It is not hard to show (though we refrain from doing so here) that to this order of approximation the effect of the TM correction term in the denominator of Eq. (11) is actually canceled by some of the terms in the numerator which correspond to the principal multipole.

[1] N. Tralli and G. Goertzel, Phys. Rev. **83**, 399 (1951), henceforth referred to as TG.
[2] H. M. Taylor and N. F. Mott, Proc. Roy. Soc. (London) **A142**, 215 (1933), henceforth referred to as TM.
[3] Appendix B, Sec. 4, of TG.
[4] The superscript (1) indicates that in the matrix element a hankel function of the first kind replaces the bessel function. Similarly, we signal the presence of a hankel function of the second kind by a superscript (2).

Gamma-Ray Spectrum and Yield from Tritium Bombarded by Protons*

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The energy spectrum and yield of the gamma-radiation[1–3] from the reaction $T^3(p, \gamma)He^4$ has been measured with a gamma-ray pair spectrometer previously described.[4,5] Tritium absorbed in a zirconium target[6,7] was bombarded by 0.96±0.06-Mev protons from the Cornell cyclotron. The proton energy was kept below 1.02 Mev so as to avoid a large neutron background from the $T^3(p, n)He^3$ reaction.[8] The zirconium used was 5.5 mg/cm² thick, and contained 0.47±0.05 atom of T^3 per atom of Zr throughout the bombardment. The gamma-rays were observed at an angle of 54.5 degrees to the proton beam in the laboratory system.

The energy region from 3 to 22 Mev was surveyed, using a 0.003-inch Pb radiator in the spectrometer. A single line was observed at an energy of 20.4±0.2 Mev. To obtain better resolution, additional data were taken around this line with a 0.002-inch Cu radiator. The data for both radiators are plotted in Fig. 1.

Correcting for the effective mean energy of the protons in the "thick" Zr target,[9] the doppler effect, and the recoil of the compound nucleus, we obtain a Q-value for this reaction of 19.7±0.3 Mev. By calculating the weighted mean Q-values from several independent cycles of more precise measurements on other nuclear reactions, Li *et al.*[10] have obtained 19.802±0.008 Mev for this Q-value.

The counting efficiency of the spectrometer decreases rapidly for lower gamma-ray energies for the following reasons: (a) the cross section for pair production in the radiator decreases; (b) each counting channel counts a smaller energy interval; (c) more electrons are lost through vertical multiple scattering in the radiator; (d) the resolution of the spectrometer decreases, due mainly to horizontal multiple scattering in the radiator. (The last reason is of importance only when considering the height of observed peaks, rather than the area under them.)

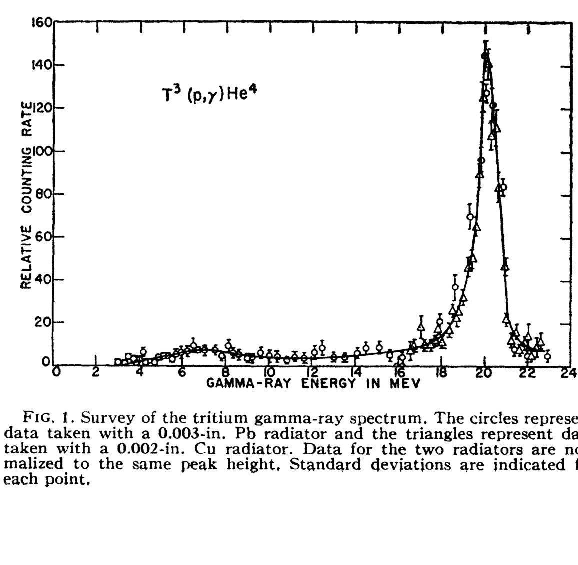

FIG. 1. Survey of the tritium gamma-ray spectrum. The circles represent data taken with a 0.003-in. Pb radiator and the triangles represent data taken with a 0.002-in. Cu radiator. Data for the two radiators are normalized to the same peak height. Standard deviations are indicated for each point.

Correcting[5] for these effects, it is estimated that any gamma-radiation from the tritium near 10 Mev and $\frac{1}{4}$ as intense as the 20.4-Mev line would have been observed if present. Near 6 Mev a line would have been observed if about 1.5 times as intense, and near 3 Mev only if roughly 40 times as intense.

The background at low energies shown in Fig. 1 is believed to come mainly from degraded radiation arising in the Pb collimator. The cosmic-ray shower background and accidental coincidences were found to be negligible.

