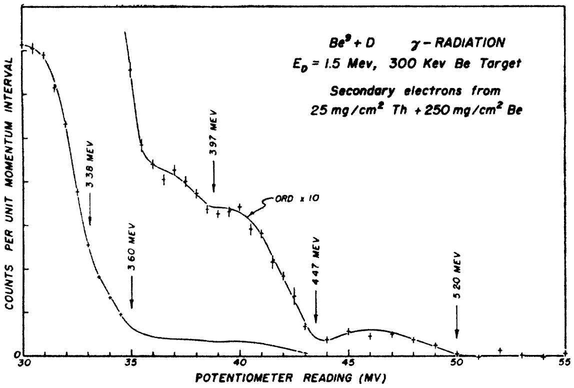

FIG. 1. Compton electrons ejected from 250 mg/cm² of beryllium by the high energy gamma-radiation produced in the bombardment of beryllium with deuterons. The abscissae are proportional to the current in the lens coil, and therefore proportional to the magnetic field and to the momentum of the focused electrons.

sulting from the 3.11-Mev gamma-ray from $C^{12}(d\ p)C^{12*}$ [2] and the 6.15-Mev gamma-ray from $F^{19}(p\ \alpha)O^{16*}$.[3] The results are given in Table I. The total intensity of the three higher energy lines is less than about 2 percent of the total gamma-intensity from the $Be^9(d\ n)B^{10}$ reaction under the conditions of the present experiment.

The assignment of these gamma-rays to particular nuclei is complicated by the fact that B^{10}, Be^{10}, Be^8 and Li^7 may all be formed by the deuteron bombardment of Be^9 as highly excited residual nuclei. Because of the agreement of the energy of the highest line with the value expected from the Q of the new neutron group it seems reasonable to associate this line with a level in B^{10}, the low intensity of the line implying that the state decays primarily either by emitting a series of lower energy gamma-rays or by heavy particle emission to $Li^6 + He^4$ ($Q = 0.84$ Mev). The fact that the total gamma-ray yield does not reflect the appearance of the neutron group would indicate that the latter mode of disintegration may be preferred in spite of the rather low energy of the alpha-particles. The 4.47-Mev line may represent a level in B^{10} for which the neutron group has not yet been observed or which is reached only by cascade from the 5.2 Mev level. The 3.97 Mev line could then result from the transition from this level to the known 0.411 Mev level. Alternatively, the 4.47 Mev line could represent a transition from the 5.2 Mev level to the known 0.713 Mev level leaving the 3.97 line still to be accounted for.

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On the Origin of Heavy Cosmic-Ray Particles

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IT has been suggested by F. Zwicky[1,2] that supernovae might produce cosmic rays, with expulsion of high-speed atoms from the stellar surface. Another mechanism, apparently not considered hitherto, is the acceleration of small solid particles, or dust grains, by the pressure of supernova radiation. The velocities reached are close to that of light. The high-speed grains would gradually disintegrate into cosmic-ray particles of the heavier elements, primarily O, Mg, and Fe. The computed density of these particles in space is consistent with the observed flux of heavy nuclei in cosmic radiation.

The absolute brightness of a supernova, according to W. Baade,[3] is 5×10^7 suns, or 2×10^{41} ergs/sec. if the surface temperature of a supernova equalled that of the sun. Interstellar grains further away than about 10^{16} cm (0.01 light year) would be heated to less than 1000°K and Fe and Mg compounds would not evaporate. A grain of radius 10^{-5} cm at this distance initially would be accelerated to a velocity of about 3×10^9 cm/sec. within a few weeks; this gives a kinetic energy of about 0.01 Bev per nucleon.

This velocity is a minimum value, since, according to R. Minkowski,[4] the actual surface temperature of a supernova is apparently much higher than 6000°. With increased temperature the total flux of radiation is greater. In addition, the wave-length, λ_m, of maximum radiation flux is decreased; the acceleration is greatest for grains whose radius is about $\lambda_m/2\pi$, and with decreasing λ_m grains of less mass per area can be more effectively accelerated. If a surface temperature of 100,000° is assumed, the minimum distance at which a grain will not evaporate becomes about 10^{17} cm (0.1 light year) and the final kinetic energy becomes about 1 Bev per nucleon for a grain of radius 10^{-6} cm.

These high-speed grains would not last long, provided that they are retained in the galactic plane by a strong magnetic field, as postulated by E. Fermi,[5] and verified by the observations of Hiltner[6] and Hall[7]—see Spitzer and Tukey.[8] In a few thousand years such a grain will collide with a low-speed grain in an interstellar cloud. Even if a grain could survive such an impact, encounters with H atoms would knock all the atoms off the surface of a high-speed grain every few thousand years, giving a relatively rapid evaporation.

To compute the density of the individual high-speed atoms produced we shall assume that all the grains between 10^{17} and 2×10^{17} cm of a supernova are accelerated, and that the resultant nuclei are retained within a cylindrical volume of our galaxy 30,000 light years in radius, and 600 light years thick. Since interstellar matter is apparently confined to spiral arms, which occupy perhaps a fifth of this volume, the mean density of interstellar matter in this cylinder may be taken as 0.2 H atom per cm³. An Fe nucleus, moving with a kinetic energy of about 1 Bev per nucleon, will lose half its energy to the interstellar H atoms in about 2×10^7 years. The frequency of supernova in the spiral arms of the galaxy we take as one per 100 years; this rate, about five times that found for external galaxies, seems warranted both by the large size of our galaxy and by the number of supernovae observed nearby. The average space density of the relevant grains, each 10^{-6} cm in radius and containing 10^6 atoms, is highly uncertain. We assume here that this density is 10^{-11} per cm³; the true value may lie anywhere between 10^{-10} and 10^{-14}. On these assumptions, the computed average density of high-speed atoms in the galaxy is 5×10^{-14} per cm³, yielding a particle flux of about 10^{-4} atom per cm² per steradian. This result is consistent with the corresponding observed particle fluxes in the cosmic radiation which, according to B. Peters,[9] are 1.0×10^{-4} for $10 < Z < 28$, and 4.3×10^{-4} for O, C, and N.

While this mechanism may apparently produce an appreciable fraction of the heavy-particle cosmic radiation, it may not be capable of generating particles with energies greater than a few Bev per nucleon. Possibly the mechanism proposed by E. Fermi[5] may be important in accelerating particles further, although the injection energies required for this mechanism apparently exceed 5 Bev per nucleon for Fe. Further observational and theoretical study of the energy spectrum seems needed. Detailed abundances of the different elements in cosmic radiation would also provide a check on the further theoretical work planned. I am much indebted to Professor John Wheeler for illuminating discussions.

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