excited by fast electrons. Presumably a specifically nuclear interaction is not involved, which suggests that there may be similarities between electron excitation of levels and Coulomb excitation by heavy particles.

Figures 1 and 2 and the data at 60° permit a rough, limited measurement of the angular distribution of the cross section for the inelastic scattered electrons. These data are plotted in Fig. 3 along with the elastic cross section. The flatter angular distributions of the inelastic electrons appear to be in agreement with a preliminary theory.[5]

Inelastic processes have also been observed in copper.

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Pion Production Ratios*

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Measurements have recently been made[1] on the production of charged pions in the reaction Be^9+p. The π^+/π^- ratio ρ shows a striking energy dependence,[2] decreasing from $\rho\approx 6$ at $E_p=1$ Bev to $\rho=1.8$ at $E_p=2.3$ Bev. The present note interprets this behavior in terms of an "excited state" of the nucleon with isotopic spin $\frac{3}{2}$.

Pion production is envisioned as follows: two nucleons collide, forming a "compound state"; on emerging, one or both of the nucleons are in an excited state, which subsequently decays by π emission. This separation of the process into two distinct stages linked by a quasi-stable excited nucleon state is without justification; it should not, however, vitiate conclusions based on charge independence arguments and forms a convenient physical picture. For the sake of simplicity the nucleon is assumed to have only one excited state, which can decay to the ground state by emission of a single π meson. The excited state must therefore have $T'=\frac{1}{2}$ or $\frac{3}{2}$; meson production can be characterized by the indices 1 or 2, according as one or both nucleons emerge from the collision in an excited state. Because of the threshold for excitation, the production cross section satisfies $\sigma_1>\sigma_2$ for low E_p, while $\sigma_2\gtrsim\sigma_1$ for high E_p. The variation of ρ with E_p can be related to that of σ_1/σ_2, provided that $\rho_1\neq\rho_2$. This immediately excludes the case $T'=\frac{1}{2}$, for then the charge symmetries of the system are identical whether 0, 1, or 2 nucleons are excited, so that $\rho=\rho_1=\rho_2=$ const.

The case $T'=\frac{3}{2}$ remains to be examined. For this purpose let $\sigma^{xy}(T^c)$ be the cross section for production of a compound state of isotopic spin T^c by the collision of incident nucleons x, y. Charge independence requires that $\sigma^{np}(1)=\frac{1}{2}\sigma^{pp}(1)=\sigma^s$, but does not relate $\sigma^a=\sigma^{np}(0)$ to σ^s; of course $\sigma^{pp}(0)=0$. Consider a p-p collision with excitation of both nucleons: the compound state has $T^c=1$, $T_z^c=1$, and the Clebsch-Gordon coefficients for decomposition into two $T'=\frac{3}{2}$ nucleons yield respective fractional weights of $\frac{2}{5}$ and $\frac{3}{5}$ for the combinations $T_z'=(\frac{1}{2},\frac{1}{2})$ and $T_z'=(\frac{3}{2},-\frac{1}{2})$. The fractional weights for decay of the excited state by π^+, π^0, π^- emission are (100), $(\frac{1}{3}\,\frac{2}{3}\,0)$, $(0\,\frac{2}{3}\,\frac{1}{3})$ according as $T_z'=\frac{3}{2},\frac{1}{2},-\frac{1}{2}$. Combining these factors leads to over-all fractional weights for π production of (13/15, 14/15, 3/15). These last are normalized to give a total production of two π mesons.

