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Energy Levels of Be^8

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The $\mathrm{Li}^6(\mathrm{He}^3,p)\mathrm{Be}^8$ reaction has been used in a study of the levels of Be^8 up to an excitation energy of 14 Mev. The protons were observed with a NaI scintillation spectrometer. The ground state, the 2.9-Mev state, and, tentatively, a 12.3-Mev state were the only levels observed. No evidence was found for levels at 4.05, 4.9, 5.3, or 7.5 Mev.

INTRODUCTION

In spite of the fact that Be^8 was one of the first nuclei to be studied with high-voltage accelerator techniques, there is still some doubt about the identities and positions of certain levels reported for this relatively simple nucleus.[1] Titterton has reviewed several papers in discussing evidence for Be^8 levels at 4.05, 5.3, and 7.5 Mev in addition to the well-established level at 2.9 Mev.[2] Levels have been reported at 2.2, 3.4, and 4.9 Mev in various other experiments in the past.[1] Recent work on α-α scattering by Steigert and Sampson has indicated a level in Be^8 at 7.5 Mev.[3] Jentschke has reported some new α-α scattering data which indicate a level at 11.8 Mev.[4]

In the past two years, a number of experimenters have reported on work in which they failed to find any low-lying levels in Be^8 except the ground state and the 2.9-Mev state. The first of these was a report from this laboratory on some preliminary work on the $\mathrm{Li}^6(\mathrm{He}^3,p)\mathrm{Be}^8$ reaction.[5] Although the statistical errors were rather large, no levels except the ground state and the 2.9-Mev state were found up to an excitation energy of about 8 Mev. Trail and Johnson have reported on a re-examination of the $\mathrm{Li}^7(dn)\mathrm{Be}^8$ reaction. By using a multichannel neutron telescope, they were able to get comparatively good statistics for the reaction. They found only the ground state and the 2.9-Mev state in the region up to 8 Mev.[6] Treacy has studied the α particles from the $\mathrm{B}^{10}(d,\alpha)\mathrm{Be}^8$ reaction and has found only the ground state and the 2.9-Mev state up to 7 or 8 Mev in Be^8, where the background of three-body breakup α particles begins to obscure the spectrum.[7] Holland, Inglis, Malm, and Mooring have studied both the $\mathrm{B}^{10}(d,\alpha)\mathrm{Be}^8$ reaction and the $\mathrm{B}^{11}(p,\alpha)\mathrm{Be}^8$ reaction at several angles and at several bombarding energies with very good statistics; they found only the ground state and the 2.9-Mev state up to 8 Mev in Be^8.[8]

The $\mathrm{Li}^6(\mathrm{He}^3,p)\mathrm{Be}^8$ reaction has several advantages in a search for levels in Be^8. Unlike the $\mathrm{Li}^7(d,n)\mathrm{Be}^8$ reaction, the outgoing particles are charged and corrections and normalizations of the data are usually more reliable. Unlike the $\mathrm{B}^{10}(d,\alpha)\mathrm{Be}^8$ and the $\mathrm{B}^{11}(p,\alpha)\mathrm{Be}^8$ reactions, the outgoing particle, being a proton, can be distinguished from the α particles following Be^8 breakup. Finally, the rather high Q-value for the $\mathrm{Li}^6(\mathrm{He}^3,p)\mathrm{Be}^8$ reaction makes a greater range of Be^8 excitation available for study. The possibility of confusion due to three-body breakup is common to all the reactions involving Be^8 except the α-α scattering process. The disadvantages of the $\mathrm{Li}^6(\mathrm{He}^3,p)\mathrm{Be}^8$ reaction are the small cross section and the fact that the Li^6 targets must be nearly free of Li^7 to avoid confusion from the competing reaction $\mathrm{Li}^7(\mathrm{He}^3,p)\mathrm{Be}^9$. Preliminary experiments using the reaction have been reported from this laboratory and also from Liverpool.[5,9]

APPARATUS

Doubly-charged He^3 ions were used in the new 625-kv Cascade Accelerator to get a bombarding energy of 1.25 Mev; by using a higher energy than was available previously, a considerable increase in yield was found compared to what had been observed in earlier runs. The targets were made by melting $(\mathrm{Li}^6)_2\mathrm{SO}_4$ in a thick layer on a tantalum backing. Since the yield curve for the reaction rises very steeply at this bombarding energy, most of the reactions occurred at or very near the surface of the thick target; thus the

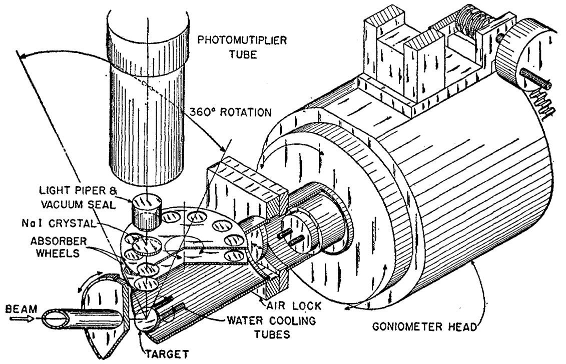

Fig. 1. NaI charged particle spectrometer.

