$=(34\pm 7)\times 10^{-5}$]. The theoretical values are:

	$E1$	$E2$	$M1$	$M2$
$\alpha_K \times 10^{+5}=$	28	68	66	165.

Both results are nearest to the coefficient of $E1$. The direction-polarization correlation measurements exclude $E2$ and $M1$. With these latter results, one is only left with a choice between $E1$ and $M2$ which puts the decision for $E1$ beyond any doubt. The decay scheme of Sr^{88} is then 3^-, 2^+, 0^+.

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Iridium-194†

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Electromagnetically enriched quantities of Ir^{193} were exposed for time intervals ranging from 0.5 to 2.0 hr on five successive occasions in the Brookhaven pile. The 19-hour Ir^{194} was found to emit gamma rays of energies 0.295, 0.325, 0.635, 0.640, 0.93, 1.14, 1.28, 1.45, 1.58, 1.77, and ~2.00 Mev. By coincidence studies, cascade relationships were established between ten pairs of gamma rays. The first and second excited states of the residual nucleus were located at 325 and 620 kev. The angular correlation function of the 0.295 Mev—0.325 Mev cascade was measured and found to correspond to a $2\to 2\to 0$ distribution, thus giving the spins of the first two excited states of Pt^{194}.

INTRODUCTION

THE 19-hour Ir^{194} has been shown on several previous occasions[1–10] to emit hard beta rays and gamma rays. It has been generally agreed that all but a few percent of the beta rays are contained in a very hard spectrum of maximum energy ~2.2 Mev. Beta-gamma coincidences have been detected,[6] showing the presence of at least one inner beta spectrum which is followed by gamma rays. Until recently,[10] only three gamma rays had been shown to be definitely related to the 19-hour period, a relatively hard one of energy ~1.4 Mev[6] and softer gamma rays at 0.3275 Mev[5–8] and 0.290 Mev.[9] Gamma rays at energies of 1.7 Mev and more have been suggested by the photodisintegration of beryllium and deuterium.[7] A far more complex gamma spectrum has been of late indicated in scintillation counter studies[10] wherein quantum energies of 0.32, 0.61, 1.18, 1.45, and ~1.8 Mev with relative intensities of 100, 22, 10, 5, and 1.2 were reported.

To investigate further the radiation characteristics and decay scheme of Ir^{194}, samples of metallic iridium of weight about 10 mg, isotopically concentrated[11] in Ir^{193}, were exposed on five successive occasions in the Brookhaven pile. The times of irradiation varied from 0.5 hour to 2 hours, and measurements were commenced at a time not exceeding twenty hours after removal of the exposed target material from the reactor and were continued in each case for a period of about three days. The gamma-ray spectrum of Ir^{194} was observed in sodium iodide scintillation spectrometers, and gamma-gamma coincidence data were obtained with two such spectrometers in coincidence. One sodium iodide detector was replaced by an anthracene counter to measure the beta spectra and observe beta-gamma coincidences.§

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11 On comparing the ratio of the activity of Ir^{194} to that of Ir^{192} in an isotopic target with the same ratio for a sample of normal elemental iridium, it was possible to conclude that the concentration of Ir^{193} was greater than 90 percent.

§ *Note added in proof.*—Since this article was submitted for publication, a paper by Johns and Nablo, Phys. Rev. **96**, 1599 (1954), has appeared. They report sixteen gamma rays from Ir^{194}, having resolved several additional quanta at high energies.

