PHYSICAL REVIEW C VOLUME 9, NUMBER 5 MAY 1974

Rationalization of measurements of the ^{4}He(γ, n)^{3}He cross section*

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(Received 8 January 1974)

Experiments to measure the photoneutron yield from a liquid ^{4}He target as a function of beam intensity have been carried out. They show that the most recent measurements of the photoneutron cross section with liquid helium targets can be made consistent with each other, and that the results are then not inconsistent with measurements of the ^{4}He(γ,n)^{3}He cross section using gaseous targets.

[NUCLEAR REACTIONS ^{4}He(γ,n), E = 35 MeV; measured σ (beam current).]

Recently Irish *et al.*[1] reported two measurements of the ^{4}He(γ, n)^{3}He 98° differential cross section which were in disagreement. Both were measured using a pulsed bremsstrahlung source. One measurement was obtained using a high-pressure ^{4}He gas target while the other was obtained using a liquid ^{4}He target at its normal boiling point. The cross-section values obtained with the gas target were approximately a factor of 1.9 greater than those obtained with the liquid target.

The result obtained in Ref. 1 for the liquid target is essentially in agreement with an earlier measurement made at Yale[2] and lower by a factor of about 2 than the recent result obtained by the Saskatchewan group.[3] All three of these measurements made use of a similar experimental technique (i.e., pulsed-bremsstrahlung, neutron time-of-flight, and liquid helium targets at or near their normal boiling point).

The result reported in Ref. 1 for the gaseous ^{4}He target is essentially in agreement with all other measurements of the ^{4}He(γ, n)^{3}He cross section using gaseous targets and various experimental techniques. (See for example Refs. 4 and 5.)

Thus the situation is confused. The authors of Ref. 1 suggested that the difference between their gas target and liquid-target cross sections may be due to a reduction of density of the liquid helium target due to beam heating. This hypothesis was supported by the fact that electron beams have been known to cause bubble formation in liquid hydrogen and deuterium targets and thus reduce their effective density.[6–9] Also very dramatic reductions in the density of liquid helium targets under bombardment by an electron beam have been observed by Walcher[10]; however, he showed that a large amount of his reduction in target density was due to the geometry of his target.

In order to determine if a reduction in density of the target could be caused by beam heating, the same Dewar as used in Ref. 1 and in the same experimental configuration was used to measure the yield of photoneutrons as a function of beam current. The yields of photoneutrons from helium and from the empty Dewar were both obtained for various beam currents. It was found that the yield of photoneutrons from the empty Dewar remained constant (to within 2%) for the various currents measured but that the yield of photoneutrons from the helium was strongly beam-dependent. The beam dependence of the yield of photoneutrons from liquid helium contained in the aluminum Dewar is shown in Fig. 1.

In order to check this result the aluminum Dewar was replaced by a glass Dewar containing a 9.5-cm-diam cylinder of liquid helium and the experiment repeated. Similar results were obtained. The variation of the yield of photoneutrons with beam current for liquid helium in the glass Dewar is also plotted in Fig. 1.

These results thus show that the "effective target density" of the liquid helium target used at Toronto was definitely reduced by beam heating. Further this data can be used to help explain the differences and similarities in the three liquid-target measurements at Toronto,[1] Yale,[2] and Saskatchewan.[3]

The experimental beam parameters used in the Toronto experiment[1] were 0.42-A peak, 15-ns pulse width, 360 pps, and 35 MeV. The bremsstrahlung target was 0.20-cm tungsten followed

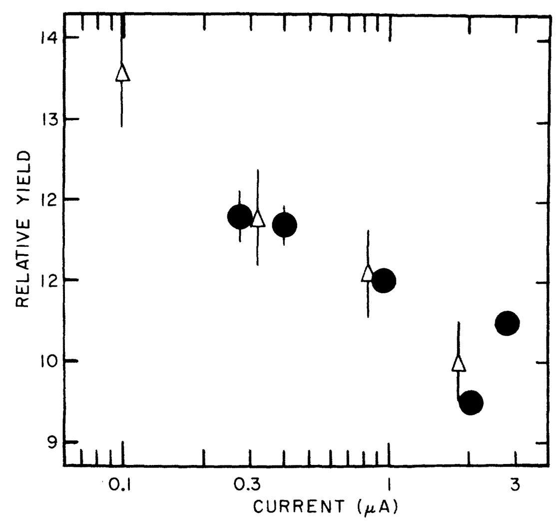

FIG. 1. Relative yield of photoneutrons from a liquid ^{4}He target as a function of average beam current: circles indicate points obtained using an aluminum Dewar and triangles indicate points obtained using a glass Dewar. The points obtained using the glass Dewar have been normalized to the points obtained using the aluminum Dewar at an average current of 0.3 μA. All points were obtained using an electron energy of 35 MeV.

