they would have to be extremely energetic and this again appears unlikely, although it cannot definitely be ruled out yet. The most probable hypothesis would seem to be that of multiple meson production in the nuclear break-up. It is possible that a light track almost vertical in the mosaic from the star is the incoming primary. An incident proton with sufficient energy to produce this star, would leave such a track. Some of the light tracks projected in other directions may also be mesons.

We have, however, observed other large stars, including a 30-pronged one, not showing such a pronounced downward cone as above although they do contain lightly ionizing tracks.

If the above hypothesis is correct, it is apparent that some of the stars are very similar to those found in cloud chambers,[5] which show associated penetrating particles. It is hoped that further work will give more definite evidence concerning the identity of the lightly ionizing particles.

We are greatly indebted to the Trans-Canada Airlines, who carried the emulsions for us on their transatlantic service.

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[1] The presence of cones in stars in Kodak NT4 emulsions was mentioned recently by Brown *et al.*, Nature **163**, 47, 82 (1949). We have also just noted the results of J. Hornbostel and E. Salant, Bull. Am. Phys. Soc. **24**, No. 5, 25 (1949), who observe these cones in stars at 93,000 feet in Eastman NTB3 emulsions.

[2] All these events were found in the same batch of emulsions, although not in the same plate.

[3] The cone is downward on the assumption that the star was formed whilst the aircraft was in level flight. The approximate zenithal direction is marked on Fig. 1.

[4] The emulsion thicknesses used were 100μ and 200μ. They were all developed by the temperature method.

[5] See, for example, C. Y. Chao, Phys. Rev. **75**, 581 (1949).

Binding Energies of Alpha-Particles in Medium-Heavy Nuclides*

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June 16, 1949

THE question of the α-stability of the elements below bismuth has been considered on several occasions in the past,[1] with the conclusion that the elements beyond the middle of the periodic system are on the average energetically unstable toward α-emission, but not sufficiently so to give detectable radioactivity. Fluctuations about this average behavior result in the α-lability of one or more isotopes of samarium and possibly a few other "missing" β-stable nuclides.[2]

Estimates of individual α-particle binding-energies can be obtained from the "empirical" atomic mass equation of Bohr and Wheeler.[3] This can be written:

$$M(A,Z)=A+D_A+\tfrac{1}{2}B_A(Z-Z_A)^2\pm\tfrac{1}{2}\delta_A \text{ or } 0,$$

D_A being the mean mass defect corresponding to mass number A and atomic number Z_A, and the other terms having their usual significance.[3] Assuming $B_A=B_{A-4}$ and $\delta_A=\delta_{A-4}$, the energy Q_α released by α-disintegration is given by:

$$Q_\alpha(A,Z)=\Delta_4D_A-D_{\mathrm{He}}-\tfrac{1}{2}B_A(2-\Delta_4Z_A)^2+B_A(2-\Delta_4Z_A)(Z-Z_A),$$

where $\Delta_4D_A=D_A-D_{A-4}$, etc., and D_{He} = mass defect of He^4 (3.61 Mev).[4] In a region where Z_A and D_A vary linearly with A, the last term can be replaced by $-B_A\Delta_1Z_A(2-\Delta_4Z_A)(A-A_Z)$, where A_Z is the value of A (not necessarily integral) corresponding to maximum β-stability for the element of atomic number Z. The approximately linear variation of α-disintegration energy with Z among isobars and with A among isotopes is responsible for many of the observed regularities among the known α-emitters,[5] and is illustrated in Fig. 1 by the plotted α-disintegration energies of Th and U.

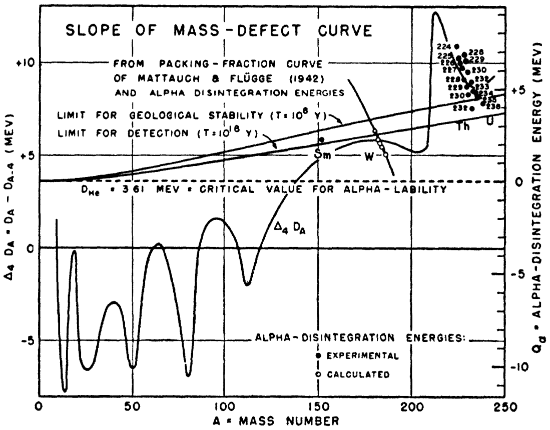

FIG. 1. Slope of the mass-defect curve. α-disintegration energies are plotted against the scale at the right.

