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SURVEY OF SEVERAL OF THE REACTIONS OCCURRING WHEN LITHIUM AND BERYLLIUM ARE BOMBARDED BY PROTONS AND DEUTERONS OF 30 - 250 KEV

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PHYSICS

ABSTRACT

Approximate cross sections based on 90° yields have been measured for the following reactions in the energy interval 30-250 kev.

1. $Li^6(p,\alpha)He^3$
2. $Li^7(p,\alpha)He^4$
3. $Li^7(p,\gamma)Be^8$
4. $Li^6(d,\alpha)He^4$
5. $Li^6(d,p)Li^7$
6. $Li^7(d,n)He^4 + He^4$
7. $Be^9(d,\alpha)Li^7$
8. $Be^9(d,p)Be^{10}$ - Long range protons
9. $Be^9(d,p)Be^{10*}$ - Short range protons
10. $Be^9(p,\gamma)B^{10}$

If an isotropic distribution of the reaction products is assumed, no unreported resonances were found. Gamow plots with the theoretical slopes pass through the measured points within experimental error.

ACKNOWLEDGMENT

We acknowledge with pleasure the assistance of A. Ronzio, who weighed the targets which made absolute determinations of the lithium cross sections possible; R. G. Thomas, who advised on theoretical considerations of the problem; and N. B. Humphrey, who aided in taking the data.

1. Introduction

This work is a continuation of the activities of Group P-7 in investigating the nuclear reactions of the light elements at low energies. A survey has now been made of several of the reactions which occur when lithium and beryllium are bombarded by protons and deuterons of energy 30-250 kev. It was of particular interest to determine whether there might be unreported resonances or whether the cross sections would give straight line Gamow plots in this energy range.

Since precise determinations of the cross sections were unnecessary, the following simplifying assumption was made: For all the reactions considered in this report it was assumed that the angular distributions of the reaction products are isotropic. This assumption does not hold for some of the reactions, but it is thought that any asymmetry will not change materially in this energy range. The cross sections were then calculated from 90^{o} yields and are to be considered only as approximate values.

2. Apparatus and Method

2.1 Target Chamber. The analyzed beam of protons or deuterons from a 250-kev Cockcroft-Walton accelerator was collimated by a series of apertures, and currents up to 25 μa were focused upon an area of about 20 square millimeters of the target. The beam current was monitored by a microammeter. The target support was water-cooled and a liquid air trap in front of the target helped to prevent the growth of contaminants on the surface of the target.

2.2 Detectors. To detect γ-rays a large NaI phosphor photomultiplier detector (3" diameter, 3" long) was placed outside the vacuum, at 90^{o} with respect to the incident beam, 5/8" from the target. The close proximity of the large detector to the target, made necessary to obtain a sufficient counting rate, led to "poor geometry," with the result that the values of the cross sections for γ-ray emission are probably low.

Reaction charged particles which came off at 90^{o} were collimated and counted by a proportional gas counter. To make the assignment of possible reactions with particular groups of pulse heights, this proportional counter could be replaced by a NaI crystal and photomultiplier. Data by Taylor, et al.[1] were used to calculate particle energy from the pulse height.

2.3 Targets. The lithium targets were prepared by evaporating LiF onto polished aluminum, copper, and platinum plates which were, in turn, screwed onto the target support. $Li^{6}F$ and $Li^{7}F$ were available as aids in identifying the reaction particles. These targets were about 8μg/cm^{2} thick. Thick targets of LiF were made by fusing the LiF onto a copper plate.

A thick beryllium target was made from 1/16" stock.

2.4 Absolute Cross Sections. The number of Li target atoms per square centimeter was determined by weighing the amount of LiF evaporated from a platinum boat onto platinum target holders. The number of counts per microcoulomb of beam per microgram per square centimeter of LiF for three such weighings agreed within 10%. The probable error assigned to the Li cross sections with the assumption of spherical symmetry for the reaction products is $\pm 25\%$.

The beryllium cross sections were calculated from thick target data using Warshaw's[2] data for the energy loss of protons in beryllium. Assuming spherical symmetry for the reaction products, the probable errors are $\pm 20\%$.

3. Results

3.1 Lithium

The measured cross sections as a function of energy are shown in Fig. 1.

