Meson Production

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McMILLAN and Teller[1] have treated the production of mesons by the collision of heavy particles with heavy nuclei. With the essential assumption that the collision time is small compared to nuclear periods, they have used the Fermi-Thomas model to calculate the effect of the presence of many nucleons in depressing the threshold. In obtaining the cross section near threshold, however, they have extrapolated from higher energies, and so overestimated the effect because of the rapid departure of the cross section from a simple power law. On the same theoretical basis, a better estimate can be obtained by carrying through the perturbation calculation near threshold.

The process is third order in the meson field interaction. The heavy particles transfer momentum by exchanging a meson; the final meson is emitted before, during, or after the exchange. In the symmetric scalar theory the matrix elements do not vary appreciably near threshold, and the integral over final states reduces to the volume in phase space in which energy and momentum are conserved and the exclusion principle[1] satisfied. The cross section is

$$\sigma_{\text{scalar}}=0.7(g^2/\hbar c)^3V(\mu c/\hbar)(\Delta E/\mu c^2)^{7/2}\ \text{cm}^2,$$

where V is the volume of the nucleus, μ the mass of the meson, and ΔE the excess of incident energy over threshold. The result depends strongly on the coupling constant, which is usually taken to be $(g^2/\hbar c)=\frac{1}{10}$.

In the symmetric scalar theory there is considerable contribution to the integral from terms in which the final meson is produced during the exchange of a virtual meson. If the mechanism for heavy particle momentum transfer were a potential interaction, these terms would not be present. The importance of these terms arises directly from the finiteness of the ratio of the meson mass to the mass of the heavy particle. Also, using a potential interaction, the contribution from terms in which scattering precedes meson emission is, at threshold, equal and opposite in sign to that in which scattering follows meson emission. This equality is destroyed if exchange of positive, negative, and neutral mesons scatters the heavy particles. These properties of the meson field distinguish it from the more familiar case of the electromagnetic field, for which a potential description of the interaction is valid.

The energies now available on the Berkeley cyclotron make especially interesting the case of bombardment with neutrons obtained by stripping an energetically homogeneous beam of deuterons. The energy distribution of a beam of neutrons so prepared is governed largely by the distribution in momentum of the neutron relative to the center of gravity of the deuteron and so can be calculated by Fourier analysis of the deuteron wave function assuming an exponential well. In the symmetric scalar theory, for velocities of the center of gravity of the deuteron between 0.8 and 1 times the threshold velocity for the neutron, the total cross section varies from 0.014 to 2.1×10^{-30} cm^2. When the center of gravity moves with threshold velocity, the cross section is that for neutrons at 16 Mev above threshold.

These results, of course, share the large uncertainty in all present meson theories.

We wish to thank Professor J. R. Oppenheimer for guidance in this problem.

[1] W. G. McMillan and E. Teller, Phys. Rev. **72**, 1 (1947).

The Disintegration Scheme of Sc^{46}*

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A SMALL 180° beta-ray spectrometer, having good resolution, has been used to study the radiations from Sc^{46}. Samples were produced by bombarding Sc$_2$O$_3$ with the external cyclotron deuteron beam. For beta-ray measurements, sources were prepared by precipitating chemically purified Sc$_2$O$_3$ on thin mica backing; for gamma-ray determinations, the photoelectrons ejected from a thin lead radiator were studied. Our results indicate that there are two groups of beta-rays of maximum energies 0.36±0.01 Mev and 1.49±0.01 Mev, as well as two gamma-rays of energies 0.88±0.02 Mev and 1.12±0.02 Mev. A comparison of the relative number of particles emitted in each beta-group shows that about 6 percent of the beta-rays belong to the higher energy group. A straight line Fermi plot is obtained for the 0.36-Mev group but not for the less intense, higher energy group, indicating a transition of the forbidden type.

Coincidence absorption experiments were carried out by Mr. Edward T. Jurney and Miss Margaret Ramsey to ascertain the mode of decay. Beta-gamma and gamma-gamma coincidences show conclusively that each beta-ray of the 0.36-Mev group is followed by the cascade emission of the two gamma-rays. Definite results have not yet been obtained from coincidence measurements for the very weak 1.49-Mev group, but it is quite likely from energy considerations that a beta-ray emission of this group is followed by the emission of a 0.88-Mev gamma-ray. A study of the photoelectron lines bears this out to some extent. By using Gray's[1] empirical curve for the variation of the photoelectric absorption coefficient with energy, it is found that the 0.88-Mev gamma is roughly 5 percent more abundant than the 1.12-Mev gamma. It is concluded, therefore, that the decay scheme is that shown in Fig. 1. This has been substantiated in part by Miller and Deutsch.[2]

Further investigation reveals the presence of a weak conversion line at 0.86 Mev. This suggests strongly that the 0.88-Mev gamma-ray is internally converted. Assuming this to be the case, one finds for the conversion coefficient a value of 0.0001. However, a careful check on the decay of the line, and further chemical separation are necessary to verify this conclusion.

It is to be noted that the values of the energies given here differ somewhat from those of Walke[3] and Meitner,[4] who have previously reported a 0.26-Mev beta-ray and a 1.5-Mev gamma-ray. In addition, Walke suggested a 1.5-

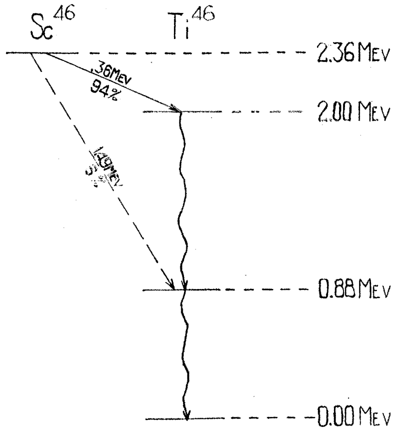

FIG. 1.

