the heat balance of the earth's core, such as that of Bullard,[9,10] in connection with his theory of the earth's magnetism, indicate that geophysically significant rates of heat generation are about 1 to 3×10^{-8} erg/g sec, comparable to the heat generated by natural radioactivity in iron meteorites. Figure 2 shows that if $n<10^{-7}$, H is less than about 10^{-10} erg/g sec, and thus neutrino produced heat may be neglected in geophysical calculations. Also, no limits on the neutrino magnetic moment may be obtained on geophysical grounds.

[9] E. C. Bullard, Proc. Roy. Soc. (London) **A197**, 433 (1949).
[10] E. C. Bullard, Monthly Notices Roy. Astron. Soc. Geophys. Supp. **6**, 36 (1950).

5. CONCLUSIONS

The neutrinos produced in the sun undergo practically no inelastic collisions in either the sun or the earth, and reach to earth with almost the same energy that they had on creation in the sun.

I should like to thank Professor A. L. Hales for discussions on the heat balance of the earth's core.

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Summing Studies of the Gamma Rays Following the Decays of Ba^{131}, Se^{75}, and Ru^{106}*

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Coincidences between the gamma rays following the decays in Ba^{131}, Se^{75}, and Ru^{106} have been examined with the summing technique. The experimental evidences lead to a new decay scheme for Ba^{131}. Some discrepancies with previous investigations are found in Se^{75}, which leads to a revision of the decay scheme.

I. Ba^{131}

THE γ rays emitted by Cs^{131} following K capture from Ba^{131} have been studied by several previous investigators.[1-3] Kurbatov *et al.*,[3] in the latest study, reported their energies to be 122, 214, 244, 370, and 496 kev. In the present investigation, the coincidences between these γ rays are studied, using the summing technique described previously.[4] It is found that the 122- and 496-kev γ rays are in cascade, whereas neither the 214-kev nor the 372-kev transition is in coincidence with any other γ rays except the K-capture x-rays. This is contrary to the findings of Kondaiah[1] and the previous belief that the 496-kev transition is the "cross-over" in parallel with the cascade comprising the 372- and 122-kev transitions.

The experimental result of the present study is presented in Fig. 1. The top curve represents the normal γ ray spectrum taken with the sample about 3 inches away from the NaI(Tl) crystal. It exhibits the existence of γ rays at 618, 496, 372, 214, and 122 kev. and a very strong peak at 30 kev due to Cs and Xe K x-rays. No positive sign of the 244-kev γ ray is noticed, though the 214-kev peak does appear to be somewhat broadened. Neither are there any positive indications of the weak γ rays at 108, 65, and 48 kev as previously reported.[3] The weak γ ray at 618 kev appears to be real, since its relative intensity changed very little when the sample is moved from 2 to 4 inches away from the phosphor. The peak at 85 kev is probably due to Ba^{133m} contamination. A weak peak at about 1.09 Mev is also noticed, (not shown) but no attempt was made to trace its half-life to see if it belongs to Ba^{131}.

When the sample was enclosed in a thin Lucite rod and introduced at the center of the phosphor, the summing spectrum, represented by the bottom curve, was obtained. Because of the sample thickness and the Auger effect, the K-capture x-rays are subjected to substantial absorption before they enter the phosphor. As a result, only part of the γ quanta entering the phosphor sum with a K-capture x-ray quantum. Indications of such summing are noticed at 122+30 kev, 214+30 kev, and 372+30 kev. The 496-kev transition sums with the 122-kev transition to form a strong sum peak at an energy somewhat higher than 618 kev because of further partial summing with K x-rays. Since the 122-kev transition is highly converted, some of the 496-kev quanta each sum with two K x-ray quanta. This leads to the odd shaped peak at 510 kev. A sum peak corresponding to the sum of two x-rays also appears at about 60 kev. No other sum peaks are noticed.