Thin target yields (Y) for several of the reactions were determined as a function of bombarding energy (E). Gamow plots of the data (ℓn YE vs $E^{-1/2}$) gave straight lines (Fig. 2). Moreover, the slopes of these lines for reactions with a common bombarding particle were the same, i.e., the ratios of the yields remained constant as a function of bombarding energy.

The absolute values of the slopes, however, did not agree with those predicted from theory. The difficulty was traced to the fact that the thin targets ($\sim 7\ \mu g/cm^2$) became "thick" targets at small bombarding energies where the cross sections vary rapidly with energy. Thick target data were taken and differentiated in 2-kev intervals, and straight lines with the theoretical slopes were obtained (Fig. 3). The yields as a function of energy for the reactions (taken for thin target data) were then corrected.

1. $Li^6(p,\alpha)He^3$ $\qquad Q = 4.017$ Mev

2. $Li^7(p,\alpha)He^4$ $\qquad Q = 17.337$ Mev

The pulse height analysis of normal LiF bombarded with protons is shown in Fig. 6a. The identity of the groups was made by using targets of Li^6F and Li^7F.

The angular distribution of the α-particles from reaction (1) has been reported[3] to be isotropic at $E_p = 200$ kev.

The total cross section at $E_p = 200$ kev reported here is in fair agreement with Burcham and Freeman[4] but high compared with others.[5]

3. $Li^7(p,\gamma)Be^8$ $\qquad Q = 17.242$ Mev

No resonances were found in this energy range. The cross sections as determined are probably low since the efficiency of the detector has been calculated ideally.

4. $Li^6(d,\alpha)He^4$ $Q = 22.357$ Mev

5. $Li^6(d,p)Li^7$ $Q = 5.020$ Mev

The pulse height analysis from a Li^6F target is shown in Fig. 6b. The protons from the $H^2(d,p)H^3$ reaction (bombarding deuterons absorbed in the target material) gave a calibration point for the detector.

6. $Li^7(d,n)He^4 + He^4$ $Q = 15.112$ Mev

A pulse height analysis gave a continuous distribution with a maximum pulse in agreement with an α-particle of energy 8.4 Mev. The measured cross section would be low in that many of the low energy α-counts were lost in the noise of the detector.

7. $Li^6(d,\gamma)Be^7$ $Q = 5.600$ Mev

No significant yield was obtained.

8. $Li^7(d,\gamma)$

A pulse height analysis of the γ-rays obtained when Li^7F was bombarded by deuterons had the same distribution as that obtained from brass bombarded with deuterons. It was therefore impossible to separate any Li^7 γ-rays from those of possible contaminants.

3.2 Beryllium

The values of the cross sections obtained for beryllium are shown in Fig. 4.

1. $Be^9(d,\alpha)Li^7$ $Q = 7.151$ Mev

2. $Be^9(d,p)Be^{10}$ - Long range protons $Q = 4.585$ Mev

3. $Be^9(d,p)Be^{10*}$ - Short range protons

The pulse height analysis from a thick beryllium target is shown in Fig. 6c. The α-particles and short and long range protons are well resolved.

It is known that the angular distributions of these reaction products are not isotropic,[6] and the cross section reported here for reaction (2) is about twice that obtained by De Jong, et al.[6]

4. $Be^9(d,t)Be^8$ $Q = 4.591$ Mev

The tritons ($E_T = 4.06$ Mev) from this reaction were unfortunately masked by the protons ($E_p = 3.02$ Mev) from the $H^2(d,p)H^3$ reaction. De Jong, et al.[6] report that at $E_D = 295$ kev the cross sections for $Be^9(d,p)Be^{10}$ and $Be^9(d,t)Be^8$ are the same.

There is a continuous distribution of pulse heights, as seen in Fig. 6c, from some three body breakup. The maximum pulse height might be attributed to tritons from the $Be^9(d,t)2\alpha$ reaction if it occurred.

5. $Be^9(p,\gamma)B^{10}$ $\qquad$ $Q = 6.585$ Mev

A resonance for this reaction is known to exist at $E_p = 336$ kev with half-width 175 kev. The cross section as a function of energy has been calculated using the Breit-Wigner one-level dispersion formula. Since a precise value of the cross section for this reaction is not known, the theoretical cross section has been normalized to the experimental data at 113 kev. The theoretical curve and the experimental points have the same shape and are shown in Fig. 5. A straight line having the slope of an expected Gamow plot which should exist at low energies is also shown.

