THE EFFECT OF TEMPERATURE UPON THE COEFFICIENT OF ABSORPTION OF CERTAIN GLASSES OF KNOWN COMPOSITION.

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INTRODUCTORY.

THE effect of temperature upon the absorption spectra of various kinds of colored glass has been investigated by Houstoun[1] and by Gibbs.[2] Their results show that in general the absorption increases with temperature, though in some instances, in certain parts of the spectrum, it decreases. In some specimens, upon heating, the absorption bands were found to remain stationary, and in others to shift toward the red. In only one case, found by Gibbs, has a shift of the absorption band toward the violet been observed, and in this specimen a permanent change in the spectrum was produced. Usually there was a complete recovery upon coming back to the original temperature.

The purpose of this investigation has been to study the changes that take place in the absorption spectra of certain glass specimens between the temperatures of −180° and 430° C. These glasses were kindly furnished by the Corning Glass Works. There are five of them, their color and material being listed as follows:

No.	Color.	Coloring Material.	Glass.	Thickness.
1	Red	Cadmium, selenium	Zinc	1 mm.
2	Orange	Cadmium, selenium	Non-lead	2 mm.
3	Light amber	Cadmium, selenium	Borosilicate	2 mm.
4	Lemon yellow	Cadmium sulphide	Zinc	2 mm.
5	Canary	Uranium	Lead	2 mm.

By mistake No. 5 was at first listed as Cd Se and hence was studied with the others. The first four comprise an interesting and instructive series since the edge of the absorption band is at a different position in the spectrum of each, though of the same general character. Conclusions may thus be drawn from a study of this series, which might not be possible with specimens of various composition whose absorption curves are entirely different in shape from one another.

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[1] Houstoun, Ann. der Phys., 21, p. 535, 1906.

[2] Gibbs, R. C., PHYS. REV., Vol. XXXI., No. 4, p. 463.

Apparatus.

These glasses were ground in the shape of circular discs about 22 mm. in diameter and from one to two mm. thick. The faces were highly polished and made parallel to within .01 mm. These precautions were found necessary in order to obtain the same and therefore the correct per cent. transmission when the specimen was moved around in its position.

To study the effect of heating, the glass *N* (Fig. 1) was placed between two iron washers and heated in the furnace *H*. A thin cylindrical shell of iron K_1 kept the specimen and washers in position. The furnace was an iron core, hollowed out as indicated. Heating was produced by passing a current through wires wound on the outside. These wires were embedded in asbestos cement and the furnace then wrapped in many layers of asbestos paper, which prevented an excessive loss of heat by radiation. A piece of mica at each end prevented air currents and thus helped to keep the temperature on the inside steady. All temperatures were measured by means of a copper-advance thermo-junction which was inserted as indicated at J_1. This was used in the usual way with a potentiometer. It was calibrated by taking readings at the known temperatures of 0° and 100°, and at 232°, 327.5° and 419° C., the melting points of tin, lead and zinc respectively. At low temperatures it was calibrated by comparing it with a thermojunction whose calibration was known, readings being taken at a number of temperatures between 0° C. and the temperature of liquid air.

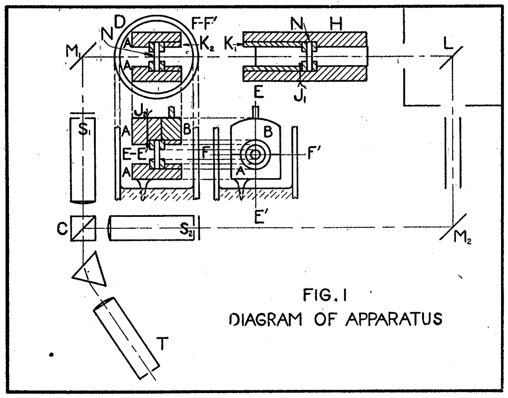

FIG. I
DIAGRAM OF APPARATUS

Fig. 1.

From the above readings a curve was drawn, and from this the potentiometer readings for any desired temperature could be obtained. The accuracy of this calibration is such that the maximum variation from any of the temperatures as given is probably not more than two or three degrees.

To study the effect of cooling, apparatus was used which had been devised and constructed by Professor Gibbs for work at low temperatures. This consisted of a solid iron support A which could be lowered and clamped into position inside of a Dewar bulb D. This support was hollowed out and part of the upper half B was cut out and made removable. The glass N could then be lowered into its position between two washers and held in position by a cylindrical iron shell K_2. Then the cover B could be lowered into place. The liquid air was pumped into the bottom of the Dewar through a glass tube and the temperature varied by varying the amount of liquid air. An iron pointer fastened to the bottom of A helped to lower the temperature quickly and keep it steady. Windows of mica were not needed here as there were no convection currents in the air, and no trouble was experienced in keeping the temperature steady. The thermo-junction was inserted at J_2 as indicated. Precautions were taken to prevent dust from settling on the inside of the Dewar in the path of the light beam or upon the specimen during the observations. Also it was found necessary, in order to prevent condensation of moisture from the air on the outside of the Dewar, to fasten heating coils on each side about the places where the light entered and left.

