Photoelectric Measurements of the Absorption of Fused and Crystalline Quartz Between 1633 and 1463A

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The transmission of eight sections of one specimen of crystalline quartz, eleven sections of another crystal, and six sections of a piece of fused quartz from the General Electric Company was determined between 1633 and 1463A. The method is the same as that used for fluorite, except that the photoelectric currents are measured by an FP-54 Pliotron with a galvanometer in the plate circuit. The fused quartz and the first crystal showed large variations in the coefficient of absorption. The other crystal was much more homogeneous, and from it the percentage of light removed at the surfaces was determined. The extraordinary variations in the coefficient of absorption show the importance of actually testing a piece of quartz in the ultraviolet before incorporating it in an instrument for use in that region.

THE procedure and the apparatus employed in these measurements are nearly the same as those used in the study of the absorption of fluorite.[1] The vacuum spectrograph is used as a monochromator, wave-lengths being changed by rotating the grating. Two alterations have been made, one in the apparatus for measuring the photoelectric currents and the other in the method of polishing.

MEASUREMENT OF THE CURRENT

Dr. J. C. Street very kindly turned over to me an amplifier tube circuit which he had used in measurements of cosmic rays in Peru last summer. This circuit is a simplification of one described by DuBridge,[2] and replaces the Compton electrometer used previously. A diagram of the circuit is shown in Fig. 1. The filament-to-plate resistance of the FP-54 Pliotron acts as one arm of a Wheatstone bridge. The variable resistance A, is the opposite arm while the two 10,000 ohm resistances form the other two arms. A variation in the potential of the sensitive grid changes the balance of the bridge. This grid is connected to the external shielding through a 5×10^{10} ohm resistance. In operating the circuit the bridge is balanced first when there is no light entering the photoelectric cell. Then the light is turned on and the resultant current causes a change in the potential of the grid. The potentiometer P is adjusted to bring the bridge back into balance again. Thus the tube circuit is used as a null instrument and the currents are strictly proportional to the voltage across the high resistance. This voltage is read directly from the potentiometer P.

The dotted lines in Fig. 1 represent shielding. All resistances except the one connected to the grid are mounted on a Bakelite panel which is inclosed in a metal lined box. Leads to the FP-54, the galvanometer, and the tube batteries B, are made of shielded wire. This allows the FP-54 and the galvanometer to be placed at any convenient distance from the controls. The two six volt storage batteries B, can be placed in a shielded box but this was found to be unnecessary. The Leeds and Northrup Type R galvanometer G, has a period of 2.6 seconds and sensitivity of about 3×10^{-9} amp./mm scale deflection at one meter distance. The photoelectric cell batteries D, were not shielded in any way. The voltage sensitivity of the electrical system is about 4000 mm/volt. The currents from the photoelectric cell range from 10^{-11} to 10^{-13} ampere. Since the capacity of the grid circuit is small, readings can be made as fast as they can be written down. There is one objection to the circuit. The FP-54 and photoelectric cell are located only three inches away from the hydrogen discharge tube which, though run on direct current, has a tendency to oscillate. This causes a disturbance in the amplifying circuit which it was found possible to reduce by shielding the discharge tube and its leads in galvanized iron. With a hydrogen discharge this effect was very small but with oxygen the effect

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[1] W. M. Powell, Jr., Phys. Rev. **45**, 154 (1934).

[2] L. A. DuBridge, Phys. Rev. **37**, 392–400 (1931).

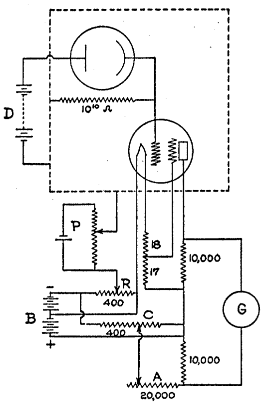

FIG. 1. Schematic diagram of apparatus.

became much greater. However, since all measurements were made with the hydrogen discharge this trouble did not affect the accuracy of the results.

The amplifying circuit is very easy to use. There are only three resistances to adjust before using the Leeds and Northrup Student Potentiometer *P*. The 20,000 ohm variable resistance *A*, is set to have approximately the same value as the filament-to-plate resistance of the FP-54. Resistance *R* is adjusted to give the proper grid voltage, -4 volts. Then resistance *C* is changed until the galvanometer reads zero. Resistances *A* and *C* remain fixed after the first adjustment. *R* alone is altered to counteract the zero shift as the tube warms up. As in reference 1 fourteen alternate readings were taken with and without the quartz in the beam. After the tube warmed up for an hour the zero drift reduced to about 0.004 volt per hour. This was almost negligible since the usual voltages measured ran between 0.05 and 0.2 volt. The complete set of readings for one point were taken in about ten minutes.

