Title

A TEST OF THE CHARGE SYMMETRY HYPOTHESIS: POSITIVE TO NEGATIVE PION PRODUCTION RATIO OBTAINED IN BOMBARDING CARBON WITH ALPHA PARTICLES AND PROTONS

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ABSTRACT

A measurement of the plus/minus ratio for the production of pions by alpha particles incident on carbon nuclei has been carried out to test the charge symmetry hypothesis. Employing an experimental procedure which eliminates residual errors in geometry, etc., the ratio was found to be 0.72 ± 0.17. The alpha particle energy was 375 Mev and the meson energy was 15 Mev observed at 90° to the beam. Coulomb effects are expected to bring about a depression of the production ratio from unity of about this magnitude. The experimental result, therefore, provides support for the charge symmetry hypothesis.

As supplementary information the same apparatus was used to measure the pion plus/minus ratio for 330 Mev protons incident on carbon. The ratio found was 5.4 ± 0.8.

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INTRODUCTION

In nuclei neutrons and protons seem to play symmetrical roles, but it has not been established nearly so well in meson production that the charge symmetry hypothesis is valid. Some measurements have been made of pion production ratios when neutrons and protons separately bombard carbon. Bradner, O'Connell and Rankin[1] observed a positive to negative ratio of 1/12.6 ± 12 percent for mesons of 50-65 Mev emerging from a carbon target at $\approx 90^{\circ}$ to a neutron beam. The neutrons had an energy spectrum peaked near 270 Mev. Richman, Weissbluth and Wilcox[2] measured the ratio for 340 Mev protons bombarding carbon. For mesons of 12-20 Mev emerging at $90^{\circ} \pm 12^{\circ}$, they found a ratio of 3.4 ± 0.8, and for the integral ratio, 5.1 ± 1. Block, Passman and Havens[3] also reported measurements for carbon bombarded by protons of 381 Mev. For 18 Mev mesons observed at 90° to the beam, their experimental points imply a ratio of 17 ± 8 and for the integral ratio they give 11 ± 3. These results indicate that protons yield a large excess of positive mesons, and neutrons a large excess of negative mesons, but only weak evidence is offered of an actual symmetry in production, particularly because no absolute production cross sections have been measured for neutrons.

EXPERIMENTAL METHOD

In order to obtain identical conditions for neutron and proton bombardment, we have carried out an experiment in which carbon was bombarded by the internal 375 Mev alpha particle beam of the 184-inch cyclotron. Pions emerging from a target at 90° to the beam were observed using nuclear track plates as detectors.

Various experimental arrangements were tried and the one finally adopted is shown in Figure 1. The apparatus was placed in the magnetic field of the cyclotron and mesons of opposite signs passed into stacks of plates A and B. To eliminate any lack of perfect symmetry for detection of positive and negative mesons, two bombardments were made. Without altering the positions of the plates between bombardments, the beam was reversed (by reversing the cyclotron magnetic field) so that the signs of mesons entering plates A and B were reversed. It is easy to show that one can thus eliminate the effects of unsymmetrical geometry and other experimental inequalities. The true plus/minus ratio, R, is given by:

$$R = \left[\left(\frac{N_+}{N_-}\right)_A \left(\frac{N_+}{N_-}\right)_B\right]^{1/2},$$

where $\left(\frac{N_+}{N_-}\right)_A$ and $\left(\frac{N_+}{N_-}\right)_B$ are the plus/minus ratios found in plates A and B respectively. Pions in the range 11-21 Mev were detected so that the ratio obtained is for this range of energies. The yield of mesons compared to background was very low and examination of 12 plates all exposed at the same time, six in position A and six in position B, yielded only 82 mesons, excluding ρ mesons. The ratio of positive to negative mesons obtained was 0.72, with a standard deviation of 0.17. To determine the ratio, π-μ decays and star forming mesons were counted, and it was assumed that 73 percent of the π^- mesons produced stars in the Ilford C2 emulsion employed. Practically complete discrimination was obtained between one prong stars and π - μ decays, in the few cases where ambiguity existed, by

grain counting. All doubtful events were studied by two or more observers. To reduce the coulomb barrier effect, another experiment at higher meson energy ($\approx$ 30 Mev) was carried out. The meson yield was so low in this case, however, that the experiment was impractical.

DISCUSSION

The experimental ratio is significantly near unity, but at the same time the probability is low that true value may actually be as high as unity.

For every process leading to the production of a positive meson, this experimental arrangement provides a mirror process leading to the production of a negative meson. Aside from slight binding energy differences of the mirror disintegration products, coulomb effects are the only ones which would cause the experimental ratio to deviate from unity if the hypothesis is valid. In this case they tend to depress the ratio. The effect of the barrier was first observed by one of the writers[4] who investigated the alpha particle plus/minus ratio at 0^{o} as a function of target atomic number for mesons having very low kinetic energies in the effective center of mass system. For targets of high atomic number the coulomb effect was shown to be profound. In the present experiment, however, the meson energy is several times greater than the barrier height. In addition the effective barrier height must be somewhat reduced by the fact that the system of nucleons, while the meson is escaping, is rapidly disintegrating. To estimate correctly the effect of the barrier on the ratio under these conditions offers difficulties. B. Fried and S. Gasiorowicz[5] have calculated the expected ratio for a point nucleus and obtained a value of about 0.5. This calculation certainly over-estimates the coulomb effect on the ratio. A calculation is being carried out on the assumption that mesons are created in the coulomb field of the residual finite size nucleus before the latter disintegrates. It is reasonably certain

that the experimental ratio agrees within its standard deviation with the value anticipated on the basis of the charge symmetry hypothesis.

