Reaction $p+p\rightarrow\pi^++d$ with Polarized Protons*†

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The 45 percent polarized proton beam[1] of the Carnegie synchrocyclotron has been used to measure the azimuthal asymmetries of the above reaction at π^+ c.m. angles of 90° and 50°. The polarized external beam of 415±5 Mev protons impinged upon liquid hydrogen, and the resulting pions were detected in fast coincidence with their associated deuterons. We define the asymmetry $\epsilon(\theta)$ to be $[I(\theta)-I(-\theta)]/[I(\theta)+I(-\theta)]$ with $I(\theta)$ the intensity at a c.m. angle of θ. θ is in the same plane as the first scattering which produces the polarized beam and positive θ is in the same sense as the first scattering. We find $\epsilon(90°)=-0.20\pm0.03$ and $\epsilon(50°)=-0.023\pm0.015$, where these refer to the asymmetries in the sense defined by the meson. These values are the average of four separate runs at 90° and three at 50°, with each run taken on a different day and of about 15 hours duration.

To exclude the reaction $p+p\rightarrow\pi^++p+n$, which would otherwise constitute about 10 percent of the counting rate in the geometry we used, sufficient absorber was placed in front of the deuteron counter to absorb the slow protons resulting from this reaction. The beam direction was determined from a beam profile obtained by using the meson counter as the defining counter. The beam polarization and energy were checked before each run as described in reference 1. By using the normal unpolarized proton beam, degraded to 415 Mev, an asymmetry measurement at 90° c.m. yielded $\epsilon=-0.01\pm0.04$.

As shown by Marshak and Messiah,[2] an azimuthal asymmetry in the reaction $p+p\rightarrow\pi^++d$ can arise through the interference of meson S and P states (but from neither alone), and the resulting asymmetry will be given by $\epsilon(\theta)=PQA\sin\theta/(A+\cos^2\theta)$, with P the beam polarization, Q a parameter of their theory, and $A+\cos^2\theta$ the unpolarized angular distribution. A recent experiment[3] by Crawford and Stevenson yields $Q=0.39\pm0.05$ at $(\text{K.E.}_\pi)_{\text{c.m.}}=11.3$ Mev. The present experiment gives $Q=0.45\pm0.08$ for $(\text{K.E.}_\pi)_{\text{c.m.}}=55$ Mev.

According to the above equation, $\epsilon(50°)$ should be given by[4] $\epsilon(90°)/(4.0\pm0.4)$, which is -0.050 ± 0.009. The difference between this and our experimental value is 0.027 ± 0.018. In this connection, it should be stated that the quoted errors are statistical only; systematic errors are probably smaller than these. It was pointed out to us by Professor L. Wolfenstein that a $P-D$ interference term will make a maximal contribution to ϵ at 50°. The fact that this difference is scarcely nonzero outside of statistics and does not include the unknown systematic error means that it cannot be interpreted as more than a possible indication of such a D-state effect.

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Search for 15-Mev Gamma Radiation from $N^{14}+d$ and $Be^9+\alpha$†

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Cohen, Moyer, Shaw, and Waddell[1] have recently reported 15.2-Mev γ radiation from the bombardment of carbon with protons and of B^{11} with deuterons, but not from the bombardment of beryllium with alphas. They suggest that the state in C^{12} involved is the isotopic spin $T=1$ analog of the ground states of B^{12} and N^{12}. The isotopic spin selection rules would then forbid the production of this state in the $N^{14}(d,\alpha)$ reaction. We have attempted to verify this.

A 1-inch Harshaw canned NaI(Tl) crystal viewed by a DuMont 6291 photomultiplier was available for the detection of γ rays. The crystal was surrounded by $2\frac{1}{2}$ inches or more of lead except for a 0.52-inch diameter aperture filled with Lucite which was directed towards the target. A $\frac{3}{4}$-inch long Bakelite plug was placed between the front face of the crystal and the lead.

This arrangement was not, of course, the best possible for detecting 15-Mev γ radiation. Its most important defect was that lower-energy pulses from other γ rays required the use of very low ($\sim0.005\mu$a) deuteron beams to avoid excessive total counting rates. Figure 1 shows the pulse spectrum obtained when a thick B_4C target is bombarded with 10.8-Mev deuterons. Although no detailed analysis of the shape of the spectrum was made, its form is not unexpected because of the small crystal size. By taking the break point in the curve as equal to $(E_\gamma-1.02)$ Mev and using the pair peak of the 4.43-Mev γ ray from C^{12} for calibration we get 15.1 ± 0.4 Mev for the highest-energy γ ray. If, as a very rough estimate, it is assumed that 15 percent of the 15-Mev quanta that enter the 0.52-inch aperture produce pulses >11.6 Mev, then our yield for this γ ray is $\sim3\times10^{-5}$ per deuteron.

