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Summary. — The excitation function and the differential cross-section of ^{12}C(d, p) reaction have been measured at low deuteron energies. The excitation functions have been measured at $\theta = 25$, 35, 90 and 140 degrees for $(160 \div 300)$ keV deuteron energy. The differential cross-sections have been measured for $E_d = 200$ to 300 keV with 5% uncertainty at 13 angles covering the angular range from 25 to 160 degrees. At 200 and 220 keV deuteron energy, the angular distribution is strongly backward peaked. As the deuteron energy increases, the angular distribution starts peaking at forward angles. The excitation functions and differential cross-section data of ^{12}C(d, p) reaction are reported for the first time below 400 keV. This data could be used to test the existing DWBA theory for ^{12}C(d, p) reaction at very low deuteron energies.

PACS 25.45.Gh – Single-nucleon transfer reactions.

1. – Introduction.

The ^{12}C(d, p) reaction is one of the very frequently studied reactions. Depending upon the energy the reaction may proceed either through the direct reaction channel or through the compound-nucleus channel [1]. Although ^{12}C(d, p) has been studied extensively over the deuteron energy range from 0.4 to 80.2 MeV [2], yet there is no data available below 0.4 MeV deuteron energy. Phillips [3] has observed large amounts of interface effects in the excitation functions and angular distribution data of ^{12}C(d, p) between 0.78 and 1.55 MeV deuteron energies. Holmgren *et al.* [4] have extracted the angular momentum of the nuclear states from the measured differential cross-section data of ^{12}C(d, p) reaction at 3.29 MeV deuteron energy. McEllistrem *et al.* [1] have also observed the interface between the stripping and compound-nucleus

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contribution to ^{12}C(d, p) reaction in the deuteron energy range of 1.9 to 3.4 MeV. The only data below 0.5 MeV is reported by Putt [5]. He has measured the angular distribution at 0.41 and 0.5 MeV deuteron energies and has fitted the differential cross-section data using DWBA calculations without absorptive potential for the distorted wave.

Due to lack of ^{12}C(d, p) data below 0.41 MeV, the angular distribution and excitation functions of ^{12}C(d, p) reaction were measured at $E_d = 160$ to 300 keV. This energy range of deuterons is also easily accessible at the 350 kV accelerator of the Energy Research Laboratory, King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia [6]. In the following, we report the results of this study.

2. – Experimental.

Angular distribution and excitation function measurements of ^{12}C(d, p) reaction were carried out at the 350 kV accelerator of the Energy Research Laboratory, King Fahd University of Petroleum and Minerals, Dhahran. The accelerator utilized an 820 Duoplasmatron ion source to deliver $(1 \div 4)$ μA d.c. beam of deuterium ions at $E_d =$ $= 160$ to 300 keV energy. The carbon self-supporting foils of $(20 \div 25)$ μg/cm^2 thickness were used as target and were mounted in the center of a rectangular chamber located at the end of the 80 degree beam line of the accelerator. The protons from ^{12}C(d, p) reaction were detected by four silicon surface barrier detectors with 100 μm thick depletion layer and 100 mm^2 effective area. For the excitation function measurements, the detectors were fixed at 25, 35, 90 and 140 degrees while for the angular distribution measurements the detector angles were varied from 25 to 160 degrees in 10 degrees step. One of the four detectors was fixed at 140 degree angle. It was used as a monitor for normalization and carbon build-up correction. With the help of apertures, the effective solid angle of each detector was reduced to 1.1 msr. In order to suppress the elastically scattered deuterons, each detector was masked with a 5 μm thick aluminum foil, which stopped the scattered deuterons but allowed the reaction protons to pass through. The energy loss of 2.5 to 3.0 MeV protons in the aluminum foil was estimated to be 131 to 115 keV. With the help of a collimator, the beam was focussed onto the target to an effective area with 3 mm diameter. The beam transmitted through the carbon target was measured at a Faraday cup behind the target. The Faraday cup was electrically suppressed by applying an electric potential of 200 V.

During the long exposure of the carbon target to the deuteron beam, carbon build-up was observed due to drive in deuterons. In order to minimize the carbon build-up it was decided to change the carbon target after every 8-10 hours. During this 8-10 hours exposure of the target to the deuteron beam, a monitor detector was used to record the instantaneous yield of the target for a fixed incident charge. The ratio of this yield to the fresh target yield was used to correct for carbon build-up. Due to the carbon build up, a maximum correction of $(4 \div 5)\%$ was applied.

3. – Results and discussion.

