We wish to acknowledge the continued interest of Professor G. T. Seaborg in this work. We are indebted to the staff of the Materials Testing Reactor, and particularly to Dr. W. B. Lewis and Dr. R. R. Smith, for arranging the neutron bombardments.†

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

[1] Thompson, Ghiorso, Harvey, and Choppin, Phys. Rev. **93**, 908 (1954)

[2] Harvey, Thompson, Ghiorso, and Choppin, Phys. Rev. **93**, 1129 (1954)

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## New Isotopes of Americium, Berkelium and Californium*

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In a recent publication,[1] the preparation of new heavy isotopes of berkelium (mass number probably 249) and californium (mass numbers greater than 248) by prolonged neutron irradiation of Pu$^{239}$ with thermal neutrons was described. As the result of neutron irradiation of Am$^{243}$ and Bk$^{249}$, it has been possible to make new observations on the radioactive decay of Am$^{244}$, and to prepare new berkelium and californium activities.

*Am$^{244}$*.—This nuclide was produced by short neutron bombardments of americium, whose principal constituent was Am$^{243}$. After bombardment the americium was rapidly purified by a combination of precipitation and ion-exchange procedures.[2] The Am$^{244}$ was found to decay by emission of $\beta^-$ particles; its half-life was 26 minutes, in good agreement with a previously published value.[3]

The beta and gamma radiations of Am$^{244}$ were studied with anthracene and sodium iodide crystal spectrometers. Only one $\beta^-$ end point, at 1.5 Mev, could be resolved. There were no prominent gamma rays.

*Bk$^{250}$*.—A sample of Bk$^{249}$ was subjected to a short neutron bombardment, followed by chemical purification, and a new activity, presumably Bk$^{250}$, was produced. It decayed by $\beta^-$ emission with a half-life of 3.13 hours.

The $\beta$ spectrum showed the existence of two groups, with end points at 900 and 1900 kev. The lower-energy $\beta$ group was in coincidence with a gamma ray of about 900 kev.

*Cf$^{250}$*.—Part of the neutron-irradiated berkelium, after chemical purification, was allowed to decay for five hours to produce the Cf$^{250}$ daughter of the Bk$^{250}$. The californium was then separated. The Cf$^{250}$ was found to emit 6.05-Mev alpha particles. From the alpha disintegration rate and the beta disintegration rate of the Bk$^{250}$ parent, the alpha half-life of Cf$^{250}$ was found to be about 12 years.

Spontaneous fissions were observed in the samples containing Cf$^{250}$. The ratio of alpha disintegrations to fissions was 400. The spontaneous fission half-life of Cf$^{250}$ is therefore about 5000 years.

*Cf$^{252}$*.—Direct alpha-decay measurements performed over a period of several months on a sample consisting largely of Cf$^{252}$ indicate a half-life for this nuclide of roughly two years. It was found that 26 percent of the alpha particles in the original californium fraction produced from the highly irradiated plutonium were due to Cf$^{250}$. Thus from the previously mentioned alpha-to-fission ratio of 400 found for pure Cf$^{250}$, its contribution (approximately 3 percent) to the observed high spontaneous fission rate in the californium fraction (alpha-to-fission ratio=42) can be calculated. The great bulk of the fission rate must therefore be due to Cf$^{252}$, and a calculation on this basis shows its spontaneous fission half-life to be about 100 years. For the purpose of this calculation it was assumed that in this case the correction for spontaneous fission from Cf$^{254}$ would be small.

*Cf$^{249}$*.—The Bk$^{249}$ grows a californium daughter Cf$^{249}$ which decays by emission of 6.0-Mev (10 percent) and 5.82-Mev (90 percent) alpha particles. From the amount of Cf$^{249}$ alpha activity which grew from a known amount of Bk$^{249}$, the alpha half-life of the Cf$^{249}$ was found to be about 400 years.

It is a pleasure to acknowledge the continued interest of Professor G. T. Seaborg in this work. We are indebted to the entire staff of the Materials Testing Reactor, and particularly to Dr. W. B. Lewis and Dr. R. R. Smith. We wish to thank Almon E. Larsh for assistance with some of the experiments.

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

[1] Thompson, Ghiorso, Harvey, and Choppin, Phys. Rev. **93**, 908 (1954).

[2] See, e.g., G. T. Seaborg in *The Actinide Elements* (McGraw-Hill Book Company, Inc., New York, 1954), National Nuclear Energy Series, Plutonium Project Record, Vol. 14A, Div. IV, Chap. 17.

[3] Street, Ghiorso, and Seaborg, Phys. Rev. **79**, 530 (1950).

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## Interaction of High-Energy Pions with Nuclei*

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Recent experiments[1-3] have shown that the interaction cross sections of negative $\pi$ mesons in the energy range of 0.6 to 1.0 Bev on protons are more than twice those of positive $\pi$ mesons of the same energy range; the $(\pi^-,n)$ cross section appears to be about equal to the $(\pi^+,p)$ cross section, as expected from charge symmetry considerations.

