series. The direct solar spectrum was recorded at 1332 hours, M.S.T., April 12, 1948, following which the coelostat was halted and the solar image was allowed to drift off the slit. With the solar image safely out of the way, the sky-scatter series was begun, and the observations were made at the following times, M.S.T.:

*S*1–1347 hours
*S*2–1351
*S*3–1355
*S*4–1359
*S*5–1403

Thus, the portions of the sky observed were, respectively, 4, 5, 6, 7, and 8 degrees removed from the sun.

It will be clear from a cursory inspection of the comparison that the sky-scattered spectrum, although relatively poorer than the direct spectrum in the longer wave-lengths, is by no means as much poorer as might be expected. The comparison suggests the inverse first power for these particular observations rather than the inverse fourth.

[1] Arthur Adel, Phys. Rev. **75**, 133 (1949).
[2] The relative intensities of the direct solar radiation and the sky-scattered radiation are separated by a factor of many hundreds. We are concerned, however, with the relative intensities within the sky-scattered spectrum itself as compared with the relative intensities within the direct solar spectrum.

Large Cosmic Stars in Electron Sensitive Emulsions

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June 10, 1949

In examining some Ilford G5 emulsions, flown for 185 hours at an average height of 14,000 feet, examples of μ-meson decay were observed, showing that the emulsion was sensitive to minimum ionization. It is also apparent that many of the stars show tracks which could not have been detected with the C2 emulsion previously used.

It is the purpose of this note to discuss some interesting large stars we have found. One case is that of a 31-pronged star containing a downward cone of at least 4 light tracks.[1] A mosaic of photomicrographs of this event is shown in Fig. 1, which also includes mosaics of a μ-meson decay, a section of a star-producing meson, 2000 microns from the end of its range (energy about 9 Mev) which could only have been detected under good conditions in C2 emulsions.[2] This latter may be compared with the star fragments thus indicating the extra tracks visible in the new emulsion. There are 7 light tracks, including the cone, and at least 4 others, which may not have been recorded on C2 emulsions.

The downward cone[3] is extremely interesting. Two tracks leave the emulsion very soon as indicated on the mosaic, but two continue at a small angle (0.64°) without being scattered, until one emerges after 3000 microns, the other after 8000 microns. The ionization is sensibly the same along these tracks and is 25 ± 2 grains/100 microns.

The grain density along random straight, thin tracks traversing this and other plates of the same batch varied between 21 and 25 grains/100 microns for different tracks. The correction for background grains for these minimum ionization tracks was 3 grains/100 microns. There appears to be no evidence for a systematic variation of grain density with depth in the emulsion.[4] In general, the characteristics of the Ilford G5 emulsions appear to be very similar to the Kodak NT4 as reported by the Bristol Group,[1] showing approximately the same grain density along the minimum ionization tracks and analogous grain density *versus* range curves for mesons. Thus the grain density of the long star tracks may be assumed to be very nearly minimum.

It seems unlikely that the particles can be electrons, and the only alternative would be protons or mesons. If they are protons