3.1. *Excitation functions.* – Figure 1 shows the excitation function curves at 25, 35, 90 and 140 degrees for the ^{12}C(d, p) reaction for deuteron energies ranging from 160 to 300 keV in steps of 10 keV. The data contains only statistical uncertainties. For contribution to $^{12}C(d, p)$ reaction in the deuteron energy range of 1.9 to 3.4 MeV. The only data below 0.5 MeV is reported by Putt [5]. He has measured the angular distribution at 0.41 and 0.5 MeV deuteron energies and has fitted the differential cross-section data using DWBA calculations without absorptive potential for the distorted wave.

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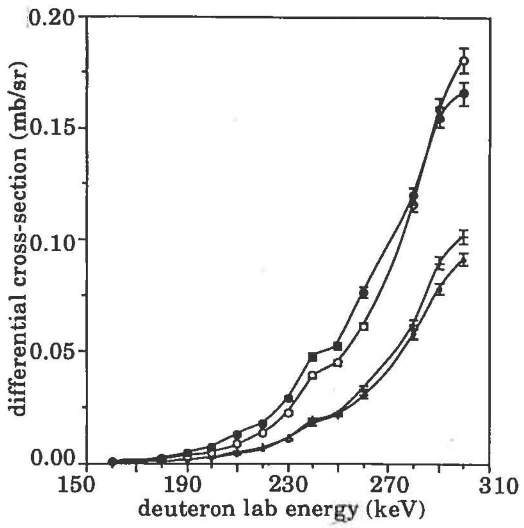


Fig. 1.

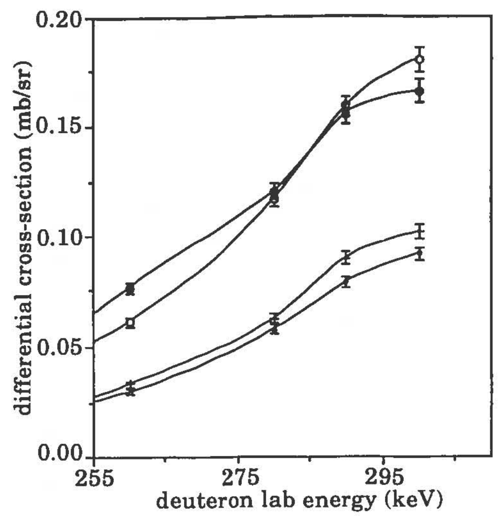


Fig. 2.

Fig. 1. – Excitation functions at ○ 25, + 35, □ 90 and ● 140 degree laboratory angle.

Fig. 2. – Excitation functions over the energy range of 255 to 300 keV deuteron energies. The meaning of the symbol is the same as in fig. 1.

25 and 35 degrees excitation functions, the cross-section is small and uncertainties are relatively large and they range from 3 to 13% while for 90 and 140 degrees excitation curves the uncertainties amount to 3 to 9%. The cross-section also shows a smoothly increasing trend with deuteron energy and a broad hump around 240 keV deuteron energy. The hump is more pronounced for 90 and 140 degree excitation function curves. The rate of increase of cross-section with deuteron energy is different for all angles. An interesting feature of the 90 and the 140 degrees excitation curves is their crossover between 280 to 290 keV deuter n energy. In order to show this effect on enlarged scale, the excitation curves over the energy range of 255 to 300 keV are plotted in fig. 2. For the 35 degree excitat'on curve, the cross-section is always higher than the 25 degree curve over the entire energy range. Over the deuteron energy range of 255 to 280 keV, the cross-section for the 90 degree excitation curve is less than that of the 140 degree excitation curve. However as the deuteron energy increases above 280 keV, the cross-section for the 90 degrees curve is larger than the 140 degree excitation curve. This means that above 280 keV deuteron energy, the cross-section at 90 degrees is increasing faster with energy than that at 140 degrees. This is due to the fact that the peak in angular distribution, which is at backward angles for deuteron energies less than 280 keV, starts shifting towards forward angles. This is clearly shown in fig. 3, which shows the angular distribution for deuteron energies ranging from 200 to 300 keV.

3·2. *Differential cross-section.* – In order to show the trend of the differential cross-section, each set of data points is connected by a solid line in fig. 3. The differential cross-sections are measured from 25 to 160 degrees in 10 degrees step at deuteron energies of 200, 220, 250, 280 and 300 keV. The errors shown in all data plots

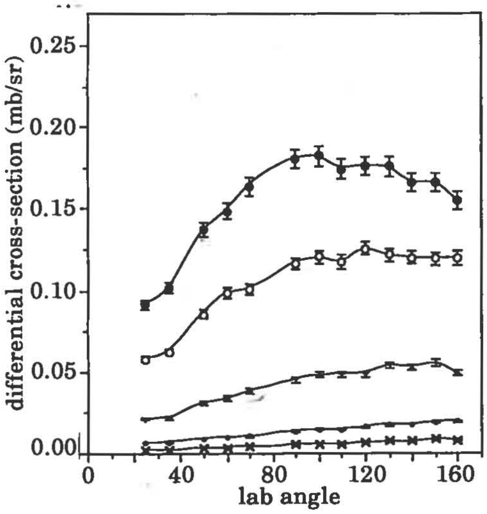


Fig. 3.

