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§2. Estimation of the Scattering Cross Section

In order to estimate the scattering cross section without solving the complicated integral equation, it is needed to choose the auxiliary potentials $U_\pm(r)$ ~~or $U(r)$~~ in (9) and (10) such that $\Psi_\pm(r,\theta)$ becomes already an approximate expressions for the required functions $\varphi_\pm(\vec{r},\theta)$. If we consider the deuteron as a sphere of diameter $\frac{1}{\alpha}=\frac{\hbar}{\sqrt{ME_D}}=4.36\times10^{-13}$ cm, and the nuclear force to have a definite range $a=2.32\times10^{-13}$ cm, the interaction between the neutron and the deuteron can be represented roughly by a potential ~~sti~~ hole with the radius b, which ~~will~~ may take a certain value between $\frac{1}{2\alpha}=2.18\times10^{-13}$ cm and $\frac{1}{2\alpha}+a$, ~~i.e.~~ Thus $=4.5\times10^{-13}$ cm

$$U_\pm(r)=U_\pm=\text{const.}\quad\text{or}\quad 0$$

according as $r<b$ or $r>b$.

A legitimate value for U_+ can be obtained by assuming that $(10)_+$ has a solution ~~sol~~ with the energy

$$E'=-E_T=-8.3\times10^6\,eV$$

corresponding to the normal state of ^3H. This method was ~~already~~ used previously by Massey and Mohr[(1)]. Thus we find ~~As, for example,~~

$$-U_+=13.8\times10^6\,eV\qquad\text{for the extreme case } b=4.5\times10^{-13}\text{ cm}$$

and

$$=32.5\times10^6\,eV\qquad\text{for the other extreme case}$$

(1) Massey and Mohr, Proc. Roy. Soc. A. 148, 206, 1935.

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We have calculated further the cross section for several values of ~~either of set of~~ these set of the neutron energy, the result being shown in Fig. 1. ~~With these values of b and U_+~~ The ~~dealdnce~~ of σ_+ on the neutron ~~energy~~ ~~of them~~ is shown ~~or can be~~

$b = 2.18 \times 10^{-13}$ cm.

The cross section of the deuteron initially at rest for ~~the~~ slow neutrons becomes

$$\sigma_+ = 2.7 \times 10^{-24}\ \mathrm{cm}^2$$

for $b = 4.5 \times 10^{-13}$ cm and

$$= 1.46 \times 10^{-24}\ \mathrm{cm}^2$$

for $b = 2.18 \times 10^{-13}$ cm. ~~For larger~~ In the former case ~~case~~ the cross section σ_+ reaches to a large maximum and then decreases as the neutron energy increases, ~~changes~~ first ~~in a complicated manner~~ owing to on account of the effect ~~The presence~~ of the virtual P- ~~and S-~~ levels, while in the latter case it decreases steadily ~~as the energy~~ with the energy, ~~as shown in the~~ Fig. 1. ~~This is~~

On the other hand, U_- can not be determined in like ~~similar~~ manner ~~as U_+~~, as little is known of the excited states of ^3H, and we can say only that this ~~it~~ is much smaller ~~than in magnitude~~ than $|U_+|$ and may even be negative. Thus the cross section σ_- in this case can ~~not~~ be determined ~~with~~ only by making use of ~~the~~ further experimental information as follows. Namely, ~~according~~ ~~Now~~, the observed cross section of the deuteron, ~~which should is~~ ~~should is to~~ ~~corresponds to~~ ~~the average~~ in heavy hydrogen

Fig. 1.

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$$\sigma = \frac{1}{4}\sigma_+ + \frac{3}{4}\sigma_-$$

~~of the above two kind these~~ of ~~two~~ the above two kinds of ~~states~~. of the above two values ~~and~~ was ~~is~~ found to be ~~about~~

$$\sigma_c = 4 \times 10^{-24}\,\mathrm{cm}^2$$

for slow neutrons of C-group according to Dunning, Pegram, Fink and Mitchell(1). ~~This value is to~~ should correspond to the average

$$\sigma = \frac{1}{4}\sigma_+ + \frac{3}{4}\sigma_-$$

of ~~the above two value~~ two ~~the~~ values, ~~determined~~ if theoretical values ~~for the~~

If we consider the effect of chemical binding of deuterons, the cross section σ_f of the free deuteron for slow neutrons ~~should~~ of several volts should be about half of that for neutrons of C-group(2), so that we obtain ~~an~~ approximate value

$$\sigma_f = 2 \times 10^{-24}\,\mathrm{cm}^2.$$

This value (~~should~~ is to) correspond to the average ~~cross~~ section

$$\sigma = \frac{1}{4}\sigma_+ + \frac{3}{4}\sigma_- \qquad (\quad)$$

of the cross sections of the deuteron for slow neutrons in two cases above considered.

