Letters to the Editor

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On Charge Independence and High Energy Scattering*

ROBERT JASTROW
Institute for Advanced Study, Princeton, New Jersey
May 15, 1950

THE Berkeley experiments on $p-p$ scattering at 345 Mev indicate a roughly isotropic cross section between 20° and 90° with a mean magnitude of approximately 4 millibarns/steradian. This is in strong contrast with the results to be expected from a central attractive potential determined by the low energy scattering,[1] from which one obtains at 345 Mev a cross section which arises from 0.2 mb at 90°, to 12 mb at 0°. A qualitative difference is also to be noted between the $p-p$ scattering and the strongly anisotropic high energy $n-p$ scattering.[2]

We wish to show that a charge-independent static[3] potential is not excluded by these results. We assume for this purpose an interaction consisting of a strong short-range repulsion surrounded by an attractive well.[4] The combination is fitted to the low energy scattering. The attractive field is perhaps to be associated with the π-meson and the short-range repulsive field with a heavier particle.

Considering first $p-p$ scattering at high energies, the repulsive core has the following effect: at energies comparable with or greater than the depth of the surrounding well the effect of the core will dominate in the S state and the sign of the ^1S phase shift will change in this energy region from positive to negative. The D state will, at energies of a few hundred Mev, still be affected only by the outer or attractive region of the potential and the D phase shift will be positive. The difference in sign between the ^1S and ^1D phases causes the $S-D$ interference term in the differential cross section to be positive at 90° and negative at 0°, thereby reducing the anisotropy obtained without the core.

The following potential is used, in which for convenience of calculation the core is represented by a hard sphere and the attraction by an exponential well:

$$V=\infty,\ r<a,$$
$$V=V_0[(\alpha+\beta\sigma_1\cdot\sigma_2)\exp[-(r-a)/R]+\gamma S_{12}\exp(-r/R_{\text{tensor}})];\quad r>a \quad (1)$$
$$a=0.6\times10^{-13}\text{ cm},\quad R=0.4\times10^{-13}\text{ cm},\quad R_{\text{tensor}}=1.0\times10^{-13}\text{ cm},$$
$$V_0=100\text{ Mev},\quad \alpha=2.18,\quad \beta=-0.52,\quad \gamma=0.65.$$

The strength of the tensor forces in (1) is of the order of that required by the deuteron constants. The scattering at 345 Mev is computed exactly for the central forces and in Born approximation for the tensor forces, neglecting central-tensor interference. The resultant cross section is shown in curve C of Fig. 1, as well as the cross sections computed under the same conditions at 32 and 250 Mev (curves A and B). In curve C the scattering at 20° is 75 percent greater than the mean magnitude of the cross section between 30° and 90°, in contradiction with the experimental distribution. By using a more complicated potential the forward scattering may be substantially reduced. However, in view of the neglect of possible non-static forces an emphasis on precision of fit is perhaps unwarranted in comparison with the importance of simplicity in the interaction.

In treating the $n-p$ scattering we assume that in the charge-antisymmetric states (^3S, ^1P, ^3D, ^1F, $\cdots$) one has the interaction of Christian and Hart.[2] These states do not enter into the $p-p$ scattering, which is, therefore, unchanged by this assumption. In this way we can estimate the contribution from triplet states of even L by using the results of Christian and Hart. The singlet contribution is one-fourth of the corresponding $p-p$ cross section as given in Fig. 1. The result is: $\sigma_{np}(90°)=0.8$ mb; $\sigma_{np}(180°)=9.7$ mb. The effect of the core does not destroy the anisotropy of the $n-p$ cross section.

It is seen thus that the introduction of a short-range repulsive force permits one to reconcile the qualitative aspects of the $n-p$ and $p-p$ scattering results with the preservation of charge independence. The arbitrary nature of the particular form of interaction employed should, however, be emphasized, as well as the fact that this result may be obtained from other types of interactions.

The influence of the core on nuclear saturation may be expected to be appreciable because of the zero-point energy arising from the exclusion of each nucleon from the interiors of the other nucleons in a nucleus. This problem is under investigation.

A more detailed account of the work is in preparation.

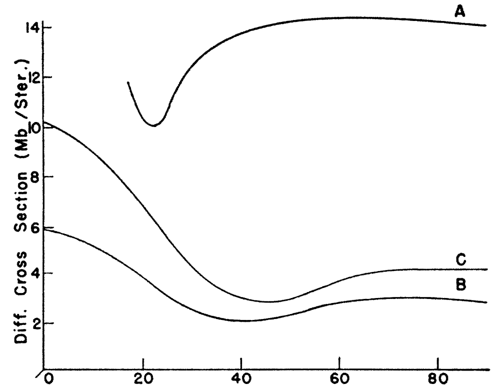

FIG. 1. $P-P$ scattering calculated from the potential (1) at A: 32 Mev; B: 250 Mev; C: 345 Mev. Curve A includes the effect of the Coulomb field, while curves B and C refer to nuclear scattering only.

* This research was supported by an AEC grant to the Institute for Advanced Study.

[1] R. S. Christian and H. P. Noyes, Phys. Rev. **79**, 85 (1950).
[2] R. S. Christian and E. W. Hart, Phys. Rev. **77**, 441 (1950).
[3] A simple velocity dependence, the spin-orbit interaction, has been investigated by K. M. Case and A. Pais, Phys. Rev. **79**, 185 (1950), who conclude that it may be possible by means of this interaction to represent the $n-p$ and $p-p$ scattering qualitatively on a charge-independent basis. See also Blanchard, Avery, and Sachs, Phys. Rev. **78**, 292 (1950).
[4] A similar type of interaction has been considered by N. M. Kroll in connection with $p-p$ scattering, and we are indebted to him for interesting and useful criticism. P. O. Olsson has examined the possibility of introducing a repulsion into the $n-p$ potential, as have also G. Parzen and L. Schiff, Phys. Rev. **74**, 1564 (1948).

Gamma-Ray Measurements with NaI(Tl) Crystals*

R. HOFSTADTER AND J. A. MCINTYRE
Palmer Physical Laboratory, Princeton University, Princeton, New Jersey
May 29, 1950

IT has recently been shown[1] by an example with Co^{60} gamma-rays that relatively sharp lines appear in the pulse-height distributions of NaI(Tl) scintillations. These lines, giving directly the full finergy of the gamma-rays, have been interpreted in terms of a photoelectric component (in iodine of NaI) as well as a component arising from capture of all scattered and recoil products of the original gamma-ray in the NaI(Tl) crystal. This method can be used to measure gamma-ray energies (as well as intensities) and proves to be sensitive since the energies are given by sharp