TABLE I. Expertmental results. h is the distance to the top of the atmosphere in meters of water equivalent. S is the magnitude of the lateral showers.

Φ	h	N_{ce} Coinc./Min.	N_{dd} Coinc./Min.	N_{cd} Coinc./Min.	N_{dc} Coinc./Min.	S Coinc./Min.
0°	10	1.689±0.027	1.527±0.027	1.467±0.027	1.399±0.026	0.070±0.004
30°	12	1.141±0.015	1.065±0.018	0.985±0.015	0.988±0.017	0.079±0.004
45°	14.1	0.702±0.011	0.668±0.012	0.644±0.010	0.631±0.010	0.073±0.003
60°	20	0.336±0.008	0.325±0.08	0.318±0.08	0.309±0.09	0.059±0.003

given by

$$\delta = 2(N_{cc} - N_{dd})/(N_{cc} + N_{dd}).$$

Furthermore, from the measurements N_{cd}, and N_{dc} we can deduce

$$\sigma_+ = 2[(N_{cc} - N_{cd})/(N_{cc} + N_{dd})],$$
$$\sigma_- = 2[(N_{dd} - N_{dc})/(N_{cc} + N_{dd})].$$

The last two expressions give us the percentage of the particles of both signs with such an energy as to undergo the deflection in the magnetized iron in relation to the number of particles arriving. The values of δ, σ_+, σ_- are given in Table II. The effect δ for $\phi = 0°$ is in excellent agreement with that of Jones,[2] Hughes,[3] and Bernardini, Conversi, Pancini, and Wick,[1] as well as with that of Quercia, Rispoli, and Sciuti.[4]

The measurements N_{cd} and N_{dc} which determine σ_+ and σ are independent of those which enter the value of δ. They confirm the values obtained for δ itself.

In the fourth column of Table II the value of δ is calculated, from the theory of Wick. We took into account here the variation of the intensity of the meson component with the zenithal height and the deformation of the spectrum due to the absorption of mesons. Φ is the angle between the axes of the telescope and the vertical; θ and φ are, respectively, the colatitude and the longitude of the direction of incidence of a particle with respect to a polar axis which has the direction of the magnetic field in the iron.

The number of particles N available for coincidences is:

$$N = \int\int\int J(E, \theta, \varphi)\Sigma(E, \theta, \varphi) dE \sin\theta d\theta d\varphi, \qquad (1)$$

where $J(E, \theta, \varphi)dE$ is the number of particles of energy between E and $E - dE$ and of direction given by θ, φ. $\Sigma(E, \theta, \varphi)$ is the effective cross section of the instrument, which depends obviously upon E, B and upon the geometrical configuration of the instrument. Here we use the formulas for $J(E, \theta, \varphi)$ deduced from those of Euler and Heisenberg, and for $\Sigma(E, \theta, \varphi)$ that calculated by Wick.

In the integration the functions are not considered until the value of the energy corresponds to the cut of the instrument. For the positive excess the best experimental value available has been taken for the calculations, i.e., 15 percent.[5]

TABLE II. Values of δ, σ_+, σ_-. h is the distance to the top of the atmosphere in meters of water equivalent.

Φ	h	δ Experimental	δ Theoretical	σ_+	σ_-
0°	10	0.101±0.02	0.105	0.139±0.02	0.079±0.02
30°	12	0.068±0.02	—	0.143±0.02	0.070±0.02
45°	14.1	0.048±0.02	0.097	0.083±0.02	0.055±0.02
60°	20	0.035±0.02	0.090	0.055±0.03	0.054±0.03

The discrepancy between the results of our calculations and the experimental ones seems to indicate that the positive excess is not uniformly distributed on the energy spectrum. It decreases apparently with the increase of the initial energy of the mesons. For example, for $\Phi = 70°$ it is reasonable to suppose that most of the incident mesons are generated nearly at the top of the atmosphere with an energy greater than $4 \cdot 10^9$ ev (corresponding to 20 m of water equivalent), because the primary proton component is absorbed rather strongly. If we calculate the positive excess ϵ which gives us some account of the experimental effect for $\Phi = 60°$, we find $\epsilon = 6$ percent (according to the hypothesis of homogeneous distribution of ϵ).