When the sample was contained in a thin copper capsule of 0.6-mm wall thickness to cut off the x-rays, and placed at the center of the phosphor, the summing spectrum represented by the middle curve was observed. It clearly indicates that neither the 372-kev nor the 214-kev γ ray is in coincidence with the 122-kev γ ray. If

* This study was supported by the Michigan Memorial Phoenix Project, University of Michigan.
[1] E. Kondaiah, Arkiv. Fysik **2**, 295 (1950).
[2] R. Canada and A. C. G. Mitchell, Phys. Rev. **83**, 76 (1951).
[3] Elliott, Cheng, Haskins, and Kurbatov, Phys. Rev. **88**, 263 (1952).
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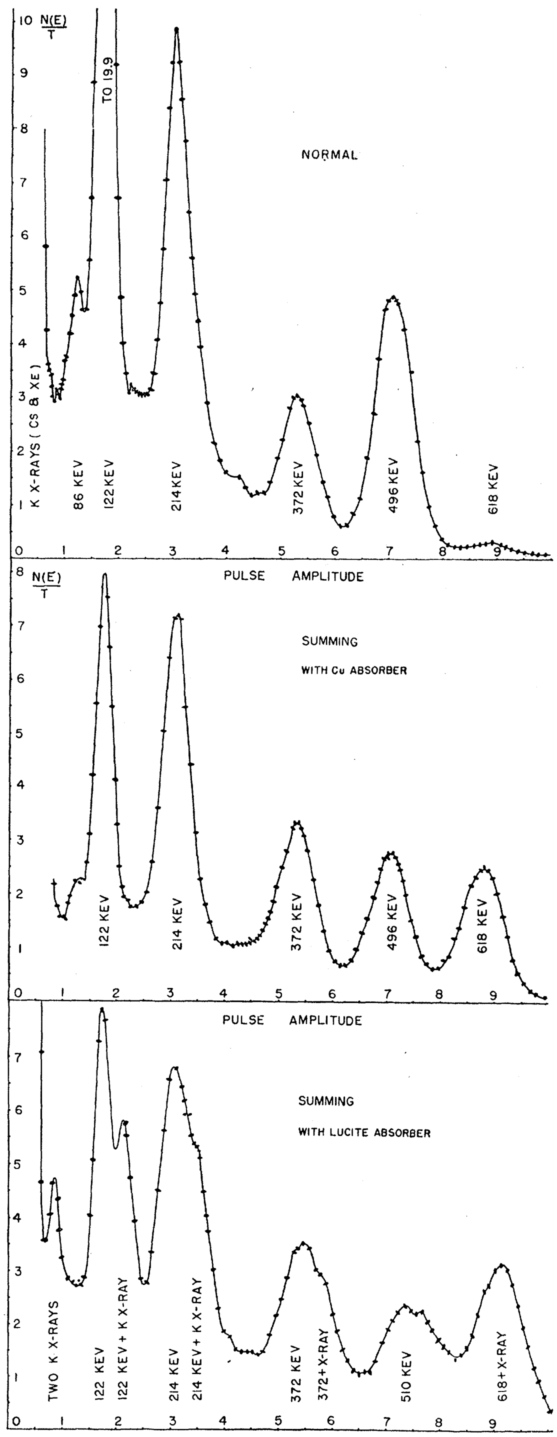

FIG. 1. γ-ray spectra of Cs^{131} following K capture in Ba^{131}. Energies in kev.

the 214- and 122-kev γ rays were in coincidence, a strong sum peak should appear at 336 kev. If the 372-kev γ ray were in coincidence with the 122-kev γ ray in the same manner as the 496-kev γ ray is, the summing effect would (a) reduce the intensity of the 496-kev peak by a factor α to form the sum peak at 618 kev, (b) reduce the intensity of the 372-kev peak, by the same factor α, to reinforce the peak at 496 kev. This would have resulted in a much higher peak at 496 than at 372 kev on the summing spectra. Similarly, using a thin gold capsule to cut off the 122-kev γ ray, one sees that the 372- and 214-kev γ rays do not sum with each other. The fact that both are in coincidence with K-capture x-rays (see Fig. 1, bottom curve) rules out the possibility that they may be in cascade through a meta-stable state. It is reasonable, therefore, to assume that they both go the the ground state, and are