The observed line width at half-maximum, which is about 5.4 percent in the case of the 0.002-inch Cu radiator, can be accounted for entirely by the resolution of the spectrometer. The resolution would not be significantly improved by the use of a thinner tritium target, since the target used caused a spread of only 1.1 percent of the total gamma-ray energy.

The yield from the $T^3(p, \gamma)He^4$ reaction was measured relative to the 17.6-Mev gamma-rays from the $Li^7(p, \gamma)Be^8$ reaction, using the pair spectrometer. The tritium-zirconium target was replaced by a thick lithium metal target. The proton energy and angle of observation were kept at the values given in the first paragraph. The proton beam was measured with a current integrator, and the two identical target holders were designed to eliminate error due to secondary electron emission. Correcting for the variation of spectrometer efficiency with energy, a (T+Zr)/Li yield ratio of 0.016±0.004 was found.

Argo *et al.*[1] made a similar yield comparison, except that they observed at 90 degrees and used a detector which counted the 14.8-Mev lithium line also. Adjusting[11,12] our value to their conditions would give a ratio of 0.012, while they[13] obtain 0.043. This discrepancy may be partly explained by a possible difference in the T^3/Zr atomic ratio in their target and ours.

From the lithium data of Fowler and Lauritsen,[11] the absolute yield of our tritium-zirconium target at 90 degrees was about 3×10^{-11} gamma-ray per steradian per proton. A $\sin^2\theta$ angular distribution[1] was assumed for the tritium gamma-rays.

In addition to its intrinsic interest for a study of the excited He^4 nucleus, the $T^3(p, \gamma)$ reaction should prove widely useful as a gamma-ray source. It provides the highest energy gamma-rays of any known nuclear reaction, is probably monoenergetic, and under suitable bombarding conditions can provide gamma-rays of an energy known to about 0.04 percent.

I want to thank Professor B. D. McDaniel for many valuable discussions.

* Work assisted by the ONR.
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[5] R. L. Walker, Ph.D. thesis, Cornell University, June, 1948.
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[10] Li, Whaling, Fowler, and Lauritsen, Phys. Rev. **83**, 298(A) (1951).
[11] W. A. Fowler and C. C. Lauritsen, Phys. Rev. **76**, 314 (1949).
[12] M. B. Stearns and B. D. McDaniel, Phys. Rev. **82**, 450 (1951).
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Properties of the Isotope Pu^{243}

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INVESTIGATION in this laboratory of the higher isotopes of plutonium produced by neutron irradiation has provided confirmation of the existence and properties of the new isotope Pu^{243}

recently reported in this journal by Sullivan *et al.*[1] The work reported here was done using the extensively neutron irradiated plutonium samples previously described in this journal.[2] Following the irradiation, the plutonium, americium, and curium were separated from each other and from fission products and impurities. The relative amounts of plutonium, americium, and curium were measured and the isotopic compositions of the americium and plutonium were determined using a mass spectrograph. The ratio of the numbers of alpha-disintegrations from the isotopes Am^{242} and Am^{243} was determined by chemical separation with measured yield of the beta-particle emitting daughters Np^{238} and Np^{239} and the measurement of their relative amounts by differential absorption methods using conventional Geiger counters as a means of detection. It was found that the ratio of Am^{243}/Am^{242} was higher by a factor of more than ten than in samples of Am^{241} which had been subjected to comparable neutron irradiations. This result is interpreted to mean that essentially all of the Am^{243} was formed according to the reaction sequence (a) rather than (b).

$$\text{(a)}\quad Pu^{242}(n,\gamma)Pu^{243} \xrightarrow{\beta^-} Am^{243}$$

$$\text{(b)}\quad Am^{241}(n,\gamma)Am^{242}(n,\gamma)Am^{243}.$$

The total amounts of the isotopes Pu^{242} and Am^{243} found in the irradiated plutonium sample allow a calculation of the cross section for the reaction $Pu^{242}(n,\gamma)Pu^{243}$. This cross section was calculated as very roughly 10^2 barns, using an estimated value for the neutron flux. The cross section is subject to a large error due to uncertainty in the estimation of the flux.

Subsequently, samples of plutonium of relatively large Pu^{242} content were produced as indicated in part by the following reactions:

$$Am^{241}(n,\gamma)Am^{242} \xrightarrow{\text{electron capture}} Pu^{242}.$$

Samples of this plutonium were then irradiated with neutrons to produce the isotope Pu^{243}. Following radiochemical purification of the plutonium, O'Kelley and Orth[3] made a rough investigation of the radiations of Pu^{243} using a beta-ray spectrograph and conventional absorption methods. They found the maximum energy of the beta-particles to be 0.39 Mev and gamma-ray energies of 0.095 Mev and 0.12 Mev, thus confirming the beta-particle energy of $\sim$0.5 Mev measured by Sullivan *et al.*[1] The observed half-life of the radioactivity was 5.0 ± 0.2 hours, and the amount of it corresponded roughly with the 10^2-barn cross section estimated above.