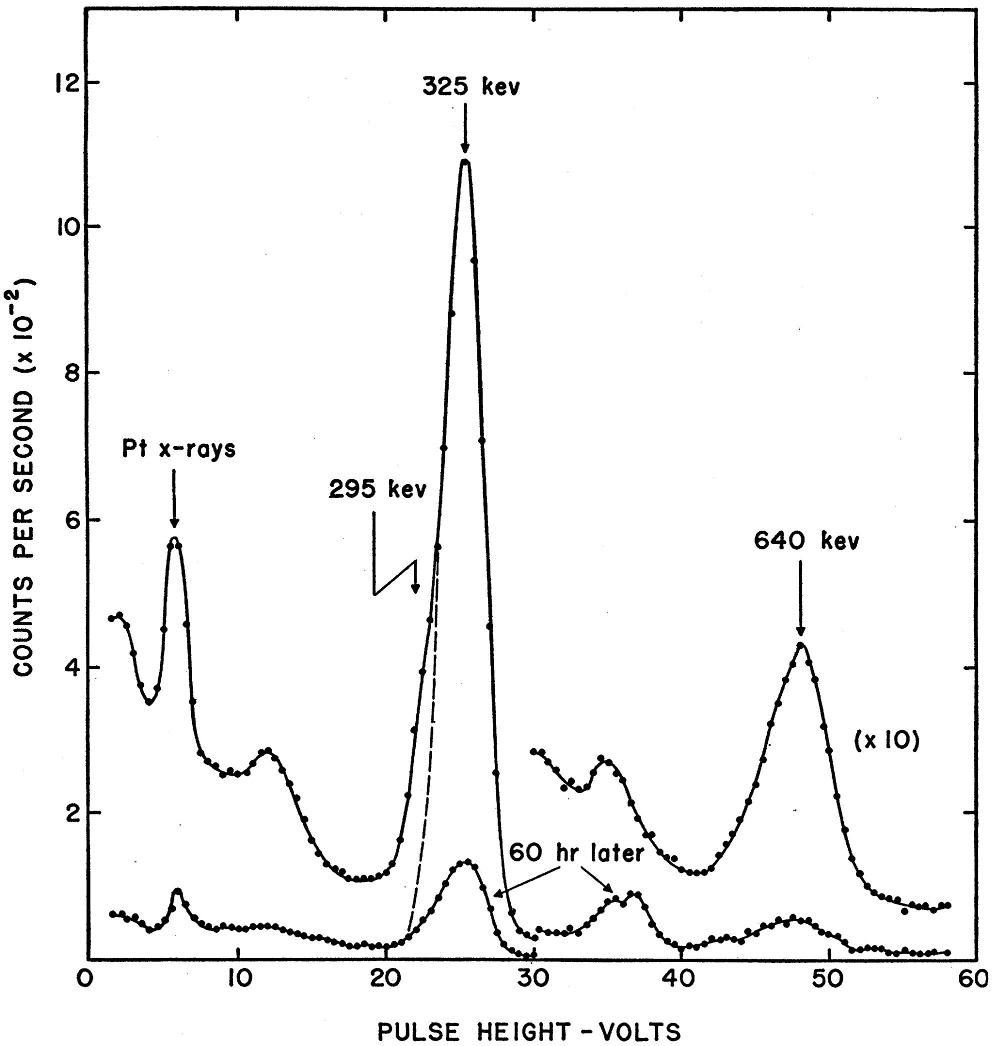

FIG. 1. Pulse height distribution in NaI(Tl) of the softer gamma rays of the 19-hour Ir^{194}.

GAMMA-RAY SPECTRA

The region of relatively low quantum energies was explored by placing before a scintillation counter a source of Ir^{194} with an intervening absorber equivalent to about 1.2 g/cm^2 of aluminum. The gamma-ray spectrum thus obtained is shown in Fig. 1. To examine the nature of the spectrum at higher energies, absorbers of 14 g/cm^2 of lead and 1.35 g/cm^2 of cadmium were interposed. The resulting data are shown in Fig. 2. From the two sets of curves and the indicated rate of decay of the ordinate values, it may be concluded that the observed gamma rays can be attributed to the nineteen hour Ir^{194}. Gamma-ray peaks are clearly present with quantum energies of 0.325, 0.640, 0.930, 1.14, 1.45, 1.77, and ~2.0 Mev. It is furthermore to be noted that deformations appear in the spectrum in the vicinity of 1.28 and 1.58 Mev. It will be later shown that the possibility of the presence of quanta of these energies is indicated by the proposed disintegration scheme. Another distortion appears at 295 kev. Coincidence studies to follow show that a gamma ray of that energy is also present in the decay of Ir^{194}. It should be pointed out that the 640-kev peak is sufficiently wide to suggest complexity. The quantum energies and relative intensities of the gamma rays of Ir^{194} are summarized in Table I.

