TABLE I. Mean multiplicities of shower particles, $\bar{m}_0$ and $\bar{m}_1$.

	2–5H $\bar{m}_0$	6–8H $\bar{m}_0$	≥9H $\bar{m}_0$	2–5H $\bar{m}_1$	6–8H $\bar{m}_1$	≥9H $\bar{m}_1$
31°	1.4±0.3	2.4±0.4	4.2±0.3	3.0±0.5	3.4±0.4	5.2±0.4
57°	1.4±0.2	1.7±0.3	2.0±0.3	2.6±0.3	2.7±0.5	3.2±0.4
1 to 8 Bev	1.3±0.3	1.5±0.4	1.5±0.4	2.5±0.4	2.4±0.6	2.7±0.5

For small stars (light nuclei), the mean multiplicities do not vary with the incident proton energy; such an energy-insensitivity would be expected if a single relativistic particle were produced in a nucleon-nucleon encounter. Multiple production is not excluded, but is rare.

Figure 1a and Table I show that the higher proton energies raise the multiplicities of large stars (heavy nuclei). An increase of energy of the incident proton can produce more relativistic particles by cascade within large nuclei, and so, in view of the energy-independence of light-nuclei multiplicities, the latitude effect for heavy nuclei is interpreted as the result of plural collisions. Furthermore, Table I shows that heavy nuclei struck by 1- to 8-Bev (median 2.5 Bev) protons give as high mean multiplicities as do light nuclei struck by protons of energy >8 Bev (median 14 Bev); the same situation is pictured in Fig. 1b. Accordingly, it seems to be inescapable that there is plural production of shower particles in heavy nuclei.[6]

The 1- to 8-Bev protons give the same multiplicity for all star sizes, which implies that they produce their maximum number of shower particles in a 12 to 16 nucleon system.

Sands estimates that six charged mesons are created in the atmosphere for every primary proton;[7] $\bar{m}_0$ for emulsion nuclei C, N, O is 1.4 (which includes outgoing relativistic protons), making it difficult to account for the six mesons. In these light nuclei, half of the p-stars are $0p$; the energy balance requires that neutral radiation (fast neutrons or other particles or both) be produced. It is, perhaps, not impossible that enough neutral mesons are created by energetic protons to supply, by decay, the required charged mesons.

A full report of these and other observations will appear later.

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On High Energy Nucleon-Nucleon Scattering*

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THE recent Berkeley experiments on high energy nucleon-nucleon scattering would seem at first sight to indicate a sizable difference between the $n-p$ and $p-p$ interactions, in contrast to the charge independence found at low energies. Thus the 350 Mev $p-p$ cross section is, at 90°, from 2 to 4 times larger than the corresponding quantity for $n-p$ scattering at 260 Mev. Also at 350 Mev $\sigma_{p-p}(\theta)$ is rather isotropic from 90° down to about 20° in contrast with the 260 Mev $n-p$ data over the same angular region.

It is the aim of this note to point out that, nonetheless, it seems at least qualitatively possible to obtain a charge-independent phenomenological theory. This can be achieved by introducing the simplest kind of velocity dependent force, *viz.* a spin-orbit interaction of the type familiar from atomic phenomena:

$$V(r)\mathbf{L}\cdot(\boldsymbol{\sigma}^1+\boldsymbol{\sigma}^2). \tag{1}$$

This coupling, superposed on an interaction of the kind proposed by Christian and Hart in their analysis of the $n-p$ data, gives a fair account of the $p-p$ experiments. Considering first the 30 Mev $p-p$ scattering, the interaction (1) gives a ^3P-state contribution at such an intermediate energy

$$\sigma(\theta)\sim(18/k^2)\eta^2\sin^2\theta \tag{2}$$

where η is the $^3P_2$ phase. Therefore the principal puzzling feature of $\sigma(\theta)$ at this energy, *viz.* its rise (after a rapid decrease away from small angles due to the Coulomb force) to a rather flat maximum around 90°, can be interpreted as a spin-orbit effect. For this purpose it suffices that $\sigma(90°)$ as given by (2) is $\sim$2 mb, corresponding to $\eta\sim3.7°$.

To see the main features of this coupling at still higher energies one can examine its effects in the Born approximation. It is readily seen that the cross section due to (1) is proportional to $\sin^2\theta$, thus favoring large angle scattering. The LS-contribution to the $n-p$ cross section at 90° is only one-fourth of that for $p-p$ scattering. (Indeed, by an appropriate choice of the exchange dependence of (1) it is possible to have this ratio hold for all angles.) The effect on $n-p$ scattering thus is rather small. Somewhat more detailed considerations actually show that, with the dearth of experimental data, it is hardly possible to draw any quantitative conclusions about spin-orbit coupling from the available high energy $n-p$ experiments.

Also for low energies the LS-term has little effect on the $n-p$ system. In particular it vanishes in S-states. From considerations on bound neutron proton states the sign of the spin-orbit interaction is determined to be such that states of highest total angular momentum lie lowest.

The main characteristics of the spatial dependence of the LS-coupling are rather closely determined by the $p-p$ experiments. The high 90° cross section at 350 Mev ($\sim$4 mb) shows that large momentum transfers are involved. Hence the potential must be quite singular at small distances. The flatness of the cross section at 350 Mev requires that the potential have a relatively small tail

It seems possible to fit all $p-p$ data with various radial forms of the potential. The form yielding the most reasonable values for the parameters is

$$V=V_0\frac{1}{x}\frac{d}{dx}\frac{e^{-x}}{x},\quad x=r/r_0. \tag{3}$$

In this case rough estimates indicate that $V_0\sim12$ Mev, $r_0\sim1$, 1×10^{-13} cm, are adequate. It should be noted that the r^{-3} singularity need not be taken too seriously since regions smaller than the nucleon Compton wave-length are not explored by particles of the energies considered thus far. The form (3) is also suggestive in that derivations of spin-orbit couplings from field theory, or as a Thomas term, usually yield this type of radial dependence.

If an interaction (1) with a radial dependence (3) is used to explain the $p-p$ data, a further conclusion about $p-p$ scattering can be deduced. This is that $\sigma_{p-p}(90°)$ should be approximately constant for energies greater than about 150 Mev up to energies (not much larger than 350 Mev) where relativistic effects start to play a preponderant role. Here the r^{-3} dependence of (3) up to small distances is decisive. This conclusion is probably also valid for any alternative interpretation using such singular potentials.

Summarizing, it would seem possible to give a charge independent description of nuclear force, in that the $p-p$ experiments can all be accounted for on the basis of an interaction involving (1), while previous interpretations of $n-p$ scattering are not drastically modified.

We note finally a possible connection with the spin orbit interaction postulated by Mrs. Mayer in her interpretation of the shell model of heavy nuclei. In fact, simple estimates indicate that a two-body spin-orbit interaction of the above type may lead to intramultiplet energy differences of the order of a Mev.

A fuller account of this work is in preparation.

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