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 σ_p and σ_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 sect on 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 σ_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 π 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 (π^+,π^-) 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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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 $<2v/c$.

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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

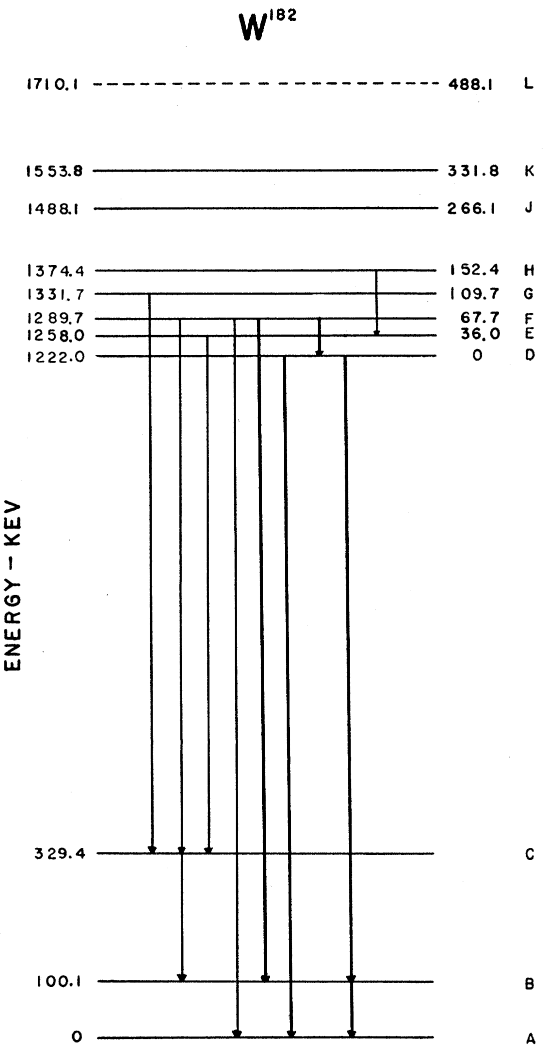

FIG. 1. Proposed energy levels in W^{182}. Transitions shown are discussed in text.

upwards to follow an approximate algebraic relation. Allowing for two additional levels, not shown on the figure for lack of accuracy, at approximately 5 and 205 kev above D, the level energies above D become asymptotic to the expression $E_L=3.70L(L+1)$. The correct energy values are shown on the right of the figure. The values of L are to be numbered consecutively from D, upward, starting with $L=1$ for the D level.

The levels A, B, and C agree well with the Bohr-Mottelson[2] formulation, with level C taken as 4+. A further level at 680±5 kev which can be justified from conversion line data would fit the third-excited state predicted by this formulation. It is interesting to note that the level D also fits, in energy, the fourth-excited state predicted by this theory, but the predicted spin value of 8 is manifestly at variance with the 1− assignment suggested above.

In addition to the papers previously mentioned, those of Beach *et al.*,[3] Cork *et al.*,[4] and Scharff-Goldhaber[5] were of considerable assistance.

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Identification of Californium Isotopes 249, 250, 251, and 252 from Pile-Irradiated Plutonium*

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IN a recent communication[1] we reported a large spontaneous fission activity associated with the californium produced from plutonium irradiated with neutrons in the Materials Testing Reactor (MTR) at Arco, Idaho. The important implications of gross amounts of spontaneous fission activity prompts us to give additional information on the mass assignments and nuclear properties of several californium and berkelium isotopes. The heavy elements were chemically separated from two plutonium samples, I and II, which received integrated fluxes of 4×10^{21} and 8×10^{21} neutrons, respectively.

Californium from sample II was analyzed in a 12-inch, 60° mass spectrometer with a multiple filament source. Californium isotopes of mass numbers 249, 250, 251, and 252 were detected in mole percentages given in column 1 of Table I. A small quantity

TABLE I. Mass spectrometric analyses of two californium samples, giving isotopic abundances in mole percent.

Cf isotope	Sample II	Sample II′
Cf^{249}	4.3±0.5	28±7
Cf^{250}	49 ±6	34±8
Cf^{251}	11 ±3	8±1
Cf^{252}	36 ±5	30±3

of californium (corresponding to about four percent of the gross californium activity of sample II) was left with the berkelium activity for five weeks, after which time the californium was again chemically separated from the berkelium (this will be referred to as californium sample II′). The mass spectrometric analysis of this californium sample is given in column 2 of Table I. The Cf^{250}/Cf^{251}, Cf^{250}/Cf^{252}, and Cf^{251}/Cf^{252} mole ratios of the two samples are constant within statistical error. The Cf^{249} in sample II′ has, however, been enhanced. This is evidence for assigning to Cf^{249} the 5.81-Mev alpha particles observed to grow into a purified berkelium fraction and to chemically elute in the californium position. The alpha half-life of Cf^{249} is calculated to be 550±150 years from the 5.81-Mev alpha-particle growth rate into a Bk^{249} sample of a measured disintegration rate.

Alpha-pulse analysis of californium sample II by a wire-screen collimator technique[2] showed two prominent alpha groups of 6.12 and 6.03 Mev. The gross 6.12-Mev/6.03-Mev alpha activity ratios in samples I and II were 0.62±0.12 and 3.3±0.3, respectively. Gamma-alpha coincidence measurements on sample II showed a fine-structure peak associated with each of the two prominent californium ground-state alphas. The intensity ratio of the fine-structure peaks was also about 3.3. This behavior is characteristic of the alpha spectra of even-even nuclides.

Alpha-pulse analysis of the californium II′ sample showed 0.4±0.1 percent 5.81-Mev alphas. The spontaneous fission activity on a plate from sample II californium, containing ini-

TABLE II. Nuclear properties of some isotopes of elements 97 and 98.

Isotope	Radiation	Half-life	Alpha energy (Mev)	β^- energy (kev)	Spontaneous fission half-life
$_{97}Bk^{249}$	β^-, α (?) branching ratio $\beta^-/\alpha\approx10^5$	~1 year	5.4 ±0.1	100±20	$>10^7$ years
$_{98}Cf^{249}$	α	550±150 yr	5.81±0.03		$>10^6$ years
$_{98}Cf^{250}$	α	9.4±2.3 yr	6.03±0.01		$\geq10^4$ years
$_{98}Cf^{251}$	(α)				
$_{98}Cf^{252}$	α	2.1±0.4 yr	6.12±0.01		60±12 years
$_{98}Cf^{253}$	β^-	18±3 days			