of cerium on strength and ductility seems to be capable of explanation entirely in terms of the change in the alpha: beta ratio rather than by a more complicated theory. This presumably arises via a decrease in the solubility of zinc in the alpha phase. This brings in mind that beautiful section of Eliot's "Little Gidding" [7]:

> "We shall not cease from exploration
> And the end of all our exploring
> Will be to arrive where we started
> And know the place for the first time."

We learn that the simplest explanation is again the most likely one (Occam's Razor) and the beauty of sophisticated explorations that lead us in a spiral to a profound simplicity. It is interesting to note that the addition of 0.07% cerium is equivalent in this case to a reduction in the copper content of the binary alloy by 1.6%: thus the effect has no practical significance since copper is more expensive than zinc. Jack Crane's original assertion is found to be justified from the practical point of view and this juxtaposition leads us to name the effect of phase proportions on superplasticity the *Crane phenomenon.*

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Effect of high temperature X-ray irradiation on the thermoluminescence of KCl crystals

Thermoluminescence induced by ionizing radiations in KCl single crystals, both pure and doped, has drawn the attention of several workers [1-4] and helped them in understanding the radiative recombinations and related electronic processes in solids. Although the reported glow peak temperatures show considerable disagreement depending on the nature of impurities, crystal growth conditions, heating rates and thermal histories of the crystals, the thermoluminescence glow peaks of KCl crystals irradiated by X-rays are well known and their origins have been explained [3] in terms of the impurities, deformations and the two types of F-centres. The existence of two types of F-centres has already been established by many authors [5-9]. However, all the reported works are mainly concerned with irradiation either at room temperature or at lower temperatures (liquid nitrogen or liquid helium temperature). It is known [10] that the mechanisms of colour centre formation at room temperature and at low temperature are quite different. But no work has been done so far on the thermoluminescence of KCl crystals irradiated at a temperature greater than room temperature. Ratman *et al.* [11] have reported, for CaF_2 crystal, the changes of thermoluminescence pattern with the rise of irradiation temperature.

The purpose of this communication is to show that the complexity of the thermoluminescence of X-ray irradiated (at room temperature) KCl crystal can be reduced by increasing the irradiation temperature, and that even for the crystal irradiated at a higher temperature, the thermal bleaching of F-centres is responsible for the thermoluminescence.

Several heat-treated (at 400° C, 1 h in vacuum and quenched to room temperature) KCl single crystals (grown in our laboratory by the kyropoulos technique from BDH Analar grade powder) of sizes 0.5 cm × 0.5 cm × 0.1 cm (all cut from the same bulk) were X-rayed at various temperatures ranging from 30 to 250° C for $\frac{1}{2}$ h in darkness using a Machlette Tube (Mo target, 30 kV, 10 mA). All the crystals (quenched to room temperature after irradiation) were found to exhibit reproducible glow patterns when heated in vacuum (10^{-3} mm Hg) at a constant rate (27° C min^{-1}); a typical set of thermoluminescence curves obtained for one sample is

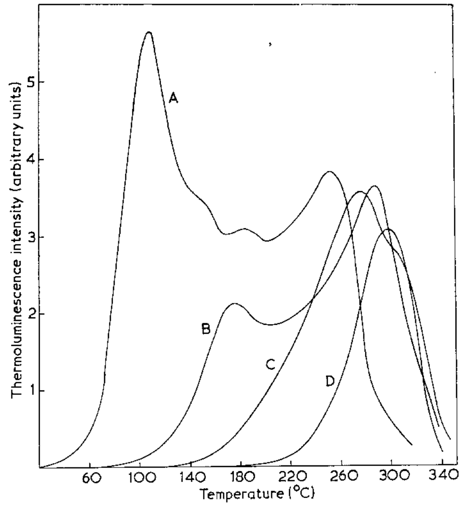

Figure 1 Thermoluminescence glow curves of KCl single crystals irradiated at various temperatures by X-rays (Mo target, 30 kV, 10 mA, ½ h). Heating rate 27° C min. (A) 30° C; (B) 100° C; (C) 150° C; (D) 200° C.

presented in Fig. 1. For all the temperatures of irradiation, the crystal gave poor thermoluminescence emissions which were conveniently recorded by a 1P28 RCA photomultiplier tube in conjunction with an electrometer amplifier (ECIL EA 812) and a mV recorder. Temperature was recorded in a similar mV recorder. Optical absorption measurements of the crystal were carried out using Beckman DU spectrophotometer.

For irradiation at 30° C, four glow peaks at 108, 150, 183 and 251° C (Fig. 1, A) were obtained. The overlapping glow maxima obtained in this case in the region of 140 to 180° C were not exhibited by the crystal when it was irradiated around the temperature of the first glow peak (100° C) (Fig. 1, B); in this case the crystal showed only two glow peaks at 172 and 284° C. However, when the crystal was irradiated at 150° C (the second glow peak temperature of curve A), the emission in the high temperature region was modified and indicated an additional peak around 300° C (Fig. 1, C). With further rise in the temperature of irradiation, i.e. to ~ 200° C, all the low temperature glow peaks were absent; only a single glow peak at 296° C (Fig. 1, D) was obtained. This result is significant in the sense that for this irradiation temperature the complexities of the thermoluminescence pattern (which were observed in previous cases of lower irradiation temperatures, Fig. 1, A to C) have been completely removed. Further, the crystal exhibited practically no thermoluminescence when irradiated at 250° C (around the temperature of the fourth glow peak of Fig. 1, A) and above; in this case no colouration was observed. In the intermediate range of temperatures from 200 to 250° C, the 296° C peak showed only a decrease in peak height (and hence these temperatures have not been included in the figure). It is clear from Fig. 1 that the thermoluminescence pattern changes greatly with the increase of temperature of irradiation. The last glow peak is most stable and is slightly affected in intensity up to an irradiation temperature of 200° C, although its position shifts to higher temperature with the increase of irradiation temperature.

