The present data do not give answer to the question of whether or not all the ν-neutrons are produced in a *single* nuclear evaporation. However, the fact that the multiplicity of neutrons is still very high with lead thickness as small as 1 inch, leads us to think that if the primary act induces further evaporations, the radiations that cause them have very short mean free paths.

[1] Cocconi, Cocconi Tongiorgi, and Greisen, Phys. Rev. **74**, 1867 (1948).

Relation between Half-Life and Disintegration Energy in Orbital Electron Capture by Heavy Nuclei

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THE large amount of energy data now available for the alpha-emitters and negative beta-emitters in the heavy region makes it possible, through the medium of closed decay cycles, to calculate the total energies corresponding to a number of electron capture decay processes. Using this method, it is possible for the first time to study rather extensively the relationship between disintegration energy and half-life in the electron capture process. The present note summarizes the results of a number of such calculations of decay energies and shows how these are connected with the corresponding half-lives. The data used here are taken chiefly from the recent compilation by Seaborg and Perlman.[1] The electron capture decay isotope Np^{233} of 35 minutes half-life, not included in the above compilation, is also used in this correlation.[2]

In order to illustrate the method of calculation of electron capture decay energy from a closed cycle we may consider the following:

$$\begin{array}{ccc} {}_{90}\mathrm{Th}^{229} & \overset{K}{\longleftarrow} & {}_{91}\mathrm{Pa}^{229} \\ \alpha\downarrow & \beta^- & \downarrow\alpha \\ {}_{88}\mathrm{Ra}^{225} & \longrightarrow & {}_{89}\mathrm{Ac}^{225}\,. \end{array}$$

It can be seen that the electron capture energy of Pa^{229} is equal to

$$E_\alpha(\mathrm{Pa}^{229})+E_r(\mathrm{Pa}^{229})-E_\alpha(\mathrm{Th}^{229})-E_r(\mathrm{Th}^{229})-E_\beta(\mathrm{Ra}^{225})$$

where E_α corresponds to the energy of the longest range alpha-particle, E_r corresponds to the energy of recoil following alpha-emission, and E_β represents the ***total disintegration energy*** corresponding to the beta-decay process. Using the best values available we have $5.69+0.10-5.02-0.09-0.2=0.5$ Mev for the electron capture disintegration energy of Pa^{229}. Since this isotope decays 99 percent by electron capture and 1 percent by alpha-emission with a measured half-life of 1.5 days, this 0.5 Mev disintegration energy corresponds to a half-life of 1.5/0.99, or approximately 1.5 days.

Calculations using an extension of this method have been carried out for 15 species for which there are reliable half-life and branching data. Where the alpha-energies have not been measured they were obtained from a recent correlation between alpha-energy, mass number, and atomic number.[3] A more serious difficulty arises in estimating total beta-disintegration energies from the published values of the beta-particle upper energy limits and the gamma-ray energies, in that a knowledge of the disintegration scheme is necessary. The values chosen on which the calculations are based are summarized in Table I.

TABLE I. Total beta-disintegration energies of some heavy isotopes.

Isotope	Energy (Mev)
Bi^{213}	1.3
Ra^{225}	0.2
Pa^{233}	0.5
Pb^{211}(AcB)	1.4
Fr^{223}(AcK)	1.3
Th^{231}(UY)	0.24
Pb^{214}(RaB)	1.0
Pb^{212}(ThB)	0.6
Ra^{228}(MsTh$_1$)	0.05

