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DECAY OF He^8

A. M. Poskanzer, R. A. Esterlund, and R. McPherson

Chemistry Department, Brookhaven National Laboratory, Upton, New York

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The possible observation of He^8 was first reported in 1961 on the basis of two hammer tracks in emulsions.[1] In 1963 Nefkens[2] tentatively reported observing its decay with a half-life of 30 ± 20 msec on the basis of beta measurements on a boron target irradiated with photons. More, recently, Whetstone and Thomas,[3] while reporting their observation by means of a E-dE/dx counter telescope of He^6 from Cf^{252} fission, reported some events which could have been He^8, although the evidence was not conclusive. Cerny, Cosper, and Gatti,[4] from a similar experiment, report definitely having observed He^8 particles from Cf^{252} fission. It is the purpose of this Letter to report the decay properties of He^8, including our half-life measurement of 122 ± 2 msec, which indicates that the work of Nefkens is erroneous.

From the known energy levels of Li^8 (see Fig. 1), it was expected that He^8 would undergo beta decay to the 0.98-MeV level and to unbound levels at 3.21 MeV and higher energies. Thus, because the ground-state transition is second forbidden, every He^8 decay would be expected to lead to the emission of either a 0.98-MeV gamma ray or a delayed neutron. From $\log ft$ calculations performed by Kurath[5] and an estimate[6] of the mass of He^8, it was predicted that the half-life would be in the hundred-millisecond range and the delayed neutron branch would be of the order of 10%. Thus the main difficulty[7] in observing He^8 was expected to be the interference from 176-msec Li^9, a delayed neutron emitter which is likely to be produced in greater yield in practically any reaction which produces He^8.

The method adopted[8] involved the diffusion loss[9] of the active He from thin plastic foils or absorbent cotton fibers irradiated by the 2.2-GeV external proton beam of the Brookhaven Cosmotron. In the diffusion-loss method a recoil nucleus comes to the end of its range and then diffuses out of the last foil or fiber.[10] The He activity is then transported to the counters by expanding some carrier helium through the target volume into the evacuated counting chambers. The apparatus is shown schematically in Fig. 2. A plastic target consisted of a roll of 1-mil foil, 2 in. in diameter and 1 in. high, placed on a wire gauze $\frac{1}{2}$ in. above the bottom of an aluminum container. The center hole in the roll of plastic was plugged, and the roll was fitted snugly into the container so that helium carrier gas below the roll would

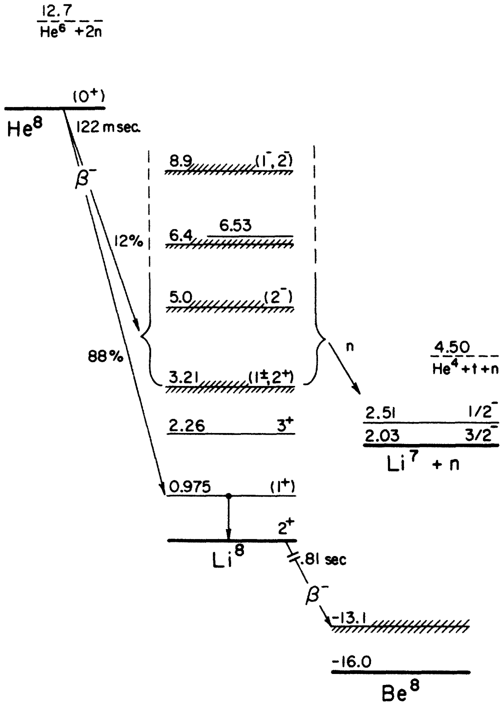

FIG. 1. The decay scheme of He^8, from Ref. 17 and the present work. All energies are relative to the Li^8 ground state.

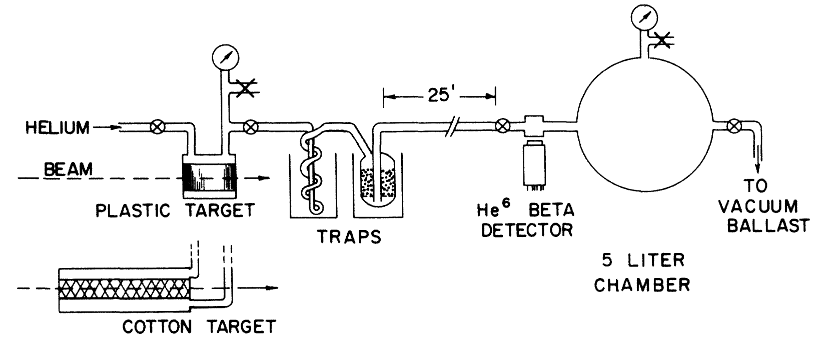

FIG. 2. A schematic diagram of the apparatus. The "X" within a circle represents a solenoid valve. Either the plastic or cotton target is used. For the measurements of the He^8 activity, neutron, beta, or gamma detectors are placed next to the 5-liter chamber.