Mev beta-ray and a 1.25-Mev gamma-ray. Meitner was unable to find a beta-group with a 1.5-Mev end point and attributed Walke's result to scattering. Careful study has convinced us that the 1.49-Mev group cannot be due to scattering inherent in the geometry of our instrument or to secondary electrons from the source or backing. Further confirmation of this group is found in the fact that it decays with the same half-life as the 0.36-Mev group. The decay has been followed for about one half-life and is found to be approximately 85 days as reported by Walke.

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[1] L. H. Gray, Proc. Camb. Phil. Soc. **27**, 103 (1931).

[2] A. Miller and M. Deutsch, paper presented at Montreal meeting of American Physical Society, abstract to be published in *Physical Review*.

[3] H. Walke, Phys. Rev. **57**, 163 (1940).

[4] L. Meitner, Arkiv f. Mat. Astron., och Fysik, **32A**, No. 6.

The $(4n+1)$ Radioactive Series: The Decay Products of U^{233}

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DURING 1944–1946 we studied the chain of decay products of U^{233}, the new isotope of uranium which was first separated and examined (1941–1942) by Seaborg, Gofman, and Stoughton.[1] These decay products, which constitute a substantial fraction of the entire missing, $4n+1$, radioactive series are listed, together with their radioactive properties, in Table I.

The radioactivity of the Tl^{209} has not yet actually been observed, its existence in the chain is inferred from the partial alpha-decay of Bi^{213}. The isotope Pb^{209} has been previously reported, as a result of its production by the (d, p),[2] (n, γ),[3] and (n, p)[3] reactions.

A number of the preceding members of this $(4n+1)$ radioactive series have been previously reported as follows:

$$_{94}Pu^{241} \xrightarrow{\beta^-} {_{95}Am^{241}} \xrightarrow{\alpha} {_{93}Np^{237}} \xrightarrow{\alpha} {_{91}Pa^{233}} \xrightarrow{\beta^-} U^{233}.$$

TABLE I.

Isotope	Type of radiation	Half-life	Energy of radiation (Mev)
$_{90}Th^{229}$	α	7×10^3 yr.	4.85
$_{88}Ra^{225}$	β^-	14.8 days	~0.2
$_{89}Ac^{225}$	α	10.0 days	5.80
$_{87}Fr^{221}$	α	4.8 min.	6.30
$_{85}At^{217}$	α	0.018 sec.	7.00
$_{83}Bi^{213}$	β^- (96%) α (4%)	47 min.	~1.2 (β^-) 6.0 (α)
$_{84}Po^{213}$	α	very short	8.30
($_{81}Tl^{209}$)	(β^-)	?	?
$_{82}Pb^{209}$	β^-	3.3 hr.	0.7
$_{83}Bi^{209}$	stable		

The 27.4-day Pa^{233} was first reported by Meitner, Strassmann, and Hahn,[4] and the doubts as to this isotopic assignment which later arose as a result of the discovery of fission were cleared up by the work of v. Grosse, Booth, and Dunning[5] and Seaborg, Gofman, and Kennedy.[6] The 2.25×10^6 year Np^{237} was first identified by Wahl and Seaborg,[7] while Pu^{241} and 500-year Am^{241} were first reported by Seaborg, James, and Morgan.[8] Also of interest are two previously reported beta-emitting radioactive isotopes, 23-minute Th^{233} [9] from the reaction Th^{232} (n, γ) and 7-day U^{237} [10, 11] from the reaction U^{238} $(n, 2n)$, which may be referred to as "collateral" members of the series.

As the name for the $(4n+1)$ radioactive decay family we suggest "neptunium" series or family; thus the longest-lived member would give its name to the family in a manner similar to the naming of the uranium and thorium decay series.

Another independent study of the decay products of U^{233} was carried on simultaneously by A. C. English, T. E. Cranshaw, P. Demers, J. A. Harvey, E. P. Hincks, J. V. Jelley, and A. N. May of the Division of Atomic Energy of the National Research Council of Canada, which has resulted in essentially similar findings.[12]

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[1] G. T. Seaborg, J. W. Gofman, and R. W. Stoughton, Phys. Rev. **71**, 378 (1947).

[2] R. L. Thornton and J. M. Cork, Phys. Rev. **51**, 383 (1937).

[3] W. Maurer and W. Ramm, Zeits. f. Physik **119**, 602 (1942).

[4] L. Meitner, F. Strassmann, and O. Hahn, Zeits. f. Physik **109**, 538 (1938).

[5] A. v. Grosse, E. T. Booth, and J. R. Dunning, Phys. Rev. **59**, 322 (1941).

[6] G. T. Seaborg, J. W. Gofman, and R. W. Stoughton, Phys. Rev. **59**, 321 (1941).

[7] A. C. Wahl and G. T. Seaborg, reported in Chem. Eng. News **23**, 2190 (1945).

[8] G. T. Seaborg, R. A. James, and L. O. Morgan, reported in Science **104**, 379 (1946) and Chem. Eng. News **25**, 358 (1947).

[9] E. Fermi, E. Amaldi, O. D'Agostino, F. Rasetti, and E. Segrè, Proc. Roy. Soc. **A146**, 483 (1934).

[10] Y. Nishina, T. Yasaki, H. Ezoe, K. Kimura, and M. Ikawa, Phys. Rev. **57**, 1182 (1940).

[11] E. M. McMillan, Phys. Rev. **58**, 178 (1940).

[12] English, Cranshaw, Demers, Harvey, Hincks, Jelley, and May, Phys. Rev. **72**, 253 (1947).