This makes it attractive to employ $\pi$ mesons as tools for the investigation of nuclear structure, in particular of the proton and neutron distributions in nuclei.[4] Johnson and Teller[5] have suggested that the neutrons in a heavy nucleus extend out to a larger radius than the protons. If this is the case, the apparent nuclear radius as measured with two different probe particles will be greater for that probe particle which interacts more strongly with neutrons.

The interaction cross sections of lead for positive and negative $\pi$ mesons of 700 Mev have been computed using the "optical model"[6] and assuming (a) that the protons and neutrons are uniformly distributed in a sphere of radius $R$ (uniform nucleus model), and (b) that the nucleus is composed of an inner zone of radius $R_1$ containing $Z$ protons and $Z$ neutrons, and an outer zone of radius $R$ containing $N-Z$ neutrons (Johnson-Teller model). In model (b) the radii $R_1$ and $R$ are chosen so that the neutron density is the same in both zones, i.e., $R_1/R=(Z/N)^{\frac{1}{3}}$.

In the optical model the nucleus is treated as a region with a complex refractive index. The total cross section may be divided into the diffraction (elastic scattering) portion $\sigma_d$ and the interaction (absorption) portion $\sigma_a$, where

$$\sigma_d=2\pi\int_0^R|1-e^{i\delta(\rho)}|^2\rho d\rho, \tag{1}$$

$$\sigma_a=2\pi\int_0^R(1-|e^{i\delta(\rho)}|^2)\rho d\rho. \tag{2}$$

Here $\delta(\rho)$ is the (complex) phase shift of that part of an incident plane wave which passes through the nucleus along a line which is at a distance $\rho$ from the center. Let $k=p/\hbar$ be the wave propagation number of the incident particle outside the nucleus, and let its propagation number inside the nucleus at a distance $r$ from the center be $k+k_1(r)+\frac{1}{2}iK(r)$. Then

$$\delta(\rho)=2\int_0^{s(\rho)}[k_1(r)+\tfrac{1}{2}iK(r)]dx, \tag{3}$$

where $s(\rho)=(R^2-\rho^2)^{\frac{1}{2}}$, and $r=(\rho^2+x^2)^{\frac{1}{2}}$.

Table I. Interaction cross sections of 700-Mev pions on Pb.

| Model | $R$ ($10^{-13}$ cm) | $R_1$ ($10^{-13}$ cm) | $\sigma_+$ (mb) | $\sigma_- - \sigma_+$ (mb) |
|---|---|---|---|---|
| *a* | 8.295 | | 1862 | 41 |
| *b* | 8.295 | 7.188 | 1827 | −114 |
| *a* | 7.110 | | 1430 | 74 |
| *b* | 7.110 | 6.161 | 1405 | −51 |

The interaction cross section depends only on $K$, which is the absorption coefficient in nuclear matter, and not on $k_1$. This absorption coefficient is related to the cross sections for elementary particle interactions; it equals

$$K=D_p\sigma_p+D_n\sigma_n, \tag{4}$$

where $D_p$ and $D_n$ are the proton and neutron densities, and $\sigma_p$ and $\sigma_n$ the cross sections for interaction of the incident particle with protons and neutrons, respectively. Equation (4) is based on the assumption that the elementary cross sections are the same for nucleons bound in the nucleus as for free nucleons, and are not inhibited by the Pauli principle. This should be valid for pions of the order of 1 Bev.

The diffraction portion of the total cross section is mainly confined to angles less than $\theta_1=3/(kR)$. For 1-Bev mesons on lead, $kR\approx 50$, so that $\theta_1\approx 3$ degrees. Therefore the interaction cross section should be relatively easy to determine experimentally by measuring the "total" cross section in geometry such that scattering through angles of less than about 3 degrees is not detected. Such an experiment has been proposed by Clark, Cool, and Piccioni.

The interaction cross sections (2) have to be corrected for the Coulomb interaction. At the energies involved this correction can be made on the basis of classical orbit dynamics, resulting in a correction factor

$$\sigma_\pm/\sigma_0=1\mp 2Ze^2/RE, \tag{5}$$

where $\sigma_+(\sigma_-)$ is the cross section for positive (negative) particles of energy $E$ (assumed relativistic and large compared to the height of the Coulomb barrier), and $\sigma_0$ is the cross section calculated from Eq. (2); $R$ is the over-all nuclear radius. This condition is obtained by noting that a particle of impact parameter $b=R(1\mp Ze^2/RE)$ just grazes the surface of the nucleus.

The calculations have been performed for $\pi$ mesons of 700-Mev kinetic energy, for which the cross sections were assumed to be $\sigma(\pi^-,n)=\sigma(\pi^+,p)=14$ mb, and $\sigma(\pi^+,n)=\sigma(\pi^-,p)=38$ mb, as inferred from a graph of the results of references 1 to 3, and the hypothesis of charge symmetry. The radius of lead was taken as $1.2A^{\frac{1}{3}}\times 10^{-13}$ cm and $1.4A^{\frac{1}{3}}\times 10^{-13}$ cm. The results are summarized in Table I.