pass up between the layers of foil to sweep the active He out of the target. The cotton target was contained between two strips of wire gauze in an aluminum cylinder 2 in. in diameter and 12 in. long. Thus the carrier gas had to pass through only 1 in. of cotton while the beam passed through 12 in. of cotton. Two Pyrex traps cooled by liquid nitrogen were used to purify the gas. The first one consisted of a helix and the second one was a cold finger filled with activated charcoal. 25 feet of $\frac{3}{8}$-in. i.d. rubber tubing connected the traps to the counting chambers situated outside the concrete shielding. Two counting chambers were used: a small one for testing the method by detection of He^6 and a larger one for the observation of He^8. The small chamber, of 60-cc volume, was used with a 5-mil brass window through which the He^6 beta particles ($E_{\beta\mathrm{max}} = 3.5$ MeV) could be detected by a plastic scintillator on a 2-in. phototube. The larger chamber was made of aluminum and was 14 in. in diameter by 2 in. thick, containing a volume of 4.8 liters. For neutron counting it was placed inside 200 lb of paraffin containing six BF$_3$ proportional counters.[11] For gamma counting, a 5-in.-diameter by 2-in.-thick NaI crystal was placed in contact with the chamber except for a total of 13/16 in. of aluminum absorber to stop the beta particles. For beta counting, a 5-in.-diameter by $\frac{1}{2}$-in.-thick plastic scintillator was placed in contact with the chamber except for a total of $\frac{1}{4}$ in. of aluminum absorber to stop only the He^6 beta particles.

Solenoid valves were used at each of the four positions: target-in, target-out, chamber-in, and chamber-out. The Cosmotron delivered one beam burst of 1-msec duration every three seconds. The procedure was to fill the target volume with helium carrier to about one atmosphere before the beam burst.[12] After the beam burst the target-out and chamber-in solenoids were opened for 200 msec to allow the gas to expand through the traps into the counting chamber. The decay of the activity was followed for two seconds by recording the counts in a multiscaler having a dwell time of 10 msec per channel. Then the chamber-out solenoid was opened for 0.8 sec in order to exhaust the gas into a large ballast tank connected to the house vacuum line.

In tests with 810-msec He^6 it was found that in 200 msec there was transported to the counting chambers 50% of the gas transported if the solenoids were kept open for a long time. Other observations indicated that most of this delay was due to hold-up in the traps and transport time through the tubing; the time for diffusion out of the plastic was less than 100 msec. Based on an estimated counting geometry of the small chamber, the cross section for the production of He^6 from cotton is calculated to be 0.9 ± 0.3 mb per carbon or oxygen atom. By comparison, the reported value[13] of the He^6 cross section from carbon is 0.6 ± 0.3 mb. This indicates that there is probably a good diffusion yield of the He^6 from cotton since it is expected that the cross section from oxygen would not greatly exceed that from carbon. He^6 was also observed in comparable yields from polystyrene, cellophane, and Teflon. It can be expected that the diffusion-loss process will be a valuable method for fast separations of many recoils from nuclear reactions which form volatile products stopping in foils or fibers of many kinds.

Delayed neutron counting was performed for the polystyrene, Teflon, and cotton targets.

A short-lived component was found which decayed to a long-lived tail equal to only one percent of the initial activity. From least-squares fits to all of the decay curves, our best value of the half-life of the short-lived component is 122 ± 2 msec. For the cotton target the beta and gamma activity in the large chamber was measured. The beta oounting also showed this short-lived component together with an approximately 800-msec tail. This tail could be due either to the Li^8 daughter of the He^8 or to the bremsstrahlung of the He^6 beta particles stopping in the aluminum absorber. A gamma spectrum was obtained by gating a multichannel analyzer on for 120 msec after the chamber-in solenoid closed. A peak was observed whose energy was determined, by means of Bi^{207} and Na^{22} standards, to be 0.99 ± 0.02 MeV, in good agreement with the expected Li^8 gamma transition of 0.975 MeV. The decay in a 20% wide channel centered on the peak again indicated this same short-lived component, which was absent when the channel was set just above the peak.[14]

We will now summarize the evidence for assigning this activity to He^8. Since the activity is a new delayed-neutron emitter produced from targets as light as carbon (polystyrene), it must be an isotope of hydrogen or helium with six neutrons or less.[15] If the activity were an isotope of hydrogen it would not come out of the Teflon target (which does not contain any hydrogen) as H_2 and thus would not pass through the liquid-nitrogen charcoal trap. Because we observe the activity in good yield from Teflon we conclude it is an isotope of helium. He^7 is reported to be particle unstable[6] and thus the isotope must be He^8. The observation of the 0.98-MeV gamma ray in Li^8 is added confirmation.

During both the neutron and gamma measurements, the beam intensity was monitored by means of foil activation in order to determine both the production cross section and delayed neutron branch of He^8. The efficiency of the neutron counter over the volume of the chamber was measured with a calibrated Ra-Be source to be (7.5 ± 0.4)%. Using the previously measured[11] energy response of this detector (which is fairly constant) and assuming an average He^8 neutron energy of 3 MeV, we must increase this efficiency by the factor 1.04. The efficiency of the gamma detector for 1.29-MeV gamma rays was determined by means of a sample of Ar^{41} which had been assayed by internal proportional counting. This efficiency (0.88 ± 0.04)%, was increased by the factor 1.25 ± 0.05, using ratios of calculated NaI efficiencies[16] and aluminum absorption coefficients, to obtain the efficiency for the 0.98-MeV photons. The results of these measurements indicate that He^8 has a delayed neutron branch of (12 ± 1)%. Its production cross section from cotton, assuming 100% diffusion yield, is 1.2 ± 0.4 μb per carbon or oxygen atom.