PREPARATION OF THE QUARTZ

The quartz was polished entirely mechanically on a machine made by Mr. David Mann. The specimens were mounted with Canada balsam on a suitable support and surrounded by other pieces of quartz to prevent rounding of the edges. The lap was an ordinary pitch lap charged with the same fine rouge employed previously[1] in preparing fluorite. The polishing was continued for about an hour after all pits and scratches had disappeared from the surfaces. All the specimens were prepared in this way and as far as could be seen the polish was always the same. No variation was observed between consecutive polishings. The quartz was cut into slices and the pieces numbered in the order in which they came off. Since not more than three mm of quartz were removed in cutting, it was possible to observe the change of absorption with change in the position of the slice in the original specimen.

RESULTS

The ratio of the intensity of the light passing through the specimen, I, to that of the direct beam, I_0, is $I/I_0=(1-r)^2e^{-\mu x}$ where r corresponds to the reflecting power only if the surfaces are perfectly polished, μ the coefficient of absorption, and x the thickness of the specimen in centimeters. If μ is constant and if $(1-r)^2$ is the same for specimens of different thicknesses, then both quantities can be determined. In only one quartz crystal was this true. This piece was cut into eleven slices arranged in the following way. Two thin pieces about 0.05 cm through were cut off, and then one thick piece 0.1 cm through, then two thin pieces and so on until there were three thick pieces altogether and eight thin ones. The slices were cut with their faces perpendicular to the optic axis. Their transmissions were plotted against thickness on a logarithmic scale, and numbered according to their position in the original crystal. It was possible to choose two of the thick pieces in preference to the third for homogeneity from the behavior of their neighboring thin control pieces. All thick pieces were then cut down to 0.02 cm and remeasured. Thus each thick piece gave two values for the transmission for each wave-length. *R* was determined from each pair of values. The two pieces which appeared to be the most homogeneous from the behavior of the controls gave practically identical results for r. The difference between the two values of r was never greater than 5 percent. Their average is given in column 1 of Table I. The third piece gave values for r which were considerably different, but since the controls had indicated a much greater change in absorption at that particular part of the original crystal these values were discarded.

TABLE I. *Measured absorption coefficients of quartz.*

Wave-length (A)	r (%)	Maximum absorption coefficient 1st crystal	Minimum absorption coefficient 1st crystal	Maximum absorption coefficient 2nd crystal	Minimum absorption coefficient 2nd crystal	Maximum absorption coefficient fused quartz	Minimum absorption coefficient fused quartz
1633.6	10.7	3.51	0.48	0.191	0.167	10.2	5.5
1613.3	11.0					10.9	6.2
1585.7	11.6	3.98	0.51	0.196	0.172	13.7	7.8
1569.7	12.0					16.6	9.5
1547.1	12.8	5.51	0.82	0.49	0.201	24.1	14.6
1533.2	13.1					37.6	25.8
1523.4	13.5					57.3	44.4
1517.4	13.7	11.05	1.86	2.92	0.70		
1489.3	14.3	26.1	5.06	4.87	2.39		
1473.9	15.7			8.92	5.15		
1462.9	16.2	35.3	18.16	19.40	14.08		

The other piece of crystalline quartz was less transparent and much more inhomogeneous. Eight pieces were cut from it with their faces parallel to the optic axis. In order to give a practical idea of the variation in transmission μ was calculated by using the values of r given by the good crystal. The maximum and minimum values of μ are given in columns 2 and 3 in Table I. F. Zernike[3] has taken some interesting shadow photographs through large quartz prisms and lenses showing the sudden changes in absorption which can be expected in crystalline quartz of the highest quality. There is no indication of this behavior in visible light. Columns 4 and 5 show the maximum and minimum values of μ for the "clearer" crystal.

Both crystals were twinned, with sharp boundaries between the different orientations of the crystal formation. There seemed to be no correlation between the amount of twinning and the inhomogeneity.

