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To cite this article: G. Bontemps (1849) LIV. Inquiries on some modifications in the colouring of glass by metallic oxides , Philosophical Magazine, 35:238, 439-446, DOI: [10.1080/14786444908646386](https://doi.org/10.1080/14786444908646386)

To link to this article: <http://dx.doi.org/10.1080/14786444908646386>



Published online: 30 Apr 2009.



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posite to the true sun; also a mock sun, G, situated 4° below the apex of the circle, BB, on the left-hand side.

0^h 33^m. The winged appearance is the only portion which now remains.

0^h 39^m. AA has just vanished.

During the whole of this phænomenon thin scud was flying rapidly over from the south, and the sky itself appeared of a muddy blue, owing to a thin veil of vapour (probably cirro-stratus) being interposed between us and the clear sky. Whilst this singular appearance lasted, a thin sprinkling of rain constantly fell. The sky became overcast at 0^h 45^m with south wind. Brilliant aurora borealis in the evening.

Villa, Beeston near Nottingham,
October 23, 1849.

LIV. *Inquiries on some modifications in the Colouring of Glass by Metallic Oxides.* By G. BONTEMPS*.

IN the presence of so many illustrious philosophers to whom the sciences are so much indebted, I must certainly apologize for my temerity in daring to call for a few minutes their attention to my humble observations; but if it is true that the greater part of the improvements in manufactures are the consequences of new scientific applications, it will be perhaps admitted that the observation of facts connected with manufactures has led to many new scientific discoveries; and I should feel happy if I could bring before you a few elements of new progress.

The revival of painted windows, and the manufacture of coloured flint-glass, first in Bohemia, and afterwards in all parts of Germany, in France and in England†, in an especial manner directed the attention of glass manufacturers, about fifteen years ago, to the colouring of glass by metallic oxides. They probably tried the receipts described in the works of Neri, Merret, Kunckel, Ferrand, Haudiquier de Blancourt, and many others, and they must frequently have met with failure; in that case their conclusion must have been, that the authors did not obtain the results which they announced. But the truth is, that they had not operated under *like circumstances*. In all cases those receipts had but an empirical value; chemistry was not yet a science; it was merely an agglomeration of facts without any co-ordination whatever; nor was natural philosophy better

* Communicated by the Author, having been read before the British Association at Birmingham, Sept. 1849.

† See Phil. Mag., vol. ix. p. 456.

able to explain the observed phænomena. In more modern times, by the aid of chemical science, we have been able to analyse the metallic oxides, and their various combinations with acids. By analogy, *glass* having been considered as a *salt* with simple or multiple bases, general *axioms* were admitted in the colouring of glass by metallic oxides. It is said, for instance, that the *silicates* of *potash* and of *soda* are *colourless*; the *silicate* of *potash* or *soda* and *manganese* is *purple*; the *silicate* of *potash* or *soda* and *cobalt* is *blue*; the *silicate* of *potash* and *deutoxide* of *copper* is *blue*; the *silicate* of *potash* and *protoxide* of *copper* is *red*; the *silicate* of *potash* and *gold* is *pink*, &c. Such axioms are quite sufficient for those who want only a superficial knowledge; but in entering more deeply into the investigation of the phænomena produced by the use of metallic oxides in glass-making, it will soon be acknowledged how fertile is the field of observations, and how incomplete is their explanation.

Allow me to mention some of the phænomena produced by a few metals; several of them will perhaps have for many persons the charm of new facts, although these metals are those most generally used for colouring glass.

1. *Iron.*

It is generally admitted that oxide of iron gives a greenish colour to glass to the mixture of which it has been added; but the truth is, that this colour is produced *only* in peculiar circumstances.

The manufacturers of china, porcelain and earthenware, are well-aware that oxide of iron is the colouring material of a fine *purplish-red* enamel fired in their muffle (and it is quite clear that *enamels* are real *glass*); if the temperature were raised too high, this enamel would lose its purplish tinge and tend towards *orange*; so that three colours of the spectrum are produced by oxide of iron, even at degrees of heat which I should call *low*, compared with the temperature of furnaces for glass melting, which we shall now consider.