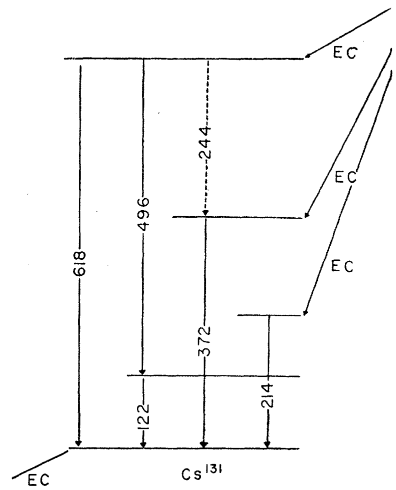

FIG. 2. Excited energy levels of Cs^{131}. Energies in kev.

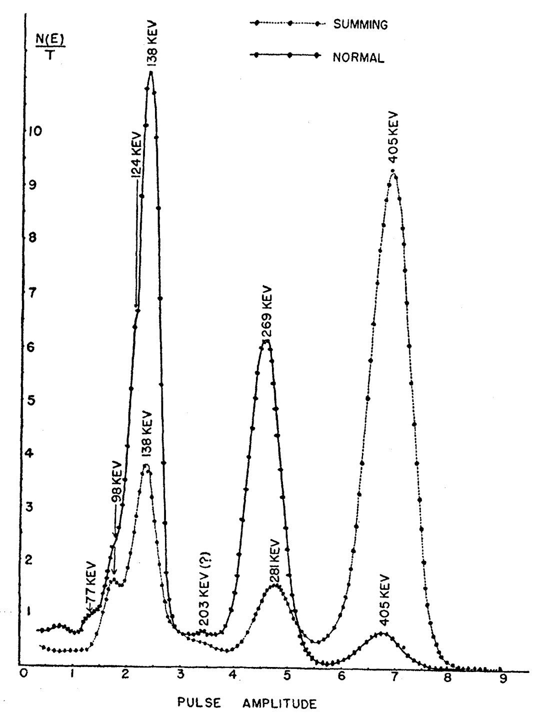

FIG. 3. γ-ray spectra of As^{75} following K capture in Se^{75}.

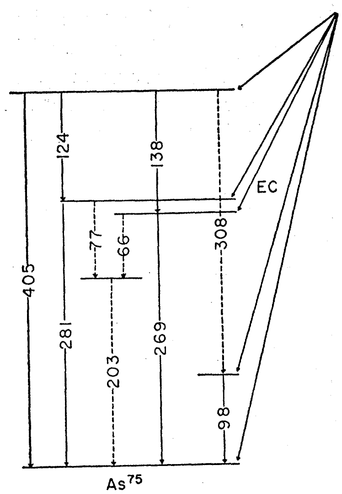

FIG. 4. Excited energy levels of As^{75}.

fed by separate electron capture processes. This leads to the decay scheme shown in Fig. 2.

The sum spectrum represented by the bottom curve in Fig. 1 also allows a rough estimate of the internal conversion coefficient e/γ of the 122-kev transition if one considers the following facts. The area under the sum peak at approximately 630 kev is proportional to the number of events of the type in which the detection of a 496-kev quantum is accompanied by the detection of a 122-kev quantum (with or without the accompanying detection of the K-capture x-ray quantum). The area under the sum peak at approximately 510 kev is proportional to the total of two types of events: (a) events in which the detection of a 496-kev quantum is accompanied by a 122-kev quantum which escaped detection; (b) events in which the detection of a 496-kev quantum is accompanied by an internal conversion with the K x-ray either being detected or not. If the efficiency of the phosphor for the detection of the 122-kev γ ray is ϵ, the relative numbers of the three types of events are evidently $\epsilon:1-\epsilon:e/\gamma$. The ratio of the area under the 510-kev sum peak to the area under the 630-kev sum peak is therefore proportional to $(1-\epsilon+e/\gamma)/\epsilon$. This must be multiplied by the numerical factor $(630/510)^{\frac{1}{2}}$ as a first order correction for the effect of the constant window width of the differential pulse amplitude analyzer. Thus

$$\frac{\text{Area}(510)}{\text{Area}(630)}=\left(\frac{630}{510}\right)^{\frac{1}{2}}\frac{1-\epsilon+(e/\gamma)}{\epsilon}.$$

While the exact value of ϵ is not known, it can be safely estimated to be 0.85 ± 0.08 from previous experimental evidence. The calculated value for e/γ is of the order of 0.6. Although this is a rather rough measurement, it is presented here since no other more accurate measurements have been reported.

