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SELECTIVE THERMAL RADIATION OF COLORED AND PURE FUSED QUARTZ

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Abstract

Thermal radiation of fused quartz.—The peculiarity of pure fused quartz in that it does not visibly radiate at all until its temperature nears the fusion point is explained by the displacement, with increasing temperature, of the ultraviolet absorption band toward the visible.

Selective thermal emission of neodymium oxide dissolved in quartz.—Quartz-neodymium rods, containing neodymium oxide were prepared. When heated they emit a radiation consisting of seven distinct bands. The wave-lengths of the centers of the bands are 8730, 8270, 7504, 6717, 5944, 5340, 4570A. Absorption measurements show bands in the same positions. A method for preparing the neodymium-quartz is described.

If a thin rod of very pure fused quartz, containing no small particles of foreign matter, is heated in the flame of a bunsen burner, there is practically no emission of light, in conformity with Kirchhoff's law, which predicts that an absolutely transparent body will not radiate, no matter how high its temperature.

However, small specks of impurities embedded in the quartz glow brilliantly, and at one time I was of the opinion that minute air bubbles were also luminous. More careful observations show, however, that this was a mistake, and that, if any luminous bubbles appear, they shine only by reflecting the light radiated by solid particles. If quartz is heated in the oxy-coal-gas flame, it becomes vividly incandescent. The blue white luminosity fades away on removal from the flame without passing through the orange and red stages exhibited by practically all substances shining by thermal radiation.

This indicates clearly that quartz exhibits selective thermal radiation because of the circumstance that, at high temperatures the ultraviolet absorption band migrates towards the region of longer wave-lengths. Radiations in the violet and near ultraviolet preponderate owing to the higher value of the absorption coefficient in this region.

This selective emission was clearly brought out by a spectrogram made in the following way: a fragment of graphite was placed in a small quartz capillary tube and the tube was fused down to a cylindrical rod, with the graphite at its center. The rod was mounted vertically, and heated with a blast lamp operated by only sufficient oxygen to bring the graphite to a bright yellow heat. An image of the glowing fragment was focussed on the center of the slit of a quartz spectrograph, and a series of exposures made with increasing oxygen supply to the flame. When the rod reached full incandescence and was just beginning to soften, it was apparent that its image on the slit was much whiter than that of the graphite fragment. Also the spectrogram showed that while the graphite was the brighter in the red and yellow region the radiation from the rod was more intense in the violet and ultraviolet as is shown by Fig. 1. This might at first sight be interpreted as short wave-length luminescence since no substances can emit a more intense thermal radiation in any region of the spectrum than a black body. The real explanation appears to be that the graphite is at a slightly lower temperature than the quartz owing to its more rapid dissipation of energy in the form of long wave radiation. Its temperature is not necessarily that of the quartz, depending upon the rate at which energy can be fed in from the quartz in comparison to the rate at which it is lost by radiation. Owing to its low emissivity fused quartz appeared to be the ideal solvent for oxides of the rare earths for exhibiting sharp bands of emission. It is well known that these oxides exhibit more or less conspicuous maxima of emissivity corresponding in spectral distribution to the absorption bands, but there is always a good deal of continuous spectrum as well. In the case of black or brown oxides, such as that of neodymium, it is obvious that little or no selective emission will be observed. Erbium oxide, which is nearly white, shows the phenomenon well, but there is much continuous spectrum which would probably be absent if a sufficiently thin layer could be employed. After a little experimenting I succeeded in getting a very satisfactory solid solution of neodymium oxide in fused quartz, a pyrosal as the physical chemists would term it.

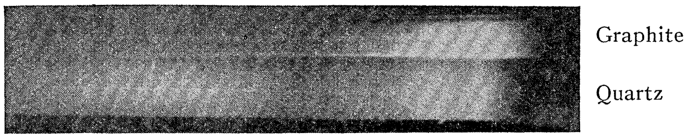

Fig. 1.

This was drawn out into thin rods and fibers which when heated in the flame of a bunsen burner and viewed through a direct vision prism exhibited a most beautiful discontinuous spectrum consisting of a red, and orange-yellow and a green band, separated by perfectly dark in intervals.

The spectrum of one of these rods was photographed from the ultraviolet region to the extreme infrared as reached with a meocyanine plate, with a comparison spectrum of neon or neon and argon. The wave-lengths at the center of the bands are given in the Table I.

Table I.

