counter telescopes.[1,2] It has, however, been found by Weisz and Swann that a cosmic ray traversing similar path lengths in two proportional counters gives pulses A and B which are unequal, A being sometimes less than and sometimes greater than B. Swann[3] has suggested, on theoretical grounds, a probable explanation for this discrepancy as being due to the statistical fluctuation in the number of high energy secondary electrons emitted within the gaseous volume of the proportional counter.

In order to test the validity of this hypothesis an experimental arrangement, schematically depicted in Fig. 1, was set up. The path of the cosmic ray was defined by three small Geiger counters P, Q, and R, using the usual coincidence circuit method and kept confined between grid and cathode of the proportional counter. The grid was maintained at a negative potential (approximately 90 volts) relative to the cathode, so that no negative ions produced in the region between grid and cathode could get to the wire. However, long-range secondary electrons emitted by the primary can pass through the grid and produce avalanches near the wire by an appropriate adjustment of the potential difference between grid and wire.

The pulse from the proportional counter was fed to a two-stage linear amplifier followed by a biased multivibrator and a Rossi tube. The latter was connected in coincidence with another similar circuit which was fed by the triple coincidence pulse from the Geiger counters after suitable modification. The triple and quadruple coincidences were recorded separately by an Esterline Angus pen-recorder.

Figure 2 shows two typical curves, obtained at two different sensitivities of the multivibrator, where the ratio of the quadruple to triple coincidences in percent has been plotted as a function of the voltage on the proportional counter. The nature of the curves most probably results from a combination of two phenomena:

(a) The increase to a maximum in the primary phenomenon under investigation, *viz*, the detection of the secondary electron, and

(b) superposition of the phenomenon resulting from the sucking of ions through the screen from the region outside, which would presumably mount at increasing rate with increase of "sucking-in" field. It is proposed to investigate more fully the phenomenon of leakage of ions by utilizing a grid having a smaller mesh of thinner wires and also by adopting two grids instead of one, the potentials being suitably adjusted.

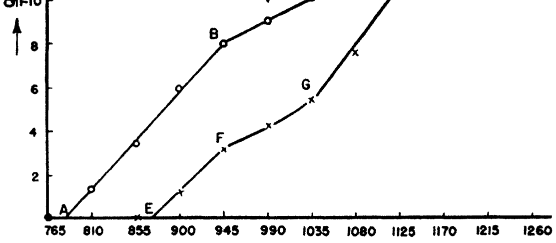

FIG. 2. The ratio of quadruple to triple coincidences in percent *vs* voltage on the proportional counter.

It may be seen, however, that the curve $ABCD$, obtained with the multivibrator operating at its maximum sensitivity, shows a point of inflection at about 9 percent. This represents probably the most acceptable value of the percentage of secondaries obtained under these experimental conditions.

It is interesting to compare this value with that deduced theoretically according to Swann's[3] method. The fraction P of the N secondaries, with energy $Q>Q_0$ is given by

$$P=Q_m/Q_0, \tag{1}$$

where Q_m is the lowest limit of Q ($\sim$10 ev), and Q_0 is the lowest energy of a secondary detectable under our experimental conditions.

Assuming that the secondaries are ejected at right angles to the path of the cosmic ray, like delta-rays accompanying swift β-particles,[4] it may be seen that the secondaries have to traverse an average length of approximately 1 cm in the gaseous mixture (5 cm of argon+15 cm of methane) before entering the sensitive volume of the proportional counter. This path length is equivalent to a range of approximately 0.2 cm in air at N.T.P. and necessitates a dissipation of approximately 3 kev on the part of the electron.[5] Moreover, the path length of 25.4 cm traversed by the primary through the gaseous volume of the counter gives about 130 primary ionizing events (N).

Therefore, the average number of cases where $Q>Q_0$ in the passage of a primary through the counter along the path designated is

$$PN=130\times3.3\times10^{-3}=0.43.$$

Now if, as a first approximation, we assume that the number of secondaries for $Q>Q_0$ shows fluctuations in accordance with Poisson's law, the fraction F of the primary rays which give n secondaries is represented by

$$F=x^n e^{-x}/n! \tag{2}$$

In this case x, the average number of secondaries per particle, is 0.43. The values of F for $n=0$, 1, 2, respectively, are 0.65, 0.28, 0.06. Thus, in only 34 percent of the cases, the primary ray is accompanied by secondaries above 3 kev, which are ejected in all directions perpendicular to the path of the former. On account of the geometry and dimensions of the cathode and grid, however, it can be shown that only 33 percent of these secondaries can penetrate through the grid into the active volume of the proportional counter. Therefore, the calculated percentage of long-range secondaries which can be detected in the present set up is about eleven, which compares favorably with our experimental finding.