The source of light used was an acetylene flame L whose pressure was kept constant by means of a water manometer. The light from this source, after passing through the specimen in the furnace or in the Dewar, was reflected by a mirror M_1 into the slit S_1 of one of the collimators of a Lummer-Brodhun spectrophotometer. The intensity of this light was compared by means of the Lummer-Brodhun cube C with the intensity of light from the same source L reflected by means of the mirror M_2 into the slit S_2 of the other collimator. A uniform contrast field was obtained by the use of ground glass screens placed in front of the slits. This field was viewed by the telescope T, used without the eye piece.

To exclude stray light, the acetylene flame and the spectrophotometer were boxed in and other screens used where needed, so that errors from this source were eliminated so far as the eye could detect.

During all observations the slits in the collimator S_1 and in the telescope T were kept constant at .80 mm., and the width of S_2 varied until a match was obtained. The amount of spectrum included by a slit of .80 mm. at wave-lengths $.46\mu$, $.56\mu$ and $.66\mu$ is indicated at the bottom of each figure. A calibration curve was first obtained by taking observations throughout the spectrum with the specimen removed but everything else in position. By repeated trials and adjustments of apparatus, a curve was obtained which varied but little throughout the spectrum, which kept constant from week to week, and which was practically independent of the acetylene pressure over a considerable range, though as stated before the pressure was kept as nearly constant as possible. Thus the errors due to calibration were small. At least three settings of the slit S_2 were made for any particular wave-length, care being taken to avoid any lost motion in the screw. If these three did not agree closely, more were taken. This was almost always necessary at the red and violet ends of the spectrum.

If the average of the settings with the specimen in position is D, and the setting with the specimen removed is I (taken from the calibration curve), then D/I is the per cent. of the incident light transmitted. But since about 4 per cent. of the light incident on each surface of the glass is reflected at that surface, the true per cent. transmission P is approximately equal to $D/.96^2I = D/I'$.

The value of the coefficient of absorption K is derived as follows. If dI' is the change in intensity of light transmitted through a thickness dx, then dI' is proportional to $-dx$ and to I', the original intensity; *i. e.*, $-dI' = KI'dx$ where K is called the coefficient of absorption of the substance for any particular wave-length. From this

$$\int_{I'}^{D} dI'/I' = -\int_0^x K dx,$$

$$\log D/I' = -Kx,$$

$$\log 1/P = Kx,$$

$$K = \frac{\log 1/P}{x},$$

where x is the thickness of the glass specimen. In computing K, the values of $\log 1/P$ were taken from a curve plotted between P and $\log 1/P$.

RESULTS.

In Figs. 2 to 9, the results of the investigation are shown graphically. In Figs. 2 to 6, the values of P, the per cent. transmission and of K, the coefficient of absorption are plotted against wave-lengths for various temperatures. In each figure, both for P and for K, there are seven curves corresponding to the following temperatures, with the two exceptions noted below.

Curve No. 1 was taken at −180°, No. 2 at −80°, No. 3 at +20°, No. 4 at 100°, No. 5 at 210°, No. 6 at 320°, and No. 7 at 430° C.

With specimen No. 3, Fig. 4, however, it happened that curve 2 was taken at −95° instead of −80° and in specimen No. 4, Fig. 5, curve 2 was taken at −60° instead of −80° C. The values for 20° are the average of the values taken just before heating, and just before cooling. The cooling effect was studied about a year after the heating effect. In Fig. 2 all the curves are numbered. In the other figures curves 1 and 7 only are numbered.

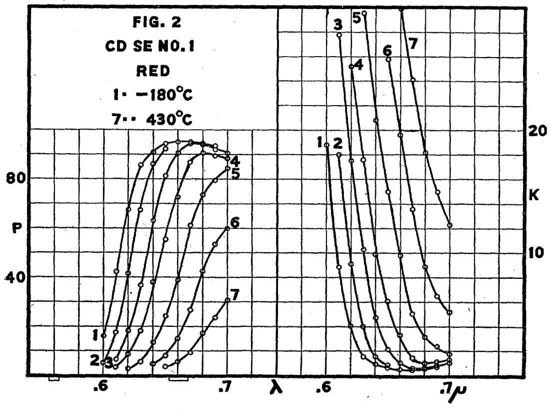

Fig. 2.