3.3 Gamow Slopes.

A plot of $\ell n\ \sigma E$ vs $E^{-1/2}$ for the reactions examined, excepting $Be^9(d,\gamma)B^{10}$, gave straight lines. The slopes of these lines have been compared to theoretical values as calculated from the equation

$$\sigma = \frac{A}{E}\, e^{-2\pi Z_1 Z_2 e^2/hv}$$

The results are shown in the following table.

Reaction	Theoretical Slope	Experimental Slope	Ratio = $\frac{\text{Experimental Slope}}{\text{Theoretical Slope}}$
$Li^6(p,\alpha)He^3$	94.2	96.5	1.024
$Li^6(d,\alpha)He^4$	133.2	128.8	0.967
$Be^9(d,\alpha)Li^7$	177.6	191.9	1.081
$Be^9(d,p)Be^{10}$	177.6	184.1	1.037
$Be^9(d,p)Be^{10*}$	177.6	189.9	1.069
$H^2(d,p)H^3$	44.4		

4. Conclusion

The cross sections have been measured as a function of energy for several reactions when lithium and beryllium are bombarded by protons and deuterons. No unexpected resonances were found, and within experimental error a Gamow plot gave straight lines with the theoretical slopes in the energy interval 30-250 kev. If isotropic distribution of the reaction products is assumed, the values of the cross sections are in fair agreement with other determinations.

5. References

1. C. J. Taylor, et al., Phys. Rev. 84, 1034 (1951).
2. S. D. Warshaw, Phys. Rev. 76, 1759 (1949).
3. Von H. Neuert, Physik. Z. 38, 618 (1937).
4. Burcham and Freeman, Phil. Mag. 41, 921 (1950).
5. Rumbaugh, Roberts, and Halfsted, Phys. Rev. 54, 657 (1938).
   Bashkin and Richards, Phys. Rev. 84, 1124 (1951).
   R. B. Bowersox, Phys. Rev. 55, 323 (1939).
6. De Jong, Endt, and Simons, Physica XVIII, No. 10 (1952).