COINCIDENCE MEASUREMENTS

A series of coincidence studies were carried out to determine the cascade relationships between the various gamma rays. In Fig. 3A are shown the curve of the single counting rate near 325 kev and the coincidence rate in that region with one detector set at the 640-kev peak. A similar set of curves is shown in Fig. 3B. To obtain this curve of coincidences, one detector was set on the high-energy side of the 325-kev peak while the other was moved through the region of lower energies

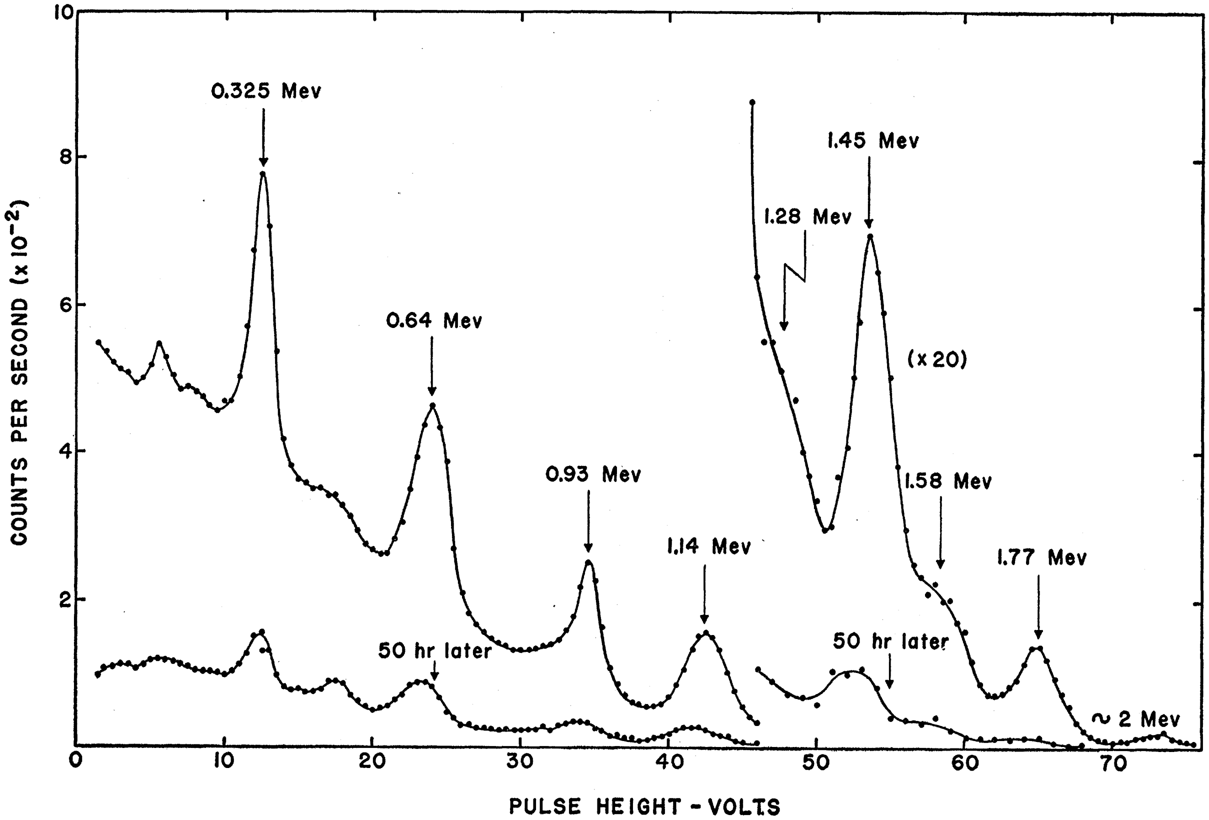

FIG. 2. Pulse height distribution of the gamma rays of Ir^{194} as observed through pre-absorption of 14 g/cm^2 of Pb and 1.35 g/cm^2 of Cd.

to locate a second gamma ray at precisely 295 kev. Returning to Fig. 3A, it is now clear that both a 295-kev gamma ray and a 325-kev gamma ray, which are themselves in cascade, are coincident with the 640-kev radiation. In Fig. 4A and 4B are plotted, along with the curves of single counts, coincidences in the neighborhood of 325 kev with one detector fixed at 1.14 Mev and 0.930 Mev, respectively. On comparing the widths of the coincidence peaks with those of the curves of single counts, it is clear that the 295-kev radiation is non-

TABLE I. Energies and relative intensities of the gamma rays of the 19-hour Ir^{194}.[a]

