Title
THE T3 (p,y) He4 Reaction

Authors
Birge, Robert W.
Jungerman, John.

Publication Date
1953-02-11

UCRL-2109

UNIVERSITY OF CALIFORNIA — BERKELEY

RADIATION LABORATORY

DISCLAIMER

UCRL-2109
Unclassified-Physics Distribution

UNIVERSITY OF CALIFORNIA

Radiation Laboratory

Contract No. W-7405-eng-48

THE T^3 (p, γ) He^4 REACTION

Robert W. Birge and John Jungerman

February 11, 1953

Berkeley, California

UCRL-2109
Unclassified-Physics Distribution

THE T^3 (p, γ) He^4 REACTION

Robert W. Birge

Radiation Laboratory, Department of Physics,
University of California, Berkeley, California

and John Jungerman

Department of Physics, University of California
Davis, California

February 11, 1953

ABSTRACT

The excitation function for the reaction T^3 (p, γ) He^4 has been extended to proton energies of 7.3 Mev. No experimental evidence is found for a resonance in the reaction up to this energy of bombarding protons.

THE $T^3 (p, \gamma) He^4$ REACTION

Robert W. Birge

Radiation Laboratory, Department of Physics,
University of California, Berkeley, California

and John Jungerman

Department of Physics, University of California
Davis, California

February 11, 1953

A. INTRODUCTION

The reaction $T^3(p, \gamma) He^4$ has been studied previously by several investigators.[1,2,3] In the work of Argo et al it was suggested that their excitation function for the reaction could be explained on the basis of an excited state of the He^4 nucleus with a half width of 1.0 Mev at 21.6 Mev above ground level. This corresponds to a resonance level at 2.5 Mev proton energy in the laboratory system. Unfortunately the proton energy available to Argo et al extended only to 2.5 Mev. The excitation function has been extended by Falk and Philips[2] to 3.4 Mev and by Perry and Bame[3] to 4.3 Mev. It is therefore of interest to find the behavior of the gamma ray yield as the proton energy is further increased.

This same proposed resonance level can be reached in other ways, in particular by the $He^4(p, p') He^{4*}$ reaction. By this method, Benveniste[4] has shown that the differential cross section for the formation of an excited level in He^4 as high as 23.3 Mev above the ground state is less than 0.1 mb/ster. at 45° (c.m.)

B. METHOD

Detector

The excitation function for the $T^3(p, \gamma) He^4$ reaction was measured by detecting the γ-rays at 90° to the proton beam with a large NaI (TI) crystal (2 inches in diam. by 2 inches long) viewed at one end by an RCA5819 photo-multiplier. The crystal was rough sanded and packed in MgO, a method employed by Borkowski and Clark.[5]

A pulse height distribution was obtained by means of a single channel differential discriminator. The resulting distributions shown in Fig. 1 are similar to that described by Stearns[6] for the same gamma ray. Because of the bremsstrahlung and scattering of the high energy pairs formed in the crystal, the peak of the distribution is lower than the calculated energy position and a good measure of the energy is afforded by the extrapolation to zero of the high energy end of the curve. In order to reduce the loss of radiation from the crystal, we employed a lead collimator which restricted the gamma rays to a circle of one inch diameter as they entered the crystal. This caused the dip on the low energy side of the peak to be more pronounced without appreciably lowering the counting rate in the peak. For all runs the crystal was surrounded with four inches of lead to reduce background from the accelerator and ambient radioactivity. Three curves are shown: (a) for 0.9 Mev protons, gamma ray energy = 20.4 Mev, (b) 3.01 Mev protons, gamma ray energy = 22.0 Mev, and (c) for the reaction $p + Li^7 \longrightarrow Be^8 + 17.6$ Mev gamma. The thick target yield from the Li reaction at 0.9 Mev gives about 20 times the intensity of the thick target tritium reaction. For the calibration of our overall gain a Po-Be source was used; this gives a gamma ray from the excited state in C^{12} at 4.45 Mev. A typical curve showing resolution of three peaks is shown in Fig. 2. The lower peak is the pair line and the upper two are the result of capturing one or both of the annihilation quanta in the large crystal. It should be noted that for this curve and for all of the low energy runs an E.M.I. 6262 end window phototube was used. However it was replaced by an RCA5819 when it was found to be temperature sensitive. The effect amounted to about 2 percent in gain per degree Fahrenheit. As a result, the equipment was temperature controlled during the early runs.