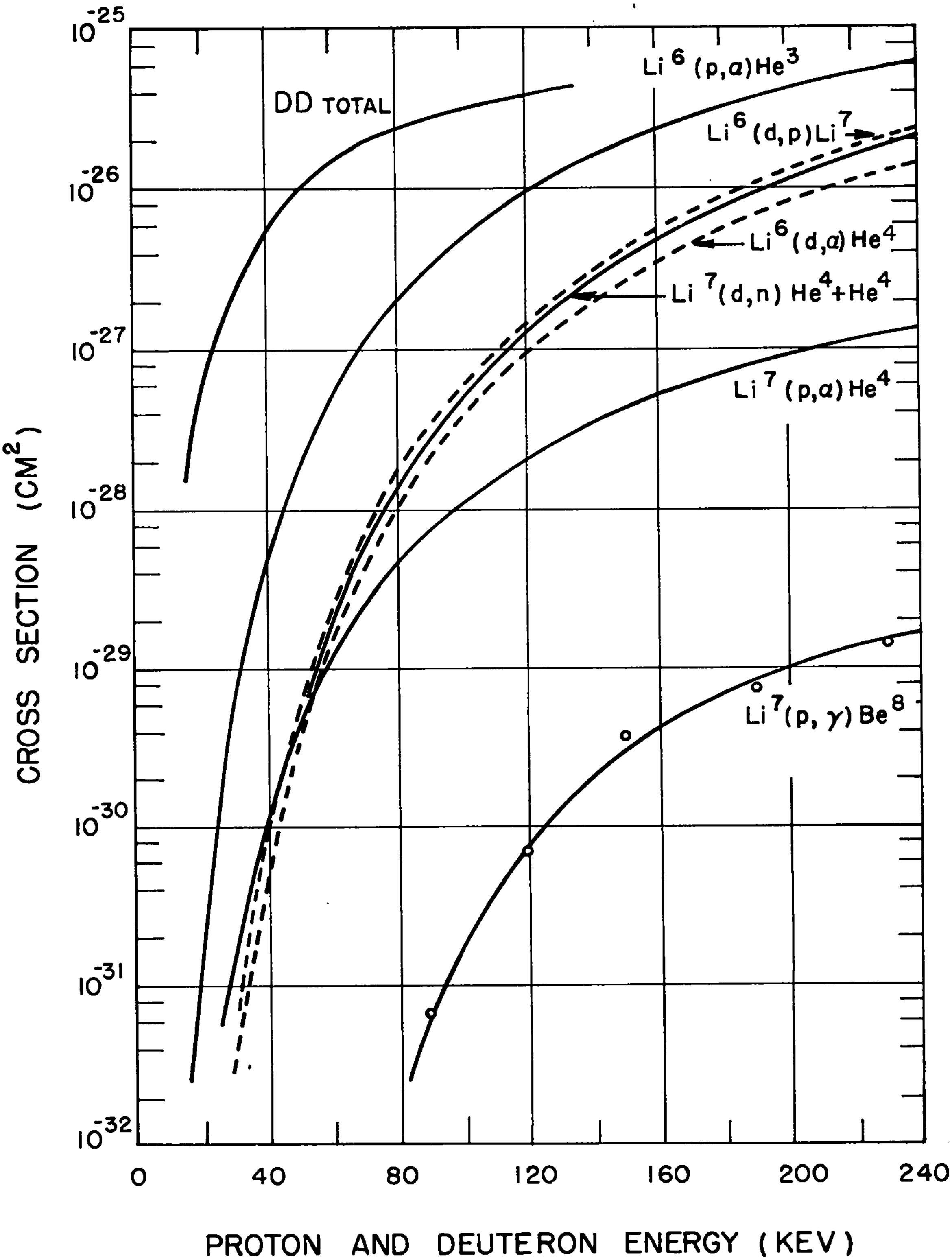

Fig. 1. Lithium reaction cross sections. DD_{total} taken from LA-1480.

