The resulting expression for σ is

$$\sigma=(3.21\pm0.01)\times10^{-5}-(0.55\pm0.03)\times10^{-5}$$
$$=(2.66\pm0.03)\times10^{-5}.$$

The error in σ given above is smaller than is necessary in order to correct any experimental data obtained thus far. Greater accuracy than this will undoubtedly be necessary, however, for some future experiments.

[1] H. L. Anderson, Phys. Rev. **76**, 1460 (1949).
[2] N. F. Ramsey, Phys. Rev. **78**, 699 (1950).
[3] E. Hylleraas and S. Skavlem, Phys. Rev. **79**, 117 (1950).
[4] G. F. Newell, Phys. Rev. **78**, 711 (1950).
[5] A. Nordsieck, Phys. Rev. **58**, 310 (1940).
[6] H. L. Anderson, private communication.

Scintillation Decay Times*

ARNE LUNDBY
Institute for Nuclear Studies, University of Chicago, Chicago, Illinois
August 21, 1950

THE decay curves for the scintillation of some molecular crystals, excited by nuclear γ-rays, have been determined using a delayed coincidence apparatus. The results are given in Fig. 1 and Table I.

In the experimental arrangement, one or two 1P21 photomultipliers were used to detect the photons emitted by the crystals. The output from the ninth dynode of the multipliers was fed through RG 7/U coaxial cables (used as delay lines) and amplified in distributed amplifiers before being applied to a germanium diode coincidence circuit. The photo-multipliers were either excited by separate crystals or by one crystal placed between them. The decay curves were measured by varying the relative length of the RG 7/U cables in the two channels.

By varying the bias on the coincidence discriminator, one can select coincidences due to a superposition of one, two, three, etc., photon pulses in the non-delayed channel with the pulses in the delayed channel. For delays exceeding the width of the pulses at the input of the coincidence circuit, the coincidence rate is then given by $\Sigma_{n\geq1}A_n\exp(-nt_d/\tau)$. τ is the decay time of the scintillation, t_d is the time delay, n is essentially the number of single photon pulses contributing to the recorded coincidence pulse from the non-delayed channel, and A_n are constants independent of t_d. The present experiment was so arranged as to record coincidences due to three or more photons only. This was done in order to obtain an effective discrimination between the true coincidence pulses and large single pulses feeding through the coincidence circuit. Furthermore, this procedure leads to an increased resolving power in delayed coincidence experiments. The half-width of the delayed coincidence curve for radiations following each other in instantaneous succession is independent of the pulse sizes in the two channels, and the coincidence rate decays with a time constant which is three times the lifetime of the crystal. The contribution from coincidences due to relatively large pulses being generated by one or two photons in the non-delayed channel or pulses due to four or more photons was observed for lower, respectively higher discriminator bias settings. In Fig. 1, the measurements corresponding to the term $\exp(-3t_d/\tau)$ are shown. The crystals and the photo-multipliers were operated at room temperature (+24°C). In order to obtain an estimate of the width of the pulses due to single electrons released from the cathode (curve F, Fig. 1), self-coincidences of thermal noise pulses from one multiplier were recorded or, alternatively, a strong Co^{60} γ-ray source was inserted between the multipliers.

The 1,4-diphenylbutadiene and the *para*-terphenyl were used in the form of microcrystalline powder[1] in Lucite containers. The luminescence of the Lucite was negligible. The *trans*-stilbene,[2] anthracene,[3] and naphthalene[4] were available as transparent crystals.

The average lifetimes of the excited crystals, being three times the decay periods deduced from the curves in Fig. 1, are listed in Table I.

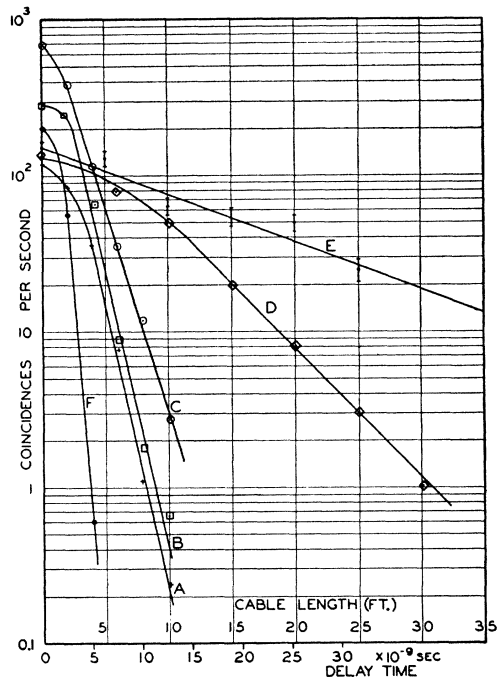

FIG. 1. The decay curves $\exp(-3t_d/\tau)$ of scintillations from: A: 1,4-diphenylbutadiene, B: *p*-terphenyl, C: *t*-stilbene, D: anthracene, and E: naphthalene. Curve F represents noise pulses. The ordinates of curve E have been multiplied by a factor of 1000. This curve also runs through a point with coordinates (55 ft., 0.004 ±0.001 sec.$^{-1}$).

TABLE I. Decay times of scintillation crystals.

Crystal	$\tau(1/e)$ in 10^{-9} sec.
p-terphenyl	4.2
1,4-diphenylbutadiene	4.2
t-stilbene	5.7
anthracene	24
naphthalene	60

The curvature of the decay curves near the ordinate axis in Fig. 1 is caused either by saturation of the multipliers or by a superposition of pulses due to several photons. This was demonstrated by recording triple coincidences between multiplier anode pulses of different integral charge and the fast double coincidences. For the large pulses, the curvature was much more predominant while for the small pulses it disappeared.

The width of the pulses due to single electrons liberated from the cathode of the photo-multiplier (curve F, Fig. 1) is apparently determined by the rise time of the distribution amplifiers (2.6×10^{-9} sec.). This was borne out by experiments without amplifiers preceding the coincidence circuit, giving a pulse width $\lesssim10^{-9}$ sec., which is in general agreement with the value calculated by Sard[5] and with the experimental results of Post and Shiren.[6] The decay constants reported here are all in the expected range of agreement with the values calculated by Kasha[7] from optical data.

I am indebted to Dr. H. L. Anderson for help throughout this work. Dr. M. Kasha has given me much valuable information.

* This work was performed with the joint support of the ONR and AEC.
[1] Obtained from Larco Nuclear Instrument Company.
[2] Grown by E. Tajima using stilbene purified from that obtained from Eastman Kodak Company.
[3] Obtained from the Harshaw Chemical Company.
[4] Reagent Merck's naphthalene recrystalized about seven times from ethyl alcohol. Obtained from M. Kasha.
[5] R. D. Sard, J. App. Phys. **17**, 768 (1946).
[6] R. F. Post and N. S. Shiren, Phys. Rev. **78**, 80 (1950).
[7] M. Kasha, *Scintillation Counters. Qualitative Treatment of the Molecular Optical Parameters* (to be published).