一、 Assessment on **cross sections for D(^{4}He, D)^{4}He and T(^{4}He, T)^{4}He forward scattering**

In previous works, several authors have been measured cross-sections for the interaction D(^{4}He, D)^{4}He and T(^{4}He, T)^{4}He forward scattering[1-7]. Energy range covers 1-3 MeV and 9-11 MeV. The scattering angles are 10^0, 20^0, 25^0, 30^0, 35^0 and 40^0 for D(^{4}He, D)^{4}He, and 30^0 for T(^{4}He, T)^{4}He. But, some disagreement among their results exists. The disparity mainly comes from the samples, measuring methods . For measurement of cross-sections on interaction D(^{4}He, D) ^{4}He, Kellock(1993) employs samples of 60nm of deuterated polystyrene$(C_8D_8)_n$, and used two detectors to allow simultaneous collection of ERD and RBS spectra. Hence deuterium differential cross section can be determined

$$\sigma_D(E^*,\theta_D)=\frac{A_D\Omega_\alpha\sigma_C(E^*)}{A_C\Omega_D\sigma_C{}^{Ruth}(E^*)}\sigma_C{}^{Ruth}(E^*,170^0)$$

Where $\sigma_C(E^*)$ is the backscattering differential cross section for carbon at 170^0 and E^* is the mean laboratory energy of incidet He^+ ions within the film. Ω_α and Ω_D are the respective solid angles of the detectors at 170^* and θ_D. The above equation is dependent of the amount of charge collected. The main error of the cross section comes from the Ω,θ and A if the ratio of C to D is exact. But, Deuterium loss of about 1% due to the ion beam bombardment during each 20 uC run is also factor of error.

In 1986, F. Besenbacher used a target consisting of self-supporting 400 $\overset{0}{A}$ Au film, upon which was evaporated 100 $\overset{0}{A}$ Ti in a D atmosphere to get a $TiD_{0.8}$ layer. The D(^{4}He, D)^{4}He –recoil yields was measured relative to the $D(^3He,\alpha)p$ nuclear reaction. the ^{3}He+D cross section that Moller and Besenbacher determined with the absolute accuracy of $\pm 4\%$ for c.m.s energies less than 500 keV. Since the detector solid angle is consult during the rotation around the center line, the laboratory cross section can be easily be obtained from the nuclear –reaction cross section as follows,

$$\left(\frac{d\sigma}{d\Omega}\right)_{lab}^{rec}=\frac{Y_{rec}}{Y_{nuc}}\frac{Q_{nuc}}{Q_{rec}}\left(\frac{d\sigma}{d\Omega}\right)_{lab}^{nuc}\left(\frac{d\Omega_{cms}}{d\Omega_{lab}}\right)^{nuc}$$

where the last factor is the solid angle c.m.s to laboratory conversion factor for the ^{3}He+D reaction. When the above statistical uncertainty of Y and Q is 2-3%, the absolute accuracy of cross section is in $\pm 5\%$, which is almost same that as alleged by Kellock.

Sawicki used same measuring principle as Besenbacher to measure the cross section for T(^{4}He, T)^{4}He forward scattering. However he employed two kinds of target, i.e., tritium –titanium target prepared by abosorption of evaporated Ti in T atmosphere film and tritium –silicon target fabricated by implantation. It was found that the Si-T target was much more stable than the T-Ti target. When the quoted accuracy of the cross section for T(d,a)n reaction is 2% and all statistical uncertainty originating from Y and Q is typically $\pm 4\%$, the total error is not larger than 10%.

In recent measuring of cross –sections for the interaction D(^{4}He, D)^{4}He and T(^{4}He, T)^{4}He forward scattering , J.F.Browning et al. used the original formula to calculate the cross section in energy range of 9-11 MeV. i.e.,

$$\left(\frac{d\sigma}{d\Omega}\right) = \frac{Y(E)\cos\theta_{t\,\mathrm{arg}\,et}}{NQ\Omega}.$$

However, because he employed some special methods to measure each items in formula, i.e., N is measured by thermal desorption, Q by a chopper system and Ω by using ^{238} Pu α source, the error of N, Q and Ω can be controlled in ±2.0, ±2.0 and ±1.0%, respectively. So the overall uncertainty in the measured cross section is to be 3.2%.

For measuring of D(^{4}He, D)^{4}He cross section, the various experimental data shows some disparity among the absolute values both within and outside of the resonance region. The work by Besenbacher is the most complete, having been done over a wide range of energies and angles. Below the resonance energies, there is a agreement with Kellock results. .However, in the resonance region there is a systematic disagreement in the magnitude of the cross section, which apparently could be explained by a constant offset of ~2° in the detector angle. Besenbacher quotes his angular precision to $\pm 2^\circ$ which would seem to cover the discrepancy with Kellock's work .The dramatic dependence on detector angle is nonetheless noteworthy, and indicates the need for special angular precision when working in the resonance region.