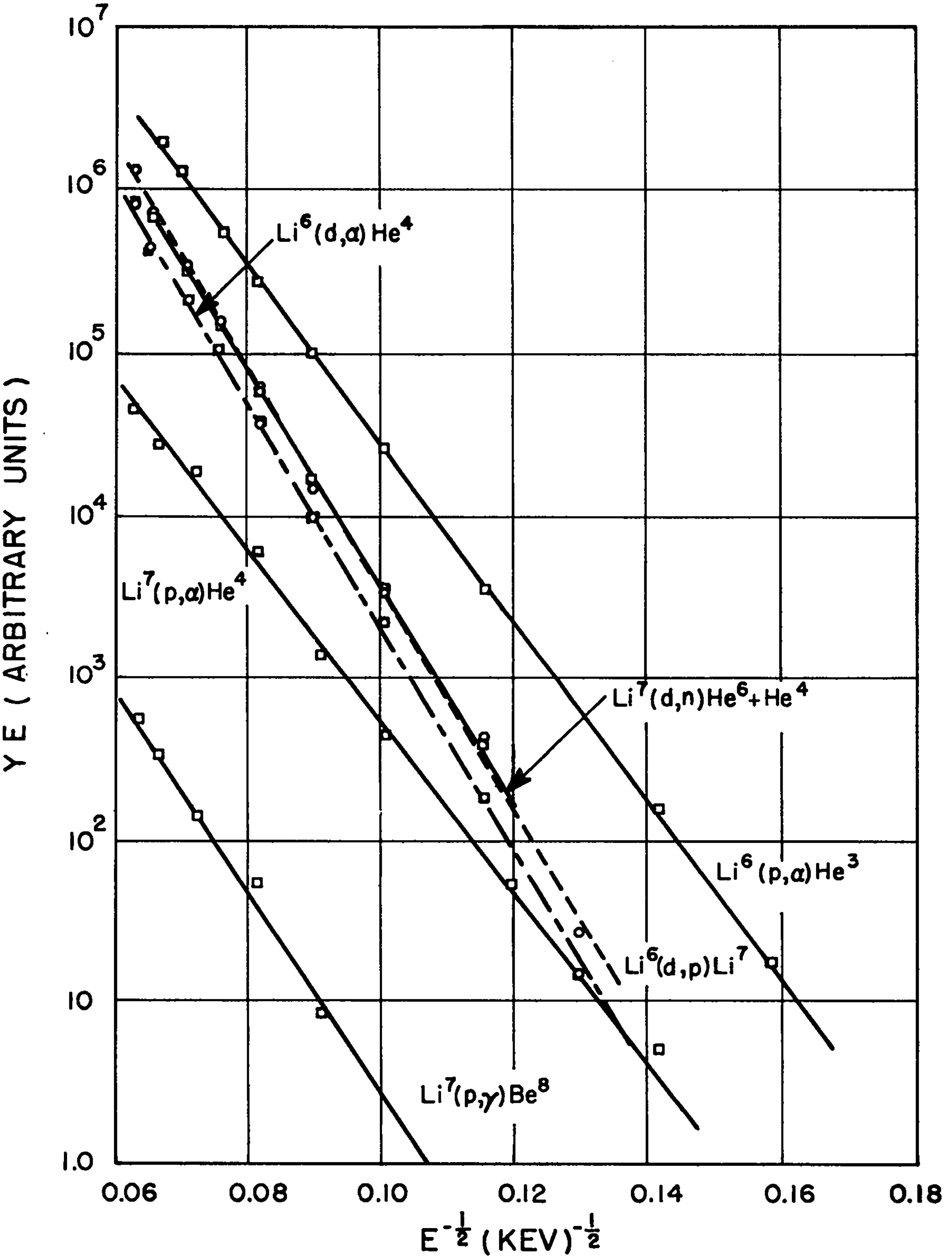

Fig. 2. Gamow plots of thin lithium target yields.