Target

The target used came from Los Alamos and was in the standard form of tritium absorbed in 16 mg/cm^2 zirconium, which in turn had been melted onto a tungsten backing. As a result, data taken below 2 Mev are difficult to interpret since the target is thick. This point will be discussed in more detail in Section C. In order to normalize the yield of γ-rays at various proton energies, the target was mounted in a Faraday Cup and the proton current was integrated by standard means.

Accelerator

We first undertook this experiment using the 4 Mev Van de Graaff, which is used as the injector for the 32 Mev linear accelerator at the Radiation Laboratory. The highest energy available from the Van de Graaff was about 4.2 Mev, giving an average energy in the target of 4.0 Mev.

Since the cross section up to 4 Mev did not decrease as would be expected were there a resonance at 2.5 Mev, we continued the experiment with higher energy protons made available by accelerating molecular hydrogen in the linear accelerator. This beam travels through the accelerator at just one-half of the proton velocity for the normal 32 Mev proton beam. It emerges with 16 Mev and can be stripped in a thin foil to give 8 Mev protons. The phase acceptance for this half velocity beam is nearly zero and hence both the Van de Graaff energy and the linear accelerator end to end voltage must be held exactly correct. These voltages for the normal 32 Mev beam are not critical. Hence both voltages drifted and required manual adjustment. As a result the beam current averaged about 10^{-10} amps and the counting rate was extremely low. Because there is no fast multichannel discriminator at the Radiation Laboratory, we were obliged to use nine integral discriminators and scalers to make up eight differential channels, whereas we previously had been using a single channel differential discriminator.

The molecular hydrogen beam from the linear accelerator was bent through 10° by a magnetic field before passing through collimating slits and into the Faraday Cup. This beam would normally require the same magnetic field as 32 Mev protons for the same angular deflection. However, the measurements indicated 14.8 Mev molecular hydrogen (7.4 Mev protons) rather than 16 Mev. The point at 4.8 Mev was then obtained by slowing down the 7.4 Mev protons in a thin aluminum foil.

In order to keep the geometry constant, the Van de Graaff runs were made by shutting off the linear accelerator voltage and allowing the proton beam to continue through the machine. This beam energy was measured in a separate calibrated 90° bending magnet. Although the intensity of the Van de Graaff beam was low due to the extreme path length, very much higher beams could not be tolerated because the beam was pulsed with a one percent duty cycle. D.c. operation was tried but because of the limited power dissipation in the source, only a few times as much average beam current could be obtained. However, the increase in beam was more than offset by the fact that the counters, instead of being gated as in the pulsed operation, were on all the time causing counts to be recorded due to cosmic rays and general laboratory background. A zirconium target not loaded with tritium was run to subtract out all background.

C. EXPERIMENTAL RESULTS

The results shown in Fig. 3 indicate an increasing cross section up to 7.3 Mev. The points at 7.3 and 4.8 Mev are subject to rather large statistical errors because the small molecular hydrogen beam limited the number of counts we could record in a reasonable time. Although a differential spectrum of scintillation pulse heights was taken, the yield itself was obtained by summing the counts in the various channels down to a point where the pulse height corresponds to 0.75 of the maximum pulse height observed from the target. Thus only two discriminator settings are involved, corresponding to 0.75 and 1.0 times the γ-ray energy. The differential pulse height distribution was useful for determining these two points and in deciding at what point the background counting rate becomes excessive. Such a spectrum taken with a zirconium target not loaded with tritium shows that this excessive background point is a function of the proton energy, being 1/2 of the maximum pulse height at 3.0 Mev and rising to 2/3 of the maximum pulse height at 7.3 Mev.

