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

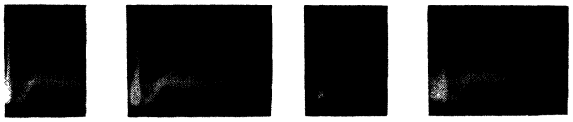

FIG. 2. Oscilloscope traces showing γ-ray continuum from Ir^{192m} (1.5 min). (A) 10-sec exposure, (B) 15-sec exposure, (C) shows, for comparison, an electronically produced pulse corresponding in height to the center of a 50-kev γ-line, and (D) shows the γ-ray of Rh^{104m} (4.7 min) indicating an energy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

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.

TABLE I. Isomeric transition energies.

Isomer	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_I, 46.0L_{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.
[b] M. Goldhaber and C. O. Muehlhause, Phys. Rev. **74**, 1877 (1948).
[c] N. Hole, Arkiv. Mat. Astron. Fysik **34B**, No. 5 (1947).
[d] der Mateosian, Goldhaber, Muehlhause, and McKeown, Phys. Rev. **72**, 1271 (1947).
[e] Reference 4.
[f] A. Flammersfeld, Z. Naturforsch. **1**, 190 (1946).
[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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[1] R. Hofstadter and J. A. McIntyre, Phys. Rev. **80**, 631 (1950); S. A. E. Johansson, Arkiv Fysik **18**, 171 (1950); Pringle, Roulston, and Standil, Phys. Rev. **78**, 627 (1950); P. R. Bell and J. M. Cassidy, Phys. Rev. **79**, 173 (1950).
[2] Goldhaber, Muehlhause, and Turkel, Phys. Rev. **71**, 372 (1947).
[3] R. L. Caldwell, Phys. Rev. **78**, 407 (1950).
[4] N. Hole, Arkiv Mat. Astron. Fysik **36A**, No. 9 (1948).
[5] Dr. E. C. Campbell of Oak Ridge informs us that he has also obtained a value of 215 kev for the Hf gamma-ray.

Quantum Effects in the Interaction between Free Electrons and Electromagnetic Fields

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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.

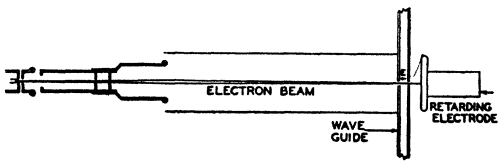

FIG. 1. Experimental arrangement.

We have detected this quantum dispersion with the arrangement shown in Fig. 1. A fine electron beam was shot through a longitudinal r-f field in the wave guide, as shown. The transit time in the guide was adjusted to an integral number of r-f cycles. After emergence from the interaction space, the energy distribution was measured by a retarding field method. This energy distribution has three main sources: (1) emission velocity distribution in the beam, (2) a classical energy exchange arising from a small functional dependence of transit time on the r-f field strength, and (3) the quantum effect sought. By using high beam voltage (10 kv), small beam angle (0.004 radian), and strong r-f field, the classical effect No. 2 was made small relative to effect No. 1, while the quantum effect No. 3 was made large.

The actual measurement was made in terms of the dependence of the current to the retarding electrode on the r-f field strength. Assuming a Maxwell-Boltzmann distribution in the beam, and applying the Smith treatment, one can calculate the current to the retarding electrode in terms of the three effects mentioned above. This current is given by the expression

$$\frac{I}{I_0}=J_0\left(i\frac{1}{4n\pi}\frac{eV^2}{V_0kT}\right)\exp\left(\frac{1}{\pi}\frac{eV}{kT}\frac{h\nu}{kT}\right),$$

where I is the current in the presence of r-f field; I_0 is the current in the absence of r-f field; V is the peak r-f voltage across wave guide; V_0 is the dc voltage at the wave guide; T is the beam temperature; and n is the number of r-f cycles of interaction time. The argument of the exponential term is a measure of the quantum dispersion in terms of the dispersion of the initial energy, while the argument of the Bessel term is a measure of the dispersion arising from the classical effect No. 2 in terms of the dispersion of initial energy.

The experiment was carried out at a free space wavelength of 1.25 cm with a pulsed magnetron oscillator as the source of r-f energy. From experimental plots of $-\ln[(I_0/I)J_0(ieV^2/4n\pi V_0kT)]$ *versus* V, one can decide whether or not he has observed the quantum effect by using the following argument: If the quantum dispersion were nonexistent, such plots would show no dependence on V. If, in addition, there occurs accidental asymmetry in the geometry of the interaction space, the plots would show quadratic dependence on V, representing a classical effect. If the quantum dispersion exists and if there is accidental asymmetry in the interaction space, the plots would again be quadratic. If the quantum effect is present and there is no asymmetry in the interaction space, the plots would show a linear relationship in V.