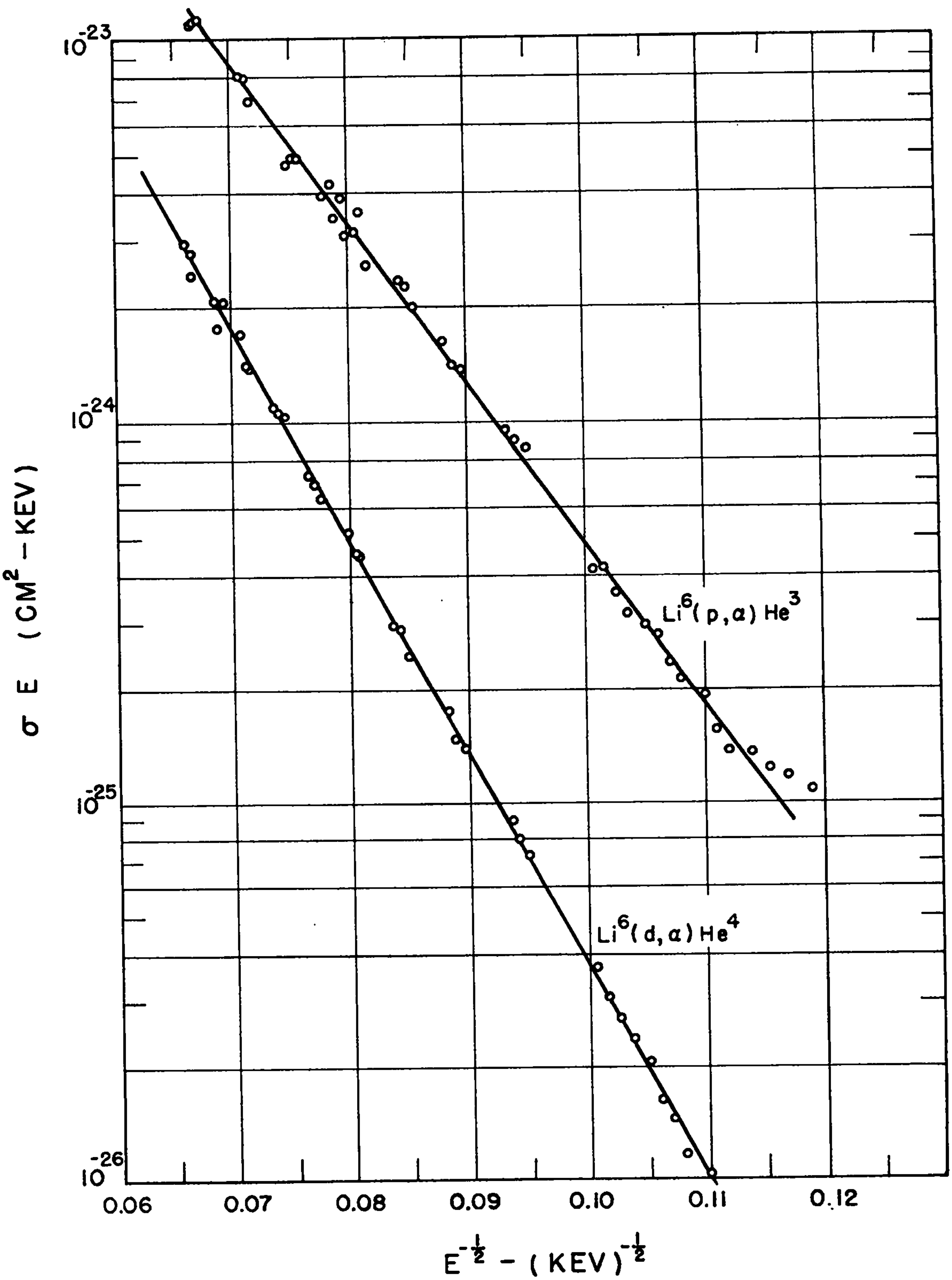

Fig. 3. Gamow plots of thick lithium target yields differentiated in 2-kev intervals.

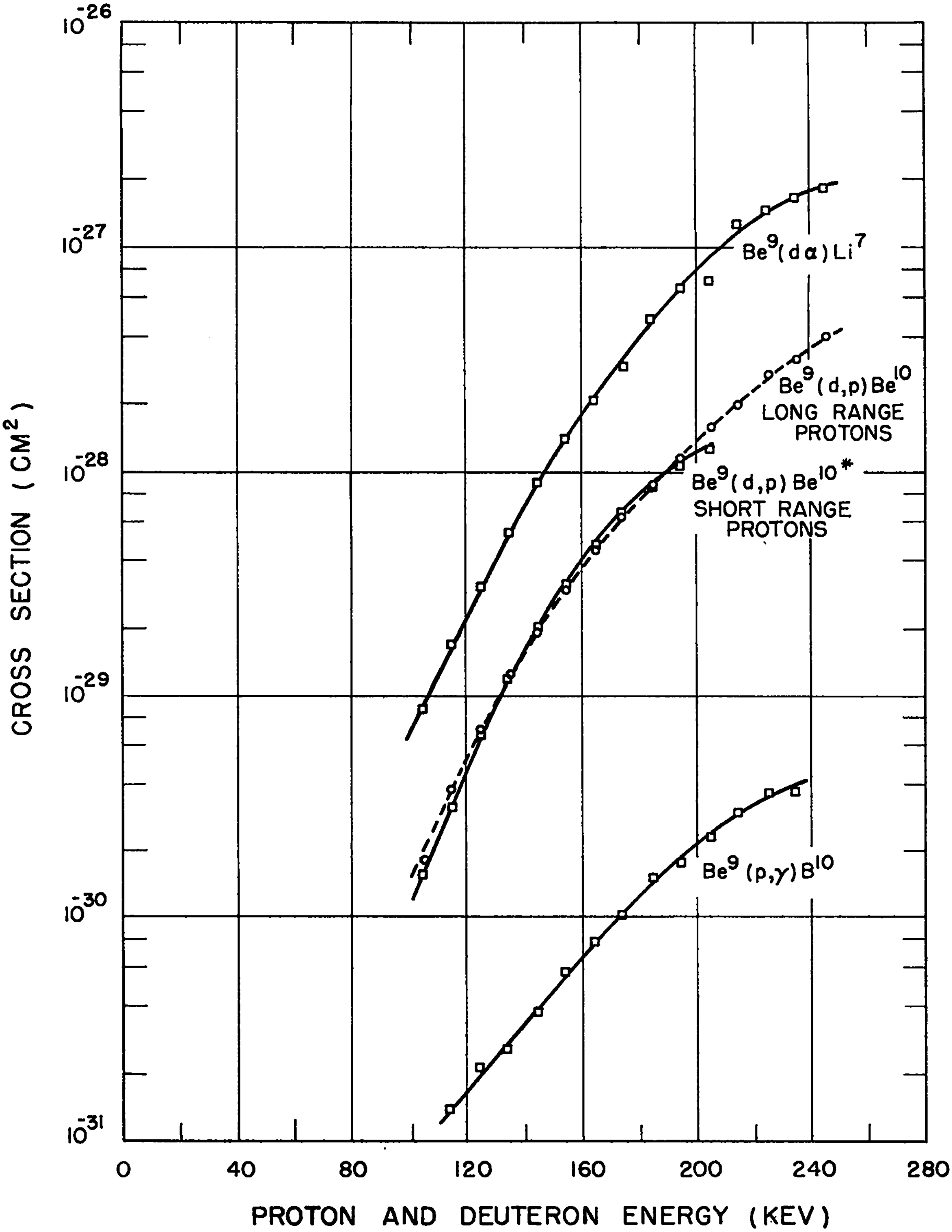

Fig. 4. Beryllium reaction cross sections.