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[5] Kunz, Moak, and Good, Phys. Rev. **91**, 676 (1953).

[6] C. C. Trail and C. H. Johnson, Phys. Rev. **95**, 1363 (1954).

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effective part of the target was thin compared to instrumental uncertainties. Target materials assaying 92.5%, 99.8%, and 99.96% isotopic purity were furnished by the Stable Isotopes Division of this Laboratory. The targets were mounted in the charged particle spectrometer shown in Fig. 1. The spectrometer is fitted with a selection of absorbers which may be placed between the target and the NaI detector. The spectrometer may be rotated with respect to the beam through the angular range from 45° to 135°. Pulses from the photomultiplier were amplified and analyzed with a 120-channel serial-memory quartz delay-line analyzer.

RESULTS

The accompanying reaction $Li^7(He^3,p)Be^9$, giving rise to several sharp proton groups and one broad proton group,[10] was used to estimate the sensitivity of the experiment to weak Be^8 levels. By gradually improving the isotopic purity of the Li^6 targets, the point was reached at which reliable detection of the contamination reaction was lost. Measurement of these weak intensities then gave an indication of the sensitivity for detection of weak Be^8 levels at various energies for the case of a sharp group and for the case of a group having a width of approximately 1 Mev. It was found that in the range of Be^8 excitation from 3.5 Mev to 14 Mev sharp groups were detected having an intensity of 1% of that of the transition to the 2.9-Mev state in Be^8. The sensitivity is only three times less than this for a level width of 1 Mev. Since the resolution of the instrument is not as great as that of typical magnetic spectrometers, the difference between a sharp group and a broad one is not as great.

At an isotopic purity of 92.5% the $Li^7(He^3,p)Be^9$ proton groups were reduced to less than 5% of the 2.9-Mev transition intensity from $Li^6(He^3,p)Be^8$. By using a target of 99.96% purity these groups were further reduced by more than two orders of magnitude so that runs could be made on Be^8 alone with no chance of spectrum contamination from the $Li^7(He^3,p)Be^9$ reaction.

At 45° the center-of-mass motion increases the energy of the protons for a given excitation in Be^8, making a greater range of excitation available for study. Runs were made at 90° and at 135° with only one-third as many counts as were taken at 45°. Results at 90° and at 135°, while covering a somewhat smaller energy range, were in agreement with the results found at 45°. An aluminum absorber was selected which would screen out the most energetic α particles arising in the reaction. The data taken at 45° and 1.25-Mev He^3 bombarding energy are shown in Fig. 2. Curve II was derived by taking account of the fact that a low-energy proton loses more energy in passing through the aluminum absorber than does a proton of higher energy; a small effect due to center-of-mass motion was also taken into account. Curve II is the derived spectrum normalized to unit energy interval in Be^8 rather than unit pulse height interval. The total count was 10^6 and the statistical uncertainties vary from 1.4% in the region near channel 60 to 0.6% at channel 84. The data indicate that for this reaction no transitions to sharp levels in Be^8 between 3.5 Mev and 14 Mev have intensities as great as 1% of the transition to the 2.9-Mev level; no transitions to a level 1 Mev wide or less occur with as great as 3% of the intensity of the transition to the 2.9-Mev level.

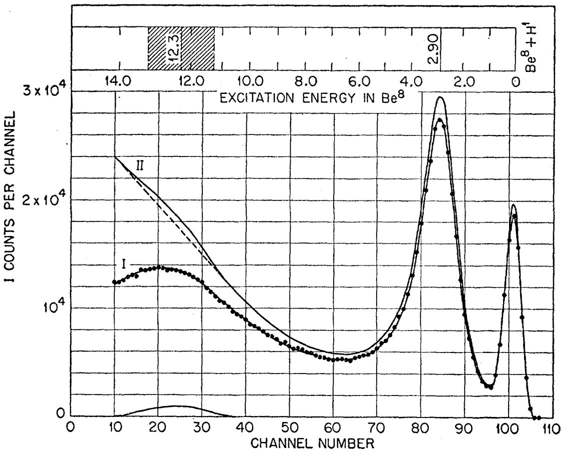

FIG. 2. I. Pulse-height spectrum in NaI for the reaction $Li^6+He^3\rightarrow Be^8+H^1$ taken at 45° with respect to the incident beam. He^3 bombarding energy 1.25 Mev. II. Data points normalized to unit energy interval instead of unit pulse-height interval and plotted to arbitrary scale.