The experimental plots show a linear dependence of $-\ln[(I_0/I)\times J_0(ieV^2/4n\pi V_0kT)]$ on V and represent detection of the quantum effect. Computations of h from measurements of I/I_0, V, T, and V_0 give a spread of values whose average is 0.7 times the accepted value with a standard deviation of 0.2.

[1] L. P. Smith, Phys. Rev. **69**, 195 (1946).
[2] J. C. Ward, Phys. Rev. **80**, 119 (1950).

Disintegration of Neon by Fast Neutrons*

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In a previous paper, measurements on the disintegration of nitrogen by fast neutrons were reported.[1] The same equipment was used to measure the cross section for the disintegration of neon by neutrons. For this purpose, the ionization chamber was filled with neon to a pressure of 30 atmospheres and operated as a proportional counter with a gas multiplication of about five. In order to obtain saturation at this pressure, the neon was purified by means of a calcium getter.

Fast neutrons of variable energy were obtained by bombarding a thin tritium target with protons from the electrostatic generator. The tritium was absorbed in an evaporated layer of zirconium having a stopping power of less than 15 kev for the protons used in the measurements. The energy spread of the neutrons entering the counter was caused primarily by the variation in energy of the neutrons as a function of angle of emission with respect to the incident protons. This energy spread could be varied by changing the distance of the counter from the target.

Figure 1 shows a pulse height distribution obtained with 2.45-

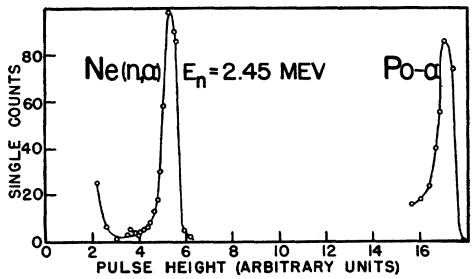

FIG. 1. Typical pulse height distribution curve obtained with fast neutrons incident on a neon-filled proportional counter. Po α-particles originate from a source mounted on the wall of the counter.

Mev neutrons. Similar distribution curves were taken at intervals of about 0.2-Mev neutron energy. Only one group of disintegration pulses was found. In addition to the neon disintegrations, pulses from a Po α-particle source in the counter were registered at each neutron energy to fix the energy scale. In this way it was found that the disintegration pulses had an energy of 0.75 ± 0.05 Mev less than the incident neutrons. This value of the reaction energy is in fair agreement with values of -0.80 to -0.85 Mev as observed by Graves and Coon[2] for the Ne(n,α) reaction. Because of the uncertainty of the masses of O^{17} and Ne^{20}, the reaction energy can be obtained from the masses only to about ±150 kev, but it agrees within these limits of error with the value measured in the present experiment.

Figure 2 shows the disintegration cross section of neon as a

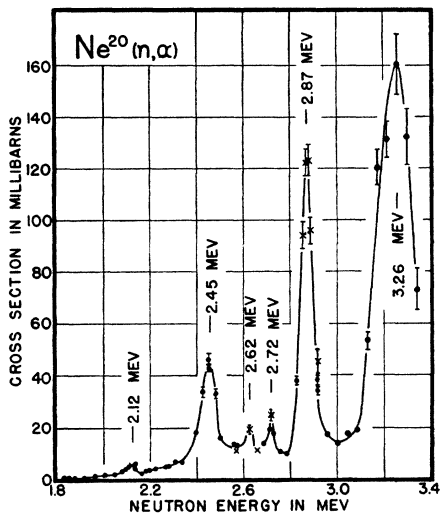

FIG. 2. Neon disintegration cross section. Circles indicate a neutron energy spread which increased from 40 kev at 1.8 Mev to 60 kev at 3.3 Mev. Crosses indicate an energy spread of 30 kev. Energies given at the resonance peaks have an uncertainty of less than 50 kev.

function of neutron energy. The magnitude of the cross section at the three prominent resonance peaks excludes the possibility that the disintegrations could be caused in any but the most abundant isotope; consequently, the cross section was calculated under the assumption that Ne^{20} is responsible for the observed disintegrations. For the three large peaks, the neutron energy spread was somewhat less than the observed width of the resonance so that the cross section should reach nearly the true value.