The principal term determining the magnitude of Q_α is Δ_4D_A, a measure of the slope of the mass defect curve. Figure 1 gives a plot of Δ_4D_A *versus* A obtained from the packing-fraction curve of Mattauch and Flügge[6] up to mass number 206, at which point it is joined to a curve derived from an analysis of α-disintegration energies. The shape of the curve in the region $50\lesssim A\lesssim 200$ is poorly determined by the data; there is possibly a peak in the vicinity of $A=150$ which may account for the α-activity of samarium.

Evidently most nuclides above $A=140$ are energetically capable of emitting α-particles, and are only stabilized by the nuclear potential barrier resulting from the high charge. The effect of the barrier has been calculated using the simple one-body theory,[7] and is shown on the diagram by the two sloping lines. The lower indicates the α-disintegration energy corresponding to the maximum half-life which can be detected by present methods, $\sim 10^{18}$ years, and the upper corresponds to the minimum half-life for geological stability, $\sim 10^{8}$ years. Between these lie the primary natural α-emitters, U^{238}, U^{235}, Th^{232}, and Sm^{152}.

As a result of the last term in Q_α, sufficiently light isotopes of elements in the region from the rare earth elements to Pb should exhibit α-activity. Among the β-stable nuclides, this term can become largest for the even elements, and it has already been suggested[2] that some β-stable nuclides (in addition to Sm^{146}) may be missing in nature as a result of α-decay. Since the present experimental upper limits for α-activity for most β-stable nuclides correspond to lifetimes of only 10^{12} to 10^{14} years, it is possible that the lighter naturally occurring isotopes of some of the even elements in this region may possess detectable α-activity.[8]

Far to the neutron deficient side of the β-stability region α-activity should be an important mode of decay. As A becomes smaller for a given Z, the lifetimes against electron capture or positron emission will also decrease, but less rapidly, so β-decay will probably be the predominant mode except for large neutron deficiencies. By nuclear bombardments with very energetic photons[9] and ions,[10] which are known to result in the formation of highly neutron-deficient nuclides, it should be possible to observe artificial α-activity in medium-heavy elements.[11]

Calculated α-disintegration energies of the isotopes of W, as a typical element in this region, are shown in Fig. 1, the circles representing the β-stable isotopes and the line through them the locus of the β-labile ones. Such calculations are subject to large uncertainty, and are only meant to be suggestive. An analysis of presently available data pertaining to mass defects in this region is in progress in order to improve the basis for these calculations.

Conversely, measurements of α-disintegration energies below bismuth would improve our knowledge of the mass-defect curve.

Experiments along the lines suggested in this letter are being planned.

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* Declassified by AEC as AECD-2060. Presented at the Madison, Wisconsin, meeting of the American Physical Society, June 21, 1948 (Phys. Rev. **74**, 1259 (1948)).

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*** Part of this work was done in 1946 at the Metallurgical Laboratory, under the auspices of the Manhattan Engineer District, Contract No. W-7401-Eng-37.

[1] G. Gamow, Proc. Roy. Soc. London **A126**, 632 (1930), *Constitution of Atomic Nuclei and Radioactivity* (Oxford University Press, London, 1931), p. 15–21, Zeits. f. Physik **89**, 592 (1934), *Structure of Atomic Nuclei and Nuclear Transformations* (Oxford University Press, London, 1937), p. 7, 38–45, 48–52; W. Heisenberg, Zeits. f. Physik. **77**, 1 (1932); A. Landé, Phys. Rev. **43**, 620, 624 (1933); E. D. Eastman, Phys. Rev. **46**, 1, 238 (1934); H. A. Bethe and R. F. Bacher, Rev. Mod. Phys. **8**, 82 (1936), section 8, 30; C. F. v.Weizsäcker, *Die Atomkerne* (Akademische Verlagsgesellschaft, Leipzig, 1937), p. 34–35, 101–102; A. J. Dempster, Phys. Rev. **53**, 869 (1938); Hahn, Flügge, and Mattauch, Physik. Zeits. **41**, 1 (1940); E. Feenberg, Rev. Mod. Phys. **19**, 239 (1947).

[2] T. P. Kohman, Phys. Rev. **73**, 16 (1948).

[3] N. Bohr and J. A. Wheeler, Phys. Rev. **56**, 426 (1939).

[4] An alternate expression is given by Feenberg (reference 1, Eq. (65)).

