Neutrons and Other Heavy Particles in Cosmic Radiation of the Stratosphere

Three sets of Imperial Process Plates, to which the technique of Blau[1] was adapted, were sent to the stratosphere inside the gondola of Explorer II, on the National Geographic Society—Army Air Corps flight of November 1935, to register the tracks of any heavy particles of either primary or secondary origin which may occur in the cosmic radiation of the upper atmosphere. 17 plates (1700 cm^2), in a flat nitrogen-filled rubber bag, were covered with materials about 1 cm thick, representing 20 elements: H, Li, Be, B, C, N, O, F, Na, Mg, Al, Si, S, Cl, K, Ca, Br, Cd, I, and Pb. 15 plates (1800 cm^2), without covering materials, were packed in two separate boxes of thin wood. These plates remained at 1/2 meter, water-equivalent, below the top of the atmosphere for about 2 hours.

Microscopic examination of 70 cm^2 of the emulsions under paraffin, aluminum, lead, carbon, and without covering, for α and H tracks at angles between 0° and 45° with the plane of the emulsion shows: (1) no α-particle tracks in plates not covered with materials, other than those tracks originating in radioactive contamination; (2) 4.5 ± 1 proton tracks per cm^2 in paraffin-covered plates, but only 0.8 ± 0.4 per cm^2 in emulsions covered with lead and with carbon, *so that these protons are evidently recoils from neutron collisions.* In addition, there is evidence that a small number of α-particles and possibly protons occur as secondaries in plates covered with aluminum.

The radioactive background of the room in which the plates were prepared and developed is low, as measured with an unshielded G–M counter.

All plates examined are compared with control plates of similar sensitive life, covered with the identical materials used with the stratosphere plates. The plates used as controls were originally prepared for the intended flight of July, 1935, and were later left on Pike's Peak (14,000 ft. elevation) for one month. The paraffin-covered plates from Pike's Peak show only 2 proton tracks in 6 cm^2 of emulsion, as compared with 27 on an equivalent area of stratosphere plates. Although the possibility of a terrestrial neutron source cannot be entirely eliminated, the foregoing constitutes good evidence that the neutron recoil tracks were produced in the stratosphere, and that the intensity of these neutrons at 6 meters of water below the top of the atmosphere is not more than 0.0005 times as great as at 1/2 meter.

Since the recoil tracks in the emulsion represent only a fraction of the total ranges of the protons, it is difficult to assign an average energy to the neutrons producing them. If one assumes neutrons of one energy uniformly distributed in angle, the number of proton recoils of maximum range R_0 having ranges between R and $R+dR$ is given by $dn=-A\ dR/R_0^{2/3}R^{1/3}$. Application of this formula to the distribution of lengths of proton tracks visible under paraffin, or to the relative numbers of proton tracks produced under paraffin and without paraffin, sets a rough lower limit of 6 MEV for the mean energy of the incident neutrons. To a rough approximation, the number of protons appearing below 1 cm of paraffin is proportional to the total energy of traversing neutrons. Hence, the direct energy in the primary cosmic radiation of this region of the stratosphere, attributable to neutrons, is calculated to be 1.2 MEV per cm^2 per sec. Although probable error cannot be computed, this value is believed to be in error by not more than a factor of 3. The maximum amount of *indirect* energy which could be released by atmospheric transformations would appear from a process similar to the hypothetical one: $N^{14}+n^1\rightarrow N^{15}+h\nu$, where $h\nu\sim9$ MEV. Consequently the maximum possible contribution of neutrons, by both direct and indirect processes, can be of little significance compared with the total cosmic-ray ionization, unless slow neutrons are present in much greater numbers than the distribution of lengths of observable proton recoil tracks indicates.

If these neutrons are primary constituents of cosmic radiation, as the present evidence indicates, the free neutron must be comparatively stable, despite its high mass.[2] Further, the presence of such neutrons suggests that the primary cosmic radiation has been associated with considerable quantities of matter, and should contain considerable gamma-radiation.

The suggestion that primary cosmic radiation at high altitudes contains a strong component of α-particles whose effects are conspicuous at about 1 meter of water,[3] is inconsistent with our observations. From the counting rates obtained with coincidence counter telescopes during the same flight in which the plates were carried aloft,[4] it is calculated that 2×10^5 primary α-particles would have traversed the emulsion examined, if 1/3 of the counter discharges were produced by α-particles. On the assumption that the apparent absorption coefficient foı such α-particles is 0.6 per meter of water, and that the plates record α-particles whose energies have been reduced to 100 MEV or less, at least 200 of these particles should have produced observable tracks, whereas none were found. This result is not in conflict with that recently reported by Wilkins and St. Helens,[5] since their tracks are all nearly parallel and came from the horizontal direction; this almost certainly excludes the possibility that their tracks were produced by primary particles. Moreover, the absence of observable primary α-particles cannot be explained by their disappearance through nuclear collisions, since, for a nuclear cross section of 10^{-25} cm^2, 0.67 of all α-particles suffer no nuclear collisions in passing through 1 meter of water-equivalent of atmosphere. The nuclear cross section for α-particles of energies equal to the potential barrier of nitrogen is 10^{-25} cm^2 or less, and varies inversely as the velocity for α-particles of greater energies, so most of the suggested primary α-particles[3] would have retained their identity to the end of their range.

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