The fused quartz was part of a large piece of the best quality which had been poured by the General Electric Company for a lens. Six sections were cut from it. It proved to be very inhomogeneous to ultraviolet light, though showing no signs of inhomogeneity in the visible. The strains in it were not sufficient to be seen by polarized light. The inhomogeneity of the fused quartz destroyed the possibility of determining the true value of r. Therefore the same procedure was adopted as before, namely, using the values of r obtained from the crystalline quartz in calculating μ for the fused specimen. Since Gleason[4] found that fused quartz reflects less light than crystalline quartz this approximation would give a lower value for μ. However, the variations in μ are so great that nothing of practical value is lost by this approximation. Columns 6 and 7 give the maximum and minimum values of μ calculated in this way for fused quartz.

DISCUSSION

The values of r can be compared with those obtained by Gleason.[4] His measurements were made at an angle of 45 degrees and no mention is made of the amount of light reflected from the back surface of the piece of quartz. Assuming no light to have been reflected back from the rear surface, and calculating the reflecting power, r, for normal incidence from his values taken at 45 degrees, we get the following: Gleason's value at 1474A is 10.8 percent while that found here is 15.7 percent; at 1634A his value is 9.36 percent while the present is 10.7 percent. The latter values agree within experimental error, but at shorter wave-lengths there is a distinct increase in my values over his. This discrepancy can be explained by poor polish on one or both specimens. A poor polish in Gleason's specimen would lower the reflecting power while a poor polish on the specimen tested here would raise the value of r. The effect of poor polish would be more pronounced at shorter wave-lengths. However, not much weight can be attached to the

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[3] F. Zernike, Physica **8**, 81–7 (1928), No. 2.

[4] P. R. Gleason, Proc. Am. Acad. Sci. **64**, 121 (1930).

apparent agreement at 1634A since the effect of the back surface is not taken into account in Gleason's values of r.

If I_1 is the intensity of the light traversing a crystal with absorption coefficient μ_1 and thickness x, and I_2 the same quantity for a crystal of the same thickness and absorption coefficient μ_2, then the ratio of the intensities is $I_1/I_2 = e^{-(\mu_1-\mu_2)x}$. It is the difference between the values of the absorption coefficients which is significant in determining this ratio. In the first crystal $\mu_{(\max)}-\mu_{(\min)}$ is 21 at 1489A. This is the most marked case of inhomogeneity. At longer wave-lengths this difference is always less, and at 1633A for the second or clearest crystal it is as low as 0.024. In fused quartz this difference never gets below 4.7. These extraordinary variations in μ show the importance of actually testing a piece of quartz in the ultraviolet before incorporating it in an instrument for use in that region of the spectrum.

There is no doubt that the values of r obtained for quartz indicate a better condition of the surface than in the case of fluorite. Because of its greater hardness quartz should take a better polish than fluorite. Furthermore the quartz surfaces are much more rugged and insensitive to abrasives which appear to destroy a fine polish on fluorite.

Experiments are now under way to make simultaneous measurements of transmission and reflecting power directly.

Magnetic Susceptibilities of Dilute Solid Solutions of Nickel in Copper at Various Temperatures

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New data on the magnetic susceptibilities of the low nickel content end of the nickel-copper alloy series present two main features. At low temperatures an approximation to the usual Curie-Weiss decrease in χ with increasing T is established, while above room temperature there is an abnormal paramagnetism, χ increasing with increasing T. The variations are continuous with respect to both concentration and temperature. Certain assumptions applied to the Curie-Weiss part of the curves lead to a magnetic moment per Ni atom in the lattice of 0.3 to 0.4 Bohr magnetons.

INTRODUCTION

NICKEL and copper have face-centered cubic crystals with nearly equal lattice constants. The two elements form a complete series of solid solutions. Since pure copper is diamagnetic the series seems ideal for studies on the magnetic moment per atom of nickel and also on the various interactions which modify susceptibility. Previous studies,[1] all of which extend to high nickel content, do not give precise information regarding the low percentage nickel alloys. For dilute solutions the expected variations with concentration and temperature are small, requiring sensitivity of such order as is used for the study of the noble metals.

APPARATUS

A Weiss-Foëx pendulum offers sufficient sensitivity. A light balsa wood beam is suspended by fine copper wires. At one end of the beam is the specimen, located at maximum HdH/dx. The force on the specimen due to the field is just balanced by that between currents in two small concentric coils, one attached to the far end of the beam and the other stationary. Motion of the beam from the null position causes a mirror, reflecting the image of an illuminated cross-hair on a distant scale, to rotate about a vertically stretched quartz fiber. Necessary data consist in

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[1] E. H. Williams, Phys. Rev. [2] **38**, 828 (1931). R. Gans and A. Fonseca, Ann. d. Physik [4] **61**, 742 (1920). M. Alder, Thesis, Zürich (1916).