λ	Wave-number	λ	Wave-number
8730	114516	5944	168190
8270	120886	5340	187214
7504	133296	4570	219381
6717	148835		

Fig. 2, number 3, gives a very good idea of the complete emission spectrum. This was made with a Bausch and Lomb one-prism spectrograph, suitable color filters being employed to compensate for the variable spectral sensibility of the neocyanine plate. The 8730 band shows faintly at the extreme right. The 5340 and 4570 bands at the lift merge into one another. There is also indication of a band of still shorter wave-length, but its center cannot be easily determined. Spectrum number 4 was taken with a larger prism spectrograph, a panchromatic plate and no filter compensation, and number 2 with a dicyanine plate.

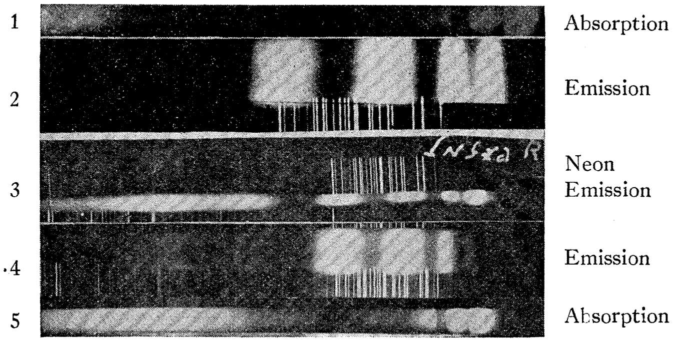

Fig. 2.

The absorption of the neodymium quartz was next investigated. Its absorption coefficient is so low, thin rods appearing perfectly transparent, that an estimated layer of about two centimeters thickness would be required. Having no facilities for preparing a large mass of the material, I drew out a large fused bead into a rod 2 cm long by 1 mm in diameter. This was mounted in a horizontal position by passing it through holes in two pieces of asbestos board with the light of a distant mazda lamp focussed on one end of the rod. The other end, imprisoned by total reflection which was of considerable intensity, was focussed on the spectrograph slit. During the exposure the quartz rod was heated to a temperature sufficient to cause the emission of a feeble yellow light. It is important to secure a record of the absorption at a temperature not far from that at which the emission spectrum was secured, since the absorption bands all move toward the region of longer wave-lengths with rising temperature.

The absorption spectra, secured in this manner are reproduced in coincidence with the emission spectra at the top and bottom of the figure.

Attempts to color quartz with other substances were not very successful. Oxides of nickel and manganese refused to dissolve. A light blue quartz was however obtained with cobalt, and a very beautiful demonstration was made with a fiber the upper part of which is colored with cobalt and the lower with neodymium. The two can hardly be distinguished by the eye, but when we heat it in a flame and view it through a direct vision prism we see a continuous spectrum supported on three colored pedistals of green, yellow and red, respectively.

A few words as to the preparation of the quartz may be of help to any wishing to prepare specimens for demonstration. Neodymium oxide can be prepared from the neodymium ammonium nitrate, obtainable from the Welsbach Light Company of Gloucester City, Pennsylvania, by precipitating the oxalate with oxalic acid, and heating the dried precipitate after washing in a platinum crucible to a white heat with constant stirring.

A speck, the size of a pinhead is introduced into the middle of a quartz tube, of say, 3 mm external and 1 mm internal diameter. The spot containing the oxide is fused in the oxy-coal-gas flame, and twisted and drawn out over an oven again. The rapid twisting of the fused bead, combined with drawing out and reforming into a bead, eventually gives a homogeneous mass. In the earlier stage we find the bead filled with spiral streaks of a bluish color. After the bead is uniform it is drawn out into a thin rod or fiber, of say, 0.5 mm diameter, and bent at a right angle to the rod which serves as a support for holding it vertically in the bunsen flame.

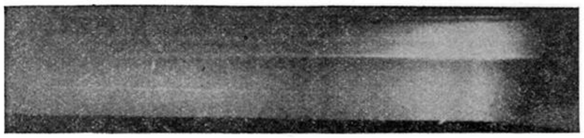

Fig. 1.

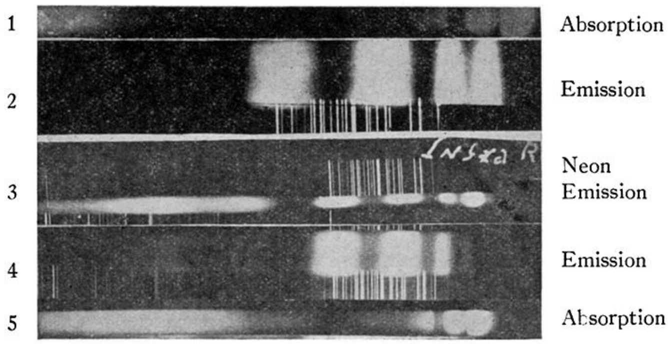
1
Absorption
2
Emission
3
Neon
Emission
4
Emission
5
Absorption

Fig. 2.