The decay scheme of Fig. 1 is based on the compilation of Lauritsen and Ajzenberg-Selove[17] and on the data presented here. In Ref. 17, the 0.98-MeV level is shown as 1^+ or 2^+. The assignment of 1^+ was indicated by shell-model calculations[18] and is now clearly a proper choice because the level is populated by allowed beta decay. Using our measured partial lifetime for the decay to the 0.98-MeV state, and a log*ft* value of 4.3 ± 0.3 calculated by Kurath[5] for this transition, we calculate that the mass of He^8 minus the mass of Li^8 is 11.5 ± 1.5 MeV, which is consistent with the published estimate[6] of 11.1 ± 0.4 MeV.

The authors wish to thank D. Kurath for communicating his log*ft* calculations to us before publication, J. B. Cumming for suggesting cotton as a target material, R. W. Stoenner for preparing and assaying the Ar^{41} activity, and M. L. Perlman for pertinent discussions.

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[10] Since in this case the range is thought to be several foils or fibers, the diffusion rate may be enhanced because of the damaged region or hole leading to the surface of the last foil or fiber. Figure 5 of R. L. Fleischer, P. B. Price, and R. M. Walker, Science 149, 383 (1965), shows a diagram of a hole which can be produced in some plastics by particles as light as a deuteron.

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[15] If it were produced in a reaction involving the emission of a negative pion or from the 1% isotope C^{13}, it could contain seven neutrons. However, its cross section from carbon would probably be two orders of magnitude lower than from heavier targets, while in fact, the yields from C, O, and F were comparable.

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SPECTROSCOPIC FACTORS AND l VALUES FROM DEUTERON STRIPPING

S. T. Butler, R. G. Hewitt, and R. M. May

Theoretical Physics Department, School of Physics, University of Sydney, Sydney, Australia

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It is the purpose of this note to report how l values and spectroscopic factors may apparently be accurately obtained from deuteron stripping results by a quite elementary computation which contains no adjustable or ambiguous parameters. This work represents a preliminary investigation of a new method for stripping recently proposed by Butler[1] and Tanifuji.[2]

We consider a (d,p) stripping reaction in which the incident and outgoing wave vectors are $\vec{k}_d$ and $\vec{k}_p$, respectively, and where the spins of the initial and final nuclei are J_i and J_f, respectively. The theoretical cross section, in terms of optical-model wave functions, is[3,4]

$$\frac{d\sigma}{d\Omega}=\frac{\frac{1}{2}m_p m_d}{(2\pi\hbar^2)^2}\frac{k_p}{k_d}\frac{(2J_f+1)}{(2J_i+1)}\sum_{lm}\frac{1}{2l+1}S(l,J_i,J_f)|M|^2, \qquad (1)$$

where the matrix element M is given as

$$M(\vec{k}_p,\vec{k}_d)=\langle\psi_d{}^+(\vec{k}_d,\vec{r}_p,\vec{r}_n)|V_{np}$$
$$\times|F_l{}^m(\vec{r}_n)\psi_p{}^-(\vec{k}_p,\vec{r}_p)\rangle\rangle. \qquad (2)$$

Here $\vec{r}_p$ and $\vec{r}_n$ are the neutron and proton coordinates, respectively. The wave function $\psi_d{}^+$ describes elastically scattered deuterons with outgoing spherical waves, $\psi_p{}^-$ describes elastically scattered protons with incoming spherical waves, and $F_l{}^m$ is the wave function of the final bound neutron with orbital angular momentum l and projection m, normalized to unity. The normal neutron-proton interaction is represented by V_{np}. In the form of Eq. (1) all other nuclear coordinates have been integrated out so that $\psi_p{}^-$ may be considered to be a known optical-model wave function. The factor $S(l,J_i,J_f)$ is the so-called spectroscopic factor which is a real positive number.

Strictly Eq. (1) may be considered to be a distorted-wave Born approximation (DWBA) cross section. However, in the usual evaluation of the matrix element M associated with DWBA calculations, the interaction V_{np} is taken to be of zero range, and in the wave function $\psi_d{}^+$ all internal distortion or polarization of the deuteron is neglected; in these calculations $\psi_d{}^+$ describes the center-of-mass motion of the deuteron as an optical-model wave function, but leaves the internal motion unpolarized, a procedure which is very difficult to justify.[3]

Extensive exploration of this DWBA approach over the past decade has left its status still somewhat obscure.[4] There are always ambiguities in the deuteron optical parameters, and until recently it was considered usually necessary to choose optical parameters different from those required to fit elastic scattering.[5] However, a satisfactory theory should, with no adjustable parameters, be able to fit data such that l values can be determined unambiguously and spectroscopic factors given accu-