The author is indebted to Dr. W. F. G. Swann for invaluable suggestions and to Dr. D. C. Rose for generous help.

* National Research Laboratories Post-Doctorate Fellow.

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Measurement of Isomeric Transition Energies with a Scintillation Spectrometer

E. DER MATEOSIAN AND M. GOLDHABER
Brookhaven National Laboratory, Upton, Long Island, New York*
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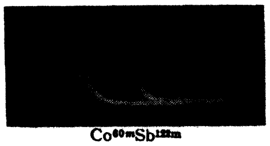
AN accurate determination of isomeric transition energies is necessary for a comparison between theoretical and experimental gamma-ray lifetimes and plays, therefore, an important role in any systematic investigation of isomers. The gamma-ray scintillation spectrometer[1] is particularly suited for the determination of isomeric transition energies whenever one or more of the following conditions are fulfilled: the isomeric transition is not too highly converted, the specific activity is low, and the lifetime is short. Under such circumstances the use of the scintillation

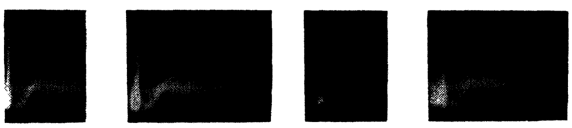


$Co^{60m}Sb^{122m}$

FIG. 1. Oscilloscope traces of Co^{60m} (10.7 min) (59 kev standard) and Sb^{122m} (3.5 min) indicating a γ-ray energy of 68 kev.

counter may yield results which are superior to absorption measurements and may compare in accuracy with those attainable with a beta-ray spectrometer. The scintillation counter shares with some other methods the disadvantage that the gamma-ray observed does not necessarily correspond to the isomeric transition. It may follow the isomeric transition or appear in a beta- or K branch. Subsidiary experiments may therefore be necessary in some cases.

We should like to report here on a series of measurements of isomeric transition energies which we have carried out with the help of a scintillation counter. We used NaI crystals activated with TlI. We found a comparatively small crystal ($\sim$2 cm^2 in area and 1 cm high) most useful for a determination of low energy gamma-rays. The crystal, covered with a layer of mineral oil, was fixed to a 5819 RCA photo-tube and backed by an aluminum foil reflector. The photo-tube was connected to a 204B Atomic Instrument Company linear amplifier and a DuMont 248 oscilloscope for display of the self-triggered pulses (sweep time $\sim 5\mu$sec). The pulse distribution was photographed with the help of a polaroid camera. The linearity of our arrangement was checked with a number of well-known gamma-ray lines (Co^{60m} (59 kev), Te^{123m} (159 kev), Te^{121m} (213 kev), Cr^{51} (320 kev), Cs^{137} (661 kev)) and found to be satisfactory in this energy range. To obtain the metastable states which we investigated, suitable samples (metals or oxides) were exposed to slow neutrons in the Brookhaven reactor and then transferred rapidly to the scintillation counter. Typical oscilloscope traces are shown in Figs. 1 and 2. Table I summarizes our results. The apparent gamma-ray continuum previously found[2] for Ir^{192m} (1.5 min) in competition with the 57.4 kev internally converted transition,[3] yields a pulse distribution with an upper limit close to this energy but of very different appearance than that obtained for gamma-rays of other isomers of similar excitation energy. This spectrum is being investigated further.



(A) (B) (C) (D)

FIG. 2. Oscilloscope traces showing γ-ray continuum from Ir^{192m} (1.5 min). (A) 10-sec exposure, (B) 15-sec exposure, (C) shows, for comparison, an electronically produced pulse corresponding in height to the center of a 50-kev γ-line, and (D) shows the γ-ray of Rh^{104m} (4.7 min) indicating an energy of 52 kev.

TABLE I. Isomeric transition energies.