Quantum energies (Mev)	Relative intensities
0.295	...
0.325	100
0.635, 0.640	10
0.93	7.6
1.14	8.5
1.28	...
1.45	1.8
1.58	...
1.77	0.9
2.00	0.2

[a] The estimates of relative intensities are those obtainable from the data of Figs. 1 and 2. Earlier investigations (see reference 9) have shown the 0.295-Mev gamma ray to have an intensity one-fifth as great as that of the 0.325-Mev radiation.

coincident with the two hard gamma rays. In Fig. 5A is shown the coincidence rate in the vicinity of 640 kev with one channel fixed to count pulses from the 295- and 325-kev quanta. This curve indicates that all gamma rays in the region of 640 kev are coincident with the two above-mentioned gammas. In Fig. 5B are shown coincidences in the region of 640 kev with one channel fixed on the high-energy side of the photopeak of single counts. It will be noted that the observations of coincidences lie upon the curve of single counts, denoting little difference in the energies of the two or more gamma rays of energy ~640 kev which give rise to the coincidence rate.

DISINTEGRATION SCHEME

Returning to the spectrum of Fig. 1, it can be shown that no other gamma ray present has an intensity approaching that of the 325-kev line. This fact remains true though the intensity of any one of the other gamma rays might be increased by an amount sufficient to take into account the presence of all the x-radiation if it is assumed produced by internal conversion of the particular gamma ray. Thus, for reasons of intensity, the 325-kev transition must originate at the first excited state of Pt^{194}. The 295-kev gamma ray has been previously shown to have an intensity one-fifth[9] as great as that of the 325-kev quantum. Since the

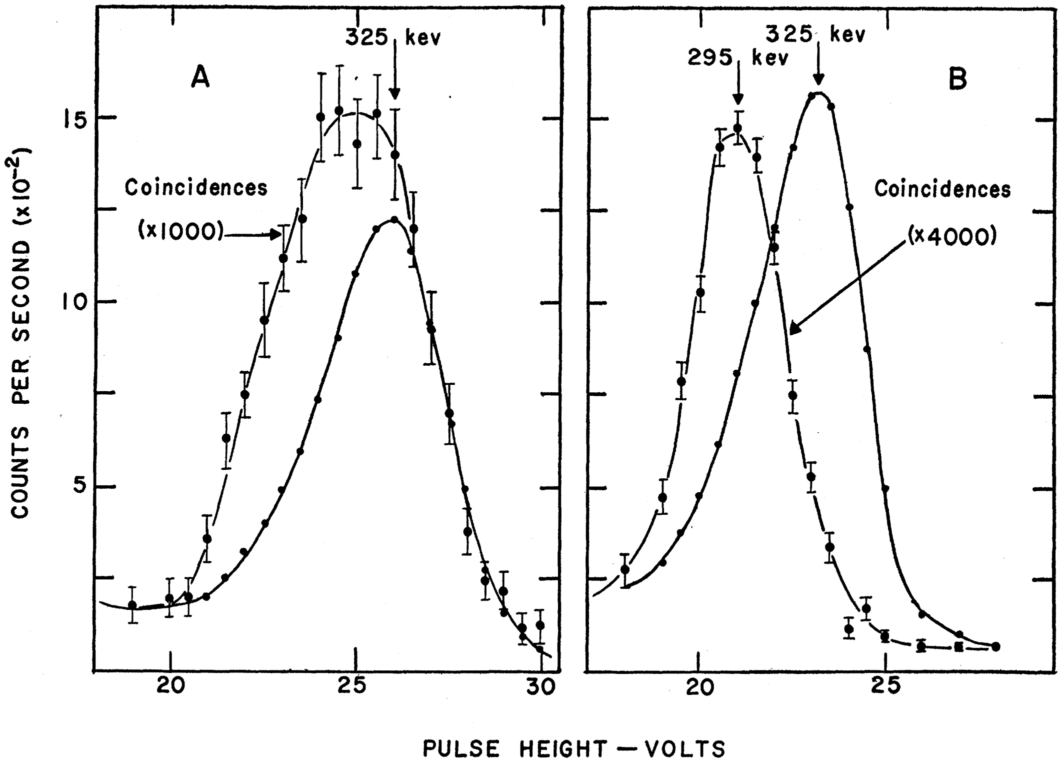

FIG. 3. Curves A, coincidences between gamma rays at ~640 kev and at ~325 kev with one channel fixed at ~640 kev. Curves B, coincidences between 325-kev and 295-kev gamma rays with one channel fixed on high-energy side of 325-kev peak.