If into a pot containing white melted glass or flint-glass we introduce during the blowing a small fragment of iron, it will, from its gravity, fall to the bottom; now, if after the blowing, this pot is taken out of the furnace, we shall see close to the fragment of iron partly oxidized, a portion of the glass coloured from *orange* to *yellow*. We have also an illustration of the *yellow* colour produced by oxide of iron in the manufacture of artificial *aventurine*. It is known that this *aventurine* is produced by the exposure of soft glass containing a large proportion of the oxides of copper and iron, to a tempera-

ture below its fusion: during this exposure the copper is reduced in the form of metallic crystals, and the glass being coloured only by oxide of iron, takes a *brownish-yellow* colour; and the greater the reduction of copper, the yellower is the glass.

Proceeding now to the usual circumstances of colouring glass by oxide of iron, we find that at a temperature not very high, for instance in covered pots for flint-glass, oxide of iron gives a *green* colour approaching nearer to yellow than to blue. It is generally by mixing oxide of iron with oxide of copper (giving blue) that all the tints of green are produced. The greenish colour of bottle-glass must also be attributed to the oxide of iron combined with the carbonaceous matters contained in the mixture. But when we melt at a high temperature, for instance in the manufacture of window-glass, we remark that the addition of a small proportion of oxide of iron to the mixture produces a glass of a *bluish* colour. It is known also by the manufacturers of bottle-glass, that when the glass is cooled in the pot, it becomes opaque *blue* before being devitrified.

We have shown by the preceding remarks that glass *receives all the colours of the spectrum from oxide of iron*; and at the same time, it will be observed that *these colours are produced in their natural order in proportion as the temperature is increased*.

2. *Manganese.*

It is generally known that oxide of manganese gives to glass a purple or pink colour, which property is used not only for the production of purple glass, but especially as *glass soap*, for neutralizing the light greenish colour produced by slight portions of iron and carbonaceous matters existing in the materials used in making white glass or flint-glass; but it is very remarkable, that the light pink colour given by oxide of manganese is very apt to fade: if the glass remains too long in the melting-furnace, and afterwards in the annealing kiln, the *purple* tinge turns first to a light *brownish-red*, then to *yellow*, and afterwards to *green*.

I shall mention also a remarkable fact relative to the presence of manganese in the composition of glass. White glass, in which a small proportion of manganese has been used, is liable to become yellow by exposure to light. Having melted for the celebrated Augustin Fresnel the glass for the first polyzonal lenses he made, and for which the whitest glass was desirable, these prismatic pieces of glass became *yellow* after a short time without losing their transparency and polish of

surface. I rightly attributed this colour to the presence of manganese; and, indeed, by suppressing the oxide of manganese in the mixture, this effect no longer took place. Besides, to prove that light had produced this colour, I took a prismatic ring recently made of glass containing manganese: I broke it into two pieces, one of which, exposed to light during a few weeks, became yellow; and the other, kept shut up in a drawer, was not at all altered in its whiteness.

It is also known that some window-panes, especially the Bohemian window-glass, take a light purple colour after having been a long time under the influence of light. The same effect is produced in window-glass or flint-glass containing a small proportion of manganese, when they remain in the flattening or annealing kilns long enough to produce incipient devitrification; in this case the interior of the glass becomes opaque white, whilst the outside takes a pink tint.

I admit that some of the facts of colouring which I have mentioned might be explained by reference to various degrees of oxidation, and that manganese, for instance, loses part of its oxygen when the glass passes from a purple to a yellow colour; but I doubt if this is sufficient to explain the phenomena which I shall call *photogenic*, which take place when the glass is in a solid state.

3. Copper.

Copper in its highest state of oxidation gives to glass quite free from iron a *sky-blue* colour, inclining more to green than to purple, and in its lowest state of oxidation imparts a *ruby* colour. In all times, as at the present day, red window-glass has always been coloured by protoxide of copper; but it is not very easy to obtain this colour, because it is not at all fixed; it must be seized at its proper time; and this production is the origin of a great many interesting and curious observations. When the red glass is in the proper state to be blown, if it is ladled into water so as to effect a sudden cooling, this produces *yellow-green* cullet; if this *yellowish* cullet is heated to the point of liquefaction and cooled slowly, the *red* colour will gradually show itself as the glass cools, becoming of the finest ruby, inclining more to *orange* than to purple: in some cases this colour is so delicate, that the cooling resulting from the usual process of manufacture prevents the manifestation of the red colour, and it is necessary to expose the manufactured piece of glass to the temperature of the annealing kiln, in which case the red colour is seen to increase gradually till it arrives at its greatest intensity: if the temperature of this kiln is too high, or if the ruby glass already