The optical absorption of the crystals, measured in the range 400 to 1000 nm at room temperature, for all temperatures of irradiation, have shown prominently the F-band (Fig. 2). Although the utmost care was taken to avoid exposure of the irradiated crystal to stray light, very weak absorption bands of higher aggregates of F-centres still appeared, due to some optical bleaching by stray light. Their concentrations are,

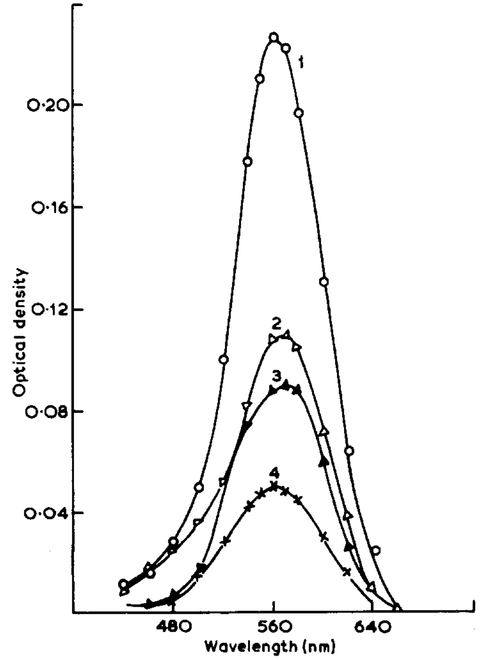

Figure 2 Optical absorption spectra of KCl single crystals irradiated at various temperatures by X-rays (Mo target, 30 kV, 10 mA, ½ h). After irradiation at the indicated temperatures, the crystals were quenched to 30° C and their optical densities were measured at this temperature. (1) 30° C; (2) 100° C; (3) 150° C; (4) 200° C.

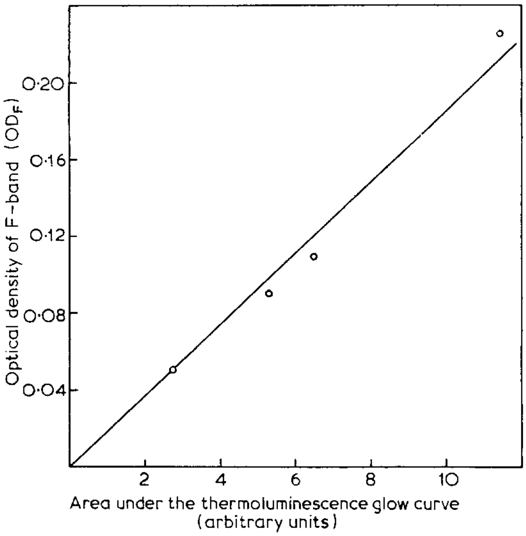

Figure 3 Variation of the area under the thermoluminescence curve with the optical density of F-band (OD$_F$).

however, negligible compared to that of the F-band and hence have not been shown in Fig. 2. From Figs. 1 and 2 it is clear that with the increase in irradiation temperature, the area under the thermoluminescence glow curve, as well as the F-centre concentration decreases progressively. Fig. 3 shows the variation in the area under the thermoluminescence glow curve with the optical density of F-band (OD$_F$). It is clear that the area under the thermoluminescence curve of KCl crystal, X-irradiated at room temperature and above, is a unique function of F-centre concentration. The thermoluminescence of a KCl crystal irradiated at either room temperature or a lower temperature, has been attributed [1-4] to the thermal bleaching of F-centres at the temperatures of different glow peaks. From our measurements it seems that the thermal bleaching of F-centres is also responsible for the thermoluminescence of KCl crystals irradiated at temperatures higher than room temperature.

It is well known that the thermoluminescence intensities depend on a number of factors, e.g. the thermal history, rate of heating, extent and temperature of irradiation. As the temperature of irradiation is increased, the energy storage becomes less and, particularly, traps corresponding to the low-temperature glow peaks become unstable and are thus suppressed. It also appears from the trends of the glow patterns that the increase in irradiation temperature affects not only the lower temperature peaks but also modifies the higher temperature peak, which is expected to be stable up to 200°C. For the crystal irradiated at room temperature, the last glow peak was at 251°C, which has been attributed [3] to plastic deformation. With increase in irradiation temperature from room temperature to 200°C, all the low-temperature glow peaks have disappeared and the last glow peak has shifted from 251°C to 296°C. This peak (296°C) is quite likely the same as that at 251°C. Following Jain *et al.*'s [3] experiments on deformation, some of second stage F-centres bleach and the electrons liberated from the F-centres are trapped in the new vacancies generated during the deformation process to form centres giving rise to the last glow peak and optical absorption under F-band. The difference in the thermal ionization energies of the last glow peaks for different irradiation temperatures, seems to be due to the environmental difference of the new vacancies formed during deformation in the above cases, although their concentrations remain practically the same.

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