The Scattering of Neutrons by Ortho- and Parahydrogen

The observed binding energy of the deuteron yields information concerning the interaction of neutrons and protons with parallel spins, but permits nothing to be deduced about the neutron-proton interaction with antiparallel spins. It has been pointed out by Wigner[1] that the large slow neutron scattering by free protons provides evidence for an antiparallel spin interaction between neutrons and protons which is weaker than the interaction with parallel spins. The numerical value of the slow neutron cross section,[2] $\sigma=13\times10^{-24}$ cm^2, can be explained by either a stable or a virtual singlet state about 2 Mev higher than the ground state of the deuteron. It is the purpose of this note to indicate that experiments on the scattering of neutrons by ortho- and parahydrogen would enable one to determine the sign of the singlet state energy and the range of the neutron-proton interaction, in addition to providing direct information concerning the spin dependence of the neutron-proton interaction.

A dependence of the neutron-proton interaction upon the relative spin orientation of the particles will manifest itself in a marked difference between the slow neutron scattering cross sections of orthohydrogen (parallel proton spins) and parahydrogen (antiparallel proton spins). Neutrons with energy less than 0.068 ev, incident upon para-H_2 in its ground state ($J=0$, $v=0$, $S=0$), may be either elastically scattered, or inelastically scattered with excitation of the molecule to the ground state of the ortho-system ($J=1$, $v=0$, $S=1$). This latter process, requiring 0.023 ev, occurs only if the neutron-proton interaction is spin dependent. Provided the neutron energy is less than 0.045 ev, the cross section for the scattering of neutrons by ortho-H_2 in its ground state will be the sum of the elastic scattering cross section and the cross section for the inelastic process in which the molecule is converted to a para-H_2 molecule in its ground state, with the neutron taking up the excess energy.

Accepting Wigner's explanation of the large slow neutron scattering by free protons, the cross sections of these four processes have been calculated with the assumption of an interaction range of 2×10^{-13} cm and a virtual singlet state of the deuteron.[3] For liquid-air temperature neutrons ($3kT/2=0.012$ ev) $\sigma_{\text{para}}(0.012)=0.21\times10^{-24}$ cm^2, while $\sigma_{\text{ortho}}(0.012)=65\times10^{-24}$ cm^2. The cross sections for neutrons at ordinary temperatures ($3kT/2=0.037$ ev), however, are $\sigma_{\text{para}}(0.037)=19\times10^{-24}$ cm^2 and $\sigma_{\text{ortho}}(0.037)=50\times10^{-24}$ cm^2. Therefore, if the present concept of the neutron-proton interaction is valid, one would expect the following results: (a) The orthoscattering cross section for liquid-air neutrons should be about 300 times the corresponding parascattering cross section. (b) The parascattering cross section for ordinary thermal neutrons should be roughly 100 times the parascattering cross section for liquid-air neutrons. For a real singlet state, however, these ratios are of the order of one.

The elastic parascattering cross section is quite sensitive to the value of the range of interaction if the singlet state is virtual. For example, the paraelastic scattering cross section at liquid-air neutron temperatures with zero range of interaction is 1.75×10^{-24} cm^2, as compared with 0.26×10^{-24} cm^2 for an interaction range of 2×10^{-13} cm. Hence, from a measurement of the paraelastic scattering cross section for homogeneous neutrons at some energy less than 0.023 ev, the range of interaction may be inferred with some degree of accuracy.

A more detailed discussion will be published shortly in the *Physical Review*.

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April 13, 1937.

[1] H. A. Bethe and R. F. Bacher, Rev. Mod. Phys. **8**, 82 (1936).
[2] E. Amaldi and E. Fermi, Phys. Rev. **50**, 899 (1936).
[3] Experiments on the magnetic capture of neutrons by protons seem to indicate the existence of a virtual singlet state of the deuteron. Cf. reference 2.

Proton-Induced Radioactivity in Heavy Nuclei

The elements $_{14}$Si, $_{20}$Ca, $_{24}$Cr, $_{25}$Mn, $_{27}$Co, $_{28}$Ni, $_{30}$Zn, $_{33}$As, $_{34}$Se, $_{42}$Mo, $_{48}$Cd, $_{49}$In, $_{50}$Sn and $_{51}$Sb become radioactive under the bombardment of protons of about 3.6, Mev from the cyclotron. $_{12}$Mg, $_{13}$Al, $_{16}$S, $_{17}$Cl, $_{26}$Fe, $_{29}$Cu, $_{47}$Ag, $_{78}$Pt and $_{82}$Pb appear to show no signs of radioactivity under the same conditions. The relative activities of the first group as measured with an ionization chamber after a 15-minute bombardment with a beam of 1 microampere are as follows: 6, 21, 5, 27, 6, 21, 40, 13, 2000, 10, 20, 3, 2, 1.

Practically none of these radioactivities have been previously reported. Mn, Co and As are of particular interest because they cannot form radioactive nuclei by the usual proton capture reaction or by the proton capture alpha-particle emission reaction. Presumably the reaction here is proton capture with either deuteron or neutron emission. For Mn this unusual type of reaction has been shown to take place by a chemical separation which proved that the active substance was an isotope of Mn. The following reaction is therefore considered to be the one taking place:

$$_{25}Mn^{55}+{}_1H^1\rightarrow{}_{25}Mn^{54}+{}_1H^2.$$

The chemical separation with Se showed active material in the As precipitate, thus indicating one of the usual types of reaction:

$$_{34}Se+{}_1H^1\rightarrow{}_{33}As+{}_2He^4.$$

Further chemical separations are being made.

The Se period (approximately 17 min.) is of the same order as the short periods in the above elements. Excluding the possibility of a large contribution from accompanying gamma-rays, the high relative activity in Se indicates a large cross section for the proton reaction. A study of the yield as a function of the proton energy showed a very slow rise from 2.2 Mev to 3.1 Mev, at which energy the yield rises almost vertically.

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