made is placed in a muffle too much fired, the bright *orange-red* colour turns first to *crimson-red*, then to *purple*; by a greater heat it takes a *bluish* tinge, and afterwards gets discoloured; it is therefore acknowledged that ruby glass must be exposed to the lowest temperature possible to obtain the brightest tints. From these observations we conclude that glass in which copper is kept in the state of protoxide by addition of tin or carbonaceous matters, is apt to *acquire successively all the colours of the spectrum*, under circumstances which do not appear to be the effect of modification by oxygen.

4. *Silver.*

Oxide of silver is seldom added to the mixtures which are to be melted in glass furnaces, but is generally used to stain glass of a transparent yellow, on the surface of which it is laid and fired. This colour is produced without any addition of *flux*; it is only necessary to lay on the surface of the glass or flint-glass a small proportion of oxide, or any salt of silver in a great state of division, mixed with a neutral medium, such as pounded clay or red oxide of iron, and to expose this glass to the heat of a muffle; the medium is afterwards taken off by brushing the surface of the glass, and the glass is stained of a yellow colour, which varies between *lemon* or *greenish-yellow* and dark *orange*, according to the quantity of silver, and especially to the quality of the glass; a *red* colour can even be produced by exposing the glass twice to the heat of the muffle. The celebrated Dumas has found by accurate analysis, that the glass which was liable to take the deep tints had its elements the nearest in definite proportions; which agrees with this observation, that the glass must have been deprived of all excess of alkali by a long melting at a high temperature, to take the deep tints of *orange* and *red*.

It is important not to heat the muffle to too high a temperature, otherwise the surface of the glass on which the silver has been laid becomes opalescent, although when seen through it still remains yellow or orange: the glass viewed obliquely reflects an opaque blue colour, and at a still higher temperature it is liable to appear of a *pink* colour when seen through, although the opacity of the surface is still increased, and becomes brownish-yellow.

If, instead of staining the glass in a muffle, silver added to a mixture of flint-glass is melted in covered pots in the shortest time possible, the result is an agatized semi-opaque matter, which, by the combined effects of refraction and reflexion, *will present all the colours of the spectrum*; this effect is most sensible, if the surface of the glass, which is generally yellowish-

green opaque, is cut to different depths. These effects are produced by inequalities of cooling, as we have seen for manganese and copper.

5. Gold.

Oxide of gold gives to the glass a pink tint, which by an increase of quantity may attain a *purplish-red*. For this purpose a small proportion of precipitated purple of Cassius is added to the mixture of flint-glass; but by the first melting this mixture gives only a colourless transparent glass, which must be heated again to show the pink colour. If, for instance, a small solid cylinder has been formed with this first melted glass, when cold it is quite white; but if this cylinder is afterwards exposed to the heat of the working-hole of the furnace, we see it acquire the red colour gradually as it is penetrated by heat; and this colour remains fixed when the cylinder is gradually cooled again in the annealing kiln.

I have remarked also, that by varying the degrees of heating a piece of this glass of some length at a high temperature, and re-cooling it several times, a great number of tints, varying from blue to pink, red, opaque yellow and green, may be produced. But I am not certain that this effect might not be attributed to some fractions of silver mixed with the gold used; and the only point that remains quite positive, is the fact of the pink colour *showing itself by a second firing* in the glass into the composition of which gold enters.

To these results of colouring by metallic oxides, I shall add an effect produced in the colouring of glass by charcoal, which effect is of the same nature as those mentioned in the colouring by copper and gold.

An excess of charcoal in the mixture of a silico-alkaline glass gives a yellow colour, which is not so bright as the yellow from silver, but good enough to be used in church windows; and sometimes, according to the nature of the wood from which the charcoal has been made and the time at which it has been cut, this yellow colour *may be turned to dark red by a second fire*.