PROTON PLUS/MINUS RATIO

The ratio of positive to negative mesons obtained in bombarding carbon by 330 Mev protons was also found using the apparatus of Figure 1. It was thought worthwhile to carry out such a separate experiment to determine this ratio afresh in view of the divergence of the published ratios. The higher yield of mesons relative to background under proton bombardment made the accumulation of data less tedious in this case. 449 mesons, excluding ρ mesons, were counted and the plus/minus ratio obtained was 5.4 ± 0.8.

ACKNOWLEDGMENT

In conclusion, one of us (H. W. W.) wishes to thank Professor E. O. Lawrence for his kindness in permitting him to work in the Radiation Laboratory and for his encouragement in the work carried out therein.

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FIGURE CAPTION

Figure 1 Median plane section of plus/minus apparatus. The magnetic field, which is nearly constant along the meson paths, is perpendicular to the paper. The apparatus was made as symmetrical as possible. The target was in the form of a carbon rod 1/16 in. x 1/8 in. in cross section. The beam traversed the 1/8 in. dimension. The channels were 1 inch deep.

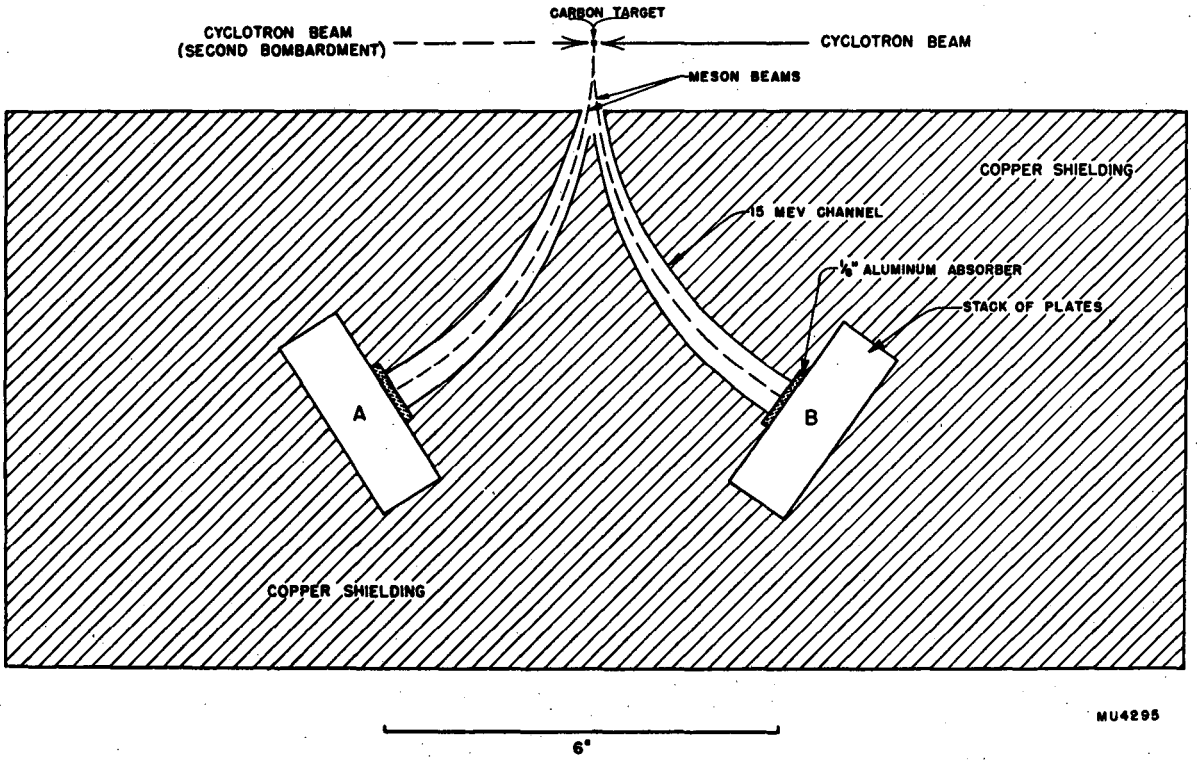
CARBON TARGET
CYCLOTRON BEAM
(SECOND BOMBARDMENT)
CYCLOTRON BEAM
MESON BEAMS
COPPER SHIELDING
15 MEV CHANNEL
⅛" ALUMINUM ABSORBER
STACK OF PLATES
A
B
COPPER SHIELDING
MU4295
6"

Fig. 1