Proton-Proton Scattering and the Triplet Range of Nuclear Force

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It is well known that the interaction between two protons, and that between a neutron and a proton, depends on whether the spins are parallel (triplet interaction) or anti-parallel (singlet interaction), giving four separate interactions between the fundamental nuclear particles. In the scattering of high energy nucleons, a non-central component of force becomes important, but if consideration is restricted to the analysis of scattering experiments below about 10 Mev, its effect is not appreciable,[1] and furthermore the calculated results are insensitive to the shape of the interaction potential,[2] so that one may use a rectangular potential well.

Considering first the singlet interaction, the *s* wave scattering of protons in hydrogen leads fairly conclusively to a singlet *p*-*p* well width of about 2.8×10^{-13} cm, and depth 10.5 Mev. It is then found that a singlet interaction of the same range for the *n*-*p* case is compatible with the binding energy of the virtual state of the deuteron, as found from low energy *n*-*p* scattering data. This is in accordance with the idea of charge independence of the forces between nucleons.

For the triplet interaction, the scattering of sub-thermal neutrons by ortho- and para-hydrogen[3] and by NaH[4] gives a range of about 1.6×10^{-13} cm for the *n*-*p* interaction; and the corresponding well depth is found from the known binding energy of the deuteron. Information on the *p*-*p* triplet interaction may be obtained by analysis of R. R. Wilson's experiments[5] on *p*-*p* scattering at 10 Mev, at which energy *p* wave scattering first becomes important. One first deduces the *p* wave scattering phase K_1 required to fit the experimental angular distribution, but two widely divergent values have previously been quoted, *viz.* $-0.8°$ by Peierls and Preston,[6] and $-0.4°$ by Foldy.[7] The present calculations lead to the value $K_1=(-0.4\pm 0.1)°$ in good agreement with Foldy. We now see whether charge independence of forces can be preserved for the triplet interaction. A relation may be obtained between the depth and width of the *n*-*p* triplet well by utilizing the known binding energy of the deuteron, and the curve showing this relation is plotted in Fig. 2 (curve a). To obtain a similar curve, (b), for the *p*-*p* triplet well dimensions corresponding to $K_1=-0.4°$, it is first necessary to graph K_1 as a function of well depth for a number of well widths (Fig. 1). Associated values of range and depth of the repulsive potential, yielding the required value of K_1 may then be read off the graph. A correction must here be made to the well depth, for in calculating the values of K_1, the Coulomb interaction was ignored inside the well. To allow for this, an amount $\delta D=1.14$ Mev (cm) calculated at 10 Mev (lab.) from the approximate formula $\delta D=\psi^* V\psi d\tau/\psi^*\psi d\tau$, was added to the *p*-*p* repulsive potential. This corrected curve (b) is shown in Fig. 2.

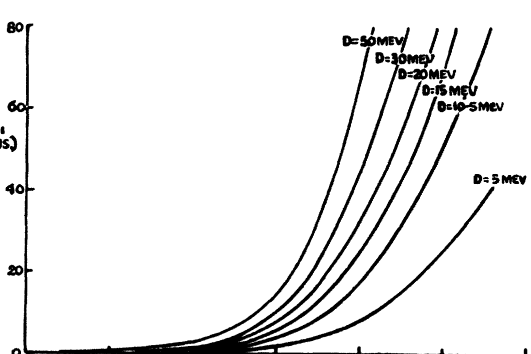

FIG. 1. Variation of phase shift K_1 as a function of well range for various well potentials, for the scattering of protons by protons.

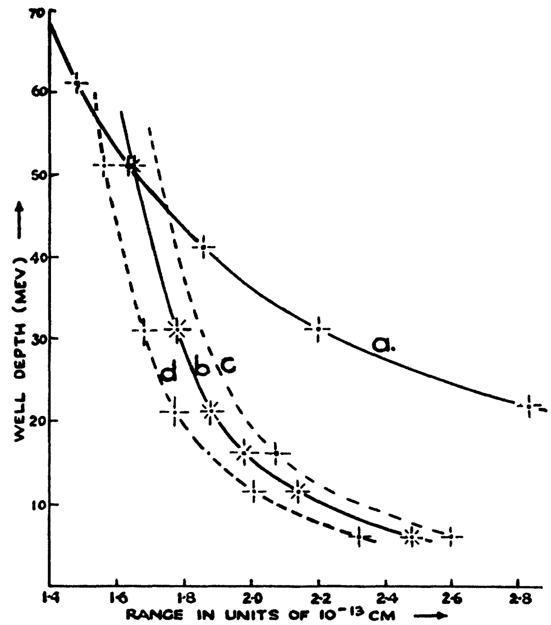

FIG. 2. Relation between well depth and range for the neutron proton interaction, as deduced from: (a) The binding energy of the deuteron; (b) the *p* wave scattering of protons by protons, taking $K_1=-0.4°$; (c) and (d) taking $K_1=-0.5°$ and $-0.3°$ respectively, and assuming charge independence of the nuclear interaction.

The intersection of curves (a) and (b) in Fig. 2 gives a unique value for a common range of the *n*-*p* and *p*-*p* triplet interactions satisfying both the experimental *p*-*p* scattering and the deuteron binding energy. This range is seen to be $1.65(\pm 0.10)\times 10^{-13}$ cm, a value almost identical with that given by the experiments on the scattering of neutrons by ortho- and para-hydrogen and by NaH. The corresponding triplet potential for the *n*-*p* interaction is 50.6 Mev, and for the *p*-*p* interaction 49.5 Mev.

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Upper Limit of Spin-Spin Interaction Factor

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We applied the method of nuclear induction[1] to determine the gyromagnetic ratio of protons in water, at a fixed frequency, first in an iron-cored electro-magnet (field *X*), then in air-cored Helmholtz coils (field *Y*). The frequency used was 3 Mc, the resonance field being then about 750 gauss.

Using the flip-coil method, we were not able to detect any difference between the resonance fields *X* and *Y*. The error was in this case smaller than one percent. This sets a superior limit for the spin-spin interaction factor introduced by Stueckelberg.[2]

It is possible to attain a higher accuracy by determining the ratio $\mu_0 F^{19}/\mu_1 H^1$ of the nuclear moments for fluorine and hydrogen nuclei successively in fields *X* and *Y*. By using this method, we found the same ratio 0.9416 to three significant figures, confirming the previous negative result.

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