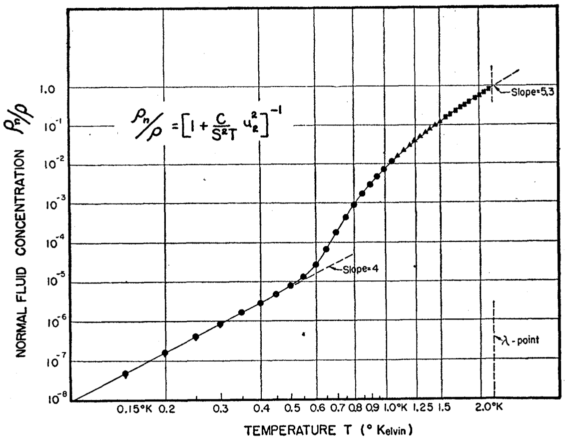

FIG. 1. Normal fluid concentration ρ_n/ρ *versus* temperature. Values of ρ_n/ρ are plotted *versus* temperature T (°K) on a log-log basis. The circles ● represent values of ρ_n/ρ computed from our recent second sound velocity measurements (see reference 1). Triangles ▲ represent those computed from earlier second sound data by Peshkov (see reference 4) and by Herlin (see reference 5). The squares ■ in the upper temperature range represent ρ_n/ρ measurements by Andronikashvilli, employing the oscillating disk technique. To avoid confusion in presenting these data, we have not shown overlap between the three sets of measurements.

in terms of entropy S, specific heat C, and the density of normal fluid ρ_n and superfluid ρ_s. Since for temperatures well below 1°K liquid helium II is composed almost entirely of the superfluid component, Eq. (1) also holds effectively for the normal fluid concentration (i.e., $\rho_n/\rho_s \simeq \rho_n/\rho$).

Our second sound measurements were combined with the specific heat and entropy data of Kramers, Wasscher, and Gorter,[2] to determine the ratio ρ_n/ρ of normal fluid density to total fluid density. The results are given in Fig. 1, where ρ_n/ρ is plotted *versus* temperature T on a $\log_{10}$–$\log_{10}$ scale.

The large circles below 1.1°K are values computed from our second sound curve[1] at temperatures for which tabulated values of C and S are available.[2] At temperatures below 0.3°K, there is some uncertainty in the values of ρ_n/ρ (the extent of uncertainty being indicated by vertical lines), since the observed velocities display an anomalous increase in the 0.05°K–0.3°K range.[1] This is apparently a superficial effect, possibly a shock wave or phonon mean free path phenomenon, without thermodynamic significance to formula (1). Accordingly, below 0.3°K we have employed values of u_2 extrapolated from our more reliable measurements above 0.3°K; these values of ρ_n/ρ are indicated as the solid circles, with vertical lines extending down to values computed on the basis of our actual (anomalous) u_2 measurements.

The solid curve drawn through these circles represents our determination of the dependence of ρ_n/ρ on temperature. Above 1.3°K we have indicated by squares ■ Andronikashvilli's[3] original values of ρ_n/ρ measured by the oscillating disk technique. Finally, in the 1.1°K–1.5°K region, values represented by triangles ▲ were computed from Peshkov's[4] and Herlin's[5] earlier velocity measurements (and Kramers, Wasscher, and Gorter's values of C and S).

The slope of $\log_{10}(\rho_n/\rho)$ *versus* $\log_{10}T$ within various temperature regions is of interest. In the upper temperature range of liquid helium II, the original Andonikashvilli results show a slope of 5.3, whereas the best straight line through the Peshkov-Herlin data gives roughly 6. With decreasing temperature the steepness of this curve continues to increase, with the result that our slope eventually reaches a maximum value of about 13 at 0.7°K. For still lower temperatures, however, our slope decreases again, rapidly reaching an eventual limiting value of 4 below 0.5°K, as indicated by the dotted line.

This fourth power temperature dependence of ρ_n/ρ near absolute zero is, of course, a direct consequence [see Eq. (1)] of the T^3 entropy (and specific heat) relationship, plus the fact that the second sound velocity u_2 has become relatively constant at these temperatures. This represents the T^4 behavior of ρ_n/ρ originally predicted by Landau[6] for temperatures approaching absolute zero, where phonon effects should predominate. In fact it was Landau's correct deductions that ρ_n/ρ would vary as T^4, and specific heat and entropy as T^3, which originally led him to the conclusion that second sound velocity should approach a constant value at absolute zero.