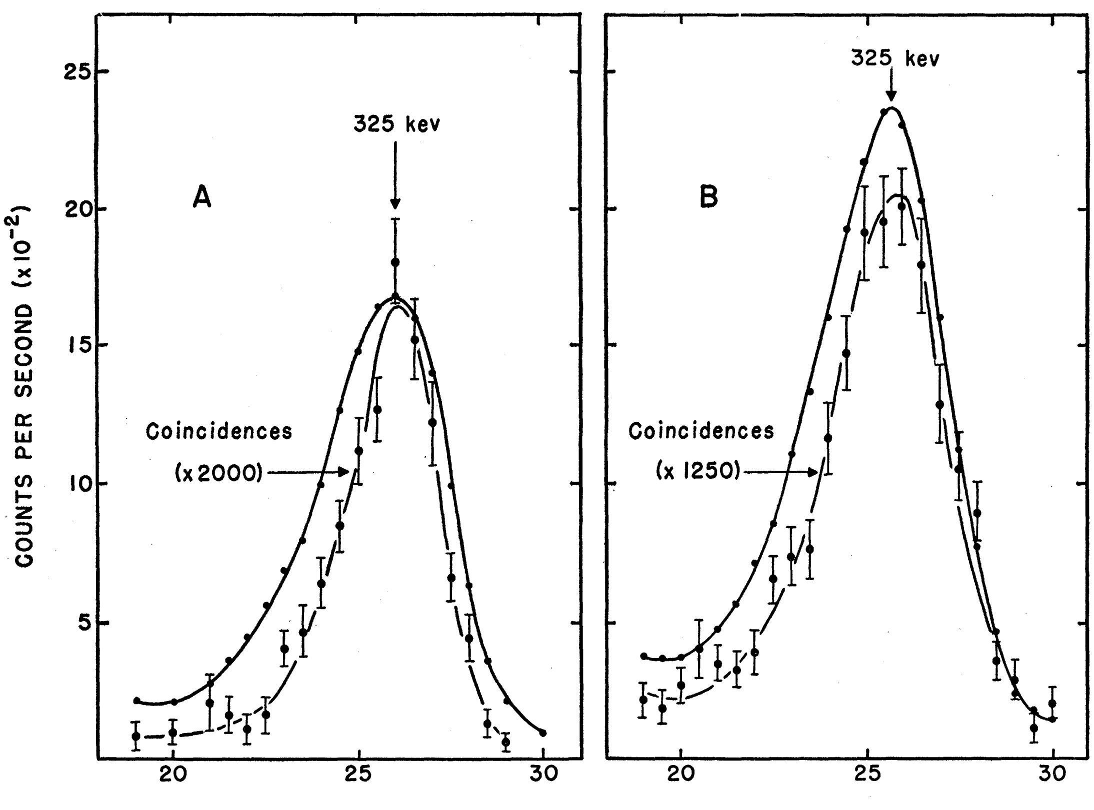

FIG. 4. Curves A, coincidences between 325-kev radiation and the 1.14-Mev line with one channel fixed at 1.14 Mev. Curves B, coincidences between 325-kev radiation and the 0.93-Mev gamma ray with one channel fixed at 0.93 Mev.

