Ytterbium: Effect of Pressure and Temperature on Resistance

Abstract. *The electrical resistance of ytterbium, measured as a function of pressure, shows a sharp maximum at 38 kb, both at 300°K and 77°K. At low pressures ytterbium is a metal because of overlap between filled and empty bands. From about 20 kb to the resistance maximum it is a semiconductor, indicating that the overlap disappears. At the maximum there is a phase transition, and beyond this pressure ytterbium is again metallic.*

The resistance of ytterbium has been measured as a function of pressure to 500 kb at room temperature and at liquid-nitrogen temperature. Several isobars have also been obtained from 77°K to 300°K at critical pressures as discussed below. The ytterbium used was 99.9+ percent pure material obtained from Kleber Laboratories. The high-pressure–resistance techniques included both the electrical cell used for previous work in this laboratory, and described in detail in the literature (*1*), and a Bridgman (*2*) tapered anvil cell.

At room temperature the resistance increases by a factor of about 6 to a distinct maximum about 38 kb. Above this pressure there is a sharp drop accompanied by drifting of resistance with time, which is typical of behavior at a first-order phase transition. This resistance maximum was first observed by Bridgman (*3*). At liquid-nitrogen temperature the rise in resistance with pressure is much larger [$R_{max}/(R_0 \sim 80) = 100$].

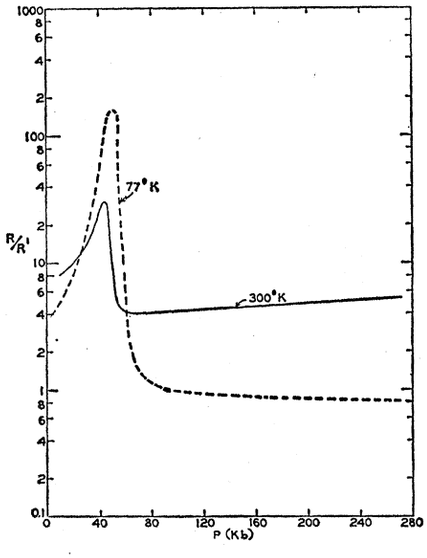

Fig. 1. Resistance of ytterbium as a function of pressure, at 77°K, and as a function of pressure and change of temperature to 300°K. Resistances are values of the ratio R/R', where, for *both* curves, R' = resistance at 77°K and 100 kb.

The maximum at 77°K is little, if any, displaced and is just as sharp as at room temperature, which is unusual for diffusion-controlled transitions. Typical isotherms are shown in Fig. 1. Isobars have been obtained at a number of pressures between 15 and 65 kb. These confirm the fact that from about 20 kb to just beyond the resistance maximum ytterbium is a semiconductor. The greatest activation energy for conduction is about 1 kb at or near the maximum of resistance. The material was the purest available, but it was, undoubtedly, electronically very impure and there may well have been a large number of carriers available with energies between the valence and conduction band. This energy then, is only a measure of the minimum possible energy gap. As well as could be determined, ytterbium becomes a metal again immediately above the transition. Ytterbium at atmospheric pressure probably consists entirely of filled atomic shells (14 4*f* electrons). It is then a metallic conductor only because of overlap between the valence band—undoubtedly the Γ_1 state arising from 6*s* atomic levels—and some empty band—quite possibly the Γ_{25} or Γ_{12} crystal bands (*4*) 15—arising from the atomic 5*d* levels in the crystal field. Apparently the levels are deformed with pressure in such fashion that the overlap disappears and ytterbium becomes a semiconductor.

Recent work by Hall *et al.* (*5*) indicates that the transition is to the body-centered cubic structure and is accompanied by a large decrease in volume which they attribute to the promotion of an atomic 6*s* electron to the empty 5*d* shell (or to the corresponding crystal band or bands).

The metallic conductivity of the high-pressure phase could then be due to the partially filled 5*d* shell (or corresponding crystal band) or to overlap of crystalline 5*d* and 6*s* shell in the new band structure. In any case, our results are entirely consistent with theirs (*6*).

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Dosimetry of Atomic Bomb Radiation in Hiroshima by Thermoluminescence of Roof Tiles

Abstract. *Thermoluminescence dosimetry is a powerful tool for obtaining the distribution of gamma dose, heretofore unknown, from the atomic bombs dropped on Hiroshima and Nagasaki. Roof tiles irradiated by the bombs show intense thermoluminescence, and the radiation dose for samples irradiated below 100 r by the bomb can be measured by this method.*

Much effort has been devoted to studying the genetic and medical damage to human beings who were irradiated by atomic bombs in Hiroshima and in Nagasaki, and detailed data have been collected. But only a few results concerning the distribution of absorbed dose of bomb radiation have been reported, and they are not conclusive about the relationship between radiation hazard and radiation dose. No method has been found for estimating the gamma-ray component except an indirect one through the value of thermal neutron dose.

Recently thermoluminescence dosimeters have been developed by employing synthetic crystals of manganese-activated calcium fluoride (*1*) or powder of pure lithium fluoride (*2*). This method has some advantages in its high sensitivity, low fading, and excellent linearity to absorbed dose. If we take the high-temperature part in the glow curve of thermoluminescence dosimeter, it serves as a dosimeter which can show total absorbed dose integrated over a very long period because the lifetime of trapped electrons corresponding to the high-temperature part of the glow curve is sufficiently long.