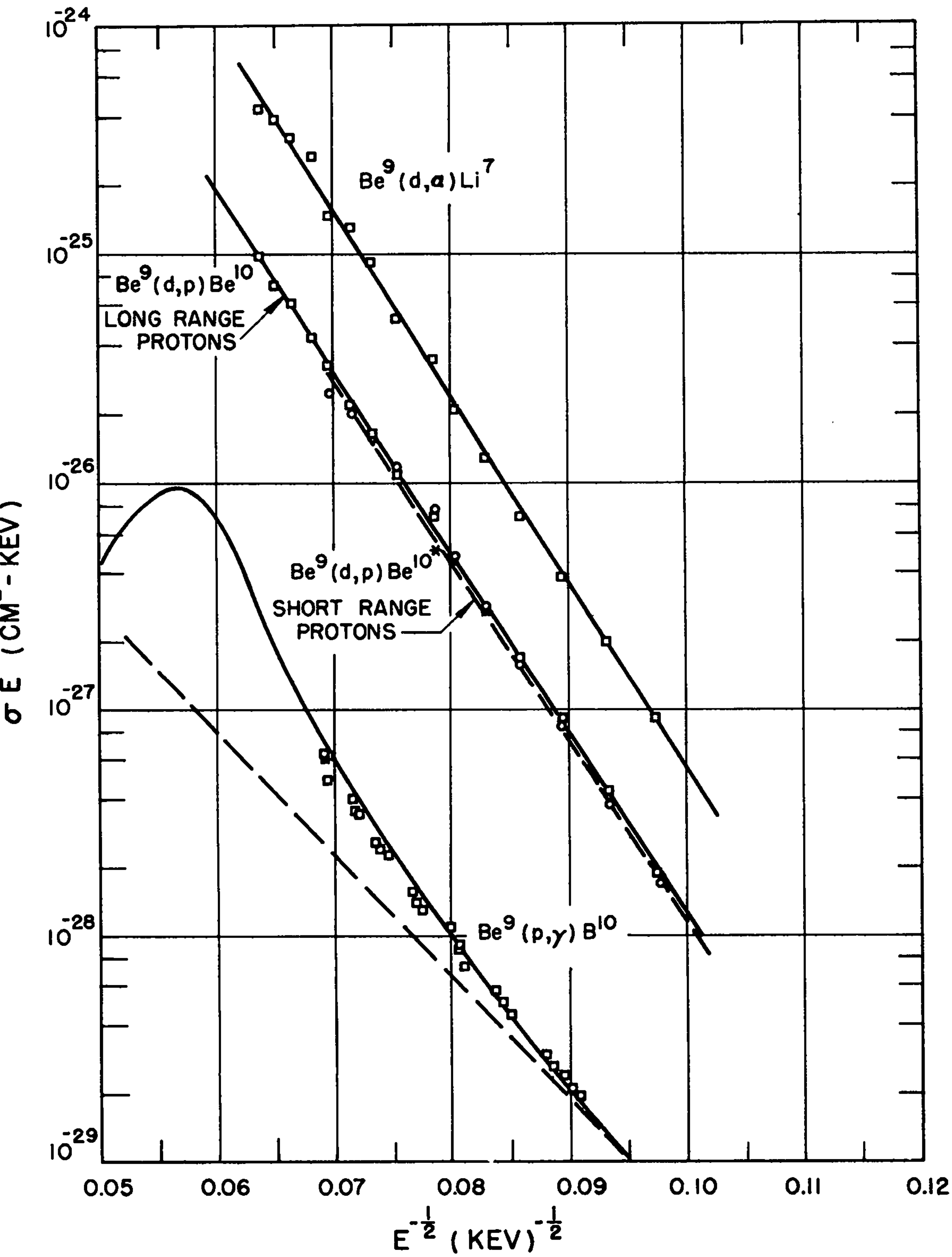

Fig. 5. Gamow plot of beryllium cross sections.