It appears that there is a difference of about 8 percent of the total cross section between the $(\pi^+,\pi^-)$ differences to be expected on the basis of the two models. Therefore experimental determinations of the interaction cross sections of lead for positive and negative pions around 700 Mev should make it possible to decide whether the uniform distribution or the Johnson-Teller distribution is more nearly correct.

It is reasonable to expect that the angular distribution of the elastically scattered mesons will depend just as sensitively on the nucleon density distributions; calculations on this point are being planned.

It is a pleasure to acknowledge stimulating discussions with O. Piccioni, G. Snow, and C. N. Yang.

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[1] Cool, Madansky, and Piccioni, Phys. Rev. **93**, 249, 637 (1954) and private communication.

[2] Shapiro, Leavitt, and Chen, Phys. Rev. **92**, 1073 (1953) and private communication.

[3] S. J. Lindenbaum and L. C. L. Yuan (private communication).

[4] This idea was suggested to the author by O. Piccioni.

[5] M. H. Johnson and E. Teller, Phys. Rev. **93**, 357 (1954).

[6] Fernbach, Serber, and Taylor, Phys. Rev. **75**, 1352 (1949).

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## Magnetic Storm Effect on Cosmic Radiation

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In a recent letter Swann[1] objects to my theory of the cosmic-ray storm effect.[2] He has not observed, however, that the beam I consider expands the whole time when travelling out from the sun, so that the magnetic field in it is proportional to $r^{-1}$ ($r$ = distance to the sun). This means that an observer travelling with the beam observes a decrease in the magnetic field in the beam, and by betatron (or "cygnotron") action this causes a decrease in the energy of the particles in the beam. Hence Swann's starting point that "an observer moving with the beam observes no change of energy" is not correct.

Swann further points out that in an example I have given, a cosmic-ray particle would have "a radius of curvature 15 times smaller than the beam width and so could never cross it." As the magnetic field in the beam is inhomogeneous, the particle, which moves in a trochoid, will drift perpendicular to the beam and could very well cross it.

The conclusion is that the relative decrease in energy could have any value and is not limited to $<2v/c$.

[1] W. F. G. Swann, Phys. Rev. **93**, 905 (1954).

[2] H. Alfvén, Phys. Rev. **75**, 1732 (1949); E. A. Brunberg and A. Dattner, Tellus (to be published); H. Alfvén, Tellus (to be published).

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## Energy Levels in $W^{182}$†

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Excited $W^{182}$, following beta-minus emission of $Ta^{182}$ is one of several complex-gamma-emitting nuclei of even-even species. Figure 1, we feel, presents the main features of the energy level scheme. The portion of the diagram from 1222 kev and up, with the exception of the level $E$, is one of several proposed by Muller[1] and co-workers. Of sixteen gamma rays cited, most of which were measured with high precision by the Dumond curved crystal spectrometer, ten were incorporated by these workers in this portion of the decay scheme. The remaining six gamma rays listed, we place at $AB$, $BC$, $EH$, $AD$, $BD$, and $BF$. These assignments are based upon measurements taken from high-field, high-resolution beta-ray spectrographs. Gamma rays $AD$ and $BD$ were found to differ by 99.9±0.5 kev, $BF$ and $BD$ by 68.0±0.5 kev, and the pair $AF$, $BF$ by 100.1±0.5 kev. The triad of lines to level $C$ were also sufficiently intense for accurate measurement of energy differences and help support the diagram. Finally, high-energy transitions from nearly all of the levels $D$ through $K$ to $A$, $B$, and $C$ have been observed and agree with the proposed scheme. We also have some evidence for the level $L$, although according to the various possibilities proposed by Muller either level $G$ or $L$ may be present, but not both. Our data actually favor a level at $G$ perhaps one kev lower than that given.

Including a few additional weak low-energy radiations between some of the levels $D$ through $L$, not previously mentioned, it is seen that this decay scheme accommodates about forty gamma rays. However, at least this many more have been observed and roughly classified by this group. For the most part, these radiations are very weak, and lead, no doubt, to additional levels between $C$ and $D$. Also there is little doubt that some arise from levels higher than $K$ (or $L$). The measurement of a single half-life of 115.5 days over a period of five and a half cycles is indication that these weak gamma rays do not arise from contaminants.

Analysis of the beta spectra has proved somewhat disappointing. A group of low-intensity conversion lines so obscures the end point (at 540 kev) that good measurements of the end points and relative intensities of the several other beta spectra present have so far not been realized.

The electron spectrum gives relative $K$ conversion of 10:8.0:8.0 for the three strong lines $AD$, $BF$, and $BD$. Borrowing the gamma-ray intensity data of Muller, the ratios of $K$ conversion coefficients for these gamma rays are 1:1.8:0.85. Taking 0+ and 2+ for the levels $A$ and $B$, the first and third conversion coefficients are compatible with a 1− assignment for $D$. This assignment also fixes the conversion coefficient for $BF$, which fits an $E2$ transition. A choice of 4+ for the level $F$ is consistent with the trend of the levels from $D$