II. Se^{75}

By using the summing technique, the γ rays of As^{75} following electron capture from Se^{75} have also been studied. The result is presented in Fig. 3. The normal spectrum shows peaks at 405, 269, and 138 kev, with indications of peaks at 124, 98, 77, and possibly 203 kev. Within experimental accuracy, these energy values are consistent with previous measurements by Ter-Pogossian *et al*,[5] Cork *et al.*,[6] and Jensen *et al.*[7] However, the intensities of the γ rays appear to be different from those measured by Jensen *et al.*,[7] who reported the relative intensities (in parenthesis) of the stronger γ rays as follows: 77 kev (14), 98 kev (6.5), 138 kev (24), 268 kev (71), and 405 kev (14). If one

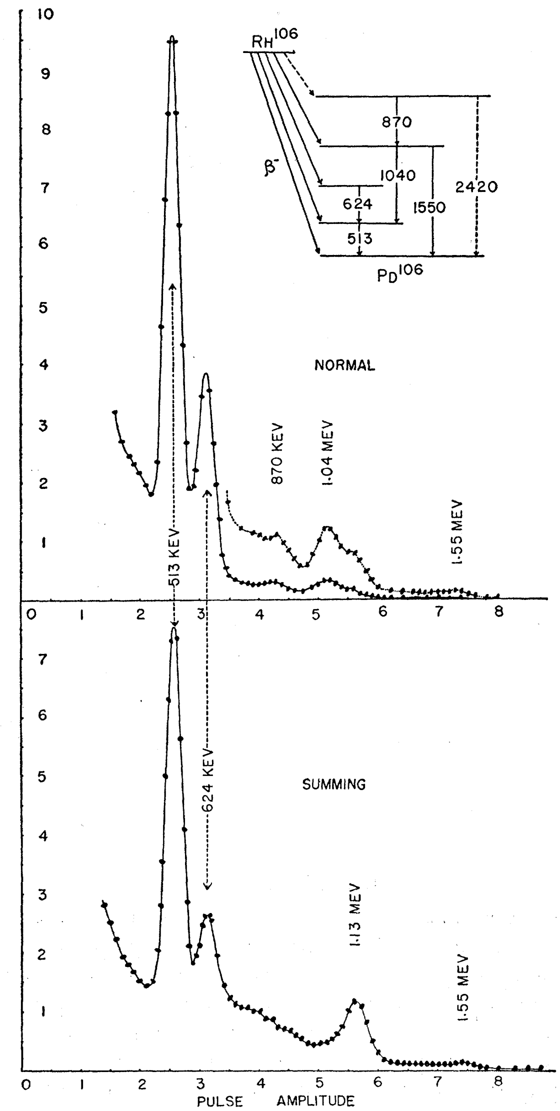

FIG. 5. γ-ray spectra of Pd^{106} following β decays of $Ru^{106}\rightarrow Rh^{106}\rightarrow Pd^{106}$.

[5] Ter-Pogossian, Robinson, and Cook, Phys. Rev. **75**, 995 (1949).
[6] Cork, Rutledge, Branyan, Stoddard, and LeBlanc, Phys. Rev. **79**, 889 (1950).
[7] Jensen, Laslett, Martin, Hughes, and Pratt, Phys. Rev. **90**, 557 (1953).

takes into consideration the energy dependent effect of the detection efficiency and the effect of the constant "window width" of the scintillation spectrometer, the present data indicates that the 138-kev γ ray is considerably stronger, and the 77-kev x-ray much weaker than measured by Jensen *et al.*[7] This is consistent with the recent work by Schardt *et al.*[8]

