The Interaction of Slow Neutrons with Gases

The slow neutron-proton interaction has heretofore been investigated through the use of solid or liquid hydrogenous materials in which the proton binding within the molecular structure has been important in determining the effective cross section values.[1–6] Theoretical calculations by Fermi,[7] Bethe,[8] Arley[9] and others have shown that, with the Born approximation, the cross section for zero energy neutrons should be proportional to the square of the reduced mass of the system, and the cross section dependence on energy level spacing and neutron energy for thermal neutrons has been indicated. The detailed calculations of Schwinger and Teller[10] on the scattering by *ortho-* and *para-* H_2 have shown the manner in which the spin dependence, the nature of the energy level system, and the range of the neutron-proton interaction enter into the problem.

As a further step in this development, an investigation has been made of the variation in cross section of a series of hydrogenous substances containing increasing numbers of protons—hydrogen (H_2), methane (CH_4), ethane (C_2H_6), propane (C_3H_8), butane (C_4H_{10}), and paraffin ($\sim C_{22}H_{46}$). Since the design of the apparatus lends itself well to the measurement of other gases, the cross sections of He, Ne, and A have been measured, and in addition, the values for N_2 and O_2 have been re-determined by this direct method.

The experimental arrangement utilized two duplicate steel cylinders 30 cm in length, fitted with duraluminum end caps designed to withstand ~3000 lb./in.² pressure. One cylinder was connected to a gas introduction apparatus, and the gas pressures measured either by a two-meter mercury manometer, or by calibrated Bourdon gauges. The other cylinder was evacuated and used as a calibrated comparison "dummy," in order to correct for the absorption by the cell itself. Alternate runs were taken with the gas cylinder and dummy cylinder interposed in the beam. The neutron beam (about 1 meter long) was accurately defined by shields and diaphragms of both boron carbide and cadmium. The cylinders were lined with Cd to prevent detection of scattered neutrons. The results are summarized in Tables I and II.

The increase in cross section per proton from liquid H_2 to H_2 gas is probably due to the additional transitions arising from the appreciable population of higher levels above $J=0$ and $J=1$ in the case of the gaseous H_2 at room temperature. It is interesting to note that in the series from methane to paraffin, the variations in cross section are quite closely proportional to the square of the reduced mass, even if considerations of energy level spacing are neglected.

TABLE I. *Interaction of ~300°K neutrons with bound protons.*

Substance	State	Cross Section per Proton ($\times 10^{-24}$ cm²)*
Hydrogen (H_2) normal	liquid	24.0[11]
Hydrogen (H_2)	gas	32.0
Methane (CH_4)	gas	45.5
Ethane (C_2H_6)	gas	46.6
Propane (C_3H_8)	gas	47.1
Butane (C_4H_{10})	gas	50.0
Paraffin ($\sim C_{22}H_{46}$)	solid	50.7

* Weighted averages obtained from a series of measurements at several different pressures. The probable errors are approximately ±1.5 percent.

TABLE II. *Interaction of slow neutrons with the nuclei of gases.*

Substance	State	Cross Section per Nucleus ($\times 10^{-24}$ cm²)
Helium	Gas	1.51
Neon	Gas	2.94
Argon	Gas	2.51
Nitrogen	Gas	12.0
Nitrogen	Liquid	12.8[11]
Oxygen	Gas	4.1
Oxygen	Liquid	4.05

The 300°K neutron-proton cross section for paraffin has been increased over previous values to 50.7×10^{-24} cm². This cross section has been shown to increase[4] by a factor of 1.31 for ~120°K neutrons, corresponding to $\theta = 65.9 \times 10^{-24}$ cm². Since the zero-energy neutron-proton cross section should be four times larger than that for the free proton (for such a large molecule), the free proton-neutron cross section must therefore be revised upwards to a minimum of about 16.5×10^{-24} cm². The energy of the virtual singlet level of the deuteron must thus be correspondingly reduced, and the various theoretical calculations based on this value readjusted.

All the rare gases measured have very small cross sections. The cooperation of Dr. F. R. Balcar and the Air Reduction Company is much appreciated.

Henry Carroll
J. R. Dunning

Columbia University,
New York, N. Y.,
September 1, 1938.

1 Dunning, Pegram, Fink and Mitchell, Phys. Rev. **48**, 277 (1935).
2 Amaldi and Fermi, Phys. Rev. **50**, 899 (1936).
3 Fink, Phys. Rev. **50**, 738 (1936).
4 Powers, Goldsmith, Beyer and Dunning, Phys. Rev. **53**, 947 (1938).
5 Goldhaber and Briggs, Proc. Roy. Soc. **162**, 127 (1937).
6 Frisch, von Halban and Koch, Kgl. Danske Vidensk. Selsk. Mat.-fys. Med. **XV**, No. 10 (1938).
7 Fermi, Ric. Scient. **8**, II, 13 (1936).
8 Bethe, Rev. Mod. Phys. **9**, 124 (1937).
9 Arley, Kgl. Danske Vidensk. Selsk. Mat.-fys, Med. **XVI**, 1 (1938).
10 Schwinger and Teller, Phys. Rev. **52**, 286 (1937).
11 Dunning, Manley, Hoge and Brickwedde, Phys. Rev. **52**, 1076 (1937); Brickwedde, Dunning, Hoge and Manley, Phys. Rev. **54**, 266 (1938); Comparison values from this paper are indicated.

Wave-Length of the New Nitrogen Line

The new nitrogen line $^4S-^2P$, which was recently reported by me with a tentative wave-length of 3471A, has been observed with an instrument of higher dispersion than the one used in its discovery and with a narrower slit. A neon comparison spectrum was used and there is now no question as to an upper limit for the wave-length of the line since it lies a fraction of an angstrom unit on the short wave-length side of the strong neon line at 3466.578. A series of measurements indicates an average wave-length of 3466.3. A new series of exposures with narrower slit and larger dispersion will soon be made and a better wave-length obtained.

Joseph Kaplan

University of California at Los Angeles,
Los Angeles, California,
September 14, 1938.