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二、 Cross sections for D(p, p) D and T(p, p) T scattering

During the about two decades(1950-1968), most measurements of the cross-section for D(p, p) D reaction have been made at certain energy in the energy range up to about 10 MeV[1-4]. In their measurement, scattering materials employed gases or hydrogen containing non-metal(such as, Nylon, p.e.t foils), and scattering particles were recorded by proportional counters. The particle beam impacting target is energy dispersed after passing foil separating gas in the scattering room from the high vacuum. Also, the direction of incidence angle in the center of scattering is a little divergent. Although all the published measurement data are declaimed in the error range of ±3-5%, the practice error may exceed much because of error sources in geometric, particle detection, beam energy, gas density and contamination and etc.(which is limited by technological level at that times).

In 1969, D.C Kocher[5] made angular distribution measurements at eight energies between 1.00-10.04 MeV (Fig.2.1). Because employing precision gas

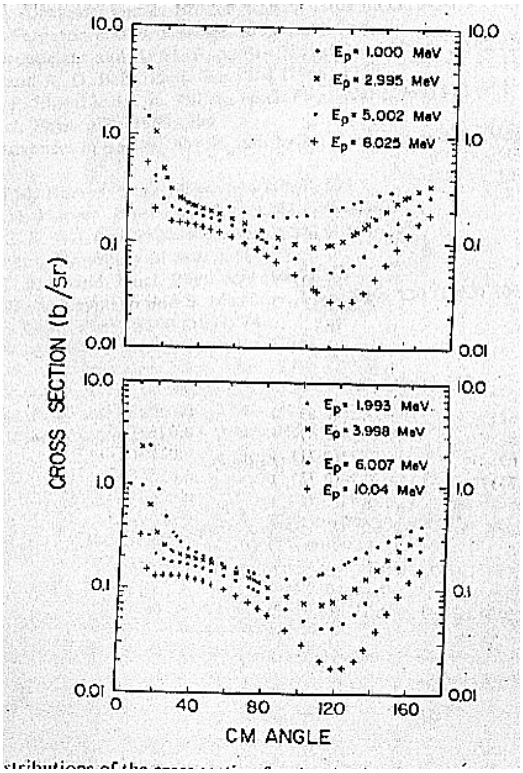

Fig.2.1 Angular distribution of the cross section for the elastic scattering of protons from deuterium

scattering chamber with differential pumping and of high resolution solid state detectors, total maximum uncertainty can be within 2.1% and median uncertainty for all data points is ±0.6%. Type of uncertainty includes background substraction in particle yield determination(0.19%), contamination corrections(0.34%), statistical uncertainty(0.1%), gas density and G-factor and integrator calibration(0.2%), angle uncertainty(1.7 %), energy uncertainty(0.98%), correction uncertainty(0.05%), and other uncertainty(0.36%).

In 1975,R. A. Langley[6] used erbium deuteride films of 800 nm deposited on kovar or alumina substrates as a solid target to measure the elastic scattering cross section for proton on deuterium at 170℃(lab.). The amount of deuterium was determined by mass spectrometric determination outgassing of the substrate. The