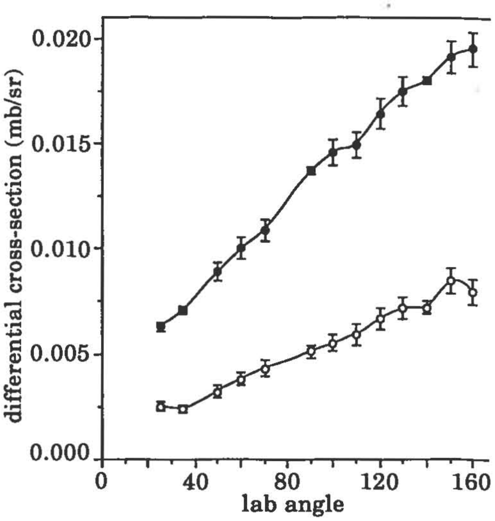


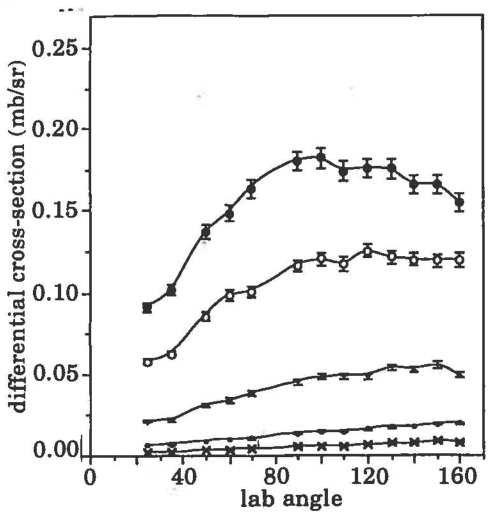
Fig. 4.

Fig. 3. – Differential cross-section of $^{12}C(d, p)$ reaction at 200 to 300 keV deuteron energy × 200 keV, • 220 keV, + 250 keV, ○ 280 keV, ● 300 keV.

Fig. 4. – Differential cross-section at ○ 200 and • 220 keV deuteron energies.

are statistical only. They vary from 3 to 5% for 200 to 300 keV. Due to lower cross sections at 200 keV, the statistical errors are larger than (220 ÷ 300) keV data an amount to 5 to 9%. Within statistical uncertainties, all distributions show a smoot trend and have no structure. For all angles, the cross-section increases with deutero energy. Figure 4 shows the differential cross-section at 200 and 220 keV deutero energy on enlarged scale. The differential cross-section shows two prominen features, namely asymmetry and backward peaking. The 200 and 220 ke distributions do not show any cross-section maxima but they have simply increasin trend of cross-section with angle. As the deuteron energy increases, the cross-sectio increases and a maximum starts to develop. The rate of increase of cross-section wit energy is different at different angles and is maximum around 90 degrees. As a resul the differential cross-section at 300 keV deuteron energy shows an asymmetri distribution with a broad maximum around 100 degrees. The asymmetric an backward peaking trend of differential cross-section at this deuteron energy indicate that the reaction proceeds through the direct channel of nuclear interaction.

The $^{12}C(d, p)$ data below 500 keV deuteron energy is published by Putt [5]. He ha measured the differential cross-section at 410 and 510 keV deuteron energies. Figur 5 shows Putt's data plotted along with 250, 280 and 300 keV data measured in thi experiment. All distributions show similar trends of increasing rate of change o cross-section with energy as the deuteron energy increases, with a maximum value o change around 90 degrees. Comparison of the shapes of the distributions reveals tha as the deuteron energy increases the broad maximum tends to become narrowe Figure 6 shows the 410 and the 510 keV data of Putt [5] along with the 300 keV dat from ERL. For these distributions the cross-section peaks at about 80, 90 and 10 degrees (centre-of-mass angles) for the 510, 410 and 300 keV data, respectively. Thi clearly indicates forward shifting trend of peak of differential cross-section wit



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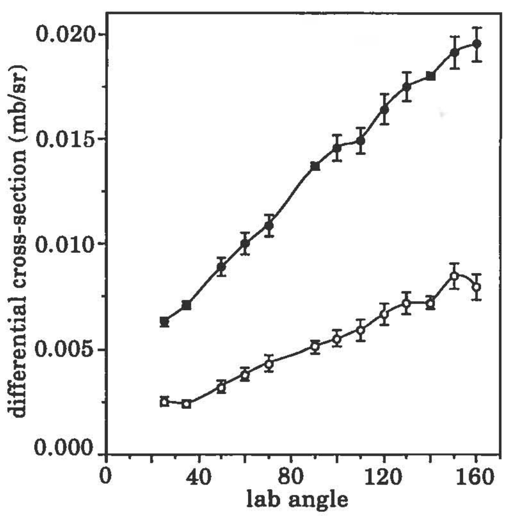

