

to measure the scattering of the carbon neutrons as nearly as possible under the same conditions as for his measurement of the scattering of the photo-neutrons (Th C'') from deuterium. The insertion of a paraffin scatterer 1.0 cm thick gave a diminution of the neutron intensity to  $0.68 \pm 0.05$  and  $0.59 \pm 0.05$  in two separate runs, an average of  $0.64 \pm 0.04$ . A one-half mm Cd shield was interposed between the scatterer and the Pf-B detector during these runs; measurements without the Cd shield gave no significant change ( $0.68 \pm 0.05$ ). Surrounding the carbon target by paraffin to crudely duplicate the effect of Goldhaber's heavy-water photo-neutron source gave a ratio in agreement with the above average within the experimental error. The value  $I/I_0 = 0.64$ , without correcting for the appreciable scattering by the carbon in the paraffin, leads to a cross section of  $5.7 \times 10^{-24}$  cm<sup>2</sup>; estimating the carbon correction, the resulting proton-neutron cross section is  $4.7 \times 10^{-24}$  cm<sup>2</sup>.

The carbon neutrons produced by a 900-kv beam of deuterons have an energy between 600 kv<sup>2</sup> and 1200 kv.<sup>3</sup> If the deuteron level is taken as  $\pm 40$  kv, Wigner's formula<sup>4</sup> predicts 5.4, 4.1, and  $3.4 \times 10^{-24}$  cm<sup>2</sup>, respectively, for neutron energies of 600, 900, and 1200 kv. If the deuteron level is  $\pm 130$  kv, the values are 4.6, 3.7, and  $3.2 \times 10^{-24}$  cm<sup>2</sup>, respectively.

Rasetti and others pointed out in discussion that these measurements with the paraffin-boron chamber would yield an erroneous cross section if a hitherto unsuspected group of slower neutrons (10 to 20 kv) accompanies the usual carbon neutrons. To eliminate this possibility we have recently made similar measurements (with rather different geometry) using as the detector a small ionization chamber filled with hydrogen to a pressure of three atmospheres and connected with the linear amplifier. This responds only to recoil protons of energies above roughly 300 kv and eliminates any effects due to slow neutrons. A 1.0-cm Pf-scatterer gave a reduction of intensity to  $0.69 \pm 0.03$ , in satisfactory agreement with the earlier measurements. To correct for scattering by the carbon in the paraffin the reduction in intensity produced by a 0.50-cm scatterer of Acheson graphite was measured using the hydrogen-pressure chamber; this result was  $0.85 \pm 0.05$ . Correcting the paraffin-intensity ratios for the carbon scattering, the cross section for the neutron-proton scattering is  $3.7 \times 10^{-24}$  cm<sup>2</sup>.

These two series of measurements may thus be taken as additional evidence for the correctness of current views regarding the proton-neutron interaction.

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<sup>1</sup> M. Goldhaber, Nature **137**, 824 (1936).

<sup>2</sup> T. W. Bonner, L. A. Delsasso, W. A. Fowler and C. C. Lauritsen, Phys. Rev. **49**, 203 (1936).

<sup>3</sup> M. A. Tuve and L. R. Hafstad, Phys. Rev. **48**, 106 (1935).

<sup>4</sup> H. A. Bethe and R. F. Bacher, Rev. Mod. Phys. **8**, 82 (1936), see page 117.

### The Separation of Isotopes by Centrifuging

Although the separation of isotopes by centrifuging has generally been abandoned as impractical,<sup>1, 2, 3, 4</sup> the development of our new air-driven centrifuge<sup>5</sup> has encouraged us to examine again the feasibility of the method. We first developed a gas<sup>6</sup> or vapor centrifuge in which the gas enters through holes in the periphery and is pumped out at the center of the rotor through a tube which is used both to drive and support the rotor. Two general types of rotors are in use. In the first, which has a horizontal circular cross section, the gas enters the rotor through a channel along the radius. In the second type, which has a triangular cross section, the gas enters the rotor through openings so directed that only those molecules with speeds greater than the peripheral speed can enter. Since in most cases the peripheral speed of the rotor is in excess of the average molecular speed, a "velocity separation" as well as a separation by centrifuging occurs.

In order to check the relative efficiency of the two types of rotors, experiments were carried out upon the separation of a mixture of N<sub>2</sub> and CO<sub>2</sub> at room temperature. Briefly, the results obtained with both rotors were in fair agreement with the simple theory.<sup>1</sup> The rate with which the gas can be centrifuged of course depends upon the design and speed of the rotor, the temperature, viscosity, density of the gas, etc. In our experiments, as high as 1 cc N. T. P. was collected every five minutes, but this probably can be increased by a new rotor design. Since the above results show that the simple theory should serve as a rough guide to the separation, the values in Table I computed for the case of an ideal gas from the formula  $K_0/K = e^{(V^2/2RT)(M_2-M_1)}$  may be of interest. The peripheral velocity ( $V = 8 \times 10^4$  cm/sec.) used in the computation was the bursting speed of our best rotor.  $K_0$  = ratio of quantities of light to heavy isotopes at the center;  $K$  = ratio of the same quantities at the periphery;  $T$  = absolute temperature;  $M_1$  = molecular weight of lighter, and  $M_2$  = molecular weight of the heavier isotopes. If the rotors could be made stronger,  $V$  and hence the separation, could be much increased as the driving turbine reaches less than half speed when our rotors explode. Although at  $T = 20^\circ$  most substances have too low a vapor pressure for gas centrifuging, many can be centrifuged at  $80^\circ$ . For this reason we have developed a rotor that will spin at liquid-air temperatures or even lower. The dependence of the separation factor on  $M_2 - M_1$  rather than their absolute values gives the centrifuge method a decided advantage over those methods which do depend upon the absolute values in the case of heavier elements. The naturally lower rate of centrifuging for heavier elements can be partly counterbalanced by improved design. The "velocity

TABLE I.

$M_2 - M_1$	$K_0/K$			
	$T = 300^\circ$	$T = 200^\circ$	$T = 80^\circ$	$T = 20^\circ$
1	1.13	1.21	1.62	6.8
2	1.29	1.47	2.61	47
3	1.47	1.78	4.23	300
4	1.67	2.16	6.9	2000

separation" increases the tabulated separation factors. For example, for neon at 300° it alone is 1.35. However, this may become a disadvantage in some cases, for it decreases the supply of gas.

We have also tried out a modification of a method first suggested by Professor Mulliken<sup>2</sup> on the separation of CCl<sub>4</sub>. The liquid was placed inside a hollow vacuum tight rotor which was spun in an evacuated chamber. The CCl<sub>4</sub> evaporated near the periphery of the rotor and the vapor passed out at the center through the "driving" tube. The lighter fractions distill off first, leaving the heavier ones in the rotor. We obtained a decided change in the density of CCl<sub>4</sub> in the two fractions, but a mass-spectrographic analysis should be made before the theory can be definitely

tested. Although the rotors burst at lower speeds with this method, the separation is quite fast, and comparatively large quantities can be centrifuged.

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