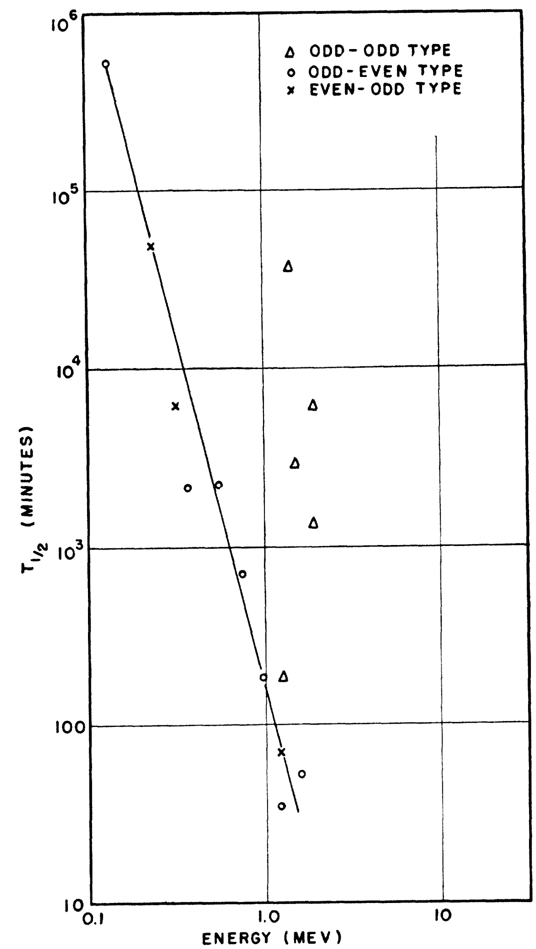

FIG. 1. Relationship between energy and half-life in electron capture decay.

Figure 1 shows a plot of the logarithm of the (partial) half-life *versus* the logarithm of the energy for the 15 species. The energy plotted here is obtained by subtracting the binding energy of the K-electron (about 100 kev in this region) from the total disintegration energy as calculated above. Thus the assumption is made that K-electron capture (rather than L-electron capture) is the predominant mode of decay. Of course the partial half-life for electron capture should be related to the energy of the particular primary transition rather than to the total energy between ground states, as is plotted here, but at present only the latter values are known. It may be noticed that it is possible to draw a line to very roughly include essentially all species other than a few of the odd-odd mass type and that the slope of this line corresponds to a half-life dependence of inverse fourth power of the energy. The number of points above this rough line is probably too small to define another line since some of these probably represent different degrees of forbiddenness and since these odd-odd nuclei seem to include more gamma-rays in their decay which should be taken into account in even a rough correlation; if a line were drawn through these points it would show a slope corresponding to a half-life dependence of greater than inverse fourth power of the energy.

It is felt that further refinements of the method presented here, in which the energy corresponding to electron capture decay to identified excited states of the product nuclei are correlated with corresponding partial half-lives, will lead to more meaningful information as to the nature of the electron capture decay process. Until more complete information is available on the gamma-rays associated with each transition, and until more is known about the ratio of K to L capture in the decay of each isotope, this relationship must be regarded as provisional.

I am indebted to Professor Glenn T. Seaborg for many interesting and helpful discussions on this subject.

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[1] G. T. Seaborg and I. Perlman, Rev. Mod. Phys. **20**, 585 (1948).
[2] L. B. Magnusson and G. T. Seaborg, unpublished work (Jan., 1949).
[3] Perlman, Ghiorso, and Seaborg, Phys. Rev. **74**, 1730 (1948).

Magnetic Deflection of Cosmic-Ray Mesons Using Nuclear Plates*

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A METHOD has been described[1] in which two nuclear plates are exposed with an air gap separating their parallel emulsion surfaces, in a perpendicular magnetic field (see Fig. 1). Using a permanent magnet weighing 65 lbs., field strength 13,300 gauss, two balloon flights were carried out with Ilford C2 emulsions, one above 90,000 ft. for 1 hour with 100-μ emulsions, the other for 3 hours with 200-μ emulsions. After development, positions of particles, stopping in the emulsion, relative to the x-ray registration dots, is plotted by means of a pantograph attached to the microscope stage,[2] and the azimuth of the track on emergence measured with an eye-piece protractor. Matching of track segments due to a single particle in the two plates is ascertained by the equality of the following quantities: (a) the dip angles, q_T and q_B in Fig. 1, between emerging track and emulsion surface, accurately measured with a tilting stage;[2] (b) grain counts, (c) estimates of scattering, and most important, (d) the two deflections, Δ_T (obtained by projecting the bottom track) and Δ_B (from projecting the top track). Where a $\pi-\mu$-decay occurs in one plate and the μ-meson crosses the air gap to stop in the other plate, the total μ-meson range gives additional certainty in matching. The magnetic radius is computed from the two independent deflection measurements, Δ_T and Δ_B. Assuming singly-charged particles, and that the energy-loss is a function of velocity only, it can be shown that $R/m=f(R/H\rho)$, where R (range), H (field), and ρ (curvature) can be experimentally determined, but m (mass) is unknown. From range-energy curves[3] for protons in an Ilford emulsion, the function f was graphed, allowing determination of the mass of other particles. The probable error in each angular deflection is the sum of: (a) theoretical average scattering angle,[4] for a particle of the range and mass determined, (b) emulsion distortion (measured "deflections" of a control series of 60 protons with *no* field approximated a Gaussian curve with standard deviation $\frac{1}{2}°$, excluding emulsion areas less than 8 mm from plate edges), (c) instrumental errors (these will be negligible when positions are re-measured with micrometer-thread stage motions readable to 1μ). As scattering introduces the greatest uncertainty, measurements on particles with range 500μ or greater are desirable. Since for a given curvature, the deflection angle will increase with the path length in the air gap, particles with small dip angles will have smaller percent errors. Events have occurred with measured deflection angles 10 times the total probable error in angle, but cases of at least twice this accuracy can be anticipated.

