

Liquid Scintillation Counters*

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EXPERIMENTS have been initiated to investigate the scintillation properties of various liquids by studying the light flashes due to ionizing particles. Measurements have been made to date on the following solutions and liquids: (a) naphthalene in benzene; (b) naphthalene plus anthracene in benzene; (c) terphenyl¹ in benzene; (d) dibenzyl in ether; (e) anthracene plus naphthalene in xylene; (f) terphenyl in xylene, (g) benzene, (h) ether, (i) xylene, and (j) melted dibenzyl. Because of the well-known inconvenience of photo-multiplier background, particularly troublesome in measurements with poor geometry, the coincidence technique shown in Fig. 1 was used. A thin-walled glass

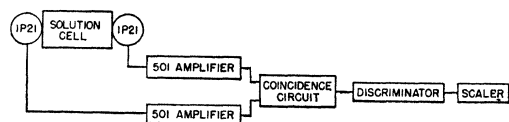


FIG. 1. Coincidence method for measurement on solutions and crystals.

cell, of inner dimensions 1 in. $\times$ $\frac{1}{2}$ in. $\times$ $2\frac{3}{8}$ in. containing approximately 20 cc of solution was mounted between two 1P21 photo-multipliers. The output pulses of the 1P21's were led into model 501 amplifiers and then into a coincidence circuit with 0.5 μ sec. resolving time. The coincidence circuit output was fed into a discriminator and scaler. Counting rates were taken with and without the presence of a Co^{60} source, counts thus being obtained from the Compton electrons in the solution.

A figure of merit for each solution was measured as follows: Suppose that θ Compton electrons are formed in the solution per second. As the result of the scintillation properties of the solution, each photo-multiplier counts n times per second where $n = x\theta$, $x < 1$. If x is small so that on the average only a few photons reach the cathode of the photo-multiplier, then the number of coincidences per second will be given by $c = x^2\theta$. Thus the ratio $c/n = x$ is a measure of the "efficiency" of the solution for the detection of charged particles. If x is found to be large, the counts in the two photo-multipliers are not independent and c/n is not strictly an efficiency but is still useful for the purpose of comparing the various samples. The "efficiencies" for some of the solutions tried are listed in Table I. Because of the particular geometry used and the spread in energy of the Compton electrons, the results given in Table I should be taken only as an indication of relative per-

TABLE I. "Efficiencies" of various solutions (at room temperature unless otherwise noted).

Liquid or solution	"Efficiency"
Benzene	0.07
Benzene at 70°C	0.07
Ether	0.07
m-Xylene	0.08
Naphthalene (40 g) in benzene (100 cc)	0.15
Naphthalene (35 g) + anthracene (0.35 g) in benzene (90 cc)	0.36
Terphenyl (2 g) in benzene (100 cc) at 60°C	0.84
Terphenyl (0.5 g) in m-Xylene (100 cc)	0.80
Liquid dibenzyl at 60°C	0.4
Naphthalene crystal	0.87

formance and not as an attempt at establishing absolute numbers. With the measured resolving time of the coincidence circuit, the number of chance twofold coincidences is of the order of 5 per minute, whereas the observed coincidence counting rate was in all cases of the order of several thousand per minute. For the sake of comparison an efficiency was measured for a fairly good naphthalene crystal of the same dimensions as the solution, and is included in the table.

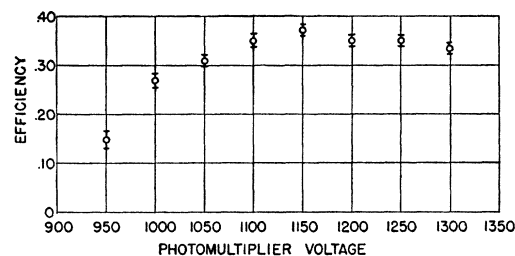


FIG. 2. Dependence of efficiency on photo-multiplier voltage for a solution of naphthalene plus anthracene in benzene.

The efficiency measured for a solution depends somewhat on the voltage applied to the photo-multipliers, in the manner shown in Fig. 2 for the case of a solution of naphthalene plus anthracene in benzene. A plateau is indicated. In Table I it is interesting to note the high efficiencies of the terphenyl solutions. The measurement on terphenyl in benzene was made at 60°C in order to get a significant amount of terphenyl into solution. The high efficiency for terphenyl in xylene was obtained at room temperature. The effect of temperature on efficiency was tested directly in the case of several solutions and the results showed that the temperature in itself had very little effect, if any.

It may be noted that the high efficiency of the terphenyl solutions is accomplished by very small quantities of terphenyl. This is consistent with the observations of Ageno, Chizzotto, and Querzoli² who measured the total fluorescence in solutions activated with γ -rays.