With a thick Melmac 404 $(N_6C_3H_6)^2$ target, we obtained a small number of counts corresponding to γ

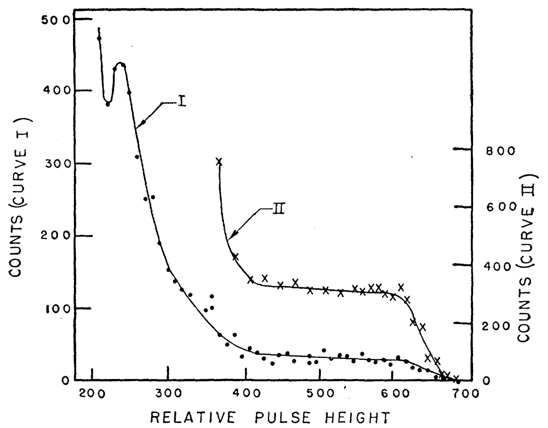

FIG. 1. Scintillation spectrum of the γ radiation from the bombardment of thick B_4C by 10.8-Mev deuterons. For Curve II more deuterons were incident on the target per point, and the discriminator was set to accept a wider range of pulse heights. A relative pulse height of 610 on Curve II was assumed to correspond to $(E_\gamma - 1.02)$ Mev. There is no significance in the apparent pulse-height shift in the two curves. The data were taken at different times and in each case a spectrum of the 4.43-Mev γ ray from C^{12*} was also taken for an energy calibration (see text).

radiation >12.5 Mev. Land Camera pictures of an oscilloscope screen indicated that this was probably the same γ ray as observed with the boron target. Comparison of integral counting rates from the Melmac and B_4C targets, after subtraction of background, gave an intensity ratio of ~ 0.03.

We have also looked for this radiation from a thick beryllium target bombarded by 21.7-Mev α particles. Gamma radiation of the same energy (± 0.5 Mev) and ~ 6 percent of the intensity of that from B_4C was observed. Examination of the original data of McMinn *et al.*[3] indicates that this yield is consistent, within an order of magnitude, with that for $Be^9(\alpha,p)B^{12}$.

Our results do not seem to have any immediate bearing on the isotopic spin assignment for this state in C^{12}. The possible small yield from $N^{14}(d,\alpha)C^{12*}$ can be explained by the approximate nature of the isotopic spin selection rules. On the other hand, it does not seem proper to say that its smallness proves that a $T=1$ state is involved, since there is no reason to expect the uninhibited (d,α) and (d,n) cross sections to be equal. However, we see no reason to doubt the $T=1$ assignment of Cohen *et al.*[1] Assuming this, we can infer that the α width of this level is small. This follows from the requirement of the charge-independence hypothesis that the $Be^9(\alpha,p)$ and $Be^9(\alpha,n)$ cross sections differ only by a factor of two[4] and from the approximate equality of the proton and γ-ray yields from $Be^9+\alpha$. After allowance for error in the yields involved, we conclude that Γ_γ is certainly less than 100 Γ_α and is probably less than 10 Γ_γ. Since 7.8 Mev is available for α emission, a strong selection rule is indicated. For this purpose, we note that as the analog of B^{12} and N^{12}, this C^{12} state might be assumed to have spin $J=1^+$, thus forbidding decay to the 0^+ ground state of Be^8 and requiring d-wave α emission to the 2^+ first excited state. Isotopic spin rules would further inhibit decay to the first excited state.

Another possible origin of the γ ray, in the cascade $C^{12} \rightarrow Be^{8*} + He^4$; $Be^{8*} \rightarrow Be^8 + h\nu$, may be ruled out, since it should have been easily observed in previous work on the $Li^7(d,n)Be^8$ reaction[5] and since a 15-Mev state in Be^8 is not energetically accessible in the bombardment of Be^9 with 21.7-Mev alpha particles.

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Calculations on Charge Independence with Repulsive Core Potentials

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BECAUSE of the current interest in two-body static potentials with repulsive cores,[1] calculations have been carried out to see whether such a potential can explain both the np and pp low energy scattering in the ^1S state, i.e., the experimental values of the scattering lengths $a_s(n-p)$ and $a_s(p-p)$ and the effective ranges $r_{0s}(n-p)$ and $r_{0s}(p-p)$. According to the effective range theory,[2] these four constants may be obtained from the solutions of the wave equation at zero energy for (a) the $n-p$ system and (b) the $p-p$ system. These two problems were coded for FERUT, the digital computer at the University of Toronto, for potentials of the form[3]

$$V = \infty \quad \text{for} \quad r < r_c,$$
$$= -V_0 f(r/r_s) \quad \text{for} \quad r > r_c.$$

The equations were solved by numerical integrations, starting with the asymptotic solutions and integrating inwards until the solutions became zero, thereby determining the core radius r_c. The integrals giving the effective ranges were evaluated using these solutions. In order to improve the accuracy of the solutions, the substitution $y = \ln(r/r_s)$ was made in the differential equations.[4] Because of this substitution, there was a