The target thickness was taken into account by computing the beam energy loss as it traverses the target. This was done by calculating the rate of energy loss by the usual ionization loss formula. The mean ionization potential, I, was assumed to be 11.5 Z or 460 e.v. in zirconium. The mean energy in the target was found to be 0.98 of the initial energy at 7.4 Mev and became 0.90 of the initial energy if that energy was 3.0 Mev.

The particles being detected above 0.75 of the maximum gamma ray energy were shown to be the tritium gamma rays by absorption in lead and by the fact that the cross section at 0^{o} was less than 10 percent of the cross section at 90^{o}, in agreement with the $\sin^2 \theta$ distribution observed by Argo et al.[1] It was also observed that the mean pulse height varied appropriately with the gamma ray energy due to bombardment with protons of different energies.

D. CONCLUSION

The excitation function that we have observed at 90^{o} to the proton beam shows no evidence for a resonance up to 7.3 Mev proton energy. This shows that there cannot be an excited state in the $_2He^4$ nucleus up to an energy of 25.2 Mev. The slope of our excitation function in the region from three to four Mev proton energy is in agreement with Falk and Philips but is steeper than that reported by Perry. In addition, Perry and Bame[3] have made a rough measurement of the absolute cross section and we have indicated these values on the right hand scale of Fig. 3 with our curve normalized at 3 Mev.

Flowers and Mandl[7] have calculated a yield for this reaction which does not employ an excited state in the alpha-particle. They find good agreement with Argo et al up to 2.5 Mev by choosing a value of their parameter $\epsilon \cong 6$ Mev. A choice of ϵ, which is of the order of magnitude of the binding energy of a nucleon in the alpha-particle, of 8 Mev produces somewhat better agreement with our experimental curve. The curve for $\epsilon = 6$ bends over even more at high energies and is also plotted in Fig. 3. The choice of $\epsilon = 8$ does not greatly affect the agreement of the theory with Argo et al since the coulomb effect is predominant up to 2 Mev proton energy and it is not dependent on ϵ to a first approximation.

We would like to thank Prof. Luis Alvarez for suggesting this problem to us. The cooperation of the crew at the linear accelerator under the direction of Robert Watt and Wendell Olsen was greatly appreciated.

REFERENCES

1. Argo, et al, Phys. Rev., 78, 691, 1950.
2. C. E. Falk and G. C. Philips, Phys. Rev., 83, 468 1951.
3. J. E. Perry and S. J. Bame, Bull. Am. Phys. Soc., 28, No. 1, 1953.
4. J. Benveniste and B. Cork, Phys. Rev., 89, 422 (1953).
5. C. J. Borkowski and R. L. Clark, Bull Am. Phys. Soc., 27 No. 1, 8, 1952.
6. Mary Beth Stearns, Phys. Rev., 87, 706, 1952.
7. B. H. Flowers and F. Mandl, Proc. Roy. Soc. A, 206, 131, 1951.