Numerical values of our determination of ρ_n/ρ will be given in tabular form in our final publication.

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* Supported in part by the U. S. Office of Naval Research.

† On a one-year leave of absence from the University of Leiden, Leiden, Holland.

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Effects of *F* Centers on the Internal Friction of Rocksalt Single Crystals*

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(Received December 15, 1952)

WE have studied the effects of introduction and removal of *F* centers on the internal friction of rocksalt single crystals. The specimens were pure synthetic crystals, obtained from the Harshaw Chemical Company. Internal friction measurements were made at room temperature over a range of strain amplitudes by the composite piezoelectric oscillator method described by Read.[1] Results for one specimen are shown in Fig. 1. In the "as grown" condition, after sawing and polishing to size, the increase of internal friction with strain amplitude (Fig. 1, curve *A*) is qualitatively similar to the behavior of any metals, for which the damping has been attributed to motion of dislocations.[1]

On mild x-irradiation at room tempertture the internal friction was markedly reduced (Fig. 1, curve *B*). The irradiation was carried out by placing the speciment directly before the beryllium window of an x-ray tube operating at 40 kv, 20 ma, for 20 minutes at each of six spots covering one entire face of the crystal. This dosage was sufficient to impart a deep amber coloration throughout the crystal with some decrease of intensity in the direction of incidence. Milder irradiations of similar specimens gave less intense coloration extending only partly through the crystal, and the consequent reduction of internal friction was smaller.

Removal of the *F* centers by bleaching with visible light, and removal by infrared irradiation of any *F′* centers that may have been formed did not return the internal friction to its initial value (Fig. 1, curve *C*). However, a mild anneal (30 minutes at 200°C, followed by slow cooling to room temperature) did increase the internal friction nearly to its initial value (curve *D*).

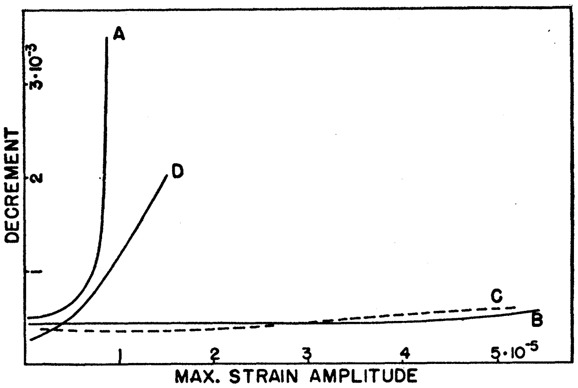

FIG. 1. Effect of room temperature x-irradiation on internal friction. *A*: before irradiation; *B*: irradiated; *C*: bleached; *D*: annealed.

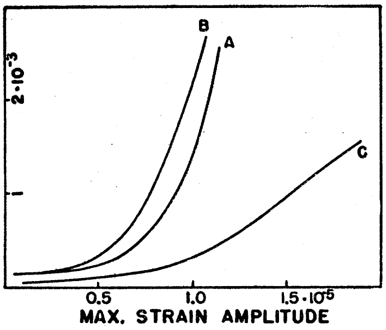

FIG. 2. Effect of cold x-irradiation on internal friction. *A*: before irradiation; *B*: cold irradiation and cold bleach; *C*: cold irradiation, and room temperature bleach.

Figure 2 shows the results obtained on another specimen which was x-irradiated at liquid nitrogen temperature. When the specimen was bleached while still cold, there was no reduction of internal friction (Fig. 2, curve *B*); but when the specimen was warmed to room temperature before bleaching, the internal friction was reduced (Fig. 2, curve *C*). These cold irradiations (40 kv, 35 ma, 20 minutes per spot) imparted only slight coloration to the crystal.

On lowering the internal friction by irradiation, the resonant frequencies of the specimens increased by a few parts in 10^4, i.e., the Young's modulus increased by about 0.1 percent.

These results may be interpreted in terms of a mechanism proposed by Seitz[2] in connection with *F* center formation. The crystal initially contains equal numbers of positive- and negative-ion vacancies, most of which are bound together in pairs. On trapping an electron in a negative vacancy, the associated positive vacancy is set free and, being mobile, will diffuse away if the temperature is high enough.

We propose that these free positive-ion vacancies diffuse to and interact with dislocations. Thus, the initial high damping is due to the motion of "free" or "loosely pinned" dislocations, and on trapping the positive-ion vacancies these dislocations become "firmly pinned," increasing the modulus and decreasing the internal friction. The binding energy of the pinning vacancies is small, since at slightly elevated temperatures they diffuse away and recombine with the negative-ion vacancies.