Radiation-induced thermoluminescence is a phenomenon widely observed in natural substances (*3*). Consequently, measurement of the thermoluminescence of some substances in na-

ture which have been irradiated long before can be used to find the radiation dose absorbed by the substance in the past. In fact, measurement of thermoluminescence of limestones has been remarkably successful in determining the geologic age of carbonate sediments (*4*), and dating of potteries by thermoluminescence is now in progress (*5*).

When this method was applied to roof tiles of Hiroshima and Nagasaki, the thermoluminescence intensity of the samples gave some information about the absorbed dose of bomb radiation because the thermoluminescence intensity contributed by natural radiation is small compared with that contributed by bomb radiation. The following experiment shows that thermoluminescence dosimetry is a powerful tool for measuring the gamma ray dose of bomb radiation sustained 17 years ago.

The experimental apparatus consisted of an oven with a silver hot plate, a photomultiplier (2″ϕ), a direct-current amplifier, and a two-pen recorder which recorded the glow intensity and the temperature of the sample. Light resulting from thermoluminescence in the sample was collected on the photomultiplier through an optical filter, a light pipe, and a shutter mechanism. The distance from the hot plate to the photomultiplier was about 10 cm.

Roof tiles, which had been exposed to bomb radiation in Hiroshima or in Nagasaki, were selected for measurement. Samples were chosen whose exact locations were known; none had been exposed to the fire which occurred in large areas of both cities at the time of explosions (*6*). A piece of the sample was ground slowly (*7*), and 300 mg of the powder was spread uniformly over the silver hot plate (25 mmϕ). The sample was heated at a rate of 75°C/min until the temperature reached 450°C, and the glow curve, contributed from the bomb radiation, was recorded. Then the sample was cooled and heated again in the same manner as before to record the background glow curve—that is, the thermal radiation. Since the thermoluminescence sensitivity of different roof tiles is not the same, some calibration must be made for each sample. The same sample was exposed to Co^{60} gamma rays, and after it had absorbed a known amount of gamma dose, the new glow curve was recorded as before for calibrating the thermoluminescence sensitivity of the sample. The equivalent gamma dose of bomb radiation was obtained by comparing the bomb glow curve with the Co^{60} gamma glow ones. The intensity of thermoluminescence from the gamma-irradiated sample was exactly proportional to the absorbed dose.

Table 1. Radiation dose from the atomic bomb.

Sample	Distance from hypocenter of explosion (m)	Equivalent dose (rad)	York's data (*8*)	
			Gamma (rad)	Neutrons (rem)
Hiroshima–1	700	2100–2500	2200	1900
Hiroshima–2	960	1200–1500	780	480
Hiroshima–3	970	700– 900	740	440
Nagasaki–1	980	1500–1800	920	60

Glow curves resulting from bomb radiation in the past and from the Co^{60} irradiation in the present are different in shape. The glow curve resulting from Co^{60} irradiation shows a steep rise above 100°C and a distinct peak at about 180°C. On the contrary, the glow curve resulting from bomb radiation has a negligible intensity below 180°C and does not show any remarkable peak. Such differences come from the natural decay of the number of electrons in shallow traps. Therefore the decay at the normal temperature during 17 years (1945–1962) must be estimated in order to obtain the true equivalent gamma dose.

Qualitatively speaking, the high-temperature part in the thermoluminescence glow curve is contributed from deep traps. When the trap is deeper, the lifetime of the trapped electron is longer. Rough calculation shows that the average lifetime of the trapped electrons corresponding to the part of the glow curve above 330°C is longer than 100 years. Therefore the calibration for the thermoluminescence sensitivity of the sample was made by using the part of the glow curve above 330°C, where the two glow curves show similar shapes.

The equivalent gamma doses thus obtained are listed in Table 1, where York's data are shown for comparison although the origin and the range of error of the data are not known. Absorbed dose of roof-tile samples by bomb irradiation is composed of four components: prompt gamma rays, fast neutrons, induced activities in the sample, and fallout radioactivities. The contribution of the latter two components is not known. But it is probably small compared with the former two when the sample was irradiated within 1.5 km from the hypocenter of the explosion, except in the Nishiyama district in Nagasaki. According to York's data, the fast neutron dose is comparable to the gamma dose in Hiroshima. (In Nagasaki, the neutron dose was much smaller than the gamma dose.) In thermoluminescence dosimetry, the energy transferred to the sample by recoil of fast neutrons is about 1/20 as large as it is in the case of soft tissue because the atomic composition of the sample is much heavier than that of soft tissue. As the first approximation, therefore, the equivalent gamma dose can be regarded as expressing the gamma component of the bomb.

There remain some unsolved problems: experimental confirmation of the decay, the exact separation of the contribution of the fast neutron dose, and the effect of self-shielding of the roof tiles for bomb radiation. The sensitivity of this dosimetry is excellent, and a bomb dose below 100 r can be measured.

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Brownian Movement in Color Photomicrography

Abstract. *Crystals, smaller than 1 micron, in Brownian movement have been photographed in color.*

A suspension of green translucent crystals mainly of colloidal size (under 1 μ), but with some crystals of up to 10 microns, has been studied by color photomicrography in which vigorous