Information Division
2/12/53   dm

FIGURE CAPTIONS

Figure 1; Pulse height distribution produced by,

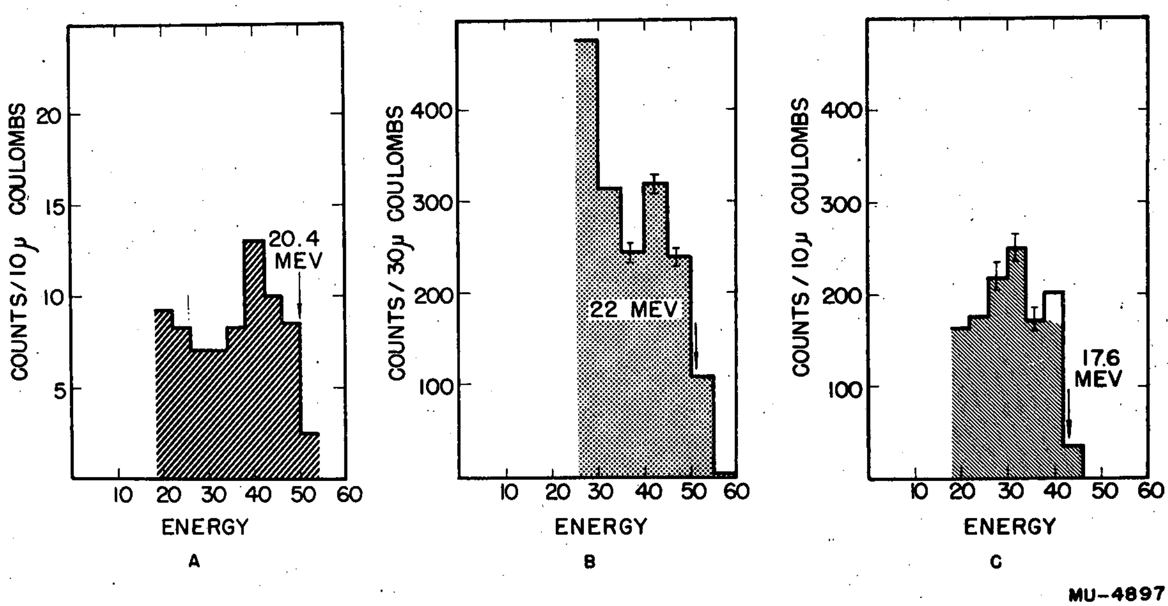
A. 20.4 Mev γ-rays from 0.9 Mev protons on Tritium.

B. 22 Mev γ-rays from 3.0 Mev protons on Tritium.

C. 17.6 Mev γ-rays from protons on thick lithium target.

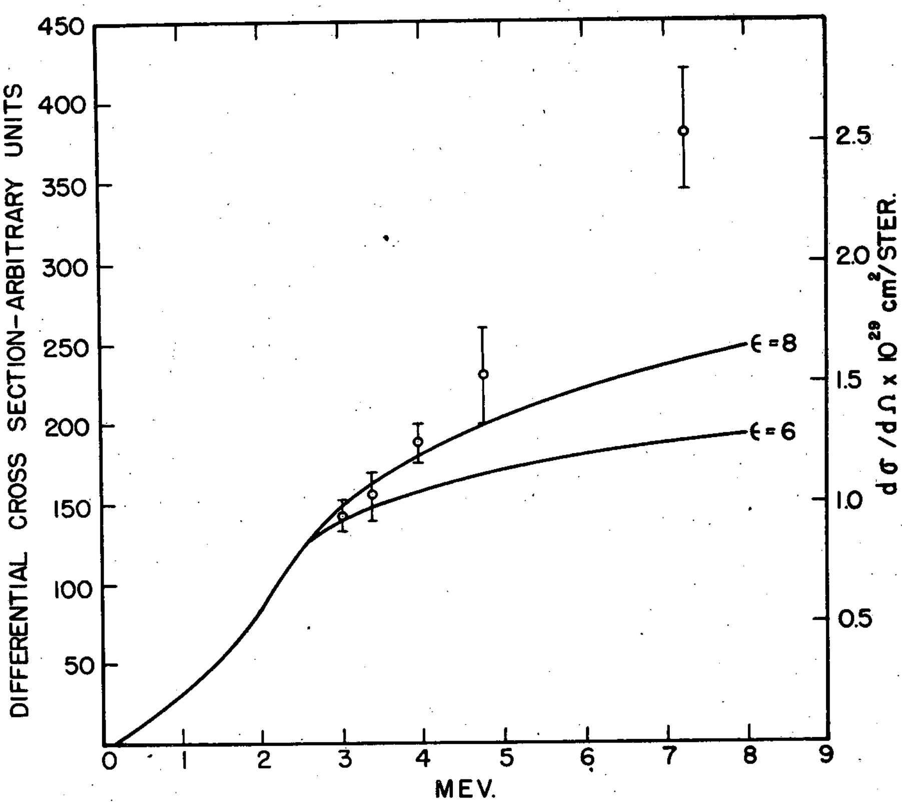
Figure 2; Pulse height distribution resulting from γ-rays emitted by the excited state in C^{12} produced in a Po-Be source.