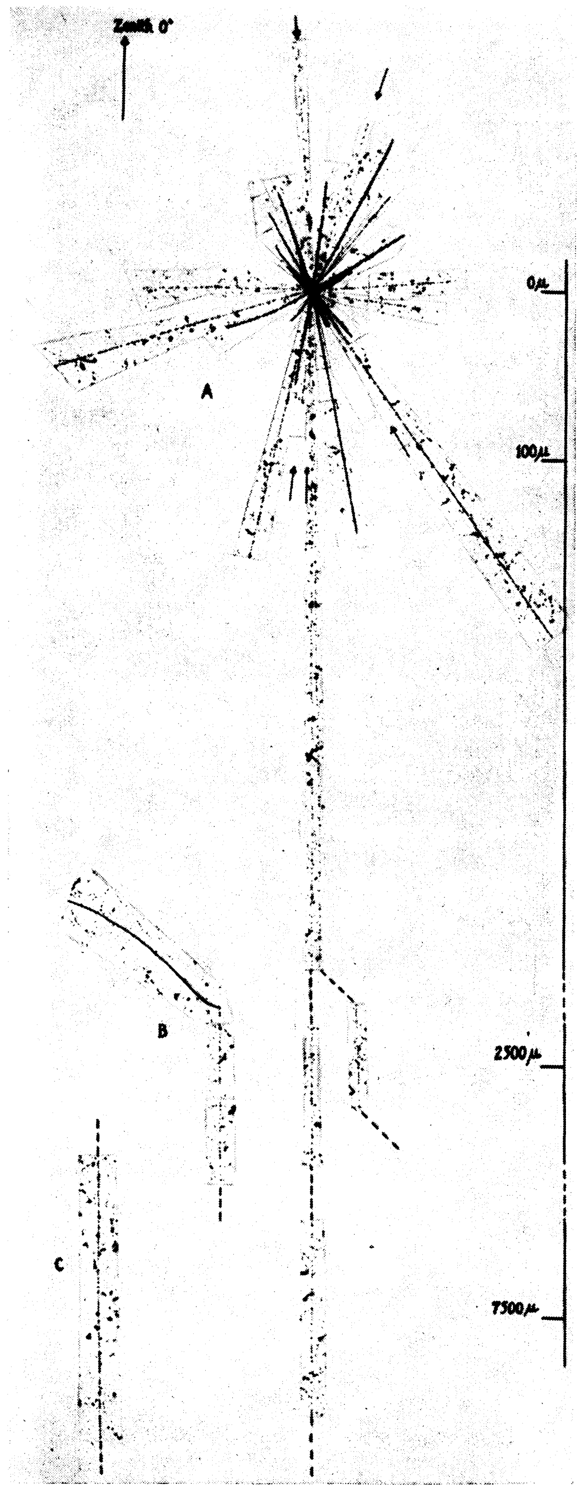

Fig. 1. Mosaics of photomicrographs showing events in Ilford G5 emulsions. A: 31-pronged star with downward cone of light tracks. Selected sections of two long tracks are shown, the tracks at 2500 microns being relatively, correctly spaced. Arrows indicate some other light tracks. B: μ-meson electron decay. C: section showing grain density of 9-Mev π-meson.

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.

[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.

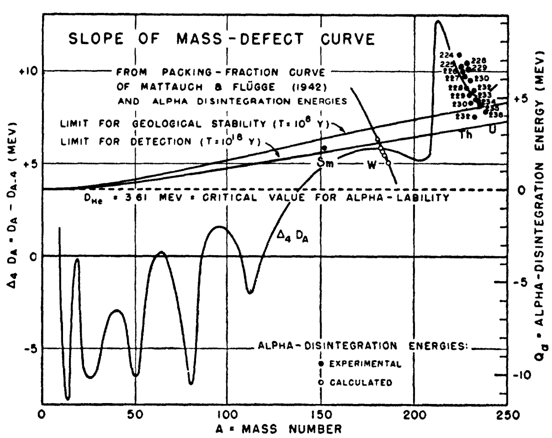

FIG. 1. Slope of the mass-defect curve. α-disintegration energies are plotted against the scale at the right.

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.

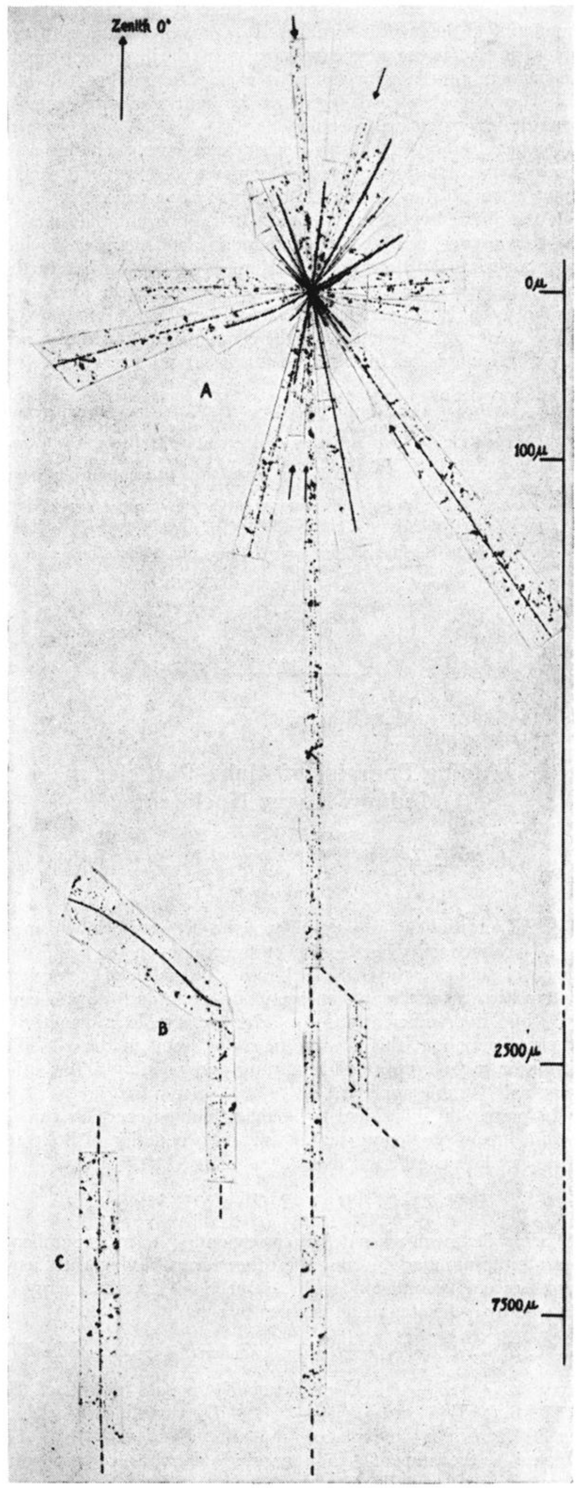

FIG. 1. Mosaics of photomicrographs showing events in Ilford G5 emulsions. A: 31-pronged star with downward cone of light tracks. Selected sections of two long tracks are shown, the tracks at 2500 microns being relatively, correctly spaced. Arrows indicate some other light tracks. B: μ-meson electron decay. C: section showing grain density of 9-Mev π-meson.