The pulses from the solutions have been observed on an oscilloscope and have been compared with the pulses from the more familiar scintillation crystals. In our experiments the rise and decay times of the pulses from dibenzyl crystals and terphenyl solutions are observed to be determined by the characteristics of the amplifiers used (rise time = 0.02 μ sec., decay time = 0.03 μ sec.). Experiments are underway to determine the response to electrons, mesons and alpha-particles with improved geometry, using end window photo-multipliers. Further investigation of the terphenyl solutions, which appear especially promising, is also under way.

Discussions with R. Hofstadter have been very helpful.

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¹ Hofstadter, Liebson, and Elliot, *Phys. Rev.* **78**, 81 (1950).

² Ageno, Chizzotto, and Querzoli, *Atti Accad. naz. Lincei* **6**, 626 (1949).

Copper 61 and 67

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A COPPER activity of 56 hr. was reported¹ as a bismuth fission product and was tentatively assigned to Cu^{67} on the basis of the mode of disintegration and half-life. A similar activity of half-life 61 hr. was also produced² as result of the bombardment of As with 200-Mev deuterons. No definite mass assignment was made perhaps because of the large charge and mass change involved in this high energy deuteron bombardment. Though later on through a private communication, the same activity was reported as having been produced by photo-disintegration³ of Zn, the mass number was still uncertain, first because non-enriched zinc had been used and second because no confirmation was available from cross reactions from neighboring isotopes. The disintegration characteristic was privately given⁴ as the emission of negative beta-particles without any reference to gamma-rays. The purpose of this present note is a definite mass assignment to this activity made possible by the availability* of highly enriched isotopes of Ni^{64} and Zn^{67} .

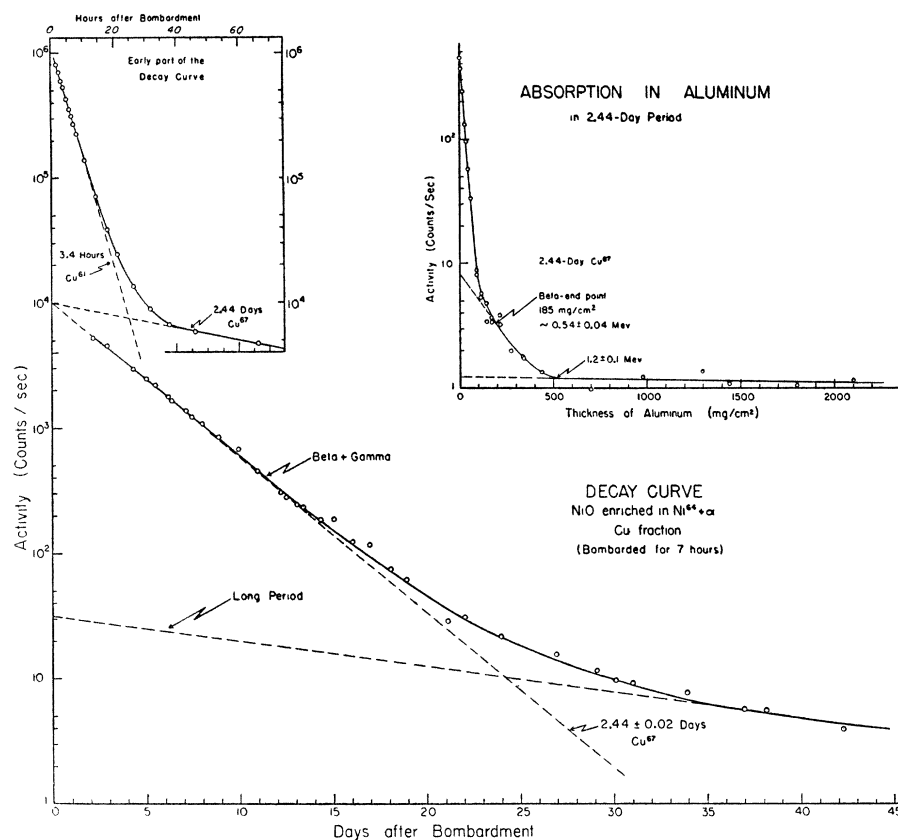


FIG. 1. Decay curve of the copper fraction from nickel oxide enriched in Ni^{64} and bombarded with 20-Mev alpha-particles showing the 2.44-day Cu^{67} activity. The inset in the left-hand corner with the expanded time-scale shows the 3.4-hr. Cu^{61} in the earlier part. In the right-hand top inset, the absorption curve with thin aluminum foils as absorbers shows the beta-end point at 0.54 Mev.

In view of the already available information,⁶ the 3.4-hr. copper activity should have been clearly assigned to Cu^{64} . However, the mass number has still been regarded⁶ as uncertain. Considerations of the percentage of enrichment are used here to check the assignment of this 3.4-hr. copper activity.