For $\Phi = 0°$, with the same hypothesis, to explain the observed value of δ, we find that the mesons which arrive vertically at the instrument (and have, therefore, energies smaller than those to be taken into account for $\Phi = 60°$) must have a positive excess of at least 14 percent.

A valid indication of this fact is also given by the effects σ_+, σ_- which seem not to remain in a constant relation to the variation of the angle. A decrease of the positive excess with the increase of the generating energy of the mesons from protons seems to indicate that the multiplicity increases with the energy. For high energies a contribution caused by non-ionizing radiation could give a further possible explanation.

We express our appreciation to Professor Bernardini for fruitful discussions on the argument.

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[1] Bernardini, Conversi, Pancini, Scrocco, and Wick, Phys. Rev. **68**, 109 (1945).

[2] Haydn Jones, Rev. Mod. Phys. **11**, 235 (1939).

[3] D. J. Hughes, Phys. Rev. **57**, 592 (1940).

[4] I. Quercia, B. Rispoli, and S. Sciuti, Phys. Rev. **73**, 516 (1948).

[5] See G. Bernardini, G. P. Puppi, and N. Cim., to be published.

Alpha-Decay Systematics of the Heavy Elements

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IN the last few years a great number of new isotopes have been prepared in the region of the natural radioactivities permitting a more extensive view of the nuclear properties in this region. In particular, regularities in alpha-decay properties can now be seen more clearly. More recently, work in this laboratory with the 184-inch cyclotron has further extended our view of alpha-decay properties by identifying isotopes of the elements in this region far on the neutron deficient side of beta-stability.

Figure 1 shows a plot of alpha-energy *vs.* mass number[1] in which the isotopes of each element are connected by a line. The alpha-particle energies rather than total transition energies have been plotted for ease in comparing with data

