, may possibly be the colour of some substances; and particularly the azure colour of the skies seems to be of this order. For all vapours, when they begin to condense and coalesce into small parcels, become first of that bigness, whereby such an azure must be reflected, before they can constitute clouds of other colours. And so, this being the first colour which vapours begin to reflect, it ought to be the colour of the finest and most transparent skies, in which vapours are not arrived to that grossness requisite to reflect other colours, as we find it is by experience."

Newton does not enter further into the matter, and it appears to me doubtful whether he had a clear view of the subject. When here, and still more plainly in another place, he says that water particles, when they increase in size, must produce clouds of different colours, in my opinion he is in error, as I shall show further on. It seems also as if by water particles he meant solid spheres instead of hollow vesicles, which supposition, according to the previous discussion, is not admissible.

After Newton, many investigators have given in their adherence to the supposition of vapour vesicles; but I find the theory nowhere mathematically developed, and it is by no means generally accepted. On the contrary, another mode of explanation, that for example of Brandes in Gehler's *Wörterbuch,* according to which the *particles of air* themselves reflect the blue light in a greater proportion than the red, seems to have obtained more general recognition than the other.

After the foregoing considerations, a few words upon this subject will doubtless appear justifiable.

As every vesicle of vapour consists of a filament of water curved spherically, if it be assumed as very thin in comparison with its diameter, it exerts upon a ray of light passing through it twice the influence that would be experienced by a ray in passing through a *plane* layer of water of the same thickness. We may therefore apply in this case the known theory of thin plates.

The Blue Color

Assuming, in the first place, the thickness of the plate as so inconsiderable that it exactly amounts to a quarter of an undulation of the extreme violet, and let the light be supposed to fall perpendicularly . . . the reflexion of these rays is thus the greatest possible. The other rays, on the contrary, will be the less reflected the greater their wave-lengths; and the mixture of all gives a whitish-blue. If the light falls obliquely on the same plate . . . the violet would no longer undergo its maximum reflexion, while the other circumstance would remain unchanged, that all the remaining rays would be still less reflected, the difference increasing as the wave-lengths diminish. The total light would be therefore weaker, but still blue.

This latter phænomenon must continually take place when the thickness of the plate is still less than that assumed above. The reflected light must appear as a darker and darker blue, until the plate becomes too thin to reflect light at all, a result which is obtained from the simple consideration of the rings of Newton, where blue is the first colour which surrounds the black centre.

Let us, on the contrary, suppose that the thickness of the plate becomes gradually greater than that assumed above, the violet will be more feebly reflected, and instead of it some other colour will undergo its maximum reflexion, and so the tint of the whole light will be changed. As the thickness increases we obtain the series of colours observed in Newton's rings, namely, blue, white, yellowish white, orange, red, violet, blue, &c.

This result must also find its application in the atmosphere, where vesicles of vapour take the place of the thin plates. Those vesicles which float in the air in serene weather must certainly be very thin; and if we assume that their thickness does not exceed the fourth part of an undulation of the violet light, the blue colour of the reflected light of the firmament would follow as a necessary consequence, and the clearer the air, that is, the finer the vesicles, the more deeply blue would it appear. (*Turn to next page*)

When, on the other hand, the air becomes more moist and the vesicles no longer possess the requisite fineness, it might be imagined that the firmament, instead of blue, ought to exhibit the other colours in their proper order. This, however, is not the case. When in moist weather the vesicles increase in thickness, new fine vesicles are in the act of forming at the same time, so that we never have a definite thickness for all, but at most a limit value, which does not exclude the smaller ones. When this limit is a little exceeded, then with a large quantity of blue we have a little white. As the thickness increases we have blue, white, yellowish-white, and again blue, white, yellowish-white, orange, etc. Hence new colours perpetually add themselves to those already present, and the mixture of all can only add to the original blue a more or less perfect white, by which the former obtains a milky appearance, and may slowly pass into white altogether.

With this the actual process in the atmosphere coincides most completely. Even in clear weather the sky towards the horizon generally appears whitish, for the eye thus directed, besides looking through a thicker mass of air, looks along the surface of the earth, where, at least at certain moist places, probably thicker vesicles are suspended than at greater elevations. As the air becomes moister the white expands and the whole appearance of the firmament becomes duller. In fogs and clouds the thickness of the bladders must be assumed to be much greater, but we must not therefore expect, as Newton did, that the clouds can produce, by reflexion, definite colours of a higher order, for it would be quite unnatural to suppose that the cloud is composed of vesicles all of the same thickness. On the contrary, we must expect here the greatest variety, so that clouds illuminated by white light must appear white, which is indeed the case.

We now pass over to the consideration of the *transmitted* light. As it is complementary to the reflected light, it follows that so far as it is sensible it must appear as orange. With regard to the quantity of the white light mixed along with it, however, an essential difference takes place. . . . so that the tint of the entire light must be very feeble. When the incidence is oblique the colouring indeed increases, but with great slowness. . . .

Orange Sunset Color

Fixing our attention on a vesicle of vapour, all possible angles of incidence are presented to us, but to the greatest and smallest angles, as is readily seen, comparatively small quantities of light belong, so that the medium angles are those to which the principal part belongs. But these produce but a very feeble tinting, and hence the *entire* light which passes through a vesicle must be but feebly coloured. Hence it is that the sun, when it stands high in heaven and the rays pass through a comparatively short length of atmosphere, appears white, particularly as we have no absolutely white beside it with which to compare it. When, on the contrary, the orb is near the horizon and has to transmit its light through numerous vesicles, the orange colour obtains a decided predominance.

Finally, the circumstance that at sunset not only the sun's disc but also a considerable portion of the horizon, and even clouds which float on high appear coloured orange, is easily explained without assuming that these colours are in the first place due to reflexion. As every object which appears white in white light, in orange light must appear orange, the same takes place on the horizon, which, as remarked above, appears whitish by day.

The explanation of the blue colour of the firmament and the morning and evening red, follow therefore from the assumption of vapour vesicles in the atmosphere, so naturally and simply, that on this account alone the above assumption ought, I think, to be regarded as probable. After having shown however in the foregoing paper that on other grounds the assumption is almost of necessity forced upon us, its easy applicability to the explanation of such grand phænomena furnishes a gratifying corroboration of the result arrived at.

Rudolf Julius Emmanuel Clausius was born in Koslin, Germany, January 2, 1822, and died in Bonn, August 24, 1888. His entire adult life was spent in the Universities of Germany, except for service at the head of a Bonn University ambulance corps during the Franco-German War. He was one of the great mathematical physicists of the nineteenth century. His greatest discovery, the formulation of the second law of thermodynamics, "Heat cannot of itself pass from a colder to a hotter body," was announced when he was 28 years of age.

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