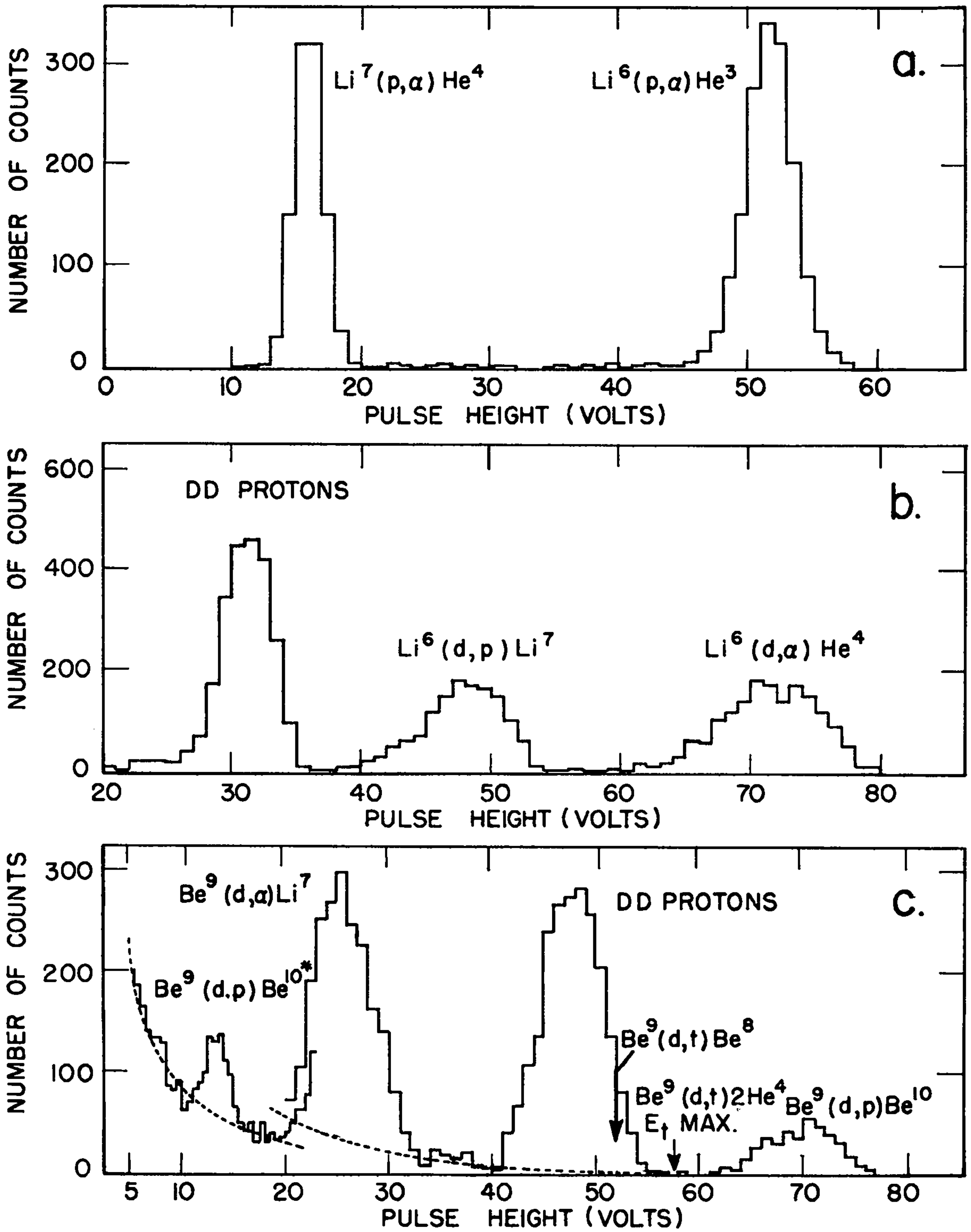

Fig. 6. Pulse height analysis of:

a) LiF bombarded by protons

b) Li^6F bombarded by deuterons

c) Be^9 bombarded by deuterons