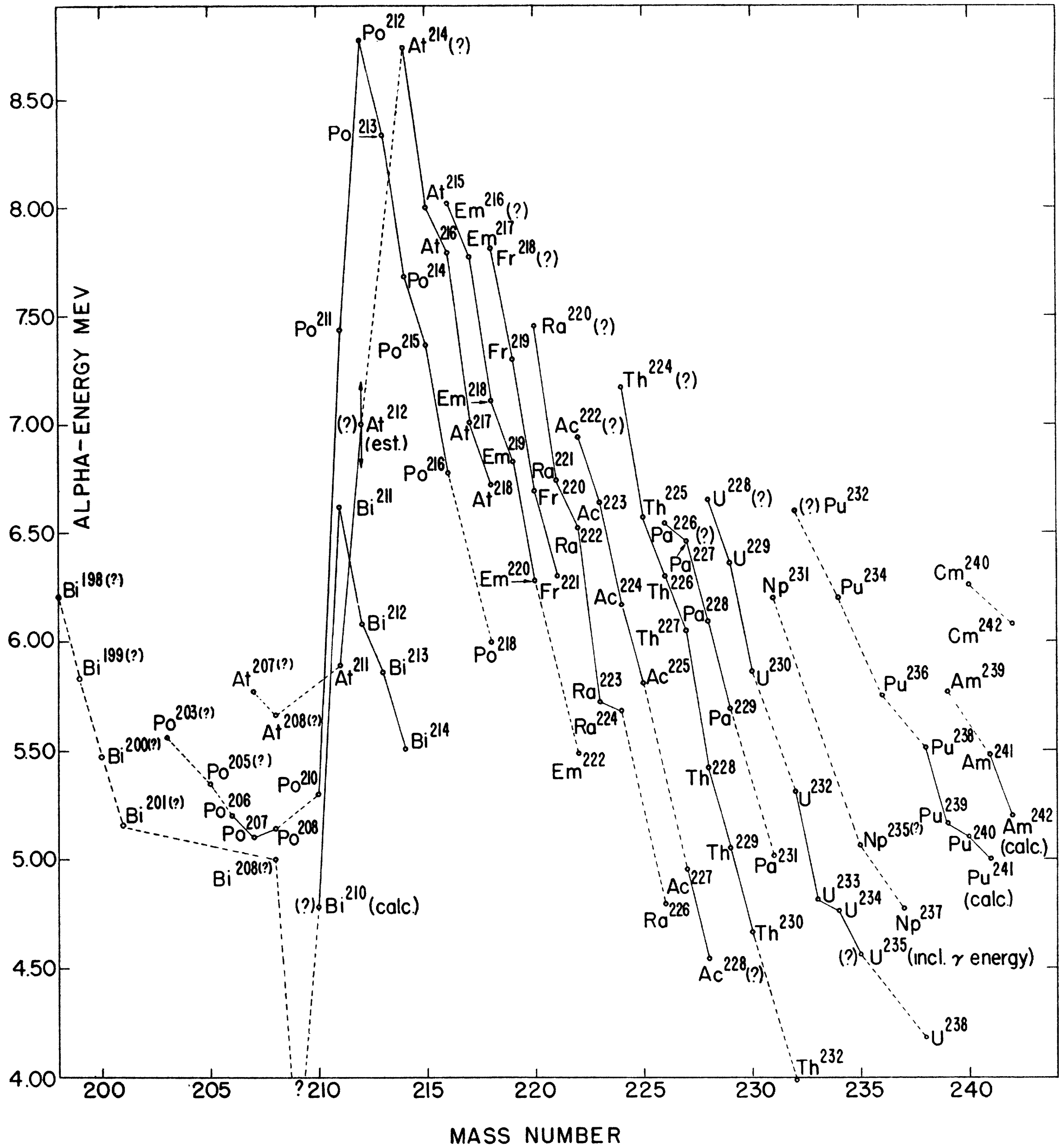

FIG. 1. Alpha-decay energies of the heavy elements. Dotted lines connect isotopes between which gaps exist or cases in which the assignment of one of the isotopes is uncertain. A question mark preceding the isotopic symbol designates uncertainty of the energy; following the isotopic symbol it signifies uncertainty in mass number and atomic number; while when used following the mass number superscript, uncertainty in mass number is indicated. The alpha-energy of At^{212} has been estimated from the half-life and the energies of Bi^{210}, Pu^{241}, and Am^{242} have been calculated from closed decay cycles.

as usually published. It is not possible to give references for the many recently prepared isotopes which are shown here but these will be found in a review article covering all of the isotopes.[2]

One feature that is immediately apparent is that each element from bismuth to curium shows a nearly parallel increase in alpha-energy with decreasing mass number, starting with the heaviest known isotope of each. In the cases of thorium and uranium this regularity extends through eight measured isotopes covering mass number ranges of nine and eleven, respectively. It is seen in the case of uranium that the regularity persists from the heaviest beta-stable isotope well into the region of instability with respect to orbital electron capture. (The isotopes U^{231}, U^{229}, and U^{228} are all unstable in the latter sense.) This effect may be visualized from an energy surface diagram in which pairs of elements differing by $Z=2$ can be compared if it is assumed that a fairly constant difference in packing fraction exists between pairs of nuclear species on the two contours separated by 5–6 mass units. Since alpha-decay proceeds between points on the two contours differing by four mass units, the energy differences between such pairs of points increase with decreasing mass number.

In the lower elements a different phenomenon appears. Although the heaviest isotopes of each show the trend noted above, the alpha-energies begin to decrease with decreasing mass number beyond a particular point. The isotopes showing maxima in alpha-energy are, for the respective elements, Bi^{211}, Po^{212}, and At^{214} or At^{213}, the latter being unknown. This trend was noted some time ago for polonium isotopes.[3] However, at still lower mass numbers for each element the initial trend of increase in alpha-energy with decrease in mass number is resumed. The exact trend cannot be followed in the case of bismuth as it can for polonium and astatine since no alpha-activity has yet been observed over the mass number range 202–210, with the possible exceptions of Bi^{208} and Bi^{210}. However, the reappearance of alpha-activity at lower mass numbers leaves little doubt that bismuth shows the same behavior as polonium and astatine.