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* This work was supported by the Office of Ordnance Research.

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Saturation in the X-Ray Coloration of Corundum Single Crystals*

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(Received December 8, 1952)

THE coloration induced in single crystals of corundum (aluminum oxide) by x-radiation in the region of 0.2A wavelength has been investigated. During the course of many irradiations, it has been observed that the characteristic absorption bands rapidly approach a low but constant saturation level with additional irradiation, for the maximum dosages utilized, having no appreciable effect on the coloration.

Two single crystals, each having a thickness of 5.1 mm and optically polished faces 20 mm×10 mm, were used.[1] The crystals were irradiated at a distance of 9 cm from the target of an industrial x-ray unit operated at 120 kv and 5 ma. Energy was absorbed in the crystal at a rate of approximately 2×10^{17} ev per cc per min. During the irradiation a small blower served to keep the crystals at room temperature. In one series of irradiations, the gamma-radiation from 300 millicuries of Co^{60} was employed in the activation. The intensity here was about one one-hundredth as great as in the case of the experiments using x-radiation.

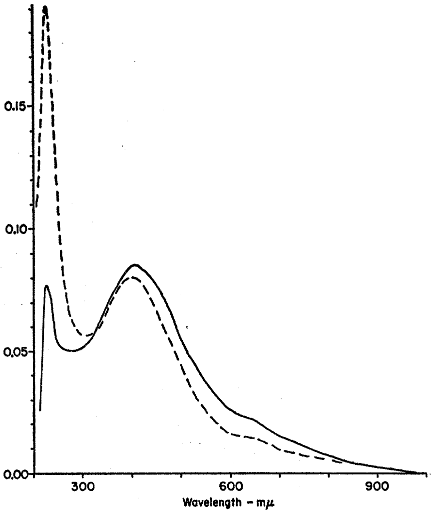

FIG. 1. Absorption spectra of x-irradiated single crystals of corundum. The optical density ($-\log I/I_0$) is corrected for the transmission of the blank crystal. The solid curve represents crystal 1; the broken curve crystal 2.

The induced coloration was visually observed to be homogeneous throughout the crystal and light brown in color, with the intensity of coloration being very low in all cases. The absorption spectrum was measured with the aid of a Beckman DU quartz spectrophotometer. In Fig. 1 are represented typical spectra (after correction has been made for the blank crystals) obtained for crystals irradiated to the saturation point. Two dominant absorption bands are noted with maxima at about 230 $m\mu$ and at 400 $m\mu$ with an additional weak band appearing in the region around 650 $m\mu$. For the band at 400 $m\mu$ the wavelength and intensity of absorption appears to be very similar in both crystals, while at 230 $m\mu$, although the band peaks occur at the same wavelength, the intensity of absorption in crystal 2 is about twice that in crystal 1. In regard to this point, it was found that before irradiation crystal 1 had a considerably lower transmission than crystal 2 in the region below 250 $m\mu$. The saturation level was found to be about the same in the case of irradiation with Co^{60} gamma-radiation as for the more intense x-irradiation.

At 400 $m\mu$ the absorption coefficient of the saturated crystal is approximately 0.4 cm^{-1}. This is two orders of magnitude lower than the saturation coefficient for sodium chloride estimated at 41 cm^{-1} from the work of Alger.[2] Since the energy absorbed in producing the coloration is less by about a factor of one hundred than that utilized in the case of sodium chloride, it is believed that the low coloration level is due not to a decrease in the intensity of absorption of the individual centers but rather to a decrease in the number of centers. Assuming an oscillator strength of unity for the absorbing center, the color center concentration is estimated to be about 2×10^{15} centers per cc.

At room temperature the coloration seems to be relatively stable over moderate periods of time, i.e., weeks. The crystals were heated for periods up to 24 hours at 1000°C and found to bleach to a blank identical to that of the unirradiated crystal. Throughout the course of numerous processings of this type, there was no observable effect upon subsequent radiation coloration. Heating of the crystals on a hot plate at about 500°C was observed to produce a pinkish thermoluminescence of low intensity with the intensity being greater for crystal 2.

Further work is in progress on the thermal and optical bleaching of this radiation-induced coloration.

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* Supported in part under contract with the U. S. Atomic Energy Commission.

[1] We wish to thank the Linde Air Products Company for their cooperation in supplying the crystals used here. The two crystals were obtained about one year apart and represent completely different samples.

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