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.

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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

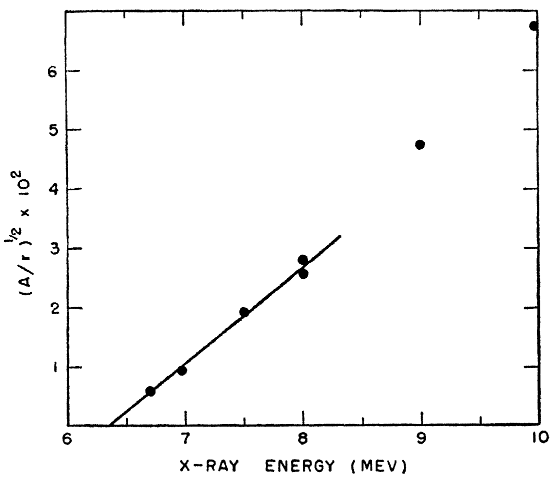

FIG. 1.

to 10 Mev. The bombarded thorium was chemically purified to remove fission products and thorium daughters. Uniform 25-mg samples of ThO_2 were prepared for counting by igniting painted layers of an organic thorium solution. The Th^{231} activity was measured with a thin window Amperex Geiger tube. The samples were covered with an aluminum absorber (7 mg/cm^2) to stop alpha-particles. Purified, unirradiated ThO_2 samples (25 mg) gave a counting rate of 3 count/min over background (16 count/min) with this arrangement. Growth of the Th^{228} daughters amounted to 1 count/min three hours after purification. Observed Th^{231} activities ranged from 2 to 60 count/min. The activities decayed with the correct half-life of about 26 hours. The x-ray beam intensity was monitored with a Victoreen integrating roentgen meter.

The square root of the total Th^{231} activity produced in each bombardment divided by the total roentgens registered by the Victoreen meter, i.e., $(A/r)^{\frac{1}{2}}$, appeared to be a linear function of bombardment energy within experimental error up to 8 Mev. The data are given in Fig. 1. Extrapolation by the method of least squares gives a threshold of 6.35±0.04 Mev for the $Th^{232}(\gamma, n)Th^{231}$ reaction. This value is in fair agreement with 6.1±0.2 Mev obtained indirectly by the method of neutron detection.[3]

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Theory of Dibaric Particles

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IN a series of seminars on the self-energy of the vector meson, J. Schwinger found it convenient to introduce as a mathematical artifice a system of spin 1 whose properties were intermediate between those of the vector meson and those of the electron. It is the purpose of this note to discuss the possible physical significance of this system.

A study was made of a quantum-mechanical system postulated to obey the equation of motion

$$(p_\mu \beta_\mu - ik)\psi = 0,$$

where β_μ was formed from the fusion of two Dirac-like matrices

$$\beta_\mu = \tfrac{1}{2}(\gamma_\mu^{(1)} + \gamma_\mu^{(2)})$$

obeying the commutation rules

$$\gamma_\mu^{(i)}\gamma_\nu^{(i)} + \gamma_\nu^{(i)}\gamma_\mu^{(i)} = 2\lambda^{(i)}\delta_{\mu\nu},$$
$$\gamma_\mu^{(1)}\gamma_\nu^{(2)} - \gamma_\nu^{(2)}\gamma_\mu^{(1)} = 0,$$

where $\lambda^{(1)} + \lambda^{(2)} = 2$. Such a system may be interpreted physically as a pair of strongly coupled spin $\frac{1}{2}$ particles of different mass.

The β's are represented as 16×16 matrices using a fusion representation developed by de Broglie.[1] The present theory is intermediate between that of Kemmer[2] (in which $\lambda^{(1)} = \lambda^{(2)} = 1$) and that of Dirac (in which $\lambda^{(1)} = 2$, $\lambda^{(2)} = 0$), but because of the occurrence of discontinuities does not include either of these extreme cases.

The system was found to have the following properties:

(1) It could exist in either of two mass states, with masses

$$m = (k/c)[2/(1 \pm \lambda)]^{\frac{1}{2}}, \quad \lambda \equiv (\lambda^{(1)}\lambda^{(2)})^{\frac{1}{2}},$$

from which it is evident that the phenomenon of dibarism is peculiar to this intermediate case and would occur in neither the Kemmer case ($\lambda = 1$) nor the Dirac case ($\lambda = 0$).

(2) The spin angular momentum operator had eigenvalues 0, $\pm\hbar$; we note that the particle is a boson.

(3) The magnetic moment was similar to that of the Kemmer particle, except for an additional term (which vanished for spin eigenstates) of value

$$\pm(ehc/2k)(\lambda^{(1)} \pm \lambda^{(2)});$$

there thus appear nonzero spin magnetic moments for states of zero spin, as might be expected from the fact that one is adding magnetic moments of particles of different masses.

(4) Transitions from the heavier (mass $(n+\Delta n)$ electron masses) to the lighter (mass n electron masses) state accompanied by gamma-emission were investigated. The lifetime of the heavier state, approximately

$$(9\times 10^{-17}/n)(n/\Delta n)^3 \text{ sec},$$

proved too short to measure except for very small mass difference.

(5) Coulomb scattering, with and without change of mass, was also investigated; the cross section for the latter case reduced to the Rutherford formula as would be expected.

In its relativistic form, the theory was found to be unrealistic, because of the existence of negative energy states which, since the particle is a boson, cannot be filled up arbitrarily. These negative energy solutions may be accounted for by the binding energy associated with the fusion of the two spin $\frac{1}{2}$ particles. It would therefore seem that the theory discussed above is meaningful only in the nonrelativistic limit.

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Note on the Relativistic Formula for Photoelectric Absorption

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RECURRING references[1] in the literature to the relativistic photoeffect formula

$$\frac{\phi_K}{\phi_0} \simeq \frac{3}{2}\frac{Z^5}{137^4}\frac{\mu}{k}\exp[-\pi\alpha + 2\alpha^2(1-\log\alpha)] \qquad (1)$$

contain comments which indicate that the degree of validity of this formula is not generally understood. The notation of Eq. (1) is Heitler's.[2]

The derivation of this formula, published in 1934,[3] was originally criticized by Hulme *et al.*[4] It appears to have escaped attention,