The dotted curve in Fig. 3 represents the summing spectrum obtained with the sample in the phosphor. The As K x-rays arising from K capture were cut off by the use of a thin Al absorber. Peaks are noticed at 405, 281, 138, and 98 kev. This infers the following: (1) The highest excited energy level involved is at 405 kev since no sum peak appears above this energy. (It is assumed here that no meta-stable states are present. DeBenedetti and McGowan[9] found no delayed coincidences in the 10^{-6}- to 10^{-3}-sec range.) Thus, any two γ rays whose energies add up to more than 405 kev cannot be in cascade. (2) The strong sum peak at 405 kev shows that the 138- and the 269-kev transitions are in cascade. (3) Since no indication of summing is noticed at 346 kev, the 77-kev γ ray appears not to be in cascade with the 269-kev γ ray as suggested by Jensen *et al.*,[7] whereas on the basis of the present investigation, there is no real objection from the standpoint of intensities in placing the 77-kev transition between excited levels at 203 and 281 kev as suggested by Cork *et al.*[6] (4) The 98-kev γ ray does not appear to sum with any γ ray of appreciable intensity. Therefore, it probably goes directly to the ground state and is fed by electron capture as proposed by Jensen *et al.*[7] (5) The 124-kev γ ray appears to sum with at least another γ ray. Among the observed sum peak energies, only 405 kev can be decomposed into combinations of observed γ ray energies involving 124 kev. It is therefore reasonable to assume that the 124-kev transition is from the 405 to the 281 excited level. The intensity of the 281 sum peak indicates that the 281-kev level is probably also fed by electron capture. These informations lead to the decay scheme shown in Fig. 4. It is a compromise between the decay schemes proposed by Jensen *et al.* and Cork *et al.*

III. Ru^{106}

The γ rays of Pd^{106}, following the successive β decays from Ru^{106} to Rh^{106} to Pd^{106}, have also been studied with the summing technique. The experimental result, represented by Fig. 5, is consistent with previous studies by D. E. Alburger,[10] and Klema and McGowan.[11]

[8] A. W. Schardt and J. P. Welker, Phys. Rev. **93**, 916 (1954).
[9] S. DeBenedetti and F. K. McGowan, Phys. Rev. **74**, 728 (1948).
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[11] E. D. Klema and F. K. McGowan, Phys. Rev. **92**, 1469 (1953).

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Gamma and X-Radiation in the Decay of Am^{241}†

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The decay scheme of Am^{241} is discussed in terms of new information on the conversion electrons, gamma rays, and L series x-rays accompanying its alpha decay. The photons were measured with a scintillation spectrometer and a bent crystal spectrometer and the conversion electron spectrum was determined with a double focusing beta-ray spectrometer.

I. INTRODUCTION

The decay properties of Am^{241} have received considerable attention because this isotope was one of the first transuranium alpha emitters which could be produced isotopically pure in amounts suitable for nuclear spectroscopic studies and the prominent gamma radiation clearly indicated a complex spectrum. Also, the specific activity was sufficiently high to permit examination of soft radiation and rare radiation. The close examination of the alpha spectrum has yielded five alpha groups which define uniquely four excited states of Np^{237}. It is of interest to coordinate these states with the electrons and electromagnetic radiation which result from their de-excitation, and from the properties to deduce something concerning the nuclear spectroscopic states of Np^{237}.

The isotope Am^{241}, first identified by Seaborg, James, and Morgan,[1] can be obtained in isotopically pure form from a mixture of plutonium isotopes which contains Pu^{241} as the only β^- emitter.[2] The alpha spectrum determined in this laboratory[3] and later modified[4] defines a series of energy levels which can form the

† This work was performed under the auspices of the U. S. Atomic Energy Commission.

[1] Seaborg, James, and Morgan, *The Transuranium Elements: Research Papers* (McGraw-Hill Book Company, Inc., New York, 1949), National Nuclear Energy Series, Plutonium Project Record, Vol. 14B, Div. IV, Paper No. 22.1, p. 1525.
[2] Ghiorso, James, Morgan, and Seaborg, Phys. Rev. **78**, 472 (1950).
[3] Asaro, Reynolds, and Perlman, Phys. Rev. **87**, 277 (1952).
[4] F. Asaro and I. Perlman, Phys. Rev. **93**, 1423 (1954).