Hence, if we ~~fix~~ ~~take a va~~ Hence, ~~we obtain a relation~~ can ~~determined~~ σ_- and ~~W_-~~ consequently

(2) Compare §3.

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$4\sigma_f = \sigma_+ + 3\sigma_-$, σ_+ takes the value determined above with the fixed value of b.

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$\frac{8}{3} - 0.9 = 2.67 - 0.9 = 1.8$

by using the relation

$$\sigma_- = \frac{4}{3}\sigma_f - \frac{1}{3}\sigma_+$$

for slow neutrons, for σ_+ with a fixed value of b. Thus

$$\sigma_- = 1.8 \times 10^{-24}\,cm^2, \quad U_- =$$

for $b = 4.5 \times 10^{-13}$ cm and

$$\sigma_- = 2.18 \times 10^{-24}\,cm^2 \quad U_- = 11. \times 10^6\,eV$$

for $b = 2.18 \times 10^{-13}$ cm.

Hence, we can choose U_- with a fixed value of b so as to give the value for σ_- for slow neutrons satisfying the relation

$$\frac{1}{4}\sigma_+ + \frac{3}{4}\sigma_- = 2 \times 10^{-24}\,cm^2,$$

where σ_+ takes the value determined with the same b. Thus, we obtain in this manner the results

$$\sigma_- = 1.8 \times 10^{-24}\,cm^2 \quad -U_- = 1.9 \times 10^6\,eV$$

for $b = 4.5 \times 10^{-13}$ cm and

$$\sigma_- = 2.18 \times 10^{-24}\,cm^2 \quad -U_- = 11 \times 10^6\,eV$$

for $b = 2.18 \times 10^{-13}$ cm. In both cases as shown in Fig. 1, the curve for σ_- has a small hump in the former case due to the virtual S-level in the former case, while it decreases

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If we change b between the above two extreme values, the shape of the curve will be altered

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It is

, so that the correct value of b will be determined when the detailed experimental results are obtained in these c

informations is steadily in the latter.

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The average cross section given by ( )

$$\sigma = \frac{1}{4}\sigma_+ + \frac{3}{4}\sigma_-$$ in these extreme cases

depends on the energy as indicated by the curves of the in Fig. 2. As there is no detailed experimental results, at present, we can hardly decide which value of b between the above extreme values is correct. The experimental cross section

$1.71 \times 10^{-24}\,cm^2$

measured by Dunning and others(1) for fast neutrons from the Ra-Be source is to correspond to an average over a wide energy range, so that further experimental

In any case, the cross section of capture of slow neutrons by deuterons will be much smaller than that by protons, as there is no true or virtual ^2S-level of ^3H of small energy, while the existence of a ^1S-level the virtual of energy about 12×10^4 eV was expected from theoretical considerations.2) This seems to be in

(1)
(2)

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agreement with the recent experimental results of Kikuchi, Aoki and Takeda, which indicate that the cross section ~~the γ-ray emission~~ by ~~neutron-deuteron~~ collision of slow neutrons with deuterons ~~and give~~ is very small and has an upper limit $0.3 \times 10^{-25}\,\mathrm{cm}^2$.

~~Thus~~ ~~It should be noticed~~ Thus far, we took only Majorana forces into account. The inclusion of small Wigner forces ~~does~~ will not give any substantial ~~ly~~ modification, while the presence of Heisenberg forces will ~~result in~~ give rise to the further splitting up and coupling of $^2S_+$ $^4S_-$ $^2S_-$ ~~states~~ .... states, but ~~it seems improbable that the general feature of the above results is~~ the above method of estimation is too crude to afford such ~~detail~~ discussions of finer details.

It should be noticed, that the angular distribution of scattered neutrons ~~are~~ is, of course, spherically symmetric in the ~~coo~~ relative coordinate system ~~and~~ for small energies, so that the probability of it being scattered into an angle between θ and $\theta + d\theta$ in the ordinary coordinate system becomes

$$\frac{1}{2}\left(\frac{3+2\cos\theta}{2\sqrt{3+\cos\theta}} + \cos\theta\right)\sin\theta\, d\theta.$$

Thus most of the neutrons are scattered into the forward direction ~~as shown in Fig. 2~~ as shown in Fig. 3.