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The $^{12}C(d, p)$ data below 500 keV deuteron energy is published by Putt[5]. He has measured the differential cross-section at 410 and 510 keV deuteron energies. Figure 5 shows Putt's data plotted along with 250, 280 and 300 keV data measured in this experiment. All distributions show similar trends of increasing rate of change of cross-section with energy as the deuteron energy increases, with a maximum value of change around 90 degrees. Comparison of the shapes of the distributions reveals that as the deuteron energy increases the broad maximum tends to become narrower. Figure 6 shows the 410 and the 510 keV data of Putt[5] along with the 300 keV data from ERL. For these distributions the cross-section peaks at about 80, 90 and 102 degrees (centre-of-mass angles) for the 510, 410 and 300 keV data, respectively. This clearly indicates forward shifting trend of peak of differential cross-section with

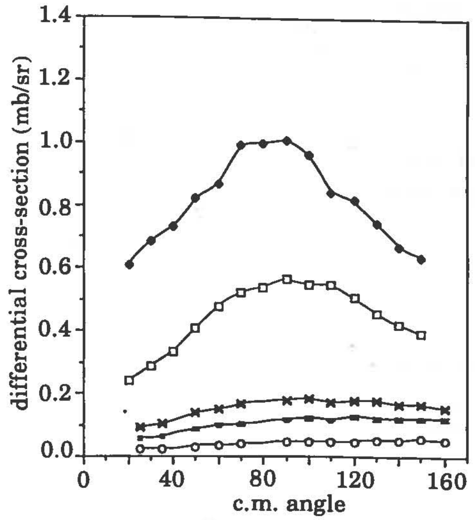

Fig. 5.

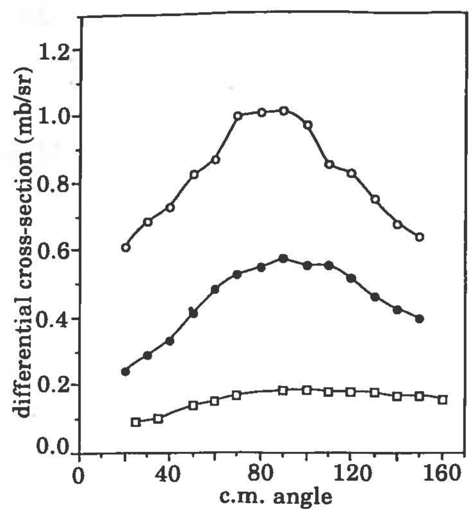

Fig. 6.

Fig. 5. – Putt's □ 410 and ◆ 510 keV data along with ERL data at ○ 250, ■ 280 and × 300 keV data.

Fig. 6. – Putt's ● 410 and ○ 510 keV data along with ERL data at □ 300 keV.

increasing energy. The 410 and 300 keV differential cross-sections are more asymmetric than the 510 keV data. Figure 6 shows the interesting feature that the difference in maximum cross-section measured for each of the three distributions is almost constant. The maximum cross-section measured for 300 keV deuteron energy is 0.185 mb while the maximum values of the cross-sections reported at 410 and 510 keV are 0.568 and 1.009 mb, respectively[5]. The maximum cross-section increases by 383 mb for a corresponding increase in deuteron energy from 300 to 410 keV while the increase in cross-section from 410 to 510 keV deuteron energy is 441 mb. This is consistent with the trend of our data that with increasing deuteron enerrgy, the rate of increase of cross-section also increases.

As a result of this study, excitations and the differential cross-sections of $^{12}C(d, p)$ reaction are measured for the first time below 400 keV. This data could be used to test the existing DWBA theory for $^{12}C(d, p)$ reaction at very low deuteron energies.

4. – Conclusions.

The excitation function and the differential cross-section of $^{12}C(d, p)$ reaction have been measured at low deuteron energies. The excitation functions have been measured at $\theta = 25$, 35, 90 and 140 degrees for (160 ÷ 300) keV deuteron energy. The differential cross-sections have been measured for $E_d = 200$ to 300 keV with 5% uncertainty at 13 angles covering the angular range from 25 to 160 degrees. At 200 and 220 keV deuteron energy, the angular distribution is stongly backward peaked. As the deuteron energy increases, the angular distribution starts peaking at forward angles. The excitation functions and differential cross-section data of $^{12}C(d, p)$ reaction are reported for the first time below 400 keV.

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