Glass No. 1. Cd, Se. Variation of the per cent. transmission P and of the coefficient of absorption K with wave-length λ at the temperatures −180°, −80°, +20°, 100°, 210°, 320° and 430° C.

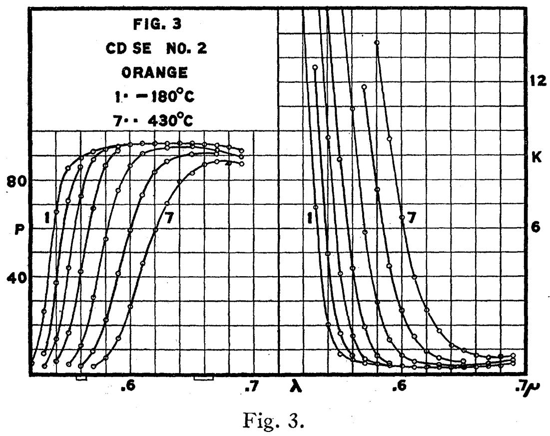

Fig. 3.

Glass No. 2. Cd, Se. Variation of the per cent. transmission P and of the coefficient of absorption K with wave-length λ at the temperatures −180°, −80°, +20°, 100°, 210°, 320° and 430° C.

In Figs. 7 and 8, values of K are plotted against temperature T for those wave-lengths which show the greatest changes. These curves are for specimens Nos. 1 to 4 as indicated. In Fig. 9 are plotted values of K at the extreme temperatures, −180° and 430°, for the four *Cd* specimens.

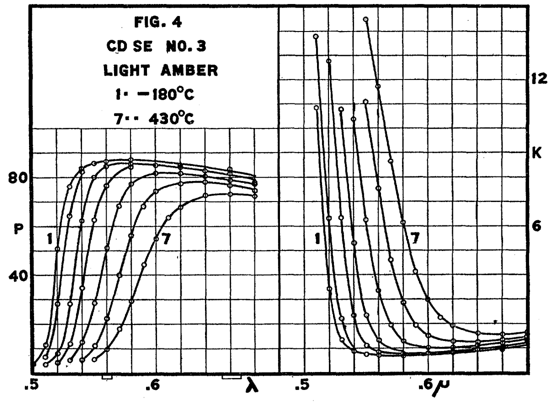

Fig. 4.

Glass No. 3. Cd, Se. Variation of the per cent. transmission P and of the coefficient of absorption K with wave-length λ at the temperatures −180°, −95°, +20°, 100°, 210°, 320° and 430° C.

Perhaps the most interesting and important result found in this in-

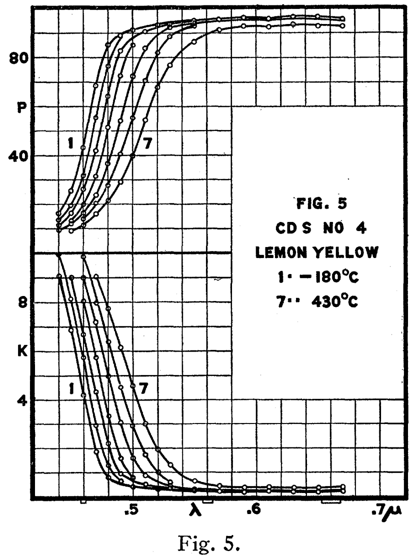

Fig. 5.

Glass No. 4. Cd S. Variation of the per cent. transmission P and of the coefficient of absorption K with wave-length λ at the temperatures −180°, −60°, +20°, 100°, 210°, 320° and 430° C.

vestigation is the enormous increase in the coefficient of absorption in certain parts of the spectrum. In the red glass for instance at certain wave-lengths, *K* is increased at 430° by more than fifty times its value at −180°; and what was nearly a transparent glass in the region of .66μ

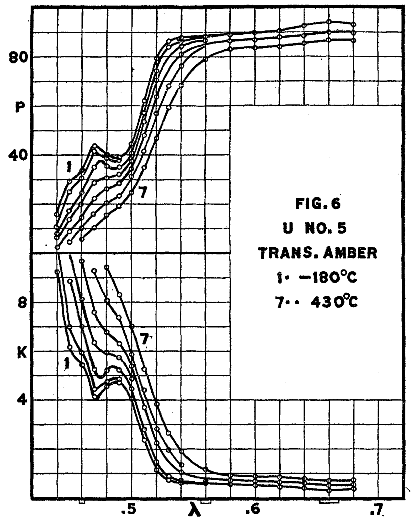

Fig. 6.

Glass No. 5. Uranium. Variation of the per cent. transmission P and of the coefficient of absorption K with wave-length λ at the temperatures −180°, −80°, +20°, 100°, 210°, 320° and 430° C.