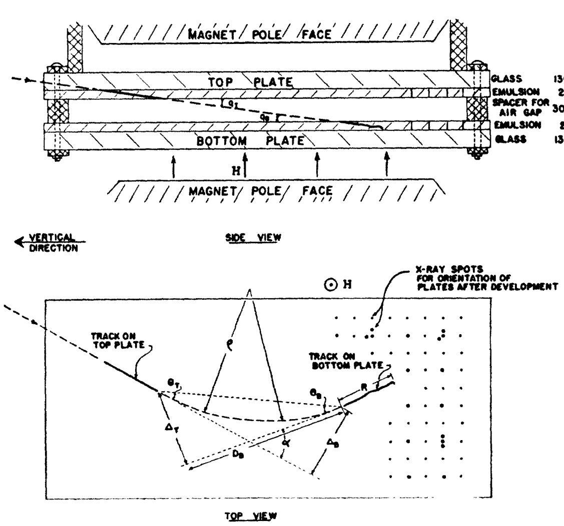

FIG. 1. Side and top view of plate assembly for magnetic deflection experiment.

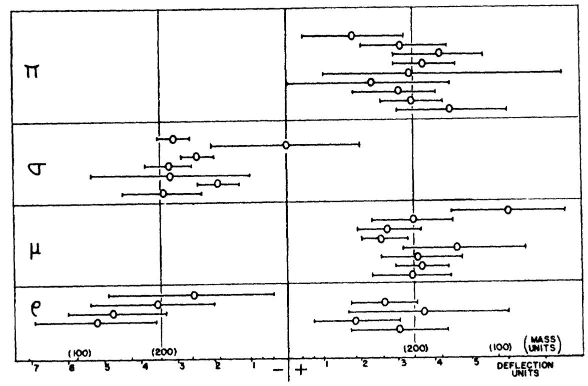

FIG. 2. Preliminary deflection measurements of cosmic-ray mesons, using nuclear plates.

After analyzing plates from the short flight, plus $\frac{1}{4}$ the emulsion area of the second flight, preliminary measurements have been obtained on 33 mesons, shown in Fig. 2. There is confirmation of the positive charge of π and μ-mesons, and the negative charge of σ (star-producing) mesons, concerning which there is no possibility of direct evidence on cosmic-ray mesons from other emulsion techniques like scattering, grain counting, etc. ρ-mesons (stopping with no visible interaction) appear about equally divided between $+$ and $-$. Mass and probable error values are plotted on a "deflection unit" scale[5] and give, combining μ and ρ, 219 ± 26; for π and σ, 270 ± 23. There is no evidence in these experiments so far for the presence in appreciable abundance of "heavy" mesons, which could usually be differentiated from protons if they were negative or interacted visibly. The possible presence of "light" mesons cannot yet be excluded, as there are several tracks still "unmatched" (since a meson of mass less than $40m_e$ would experience a very large deflection, a much larger area of the opposite plate must be scanned for a possible matching segment from such a particle). After completion of analysis of the remaining $\frac{3}{4}$ of these plates, another flight is planned in which longer exposure and use of larger plates should give better statistics and accuracy.

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