[5] For example, K. Fajans, *Radioelements and Isotopes* (McGraw-Hill Book Company, Inc., New York, 1931), Chapter I; Perlman, Ghiorso, and Seaborg, Phys. Rev. **74**, 1730 (1948).

[6] J. Mattauch and S. Flügge, *Nuclear Physics Tables* (Verlag Julius Springer, Berlin, 1942; Interscience Publishers, Inc., New York, 1946), plate 1.

[7] R. W. Gurney and E. U. Condon, Nature **122**, 439 (1928); G. Gamow, Zeits. f. Physik **51**, 204 (1928). For computation, the formulation of H. A. Bethe, Rev. Mod. Phys. **9**, 69 (1937), section 66, was used.

[8] According to the present considerations, Gd^{152} should not have the special α-lability suggested for it by Feenberg (reference 1). K. K. Keller and K. B. Mather (Phys. Rev. **74**, 624 (1948) were unable to detect α-activity in natural gadolinium. Ti^{44} and Zr^{88}, in which N. E. Ballou (Phys. Rev. **75**, 1105 (1949) unsuccessfully sought α-activity, would be expected to be stable against α-decay.

[9] G. C. Baldwin and G. S. Klaiber, Phys. Rev. **70**, 259 (1946).

[10] Seaborg, Cunningham, Hopkins, Lindner, Miller, O'Connor, Perlman, and Thompson, Phys. Rev. **72**, 739, 740 (1947); D. H. Templeton, U. S. AEC Doc. 1525 (1947).

[11] Templeton (reference 10) observed short α-periods in light isotopes of Bi and Po and inferred that "the very light isotopes of the lighter elements" might also be α-active.

The τ-Meson

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June 13, 1949

THREE particles of mass about 725 electron masses have been found in an Ilford C2 emulsion exposed to cosmic radiation at high altitude. Mesons of masses in this range have been reported,[1] but the number observed has been small and the mass determinations inadequate to definitely establish the existence of the particle. In the present experiment, high mass resolution has been achieved by minimizing the fading of the latent image and confining the observations to a single plate.

Ilford C2 plates, wrapped in a paper heat insulating envelope, were exposed to cosmic radiation for 6 hours at 90,000 to 100,000 ft. The temperature variation near the envelope during the flight was about 10°C. The plates were developed using a two bath process similar to that described by Blau and DeFelice.[2] Fifty-six mesons of residual range greater than 200 microns, including two $\pi-\mu$-decays, have been found in the single plate that has been analyzed.

One of the 725 m_e particles originated in a very high energy nuclear disintegration (Fig. 1, point *A*). Eighteen tracks emerge from this disintegration near the center of the 200-micron emulsion, but only the track τ and a 23-micron track of a particle heavier than an alpha-particle end in the emulsion. The characteristics of the track τ indicate that the particle reached the end of its range and was captured at *B*. Grain counting established that the short-range particle from *B* was at least as heavy as a proton, and the other product, although it passed out of the emulsion, was heavier than the meson. No nuclear events were associated with the other two 725-m_e particles, although both appeared to have reached the end of their range.

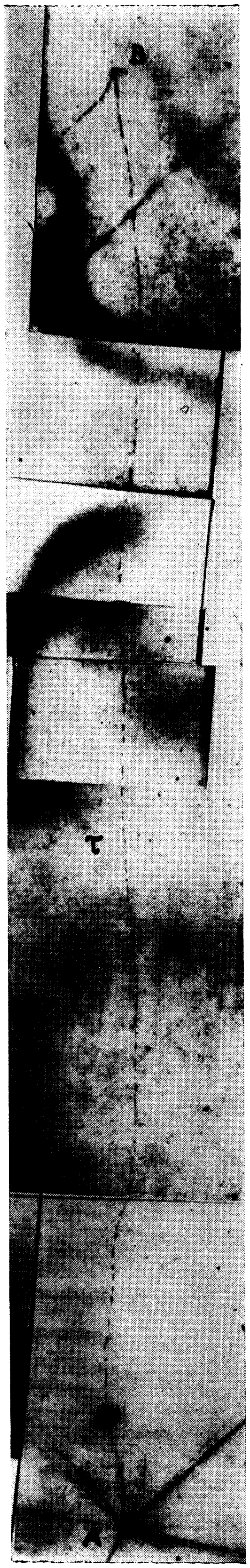

FIG. 1. τ-particle track of length 700 microns originating in disintegration *A* and initiating the secondary event at *B*.