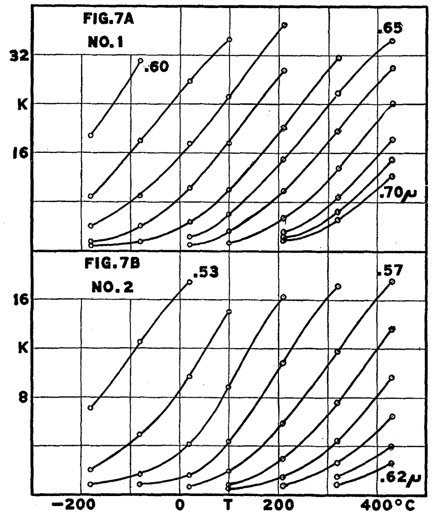

Fig. 7.

Glasses Nos. 1 and 2. Variation of the coefficient of absorption K with temperature T at certain wave-lengths.

became nearly opaque. In spite of these big changes, there was in all the specimens nearly a complete recovery after the heating; and after cooling no change at all was found in the room temperature curves.

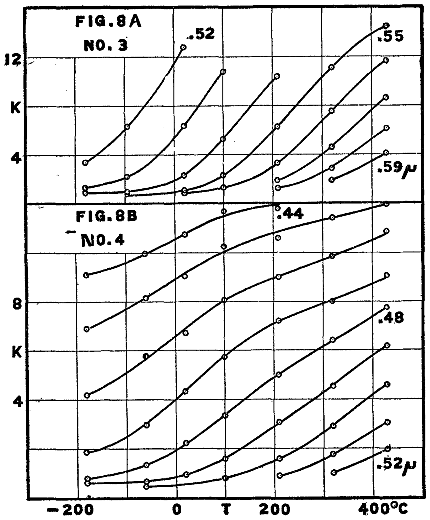

Fig. 8.

Glasses Nos. 3 and 4. Variation of the coefficient of absorption K with temperature T at certain wave-lengths.

The biggest changes occur on the edge of the general absorption region,

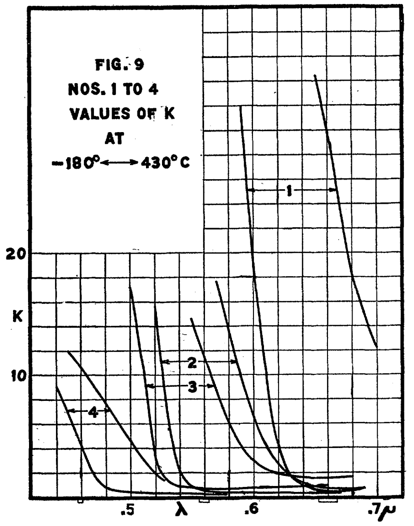

Fig. 9.

Glasses Nos. 1 to 4. Variation of the coefficient of absorption K with wave-length λ at the extreme temperatures, −180° and 430°, only.

and this results in some cases in a shift of the point of maximum per cent. transmission as can be seen from the curves. Also as might be expected, in some of the specimens there was a change in color, the orange glass becoming yellow at −180° and turning to a brilliant red at 430°. The light amber glass became pink at 430°. The other specimens did not show marked color changes, though the red glass changed from a bright to a very deep red at 430°.

It is also interesting to notice (Fig. 9) that the edge of the absorption band is much sharper in the red glass than in the lemon yellow one, where the edge is in the violet, and that the curves for the other two specimens are intermediate in slope. But as the specimens are heated and the edge of the absorption band shifts toward the red, it becomes less sharp, though the difference is not great.

Also it will be noticed that the red specimen, which has the steepest curve, shows the greatest change in the value of K at different temperatures, the change becoming less and less in the other specimens as we go toward the violet.

A change in the per cent. transmission of "red pyrometer glass, presumably made with copper oxide" has recently been observed by Hyde, Cady and Forsythe.[1] Values of the coefficient of absorption at 20° and at 81° C., computed from their curves, show a change of the same order of magnitude as those noted above for the red specimen.

The specimen of canary glass containing uranium, No. 5, Fig. 6, though of different material and with a very irregular curve, yet shows the same effects upon change of temperature as the others. This glass is also interesting as showing how the absorption bands near the region of general absorption disappear upon heating. The specimen shows a green fluorescence, probably due to the absorption band at $.49\mu$. It would be interesting to study the fluorescence and see if it disappeared at the same temperature as this absorption band.

CORNELL UNIVERSITY,
Sept., 1915.

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[1] E. P. Hyde, F. E. Cady and W. E. Forsythe, PHYS. REV., p. 74, July, 1915, and Astrophysical Journal, Nov., 1915.