We wish to acknowledge the advice and assistance of Professor Glenn T. Seaborg whose help contributed greatly to the success of this work.

The successful handling in a safe manner of the radioactivity involved was made possible through the use of remote control equipment and excellent protective devices provided by Nelson Garden and the members of his Health Chemistry group. In this connection we especially wish to thank C. M. Gordon, W. G. Ruehle, and J. M. Davis for assistance during the experiments.

* This work was performed under the auspices of the AEC.

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Volkoff's Massive Spheres

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If one writes the static spherically symmetric line element in the form

$$ds^2 = -e^{\lambda}dr^2 - r^2(d\theta^2+\sin^2\theta d\varphi^2)+e^{\nu}dt^2\ldots \quad (1)$$

where λ and ν are functions of r alone, one gets for a sphere of constant density ρ,

$$e^{-\lambda} = 1-x^2+(K/x)\ldots \quad (2)$$

where $x=r/R$, $R^2=3/8\pi\rho$ and K is an integration constant.

While in the usual Schwarzschild interior solution, K is put equal to zero to avoid a singularity at the origin, Volkoff[1] and Wyman[2] have recently considered interesting solutions with $K>0$ and have found that as K increases the radius of a sphere of a given density increases, tending to infinity as K is indefinitely increased. However they have restricted their considerations to the coordinate radius which has no physical significance. If instead, one considers the proper radius r_0 given by $\int_0^{r_b}e^{\lambda/2}dr$, one gets the interesting and rather surprising result that as K increases, the proper radius r_0 decreases monotonically, tending to a finite lower limit as $K\rightarrow\infty$. From the point of view of radial length, therefore, these spheres for a given density have definite upper and lower limits to their dimension.

One may, however, also consider the proper volume given by $v_0=4\pi\int_0^{r_b}e^{\lambda/2}r^2dr$ and this quantity is found to tend to infinity as K tends to infinity.

Another point of some interest in the Volkoff-Wyman solution is the influence of the singularity on the field. For weak fields, $\frac{1}{2}\nu'(\equiv\frac{1}{2}d\log g_{44}/dr)$ gives the newtonian gravitational force and, although this approximation breaks down for strong fields, ν' always gives qualitatively some idea about the nature of the "field of force." In the Volkoff-Wyman solution, the condition of fit gives [Eq. (3.13) of Wyman's paper]—

$$m=(4/3)\pi\rho r_b^3-\tfrac{1}{2}KR\equiv M-\tfrac{1}{2}KR \quad (3)$$

and in the outside space $r\geqslant r_b$, $e^{\nu}=1-2(m/r)$, so that

$$\tfrac{1}{2}\nu'=m/r^2=(1/r^2)(M-\tfrac{1}{2}KR).$$

Thus in this region the effect of the singularity is to decrease the attractive field. Near the origin, as $r\rightarrow0$, with $K=0$, $\nu'\rightarrow0$, and one gets a vanishing gravitational intensity at the center just as in newtonian theory; however, with $K>0$, ν' tends to $+\infty$ as $1/r$. Thus, in the neighborhood of the origin, the singularity introduces an attractive field of force. The presence of an infinite attractive field in this region is also apparent from the infinite negative pressure gradient.

Equation (3) suggests an identification of the singularity with a negative mass particle; in fact, if ρ and K together tend to zero keeping $K/\rho^{\frac{1}{2}}$ constant, the solution degenerates to the Schwarzschild solution for a particle of negative mass at the origin. The foregoing considerations therefore seem to indicate that a negative-mass particle (placed at the center of a sphere of positive density) acts as the source of an attractive field at short distances and a repulsive field at large distances.

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Threshold for Photoneutron Reaction in Th^{232}

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The mass difference between the $4n+3$ and $4n$ series is accurately known at lead from various experimental measurements.[1] An accurate value for the Th^{232} photoneutron threshold would enable one to check alpha- and beta-decay energies by closed cycle calculations.

The method of detecting the (γ, n) product nucleus used for the U^{238} threshold[2] was applied in a similar manner for determination of the Th^{232} threshold. Samples of thorium nitrate were bombarded in the betatron x-ray beam at six energies in the range 6.7