by a 4.45-cm aluminum beam stop. These beam parameters give a peak electron beam power of 14.7 MW or an average electron beam power of 79.5 W. Using information from Refs. 11, 12, and 13, the bremsstrahlung conversion efficiency is estimated to be 0.33 for this bremsstrahlung target. Thus the bremsstrahlung power falling on the liquid helium target was of the order of 4.9 MW peak or 26.2 W average.

The experimental beam parameters used in the Yale experiment[2] were 3-A peak analyzed current, 5-ns pulse width, 330 pps, and 35 MeV. The bremsstrahlung target was a 10-cm-thick block of aluminum. These beam parameters give a peak electron beam power of 105 MW or an average electron beam power of 173 W. Using information from Refs. 12 and 13, the bremsstrahlung conversion efficiency is estimated to be 0.13. Thus the bremsstrahlung power falling on the liquid helium target was about 13.6 MW peak or 22.5 W average.

Thus the power levels in the Toronto and Yale experiments were of the same order of magnitude and thus it would be expected that similar values for the cross section would be obtained in the two experiments.

The experimental beam parameters used in the Saskatchewan experiment[3] were 50-mA peak analyzed current, 10-ns pulse width, 750 pps, and energies of 50, 62, 75, 100, and 110 MeV. The bremsstrahlung target was a 0.005-cm tantalum foil, which was followed by a magnetic beam dump. For an energy of 75 MeV, these beam parameters give a peak electron beam power of 3.7 MW or an average electron beam power of 28 W. Using information from Ref. 13 the bremsstrahlung conversion efficiency was estimated to be 0.013 for the 0.005-cm tantalum foil. Thus the bremsstrahlung power falling on the liquid helium target was approximately 0.048-MW peak or 0.36 W average. The other electron energies would give power estimates within $\pm 45\%$ of those calculated above.

Thus the average power levels in the Saskatchewan[3] experiment were approximately a factor of 65 lower than the average power levels used in the Toronto[1] and Yale[2] experiments.

The Toronto[1] liquid-target result gives a cross-section value equal to 0.54 of the Toronto gas-target result. On the assumption that average bremsstrahlung beam power is the determining factor in the variation of neutron yield with beam current, it is possible from an extrapolation of the data in the figure to estimate that the Saskatchewan apparent yield will be 1.6 times larger than the yield obtained at Toronto and Yale. Then it would be expected that the ratio of the Saskatchewan yield to the Toronto gas target result could be 0.54×1.6 or 0.86. The ratio is in fact 1.13. The fact that the Saskatchewan liquid target was slightly pressurized (0.03 bar overpressure) could suppress some of the effect of beam heating and increase the yield of photoneutrons. Also the higher energies used in the Saskatchewan experiment would increase the yield of photoneutrons slightly due to the ^{4}He-$(\gamma, 2n)2p$ process. Taking these two facts into account and considering the quoted errors on the two cross-section measurements, the measured ratio of 1.13 and the calculated ratio of 0.86 are in reasonable agreement.

Although these calculations are very rough and do not take into account the finer points such as Dewar construction, bremsstrahlung spectral differences, and beam focussing, they point out that similar results would be expected in the Yale[2] and Toronto[1] measurements and that a different, more nearly correct, result would be obtained in the Saskatchewan[3] measurement. The calculations also assume that average power rather than peak power is the important parameter—a similar conclusion would however be reached using peak powers.

Although the present calculation cannot explain the Livermore[14] result as the power levels in an in-flight positron annihilation experiment are orders of magnitude lower than those in a bremsstrahlung experiment, it shows that all of the other liquid-target measurements of the ^{4}He-$(\gamma, n)^3$He cross section, when "effective target density" reduction due to beam heating is taken into account, do not conflict with measurements of this cross section using gaseous targets.

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*Work supported in part by the National Research Council of Canada.

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