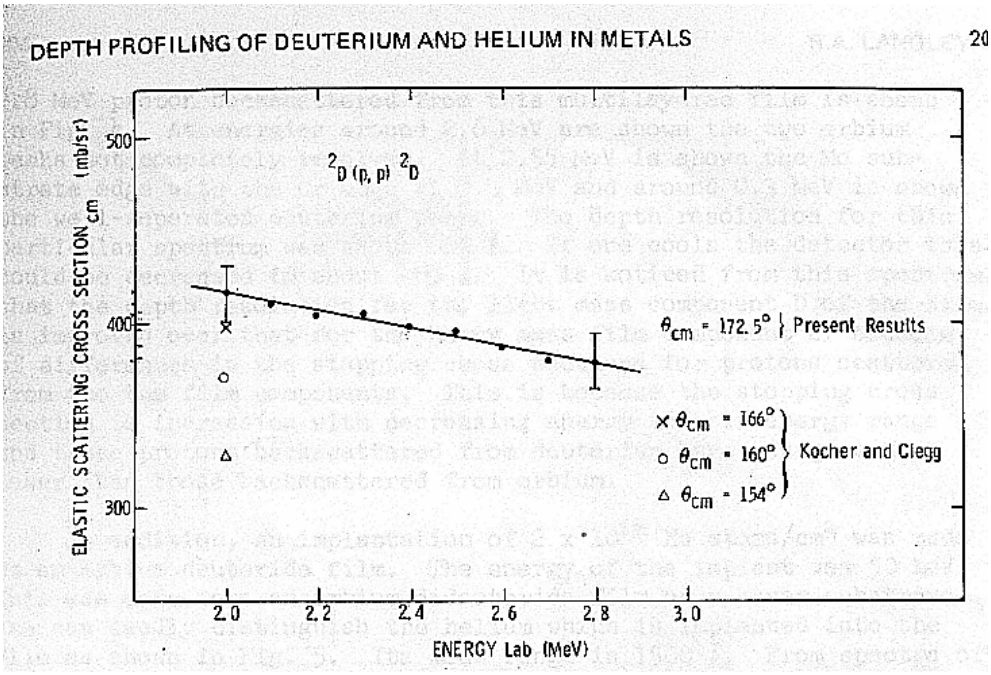

Fig. 2.2 Experimental elastic scattering cross section for p on D for ϑ_{cm}=172.5^0

amount of erbium was measured by weight. The elastic scattering cross section was determined by measuring the area under the deuterium peak and area under the erbium peak, assuming that elastic scattering of proton from erbium is Rutherford and independently measuring the loading ratio([D]/[Er]). Fig. 2.2 shows the cross section enhancement vs energy in the lab system. The error associated with this measurement is ±2% for the cross section and less than ±0.5% for the energy.

As for the differential cross section for the scattering of proton by tritons, R. S. Classen[7,8] made a measurement in the angular range of 41.85° to 163° in the lab(54.7° to 168.7° in the center-of-mass system) at five energies between 2.54 and 3.5 MeV. A small volume(42 cc) scattering chamber with an angular range of 17° to 163° was used these measurement. It was found that the results were not valid at all angles and energies, the results being high at the lower scattering angles. The presence of hydrogen contamination in the tritium must deal with. This experiment depended on an ability to measure the tritium concentration. Fig.2.3 shows the measured data of cross section. The error estimated for the measurement of charge was ±1%. The pressure and geometry factor measurements were good to ±0.5%. The error in the measurement of hydrogen concentration, estimated to be good to ±1%, the 3% correction for the chamber characteristics, and the correction for background at high

scattering angles. For all these reason, the total probable error estimated to be ±5% The measured results shows in Fig. 2.3.

However, in the region of minimum cross section, around 100° scattering angle(c.m.), the results at 2.11MeV and 2.54MeV are about 10 percent lower than these of the Los Alamos group[9]. This difference is the sum of the estimated probable error sources.

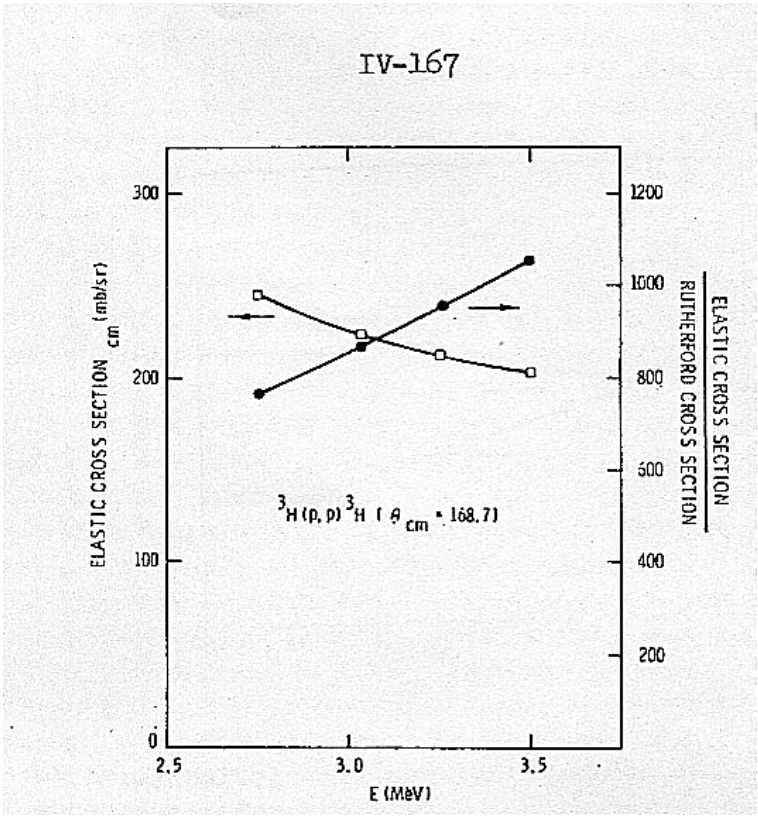

Fig. 2.3 Experimental elastic scattering cross section for p on T for ϑ_{cm}=168.7
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