In addition to the monotonic rise toward low pulse height attributable to $Li^6(He^3,p\alpha)\alpha$, the three-body breakup, there is some indication of a broad peak in the curve in this region. The broad level which appears to exist at 12.3 Mev in Be^8 may be removed by constructing a fictitious range-energy relation for the aluminum absorber to straighten out the upper curve in that region. This was done and it was found that the new normalization curve would indicate errors in the dE/dx values for Al in excess of 20% over a range of several Mev. Since these values are believed to be known far more accurately than this, it is concluded that the data give tentative evidence for a broad level in Be^8 near 12.3 Mev with a width of approximately 2 Mev and an intensity 5.6% of that of the 2.9-Mev transition. It is believed that this may be the level observed in the α-α scattering experiments described by Jentschke.[4]

SUMMARY

The $Li^6(He^3,p)Be^8$ reaction has been carefully examined for Be^8 levels in the range zero to 14 Mev. The ground state, the 2.9-Mev state and, tentatively, a 12.3-Mev state have been found. No other levels were observed, and it is believed that a sharp level for which

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[10] Moak, Good, and Kunz, Phys. Rev. **96**, 1363 (1954).

the transition is 1% as intense as the 2.9-Mev transition would have been observed.

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Radiation Widths of Nuclear Energy Levels*

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The highly excited energy levels formed by capture of slow neutrons can be studied by means of the resonances in neutron cross sections as functions of energy. In the present work the radiation widths of levels in heavy nuclei have been measured by means of total cross section curves obtained with the Brookhaven fast chopper. The "shape," "area," and "interference" methods of analyzing the neutron transmission data are described. The radiation widths obtained, together with results of similar measurements, show that radiation widths of levels in the same nuclide are nearly constant, the observed variations from level to level being of the order of the experimental error. The radiation widths decrease slowly with atomic weight, except for discontinuities at nuclear shells; these discontinuities can be satisfactorily correlated with variations in excitation energy and level spacing at the shells. The variation of radiation width with excitation energy and level spacing is consistent with theoretical calculations for electric dipole transitions; the absolute theoretical widths are too large by an order of magnitude, however.

I. INTRODUCTION

THE purpose of this investigation is to study the dependence of the radiation widths of slow-neutron resonances on atomic weight, excitation energy, level spacing, and other nuclear properties. Such information is needed to assist the advance of theoretical understanding of electromagnetic radiation phenomena in nuclei. For many years arguments have been offered to show that nuclear electric dipole radiation is improbable[1,2]; in fact, for a model which views the nucleus as a liquid drop in which the motions of the neutrons and protons are strongly correlated, no electric dipole radiation is possible. These arguments, however, do not affect magnetic radiation or higher electric multipole radiation. Theoretical estimates[3] of radiation widths of slow-neutron resonances, based on a modified independent-particle model, are a factor of 300 larger than the experimentally observed values. On the other hand, for those cases where it has been possible to compare the emission probability of competing radiations of different multipole orders, it has been found[4] that the relative probabilities are in good agreement with the predictions of the independent-particle model.

The interpretations of several recent experiments also depend on a knowledge of Γ_γ as a function of atomic weight and excitation energy. Hughes *et al.*[5] have measured the capture cross section of many elements for a spectrum of unmoderated fission neutrons. It has been shown by Bethe[6] that these cross sections are proportional to Γ_γ/D, where D is the average spacing of neutron resonances. In inferring D from these capture cross sections, Hughes *et al.* assumed a monotonic dependence of Γ_γ on atomic weight A, as given by Heidmann and Bethe.[7] If this dependence of Γ_γ on A is not monotonic, but instead shows structure, it may modify the conclusions drawn concerning the dependence of nuclear level density on atomic weight, particularly in the region of magic numbers. Another example of an experiment where information about Γ_γ is needed is found in the analysis of neutron resonances by area methods, where it is often necessary to know the radiation widths in order to obtain the other parameters of the levels. The recent work of Carter *et al.*[8] on the dependence on atomic weight of the ratio of the average reduced neutron width to the average level spacing is such a case.

At the time this study of radiation widths was begun, all the information available on Γ_γ had been summarized by Teichmann,[9] Blatt and Weisskopf,[10] Heidmann and Bethe,[7] and Feld.[11] The radiation widths of only a

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