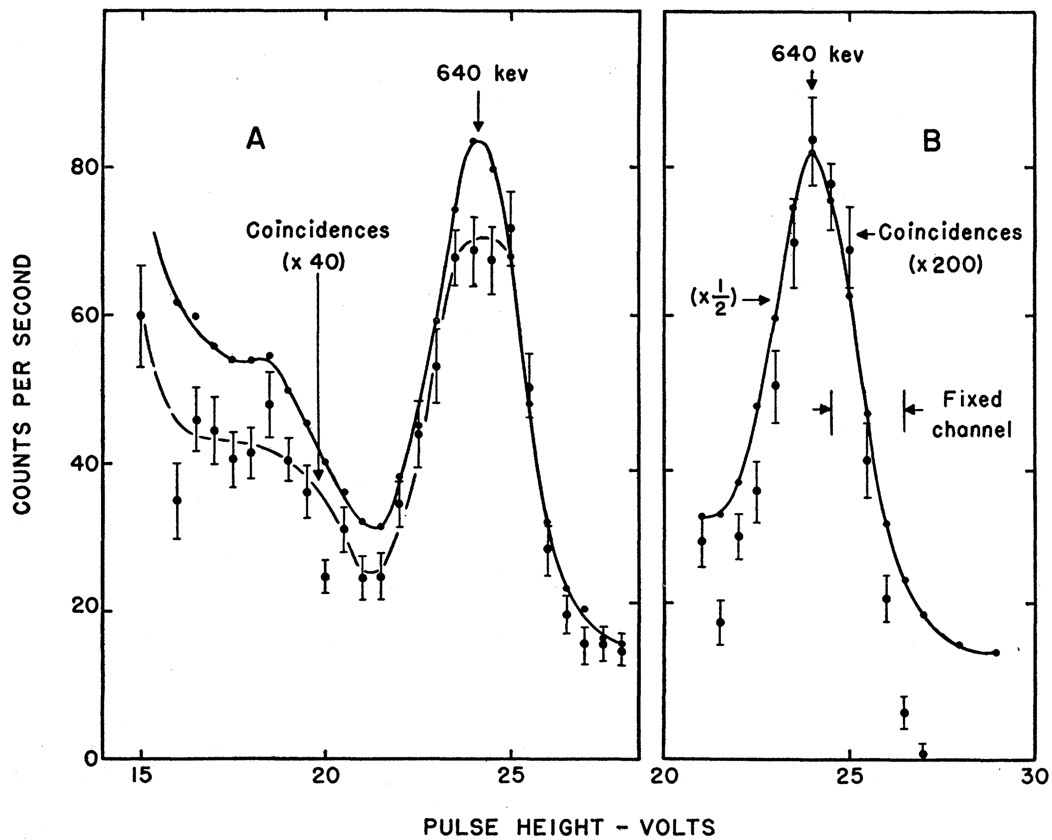

FIG. 5. Curves A, coincidences between 325-kev radiation and 640-kev peak with one channel fixed at 325 kev. Curves B, coincidences between gamma rays in the region of 640 kev with one channel fixed on the high-energy side of the 640-kev peak.

composite peak at 640 kev has one-tenth of that intensity (see Table I), it must be assumed that the level from which the 295-kev line is emitted must be fed by more beta rays than any level other than the first excited state. Thus, the 295-kev radiation is emitted from the second excited state. The 635-kev→295-kev→325-kev cascade was established from the data of Fig. 3A. Figure 4B indicates the 935-kev→325-kev cascade; so the third excited state is located at about 1.25 Mev. The coincidences of Fig. 4A and the absence of coincidences between the 1.14-Mev gamma ray and any quanta other than the 325-kev radiation show that the fourth excited state lies at ~1.465 Mev above the ground state. Though the data have not been depicted in any figure, it was found that the 1.45-Mev radiation is coincident only with 325-kev quanta. Thus the fifth excited state must lie at ~1.775 Mev. By observation of coincidences between the 640-kev radiation and the 930-kev quanta, the sixth excited state was placed at 1.895 Mev. Moreover, the 640-kev→635-kev cascade studied in Fig. 5B is consistent with a 640-kev→930-kev cascade. Specific full-energy peaks corresponding to 1.58- and 1.28-Mev gamma rays were not detected because of their low intensities relative to other gamma rays present. However, the single counting-rate spectrum of Fig. 2, the general trend of coincidence curves, and energy considerations suggest the indicated positions in the decay scheme of Fig. 6. Because of these various uncertainties, these transitions are represented by broken lines. No coincidences between gamma rays of energy more than 1.6 Mev and the 325-kev quantum were detected. From this observation and from energy considerations, the 1.77-Mev transition was given its position in the decay scheme. Though no coincidence studies could be carried out in relation to the weak 2.0-Mev radiation, energy considerations evolving about the maximum energy of the hardest beta spectrum suggest it to proceed directly to the ground state.