Isomer	Present work: Half-life time	Present work: Energy of γ (kev)	Previous data: Energy of e^- (kev)	Previous data: Energy of γ (kev)	Previous data: Transition energy (kev) as given by K. Way *et al.*[a]
Sc^{46m}	19.5 sec	135	165 (abs[b])	180 (abs)	180
Se^{77m}	17.5 sec	150	150 (abs)	150 (abs)	150
Rh^{104m}	4.7 min	52	69.5 (spect[c])	50 (abs)	80; 50
Sb^{122m}	3.5 min	68	$\sim$110 (abs[d])		140
Hf^{179m} [g]	19 sec	215	86.1, 135.1 (spect[e])		150
			190 (abs[f])		190
Ir^{192m}	1.5 min	Continuum	$44.1L_{\mathrm{I}}$, $46.0L_{\mathrm{III}}$	Continuum	57.4

[a] Previous data for which no explicit references are given are taken from K. Way *et al.*, Nuclear Data, Nat. Bur. Standards (U. S.), Circ. 499.
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[g] This mass number was recently assigned by C. O. Muehlhause by bombarding enriched Hf isotopes with slow neutrons (private communication).

Antimony was used in isotopically enriched form (97.7 percent Sb^{121}). Our energy values are estimated to be accurate to 10 percent. The only serious discrepancy between our values and earlier ones appears in the case of Hf^{179m} (19 sec), where Hole[4] had found a transition energy of 150 kev with a beta-ray spectrograph, and where our value is considerably higher (215 kev).[5] The possibility that we are dealing here with a two-step isomeric transition is being investigated.

We wish to thank Dr. C. E. Larson, Oak Ridge, for putting hafnium metal at our disposal and Dr. Keim's group for the isotopically enriched antimony sample. Thanks are also due to Mr. Jack Floyd for help in making the neutron exposures.

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Quantum Effects in the Interaction between Free Electrons and Electromagnetic Fields

CARL SHULMAN
RCA Laboratories Division, Radio Corporation of America, Princeton, New Jersey, and Princeton University, Princeton, New Jersey
(Received January 22, 1951)

THE quantum nature of the exchange of energy between free electrons and electromagnetic fields implies a dispersion in energy exchange which the classical theory cannot predict. Smith[1] has treated the quantum mechanical description of this process in some detail, and he has calculated probabilities for the exchange process in a few simple cases. The standard deviation is shown to be proportional to the square root of the number of photons handled by an interacting electron, while the mean expected energy exchange is proportional to the total number handled. Hence, the transition to the classical description may be understood in terms of the vanishing of the ratio of the standard deviation to the mean expected exchange in the limit of large number of photons handled. This calculation suggests that the quantum dispersion might be observed in the presence of a strong electric field if the mean exchange could be made small. One could, for instance, use a high velocity beam whose energy distribution is characterized by a temperature T, sending it through a strong oscillating electric field such that the standard deviation arising from quantum processes is at least of the order kT, while the mean exchange is held to zero by adjusting the transit time to an integral number of cycles. The apparent temperature of the beam on emerging from the interaction space would be increased owing to the quantum effect by an amount proportional to the square root of the total number of photons handled during transit. Such a method circumvents the limitation suggested by Ward,[2] that in order to use electron beams to detect quantum effects of this kind, one must use a beam mono-energetic to within less than one quantum.

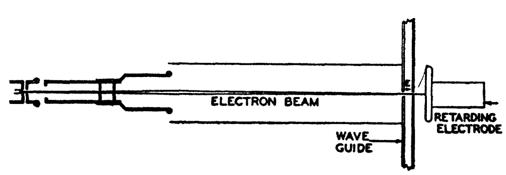


FIG. 1. Experimental arrangement.

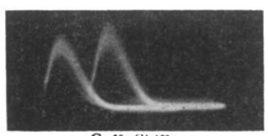
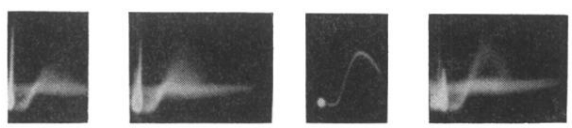


FIG. 1. Oscilloscope traces of Co^{60m} (10.7 min) (59 kev standard) and Sb^{122m} (3.5 min) indicating a γ-ray energy of 68 kev.



(A) (B) (C) (D)

FIG. 2. Oscilloscope traces showing γ-ray continuum from Ir^{192m} (1.5 min). (A) 10-sec exposure, (B) 15-sec exposure, (C) shows, for comparison, an electronically produced pulse corresponding in height to the center of a 50-kev γ-line, and (D) shows the γ-ray of Rh^{104m} (4.7 min) indicating an energy of 52 kev.