Angular Correlation in the Reaction $B^{11}(p; \gamma_1, \gamma_2)C^{12}$†

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THICK targets of natural boron have been bombarded with 170-kev protons from the kevatron[1] at the State University of Iowa. The excited state of C^{12} resulting from this bombardment decays among other ways by the successive emission of 11.8- and 4.5-Mev gamma-rays. The angular correlation of these gamma-rays and the angular distribution of the 11.8-Mev gamma-ray has been measured. RCA 5819 photomultiplier tubes and NaI(Tl) scintillation crystals were used as the gamma-ray detectors.

The angular distribution of the 11.8-Mev gamma-ray was found to be proportional to $1+(0.23\pm0.04)\cos^2\theta$. This implies that p-wave protons are predominant in the formation of the compound nucleus. Thus, the triple angular correlation theory of Biedenharn, Arfken, and Rose[2] is applicable.

The angular correlation of the successive gamma-rays was measured in two counting geometries. In the first geometry the 4.5-Mev gamma-ray was counted parallel to the proton beam and the 11.8-Mev gamma-ray at an angle θ with respect to the proton beam. The resulting angular correlation function was found to be proportional to $1+(0.39\pm0.15)\cos^2\theta$. In the second geometry the 4.5-Mev gamma-ray was counted at right angles to the proton beam and the 11.8-Mev gamma-ray at an angle θ with respect to the proton beam and in the plane defined by the fixed counter and the proton beam. The resulting angular correlation was found to be proportional to $1-(0.2\pm0.1)\cos^2\theta$.

The spins of the proton, the ground state of B^{11}, and the ground state of C^{12} are known[3] to be 1/2, 3/2, and 0, respectively. The spin[2] of the 16.3-Mev excited state of C^{12} is 2 since this state decays[4] by both gamma-ray emission and alpha-particle emission. This leaves only the spin of the 4.5-Mev excited state of C^{12} and the relative angular momenta of the two gamma-rays unknown. The three independent measurements on the gamma-rays (the 11.8-Mev gamma-ray angular distribution and the angular correlation with two geometries) should then give experimental values for these unknown quantities. Using the theory of Biedenharn, Arfken, and Rose,[2] Professor J. M. Jauch of this department has shown that the above measurements are consistent with the spin of the 4.5-Mev excited state of C^{12} being 2, the 11.8-Mev gamma-ray being dipole radiation, and the 4.5-Mev gamma-ray being quadrupole radiation. This is in agreement with Haefner's[5] analysis of the alpha-particle model of C^{12}.

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High Energy Nuclear Collisions and the Fermi Model

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WE have recently[1] considered the question of correlating the differential cross section for inelastic nucleon-nucleon collisions with experimental data on the angular and radial spread of the nucleon component of the cosmic radiation. Since our results were communicated, other results[2] have been published which bear on this topic, from a different point of view. It appears to us of great interest to compare the conclusions thus reached by independent methods.

Our results showed that neither the Fermi-model,[3] nor an alternative model[4] with a differential cross section quasi-isotropic in the center-of-mass coordinates, could explain the relatively small angular and radial spreads[5–9] of the nucleon component of the cosmic radiation in the atmosphere. By a detailed mathematical analysis of the cascade processes in the nucleus and the atmosphere, we found that theory could be reconciled with experiment only by supposing that the scattered nucleons in nuclear collisions are confined to a much narrower cone than that required by the relativistic transformation. Moreover, the differential cross section must decrease something like exponentially from the forward direction to ensure that not too many particles escape at wide angles.

Hazen, Heineman, and Lennox[2] have attempted to compare the predictions of the Fermi-model with experimental data. They considered nucleon-nucleus collisions, but they did not employ a quantitative cascade theory, with the result that their numerical comparisons were of a qualitative nature only. Nevertheless, their conclusions do not differ essentially from our own. Under the most favorable conditions that they could envisage, there remained a discrepancy of almost an order of magnitude between the half-width predicted by the Fermi-model and that required by experiment.

This discrepancy would have been increased if the moments of the angular distribution had been considered instead of the number of particles within a given angle. The singularities of the Fermi distribution at 0° and 180° in the center-of-mass frame are of a very weak type which results in moments not very different from those of a quasi-isotropic distribution.[4]

Hazen *et al.* were concerned to a greater extent with the mesons than the nucleons that are generated in nuclear encounters. However, it is obvious that the distributions in the atmosphere of the two components cannot be very different.

There is thus an increasing amount of evidence that neither the quasi-isotropic distribution[4] nor the Fermi distribution can even approximately describe the facts and that some unknown process is in operation at very high energies, which results in an intense concentration of the particles scattered in nuclear collisions in the forward and backward directions.

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Measurement of Short Beta-Decay Lifetimes*

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A NEW method for measuring the lifetimes of isotopes has been developed. The isotopes are produced in the bombardment of various targets by the internal proton beam of the Harvard FM cyclotron. The decay particles are detected by a crystal, Lucite probe, and photomultiplier arrangement. The target is located in the median plane about four inches directly below the detecting crystal. Many of the decay particles follow helical paths in the magnetic field through an opening cut in a one-inch thick brass cap shielding the anthracene crystal. An eight-foot long Lucite probe enclosed in a vacuum-tight tube collects the light flashes and conveys them to a RCA 5819 photomultiplier located outside the vacuum tank. The signal is fed from the photomultiplier to a cathode follower and from there to a linear amplifier in the control room. The pulses from the discriminator output go into an integrating circuit; the resulting current is registered on