Figure 3; Differential cross section as a function of incident proton energy, normalized to data of Perry and Bame at 3 Mev. Experimental points are shown with standard deviation due only to statistical fluctuation in the number of counts. The theoretical curve of Flowers and Mandl is plotted for two different values of their parameter ϵ.



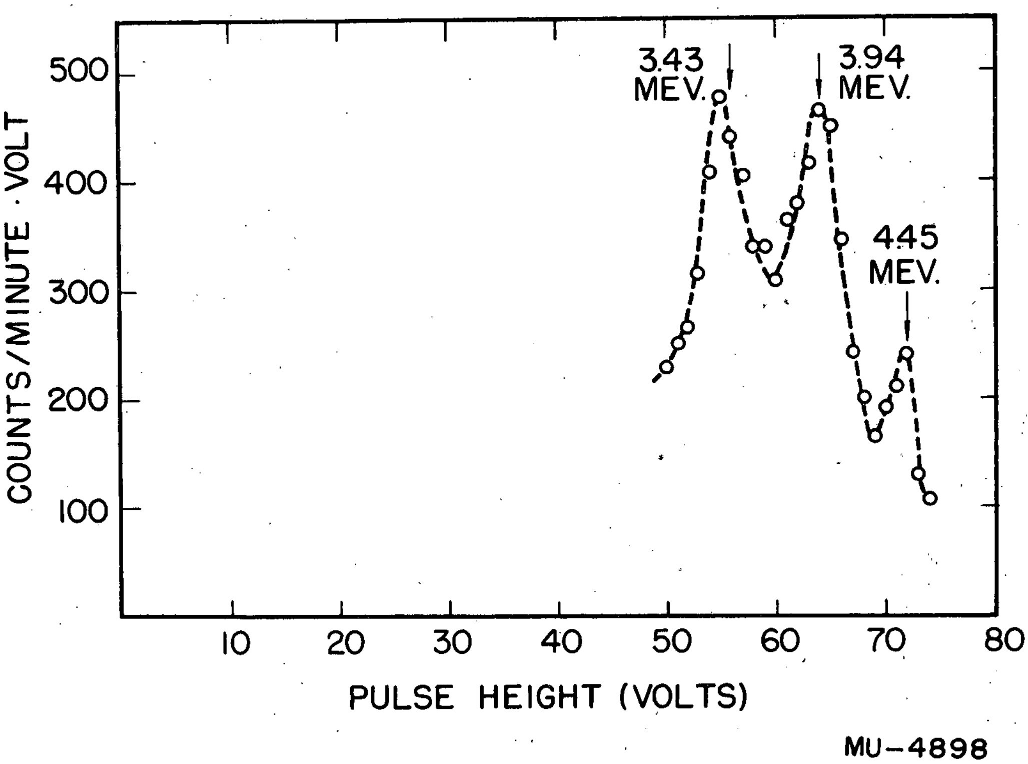
COUNTS/10μ COULOMBS
20
15
10
5
20.4
MEV
10 20 30 40 50 60
ENERGY
A
COUNTS/30μ COULOMBS
400
300
200
100
22 MEV
10 20 30 40 50 60
ENERGY
B
COUNTS/10μ COULOMBS
400
300
200
100
17.6
MEV
10 20 30 40 50 60
ENERGY
C
MU-4897

Fig. 1


DIFFERENTIAL CROSS SECTION-ARBITRARY UNITS
450
400
350
300
250
200
150
100
50
0
1
2
3
4
5
6
7
8
9
MEV.
2.5
2.0
1.5
1.0
0.5
dσ / dΩ x 10^29 cm^2/STER.
ε=8
ε=6

MU-4899

Fig. 3



3.43
MEV.
3.94
MEV.
4.45
MEV.
500
400
300
200
100
COUNTS/MINUTE · VOLT
10
20
30
40
50
60
70
80
PULSE HEIGHT (VOLTS)
MU-4898

Fig. 2