A fuller account of this work will be published elsewhere. We are indebted to the South African Council for Scientific and Industrial Research for a grant, to Dr. M. E. Szendrei for the design of the amplifier used, and to Dr. S. W. Watson for the preparation of the Po^{210} source.

[1] J. B. Birks, Proc. Phys. Soc. (London) **A63**, 1294 (1950).
[2] J. B. Birks, Phys. Rev. **84**, 364 (1951).
[3] J. B. Birks, Proc. Phys. Soc. (London) **A64**, 874 (1951).
[4] Taylor, Jentschke, Remley, Eby, and Kruger, Phys. Rev. **84**, 1034 (1951).
[5] J. B. Birks, Phys. Rev. **86**, 569 (1952).

Theory of the Response of Organic Scintillation Crystals to Short-Range Particles

J. B. BIRKS
Department of Physics, Rhodes University, Grahamstown, South Africa
(Received April 2, 1952)

A GENERAL exciton theory has been previously formulated[1,2] to account for the dependence of the specific fluorescence dS/dr of an organic crystal on the specific energy loss dE/dr of the exciting particle. If AdE/dr is the number of excitons produced per unit path length, BdE/dr is the local concentration of molecules damaged by the incident particle, and k is the relative exciton capture probability of a damaged molecule, then

$$dS/dr=\frac{AdE/dr}{1+kBdE/dr}. \tag{1}$$

This theory accounts satisfactorily for the scintillation response of organic crystals to all types and energies of incident ionizing particles, except those of short range.

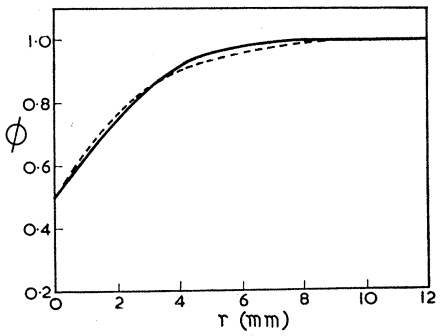

FIG. 1. ϕ *versus* r for electrons in anthracene. ——— Experimental (Taylor *et al.*); - - - Theoretical ($a_0=1.6$ mm air).

Taylor *et al.*[3] have observed that the specific fluorescence of anthracene excited by electrons of energy <20 kev (i.e., of residual air range $r<$about 7 mm) falls below the general smooth curve of dS/dr *versus* dE/dr, that is below the value given by (1). The specific fluorescence $(dS/dr)_{\text{expt}}$ for electrons in anthracene has been calculated from these observations, using the range-energy data of Curie,[4] and it has been compared with the value $(dS/dr)_{\text{theor}}$ given by (1). The ratio $\phi=(dS/dr)_{\text{expt}}/(dS/dr)_{\text{theor}}$ is plotted as a function of r in Fig. 1. ϕ decreases from unity at $r>$about 7 mm to 0.5 at $r=0$. Very similar behavior has been observed by King and Birks,[5] when anthracene and other organic crystals are excited by short-range α-particles. The experimental curve of ϕ *versus* r for α-particle excitation is similar to Fig. 1 for electron excitation.

This effect may be accounted for by an extension of the exciton theory. Equation (1) is valid for exciton production and capture within the bulk of an organic crystal, but an additional multiplying factor ϕ, which is a function of r, must be introduced into (1) to account for the behavior of excitons produced near the crystal surface. If the exciton originates at a point O, then its probability of travelling a distance a from O is $\exp(-a/a_0)$, where a_0 is the mean free path of the exciton. If O is at a distance r from the crystal surface (Fig. 2), and it is assumed that an exciton reaching the surface without capture escapes from the crystal, then the probability of exciton capture within the crystal is given by

$$\phi=\int_{-\infty}^{r}dz\int_{0}^{\infty}\exp(-a/a_0)2\pi x dx\Big/\int_{-\infty}^{\infty}dz\int_{0}^{\infty}\exp(-a/a_0)2\pi x dx$$
$$=1-\tfrac{1}{2}(r/a_0+2)\exp(-r/a_0). \tag{2}$$

The complete theoretical expression for dS/dr is now given by the R.H.S. of (1), multiplied by ϕ. ϕ decreases from unity to 0.5,

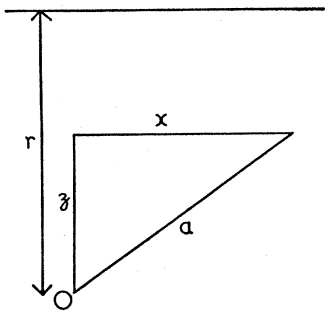

FIG. 2. Coordinates for Eq. (2).

as r decreases from ∞ to zero. The curve of ϕ *versus* r from (2), taking a value of $a_0=1.6$ mm air equivalent, is plotted in Fig. 1. It is in fair agreement with the experimental curve, considering that no allowance has been made for electron scattering. The probable existence of preferred directions of exciton propagation has also been neglected in the derivation of (2).

A similar comparison with the α-particle observations[5] gives a_0 about 3–4-mm air equivalent for anthracene, terphenyl, and stilbene. The relative stopping power of each material for slow α-particles[6] is about 1200, so that the exciton mean free path within the crystal is the order of 3 microns, corresponding to about 5000 molecular lengths.

The results of Taylor *et al.*[3] on the scintillation response to protons and deuterons of energies >1 Mev, indicate that at lower energies ϕ decreases in a similar manner, but no direct measurements are yet available for these particles at low energies. Experiments are now in progress on the response to low energy electrons produced *within* the crystal by x-rays. According to the theory outlined above, ϕ should be equal to unity for such internal electrons, and the response should differ from that excited by external electrons of the same energy. An investigation is also being made of the properties of very thin crystals.

I am indebted to the South African Council for Scientific and Industrial Research for a grant in support of this work.

[1] J. B. Birks, Phys. Rev. **84**, 364 (1951).
[2] J. B. Birks, Proc Phys. Soc. (London) **A64**, 874 (1951).
[3] Taylor, Jentschke, Remley, Eby, and Kruger, Phys. Rev. **84**, 1034 (1951).
[4] Mme. P. Curie, *Radioactivité* (Hermann & Cie, Paris, 1935).
[5] J. W. King and J. B. Birks, Phys. Rev. **86**, 568 (1952).
[6] M. S. Livingston and H. A. Bethe, Revs. Modern Phys. **9**, 245 (1937).

Composition and Time Variation of Primary Cosmic Radiation

D. LAL, YASH PAL, M. F. KAPLON, AND B. PETERS
Tata Institute of Fundamental Research, Bombay, India, and University of Rochester, Rochester, New York
(Received March 24, 1952)

THE flux of heavy primary nuclei at geomagnetic latitude $\lambda=3°$ has been measured in nuclear emulsions exposed during balloon flights in the stratosphere.[1] This experiment com-