For a p-p collision with excitation of one nucleon, the compound state decomposes into $T'=\frac{3}{2}$, $T=\frac{1}{2}$ with fractional weights $\frac{1}{4}$ and $\frac{3}{4}$ for T_z', $T_z=(\frac{3}{2},-\frac{1}{2})$ and $(\frac{1}{2},\frac{1}{2})$, respectively. The resultant over-all fractional weights for π production are $(\frac{1}{2},\frac{1}{2},0)$, normalized to a total of one meson. The total cross sections for π production in a p-p collision are then

$$\begin{aligned}(\pi^+)&:\ (1/15)[26\sigma_2^s+15\sigma_1^s],\\(\pi^0)&:\ (1/15)(28\sigma_2^s+15\sigma_1^s],\\(\pi^-)&;\ (1/15)[6\sigma_2^s].\end{aligned}\tag{1}$$

In a similar way the cross sections for meson production in an n-p collision are

$$\begin{aligned}(\pi^+\text{ or }\pi^-)&:\ (1/15)[14\sigma_2^s+(5/2)\sigma_1^s+10\sigma_2^a],\\(\pi^0)&:\ (1/15)[2\sigma_2^s+10\sigma_1^s+10\sigma_2^a].\end{aligned}\tag{2}$$

Combining Eqs. (1) and (2) in the ratio 4 to 5 for a Be^9 nucleus leads to

$$\begin{aligned}(\pi^+)&:\ [1.28\sigma_2^s+0.54\sigma_1^s+0.37\sigma_2^a],\\(\pi^0)&:\ [0.90\sigma_2^s+0.82\sigma_1^s+0.37\sigma_2^a],\\(\pi^-)&:\ [0.70\sigma_2^s+0.09\sigma_1^s+0.37\sigma_2^a].\end{aligned}\tag{3}$$

When $\sigma_1\gg\sigma_2$, $\rho\approx 6$; when $\sigma_2\gg\sigma_1$, $1\lesssim\rho\lesssim 1.8$, depending on the relative magnitudes of σ_2^a and σ_2^s.

Of course these considerations are subject to many qualifications, but in terms of the model employed they indicate that (i) wide variation in ρ implies $T'=\frac{3}{2}$ for the excited nucleon state; (ii) the observed variation of ρ suggests $\sigma_1\gg\sigma_2$ for $E_p=1$ Bev, $\sigma_2\gg\sigma_1$ for $E_p=2.3$ Bev. The variation (ii) is plausible if the $T'=\frac{3}{2}$ state is identified with the "resonance" appearing at about 0.2 Bev in π-nucleon scattering, as has been suggested from energy analysis of the produced mesons.[1] According to (ii) and Eq. (3), the relative π^0 production should also show a marked variation with energy: for low E_p, π^0 production exceeds the total charged π production; for high E_p, π^0 production is intermediate between π^+ and π^-.

The same model can be applied to calculation of various other production ratios. For example, in n-p collisions the ratio of (π^-,π^0) plus (π^-,π^+) production to single π^- production is $(5.6\sigma_2^a+4\sigma_2^a)/\sigma_1^s$. For neutrons in the 1–2 Bev range, this ratio is observed[3] to be of order 5, suggesting that $\sigma_2\sim\sigma_1$ for an average $\bar{E}_n\sim 1.5$ Bev. This is compatible with the conclusions from Be^9+p.

It is tempting to speculate on the existence of a further "excited state" of the nucleon with $T''=5/2$, which would decay to the ground state by emission of two mesons. It could not appear in π-nucleon scattering but would be associated with three- and four-meson production in a nucleon-nucleon collision. If the T'' state has a well-defined energy, the threshold for these processes may be high. We could, for example, compute ρ for a p-p collision involving $T''=5/2$ states. The cross sections concerned are σ_3^s (excitation of one nucleon to $T'=\frac{3}{2}$, the other to $T''=5/2$) and σ_4^s (excitation of both to $T''=5/2$). The meson production cross sections are

$$\begin{aligned}(\pi^+)&:\ (1/50)(78\sigma_3^s+76\sigma_4^s),\\(\pi^0)&:\ (1/50)(39\sigma_3^s+88\sigma_4^s),\\(\pi^-)&:\ (1/50)(33\sigma_3^s+36\sigma_4^s).\end{aligned}\tag{4}$$

Excitation of the $T''=5/2$ state gives a characteristic value $\rho\approx 2$, more or less independent of the ratio σ_3/σ_4. To (4) must of course be added to cross sections (1), which give $\rho>4$. Thus observation of $\rho<4$ would be indication of a $T''=5/2$ state.

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