I doubt, indeed, whether all the results which I have mentioned can be explained only by various degrees of oxidation of the metals. This multiplicity of colours, greater than the number of oxides described for each metal, must lead us to consider whether those phenomena are not the consequence of *physical laws*. It is the peculiar character of our time, and the result of the immense progress accomplished in chemistry and natural philosophy, to bring their study to some united views, which render the connexion of these two sciences indissoluble.

The various facts observed in the colouring of glass, which are especially produced by the influence of different temperatures, are probably to be *attributed to some modifications in the disposition of the composing particles*; which effects occasion modifications in the reflexion and refraction of the rays of light: indeed it might be remarked, that parts of the results which I have mentioned are *produced under some circumstances which appear to place the glass in a condition of crystallization.*

In the last century, Edward Hussy Delaval, starting from the experiments made by the immortal Newton in the colouring of thin plates, instituted some researches into the causes of the modifications of colours in bodies; but he found chemical science not in a state sufficiently advanced to establish his observations on rational experiments. But at the present time we have only to collect a sufficient number of precise facts to be able to deduce from them the scientific explanations, which might probably lead to some new improvements in manufactures.

As for glass, the observations relating to the constitution of its particles are extremely delicate. This is proved by the difference of the action of light on it, according to the degree of annealing. It is known that even a very slight pressure, acting on a point of its surface, is sufficient to produce the doubly refracting power, which is also given by incomplete annealing; and this effect takes place, not only when the glass, having been quickly cooled from a red heat to the ordinary temperature, is liable to break by itself, but even in pieces of glass of some thickness, which might be considered to be well annealed, and which would really be sufficiently annealed for common use: it is a fact, that the greatest part of such a glass shows sensibly the phænomena of polarization. This fact has still increased the difficulties, which were already very great, in manufacturing glass for optical purposes. The difficulty, which is not a small one for discs of three or four inches in diameter, is of course greater for discs of ten and twelve inches; we have however surmounted it at Messrs. Chance's glass works for discs up to twenty-four inches: but before working such discs, or larger ones, we think that it would be desirable that practical opticians should throw sufficient light on the various parts of the processes which are used in the construction of achromatic telescopes; because we could not warrant that the glass which we consider to be free from defects, may not, with very high magnifying powers, give evidence of new imperfections which we have not yet suspected.

I have laid before you practical facts. If they be found interesting enough to form the basis of new studies on the

modification of the atomic constitution of glass, I shall be content to have brought the subject before the British Association: if these observations, on the contrary, are considered not worthy of the importance I attach to them, I shall have my excuse in the love of an art to which I have all my life been zealously devoted.

LV. *On the Cause of Auroræ Boreales.* By AUGUSTE DE LA RIVE, being an *Extract from a Letter to M. Regnault*.*

I HAVE just read, in a memoir by M. Morlet on the *Auroræ Boreales*, inserted in the *Annales de Chimie et de Physique*, 3rd series, vol. xxvii. the following passage:—

“With regard to the origin of this luminous matter (that of the aurora borealis), it seems natural to attribute it to the electric fluid contained in the atmosphere, and which, at great heights where the air is rarefied, must become luminous as under the receiver of the air-pump and in the barometric vacuum: this hypothesis would acquire a great probability if we succeeded in proving, by direct experiments, that magnetism exerts an influence on electric light.”

This last expression induces me to request you to have the goodness to communicate to the Academy of Sciences an experiment which I mentioned to you on my passage through Paris last June, and which you may perhaps remember; its object was to show, in support of the theory which I had advanced of the aurora borealis, the influence exerted by magnetism upon the light which is produced in ordinary electric discharges. Hitherto this influence has only been shown in the case of the luminous arc which escapes between two conducting points, each communicating with one of the poles of a voltaic battery; which is very different, both as concerns the phænomenon itself, and in what concerns its application to the theory of the aurora borealis. The following is my experiment.

I introduce into a glass globe about 30 centimetres in diameter, by one of the two tubulures with which it is furnished, a cylindrical iron bar, of such length that one of its extremities reaches nearly to the centre of the globe, whilst the other extends from 3 to 4 centimetres out of the tubulure. The bar is hermetically sealed in the tubulure, and covered throughout its length, except at its two ends, with an isolating and thick layer of wax. A copper ring surrounds the bar above the isolating layer in its internal part the nearest to the side

* From the *Comptes Rendus* for Oct. 15, 1849.