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Photoelectric Measurements of the Transmission of Fluorite in the Schumann Region

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The absorption of several pieces of clear, colorless fluorite from Zell in Baden was measured in the Schumann region at ten different wave-lengths between 1600 and 1235A. A grating vacuum spectrograph was used with a photoelectric cell taking the place of the photographic plate. The relationship between the intensity of the light entering the cell and the current from the cell was found to be of the form $I = \text{const.}\, i^z$. Z was found for all the wave-lengths used. All intensity ratios were determined with an inaccuracy not exceeding one percent. It has been possible to distinguish between the light absorbed by the body of the fluorite and that removed by the surfaces. Although every precaution was taken to produce a good polish, the loss of light at the surfaces was much greater than would be expected from Fresnel's law of reflection and the index of refraction of fluorite.

INTRODUCTION

IN 1901 Kreusler[1] used a hydrogen-filled photoelectric cell with a platinum cathode to measure the absorption of a number of substances including fluorite down to λ1850. Later Meyer[2] used the same apparatus to measure the absorption of ozone. In 1912 Kruger and Moeller[3] used a potassium cell filled with hydrogen or helium for the same purpose. No absorption measurements appear to have been made for wave-lengths shorter than λ1850 with a photoelectric cell.

APPARATUS

The vacuum spectrograph, Fig. 1, is used as a monochromator to throw light of different wave-lengths into the photoelectric cell L, which is stationary. The light from the large hydrogen discharge tube H enters the spectrograph through a small slit 0.025 mm wide and 2 mm long not shown in the diagram. The monochromator is focussed by moving the slit F, with a device working through the vacuum taper E, the photoelectric cell itself remaining fixed. By turning the grating C around a vertical axis with the vacuum taper A, light of any wave-length can be sent through the slit F into the photoelectric cell. The piece of fluorite under observation can be placed between slit F and the cell by turning the vacuum taper D. To prevent grease vapors from contaminating the surfaces of the piece J, the fluorite is situated inside a small cylindrical box closed at one end, except for the small slit F, 0.05 mm wide, and at the other by the large fluorite window K. The grating is made of speculum metal, has a 1-meter radius of curvature and 15,000 lines to the inch. The ruled surface measures approximately 7.8 by 3 cm.

The discharge tube H is made in two parts. The cathode is connected to a 3000 volt d.c. generator delivering one ampere through 1000 ohms resistance. The large Pyrex tube H, contains a cylindrical aluminum cathode 252 cm^2 in area in contact with the glass. The quartz capillary, internally coated with platinum, is waxed to the mouth of the cathode tube. The inside diameter measures 1.7 mm. Its other end is waxed to the housing of the slit through which the light enters the spectrograph. This housing also acts as the anode. All parts are cooled by a rapidly circulating stream of water.

The photoelectric cell L is made of Pyrex glass with a fluorite window waxed to one end. The cathode consists of a thin sheet of platinum. It is connected to one pair of quadrants of a Compton electrometer. The anode is connected to a battery delivering from 300 to 450 volts. The cell is filled with argon at a pressure of a few mm of mercury. A high resistance of 1.18×10^{11} ohms[4] connects the cathode with a po-

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[1] H. Kreusler, Ann. d. Physik **6**, 412 (1901).

[2] Meyer, Ann. d. Physik **12**, 849 (1903).

[3] Kruger and Moeller, Phys. Zeits. **13**, 729 (1912).

[4] A. K. Brewer, Rev. Sci. Inst. **1**. 325 (1930).

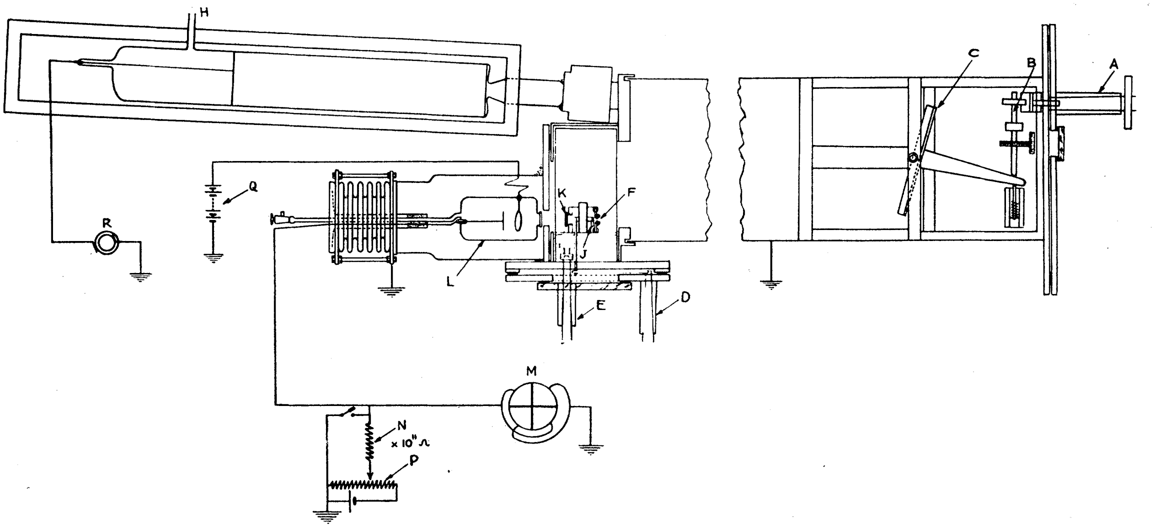

FIG. 1. Diagram of apparatus.