Gamma rays of energies 328 and 291 kev have been reported[12] emitted in the decay of Au^{194}. The measured K/L ratios[12] for the two transitions are such as to suggest that both are of multipole order $E2$. Since Pt^{194} is an even-even nucleus ($I_0=0+$), the spin value of the first excited state is 2+, in agreement with the Goldhaber rule.[13]

Earlier beta-gamma coincidence studies[6] have shown

[12] Steffen, Huber, and Humbel, Helv. Phys. Acta **22**, 167 (1949).
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that most of the beta rays of Ir^{194} proceed to the ground state of Pt^{194} in the 2.2-Mev spectrum whereas a few are coincident with gamma radiation. Though the results are not shown in any figures, beta-gamma coincidence measurements were carried out in the present investigation which showed three inner beta spectra of end points 1.88, 0.94, and 0.74 Mev, coincident respectively with the gamma rays of energies 0.325, 0.930, and 1.14 Mev.

To obtain information with regard to the second excited state of Pt^{194}, the spatial correlation function of the 295-kev→325-kev cascade has been studied. The channels of the two pulse-height analyzers were set at the photopeaks of the two gamma rays, one at the 325-kev peak, the other on the low-energy side of the same peak (see Fig. 1), and adjusted to give the maximum genuine coincidence rate. A two-volt width was employed in either channel. With one detector

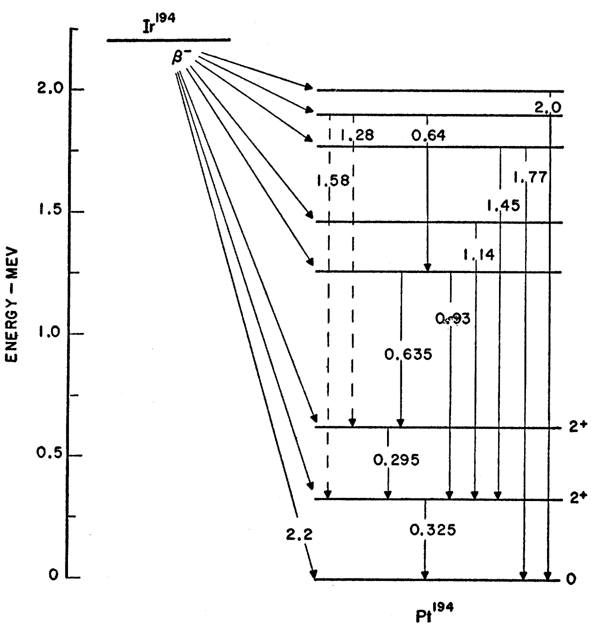

FIG. 6. Disintegration scheme of Ir^{194}.

fixed, the coincidence rates with the other at angles of 112.5°, 135.0°, 157.5°, and 180° with the axis of source and fixed detector were compared with the coincidence rate at 90° to measure any asymmetry. At least ten to twelve thousand true coincidences were obtained at each of the above listed angles. The experimentally

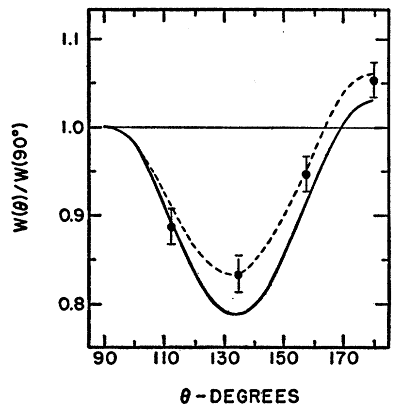

FIG. 7. Angular correlation function of the 295-kev—325-kev cascade.

determined asymmetries for the several angles of observation are shown in Fig. 7 along with a "least squares fit" (broken line) of quadratic form,

$$W(\theta)=1-0.725\cos^2\theta+0.787\cos^4\theta.$$

The theoretically expected correlation function for a 2→2→0, quadrupole-quadrupole transition is also shown, modified for the finite angular resolution of the detectors (half-angle 9.25°). The actual polynomial series, corrected for angular resolution, gives a correlation function of the form

$$W(\theta)=1-1.05\cos^2\theta+1.16\cos^4\theta.$$

The probable errors in the coefficients of the cosine terms are about five percent. The absolute values of the coefficients are not inconsistent with a pure quadrupole-quadrupole cascade. Because of the probable errors in the coefficients, the possibility of an $E2-M1$ mixture cannot be excluded. The deviation from the theoretically expected curve shown in Fig. 7 might also be explained by the presence of Ir^{192} and by coincidences between Compton recoils of high-energy gamma rays and photoelectrons of the quanta at 325 kev and 295 kev.

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