A sample of nickel oxide enriched in Ni^{64} to 80.6 percent from the low natural abundance of 1.16 percent in ordinary nickel was bombarded with approximately 20-Mev alpha-particles. The decay curves of the copper fraction after chemistry, followed with Geiger counters and a Wulf electrometer, showed activities (Fig. 1) of half-lives 3.4 hr. through 8 half-lives, no 12.8 hr., 2.44 ± 0.02 days through 12 half-lives and a long period in minute amount. The 3.4-hr. copper activity is confirmed at Cu^{61} from the reaction $\text{Ni}^{58}(\alpha, p)\text{Cu}^{61}$ resulting from the 11.5 percent of Ni^{58} present in the target sample. The 2.44-day half-life must be assigned to Cu^{67} and this is produced through the reaction $\text{Ni}^{64}(\alpha, p)\text{Cu}^{67}$. This assignment is further substantiated by fast neutron bombardments of zinc oxide containing zinc enriched in Zn^{67} to 56.0 percent from its natural abundance of only 4.07 percent. The decay curve of the copper fraction showed the 2.44-day half-life in addition to the 12-hr. and a long period. The 2.44-day activity clearly arises from the reaction $\text{Zn}^{67}(n, p)\text{Cu}^{67}$.

An absorption measurement with thin aluminum foils shows the beta-end point at 0.54 ± 0.02 Mev. The second end point at 1.2 Mev is, perhaps, to be ascribed to the long period because the extrapolated zero-foil intensity approximately corresponds to the intensity of the long period at the time of the absorption. The ratio of the ionization in the ion chamber of the electrometer due to beta- and gamma-rays in the 2.44-day period was 135:1, thereby indicating the presence of one gamma-ray per beta-particle on the basis of the ionization characteristics of the chamber used.

The absence of any appreciable amount of the 12.8-hr. Cu^{64} in the $\text{Ni} + \alpha$ -bombardment may be due to the fact that the enriched nickel sample contained only 0.4 percent of Ni^{61} isotope. In the $\text{Zn} + n$ bombardment, however, where Zn^{64} was present in 18.7 percent, the 12.8-hr. activity was produced due to the reaction $\text{Zn}^{64}(n, p)\text{Cu}^{64}$. Noting that there is 54 percent K -capture in the 12.8-hr. activity, the ratio of the cross sections for the two reactions was $\text{Zn}^{64}(n, p) : \text{Zn}^{67}(n, p) = 23:1$. This order of magnitude may be examined in the light that though Cu^{64} and Cu^{67} both emit beta-particles of about the same energy, the gamma-ray associated with Cu^{67} may put this nucleus at a much higher energy state from the ground level than is the case with Cu^{64} where the gamma is associated with K -capture. The saturation yield ratio for the (α, p) reaction from Ni^{58} and Ni^{64} was 88:1. The cross-section ratio cannot be estimated, however, because whereas the reaction $\text{Ni}^{64}(\alpha, n)$ causes no complication, the product nucleus Zn^{67} being stable, the reaction $\text{Ni}^{58}(\alpha, n)$ introduces the corresponding cross section of unknown magnitude into the computations. Because Zn^{61} , produced if any, will be radioactive, it will continually decay into Cu^{61} . In fact, the observed high yield ratio 88:1 may be taken to indicate that a short-lived isotope Zn^{61} is produced and within the time of bombardment and chemistry decays into Cu^{61} , thereby giving a high saturation intensity as calculated from the decay curves. By a rough extrapolation method,⁷ the half-life of Zn^{61} would be of the order of a minute.

¹ R. H. Goeckermann and I. Perlman, Phys. Rev. **73**, 1127 (1948).

² H. H. Hopkins, Jr. and B. B. Cunningham, Phys. Rev. **73**, 1406 (1948).

³ R. B. Duffield and J. D. Knight (private communication, 1948), quoted by G. T. Seaborg and I. Perlman, Rev. Mod. Phys. **20**, 585 (1948).

⁴ H. H. Hopkins, Jr. (1948) quoted by G. T. Seaborg and I. Perlman, Rev. Mod. Phys. **20**, 585 (1948).

⁵ Kindly supplied by the Y-12 Plant, Carbide and Carbon Chemicals Corporation, US-AEC, Oak Ridge, Tennessee.

⁶ Leith, Bratenahl, and Mayes, Phys. Rev. **72**, 732 (1947).

⁷ G. T. Seaborg and I. Perlman, Rev. Mod. Phys. **20**, 585 (1948).

⁸ D. N. Kundu and M. L. Pool, Phys. Rev. **78**, 488 (1950).