tentiometer P, which is adjusted so as to make the electrometer read zero potential. The difference between the potentiometer settings with and without the light entering the cell gives the change in the potential across the high resistance due to the light alone. This procedure automatically subtracts the potential due to the dark current of the cell. The voltage readings range from 0.7 to 0.08 volt. The sensitivity of the electrometer is 2480 mm/volt. The capacity of the electrical circuit is about 75 micromicrofarads.

The quantities measured are all ratios of the current i produced by the light passing through the fluorite of intensity I to the current i_0 resulting from the unobstructed beam of intensity I_0.

If we let $(1-r)$ be the fraction of the light removed by one surface, μ be the absorption coefficient and x the thickness of a piece of fluorite, then $I = I_0(1-r)^2e^{-\mu x}$. By finding the value of I/I_0 for two pieces of fluorite of different thicknesses, x_1 and x_2, it is possible to calculate the value of μ and $(1-r)$ or of r. This is true only if μ is a constant throughout the medium and if the polish on all surfaces is the same. If the polish were perfect then r should correspond to the coefficient of reflection.

It was necessary to use three abrasives consecutively to give a polish sufficiently reproducible. The first abrasive was a very fine alundum with no particles larger than 0.0025 mm in diameter.[5] A large lead lap was charged with the alundum, and very slightly dampened with kerosene. The second abrasive was a fine rouge used on a piece of silk backed by a square of plate glass. Sufficient rouge and kerosene were used to produce a shiny paste after a little polishing. Chemically precipitated fluorite powder mixed with water on silk on glass formed the third abrasive. The surface of the lap was of the consistency of ordinary flour paste.

CALIBRATION OF THE PHOTOELECTRIC CELL

The ratio i/i_0, where i is the current produced by the light traversing the fluorite of intensity I and i_0 that from the unobstructed beam of intensity I_0, was found not to be a function of the brightness of the source. Now, since I/I_0 is not a function of the brightness of the source, the current-intensity relationship must be of the form $I = \text{const.}\ i^z$. This form of relationship is a common one for gas-filled cells.[6, 7] The following experiment was performed to find the value of the exponent z.

A fluorite lens was placed between the exit slit F of the monochromator and the photoelectric

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[5] J. W. Vanderwilt, *The Nature of Polished Surfaces, Abrasion instead of Amorphous Flow,* Doctor's Thesis, May, 1930. Roche Laboratory Library.

[6] G. Kortum, Phys. Zeits. **32**, 417 (1931).

[7] Steinke, Zeits. f. Physik **7**, 18 (1921).

cell L in such a position that an image of slit F was formed on the cathode of the cell. Two doors were placed between slit F and the lens, close to the lens. When both doors are open the brightness of the image on the cathode is I. With door 1 closed the brightness is I_2 and with door 2 closed I_1. With both closed, the light coming through the crack between them gives a brightness I_b. The optical arrangement makes $I = I_1 + I_2 - I_b$. The corresponding currents obey the law $i^z = i_1^z + i_2^z - i_b^z$. If z equals 1 then the currents will add. If they do not add they can be made to add by raising them to the correct power, z. Z was found at three wave-lengths with a probable error of 0.0003. A curve was drawn through the three points and used to interpolate to other wave-lengths. An added check was made by moving the doors perpendicular to the beam of light and testing the cell with the doors in several different positions. The values of z for any one wave-length remained the same. Then the transmission of a piece of fluorite was measured with the lens in focus and out of focus with the hope of finding some variation in z with the size of the spot of light on the cathode of the cell. No variation in the value of i/i_0 was found and therefore no variation in z.

Errors introduced through inaccuracy in the determination of the current-intensity relationship are around 0.1 percent. Those arising from fluctuations in the source, which did not change more than 10 percent during a set of readings, never amounted to more than 0.5 percent. This is due to the fact that each point is the average of 14 alternate readings with and without the fluorite in the beam.

RESULTS

A large crystal of clear, colorless fluorite from Zell in Baden was cut up into six small pieces varying in thickness from 0.0767 to 0.4321 cm. These were measured at ten different wave-lengths. Then the thickest piece was cleft parallel to the polished surfaces and the two pieces polished and measured. The logarithm of the transmission for each wave-length was plotted against the thickness of the piece. If the transmission coefficient μ were constant throughout the body of the fluorite and the condition of all the surfaces the same, then this curve should be a straight line. However, the points did not lie on a straight line. Since the transmission of any one piece did not vary more than 1.5 percent when it was repolished and since the average of three polishings was taken in all cases the trouble must be laid to inhomogeneity in the fluorite or a variation in μ from one specimen to the other.