In order to explain the course of those curves of Fig. 1 that go through maxima, and minima it is necessary to modify the smoothly varying energy surface by replacing in it a depression or ridge (or both), but the exact shape and position of the irregularity cannot be determined without more data including that of beta-decay energies in this region. It is of interest to speculate whether or not this irregularity becomes smoothed out above the region around lead or extends to the higher elements. It may be pointed out that Bi^{209}, Po^{210}, and At^{211}, which are situated at or near the minima of their respective curves, contain 126 neutrons, possibly an especially stable configuration.[4]

The difficulty of observing this effect for higher elements is apparent from the relative positions of the curves for each element with respect to the region of beta-stability. In the cases of bismuth and polonium it is seen that the peak in alpha-energy occurs either in the region of beta-stability or on the β^--unstable side. It is, therefore, possible to prepare and observe isotopes of considerably lower mass number. In the cases of the higher elements the regions of beta-stability occur at relatively higher mass numbers, and the alpha-decay energies are still increasing for isotopes which become difficult to prepare and which are on the neutron deficient side of beta-stability. However, there is some hope for preparing more highly neutron deficient isotopes of emanation and francium as decay products of highly neutron deficient isotopes of the heaviest elements in the same manner in which At^{214} results from an alpha-decay chain starting with Pa^{226}.

It is not possible to discuss in this communication a number of other correlations which can be made regarding alpha-decay energies and half-lives and regions of beta-stability. These will be dealt with in a later paper.

Besides the measured alpha-particle energies, some others can be calculated for cases in which the alpha-decay completes an otherwise known decay cycle of two alpha- and two beta-emissions. A few of these have been entered in Fig. 1 for those cases in which indirect evidence for alpha-emission has been obtained by observing the growth of the daughter.

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[1] For similar treatment of alpha-decay data see, for example: K. Fajans, *Radioelements and Isotopes* (McGraw-Hill Book Company, Inc., New York, 1931); J. Schintlmeister, Oesterr. Chem. Z. **41**, 315 (1938); A. Berthelot, J. phys. rad. (Series VIII) **3**, 17 (1942).

[2] G. T. Seaborg and I. Perlman, Rev. Mod. Phys. **20** (October 1948 issue).

[3] For discussion of early work see: K. Fajans, *Radioelements and Isotopes* (McGraw-Hill Book Company, Inc., New York, 1931).

[4] Maria G. Mayer, Phys. Rev. **74**, 235 (1948).

Evidence for a *p,d* Reaction in Carbon

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The reaction $C^{12}(p,pn)C^{11}$ has been investigated at proton energies up to 140 Mev in the 184-inch cyclotron by Chupp and McMillan[1] and McMillan and Miller,[2] both as to excitation and absolute cross section. The high energy behavior of this reaction is taken as evidence for the ideas of Serber,[3] explaining these processes by a direct knockout, rather than a compound nucleus process.

In this experiment excitation curves of this reaction were obtained in the region from threshold to 32 Mev using the Berkeley linear accelerator. Stacks of polystyrene (C_nH_n) foils were bombarded in the beam of the accelerator; specially molded 10 mil (25 mg/cm) foils were used from 32 Mev to 21 Mev, commercial 5 mil and 2.5 mil foils were used from 21 Mev to 16 Mev. All foils were weighed and calibrated for uniformity. The β^+ from C^{11} were counted in standard geometry in a thin window G-M counter and compared with a UO_2 standard sample. The resultant curve is shown in Fig. 1. The absolute cross sections were obtained by bombarding a foil at 32 Mev in vacuum and collecting the protons in a Faraday cup. The beam passed through an open cylinder maintained at 8000 volts in going from the sample to the collector cup, in order to suppress secondary electrons. The current to the cup was integrated on a low leakage condenser and the voltage read on a balanced electrometer. The entire electrometer apparatus is in vacuum. Bombardments were also made with the sample located directly in the collector cup and gave results in agreement with the results obtained when bombarding in the beam ahead of the secondary electron suppressing cylinder. The result is

$$\sigma_{32\text{ Mev}} = (0.075 \pm 0.02) \times 10^{-24}\text{ cm}^2.$$