In the plot of the logarithm of the transmission against thickness the results for two specimens appeared to lie far off the best straight line. These results were discarded in the determination of μ and r. This proceeding was further justified by the fact that when the thickest piece was cut in half the two halves gave the same value for the transmission, for this implies that this particular specimen was comparatively free from inhomogeneity.

The best straight line through the points corresponding to the remaining specimens was determined by the method of least squares.

The high probable errors in μ and r are not due to experimental error, which is never more than 1 percent. They are an indication of the inhomogeneity to be found in a single crystal of the best Zell fluorite or fluorite chosen with the greatest possible care for homogeneity. The method of measurement of intensities is accurate to at least 0.5 percent and is much simpler to use than the photographic plate. The errors introduced by variations in polish are never more than 1.5 percent. Therefore, entire responsibility for the large probable errors rests with the variations in the absorption of the fluorite. The

TABLE I.

Wave-length	μ	% probable error in μ	r	% probable error in r	z
1603.3	0.488	8.4	5.91	8.70	1.0387*
1495.5	0.538	18.0	10.73	11.09	1.0360
1403.8	0.475	28.6	15.09	10.76	1.0321*
1363.4	0.509	27.0	15.91	10.31	1.0298
1312.9	0.791	16.6	16.63	9.46	1.0262
1283.4	1.127	9.7	18.15	7.17	1.0235*
1257.1	1.740	7.3	21.34	5.22	1.0211
1247.3	2.127	1.1	23.74	3.59	1.0201
1241.5	2.815	0.7	25.34	0.85	1.0195
1235.8	3.506	0.7	28.80	1.76	1.0189

* These values of z were experimentally determined. The others were found by interpolation.

fact that these high errors appear only between λ1495.5 and λ1312.9 shows that they are due to the presence of some impurity in the fluorite which absorbs strongly in that region. At shorter wave-lengths the effect is less because the absorption of the pure fluorite predominates, while at longer wave-lengths the impurity has a smaller absorption and therefore does not affect the accuracy of the results as much. (See Table I.)

The absorption coefficient μ is curve 1 in Fig. 2. The units are defined by the equation $I/I_0 = (1-r)^2e^{-\mu x}$ where x is in centimeters. μ is almost constant at 0.48 from λ1600 to λ1400. Beyond this point it begins to increase until it becomes too great to measure, just after λ1235.8.

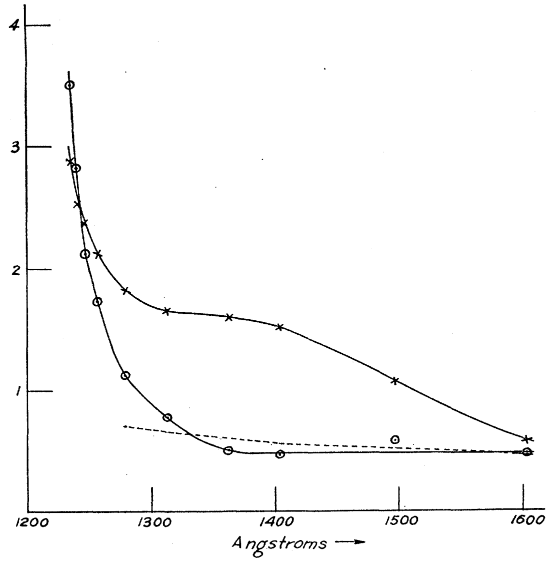

FIG. 2. Absorption and reflection coefficiency of fluorite. Curve 1 (with circle-dots) absorption coefficient. Curve 2 (with crosses) reflection coefficient $\times 10^{-1}$. Broken curve, theoretical reflection coefficient $\times 10^{-1}$.

Curve 2 gives the value of r. The dotted curve is the reflection coefficient calculated from the index of refraction. In all cases r is larger than the theoretical reflection coefficient. The flat character of the curve around λ1400 is a real phenomenon and not due to experimental error. It is more pronounced when the polish is poor. Cleaved surfaces were not smooth enough to give any improvement over the polished ones.

There are three possible explanations for the high value of r. First, polish may be the cause. Second, there may be an adsorbed layer of water vapor. Third, the surface may be covered with a thin layer of abrasive. The first explanation is suggested by a number of properties of the surfaces. A poor polish would be expected to be worse at short wave-lengths first because of the decrease in wave-length and second because of the increase of the index of refraction. It is found that if a piece of fluorite is given a better polish the increase in transmission is greater at shorter wave-lengths than at longer.

The second explanation is not contradicted, for the absorption of water vapor though not accurately known is found to be quite high in this region.[8]

The third explanation seems unlikely because there is no marked change when a different abrasive is used. Also, the last abrasive is fluorite powder which should absorb only a very small amount of light.

In conclusion the author wishes to express his thanks to Professor T. Lyman for suggesting this problem and for his helpful guidance in completing it.

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[8] Liefson, Astrophys. J. **63**, 73 (1926).