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# Reactions Induced by the Alpha Particle Bombardment of $B^{11}$

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Abstract.

Alpha particles from the tandem Van de Graaff generator were used to bombard a $B^{11}$ (98%) target on a copper backing in steps of 16.6 kev or 33.3 kev from 6.5 to 10 Mev. The energy spectra of the charged particles from the reaction were found by using lithium drifted silicon surface barrier detectors, placed at angles of $90^{\circ}$, $135^{\circ}$ and $160^{\circ}$ to the beam. Neutrons were detected by a long counter at $0^{\circ}$, and low energy gamma rays by a 3 x 3 in. NaI (Tl) crystal-photomultiplier setup at $135^{\circ}$.

## Introduction.

Alpha particles in the range from 6.5 to 10 Mev have not previously been used to bombard $B^{11}$ to investigate nuclear levels. Shire *et al*[1,2], investigated the reaction from 1.4 to 2.4 Mev, Trumble[3] to 3 Mev, Manni *et al*[4] up to 4.6 Mev, Bonner *et al*[5] up to 5 Mev and Haddad *et al*[6] up to 6.89 Mev. Walker[7], using a polonium source, found the total cross section for neutron emission to be 0.17 b at 4 Mev, and 0.22 b at 5 Mev, in rough agreement with the results of Bonner *et al*.

Other investigations in this region of the compound nucleus $N^{15}$ have also been made using the reaction $C^{13} + d$[8]. Results from the reaction $C^{14} + p$ do not extend this far, although the reaction $N^{14}$ $(n, \alpha)$ exhibits resonances in this region[9,10,11], as do $C^{12} + t$ reactions[12].

The present experiments were performed to investigate the level structure and hence the validity of the compound nucleus model, in this highly exited region, which is of interest because of the collective motion of the giant resonance.

## Apparatus.

A beam of alpha particles was provided by the tandem Van de Graaff generator at the California Institute of Technology. The alpha particles were accelerated initially by a small (600 kev) Van de Graaff generator, and passed through a charge adding canal, to provide as large a percentage of neutral atoms as possible. These drifted to the center of the terminal of the tandem accelerator, where they were stripped of electrons, and the doubly charged alpha particles accelerated to the required energy (up to 11 Mev) in the second stage of the tandem. They were then analyzed by a resolving magnet and focused using quadrupole lenses into the target box shown in Figure 1.

The target was prepared by cracking $B^{11}$ in the form of gaseous diborane, on to a copper backing, using radiofrequency heating. Three methods were employed to measure the thickness. The first involved finding the minimum width of all the levels investigated. In the second, the energies found for our levels were compared with those for other workers using thin targets. The third method employed comparing the yield from our target with the yield found by other workers at low energies. This last method did not agree well with the other two, possibly because of contamination of the target. The level widths indicated a target thickness of 210 ± 33 kev at 5 Mev. This corresponded to only 125 kev at 10 Mev. The comparison of levels at 4.96 and 5.00 Mev with the work of Bonner et al[5] gave 220 kev for the thickness.

The target was attached to a rod at the center of the scattering chamber, and this was adjusted so that the alpha particle beam fell on the middle of the target at an angle of 45°. The target and holder were insulated from the chamber, and held at a positive potential to suppress secondary emission. Total charge falling on the target was measured using a current integrator. The chamber, which was a cylinder approximately twelve inches in diameter, had three rotatable arms inside, at the outer ends of which were mounted three lithium drifted silicon surface barrier detectors. These faced the target and had stops a quarter inch in diameter arranged in front, four inches from the target, to define the beam, and also aluminum foils .003 inches thick to prevent elastically scattered alpha particles from entering the counters and giving rise to pile-up. Three such counters were used, placed at angles of 90°, 135° and 160° to the incoming beam. The pulses from the counters were fed through Tennelec type preamplifiers and conventional amplifiers to an R.I.D.L. four hundred channel analyzer, split so that 0-100 channels were for the 90° counter, 100-200 for that at 135°, and 200-300 that at 160°. The remaining 100 channels were fed from a three-inch sodium iodide crystal - photomultiplier setup placed at an angle of 135° to the target and six inches away from it. A typical spectrum is shown in Figure 2. A long counter, at 0° to the beam, was employed to measure the neutrons, and had its face 18 inches from the target, as shown in the figure. Each detector also fed a scaler, to record the total counts.

## Results.

### Excitation function.

The excitation function (Figure 3) was obtained using the scalers, which were biased to record the three most energetic charged particle groups, low energy gamma rays, and neutrons. The level structure is given in Table 1. It will be seen that most of the levels correspond to those found by other workers. The structure is surprisingly complex. Le Couteur et al[13] predict a much larger level density ( 1 level per kev), but the magnitude of the peaks seems to rule out Ericson fluctuations.[14] Corrections have been applied for target thickness.

### Yields and cross sections.

The ratio of the yields of neutrons to charged particles was obtained by a comparison with the results of Shire[2] and with the results of Bonner et al[4]. If we accept Walker's value for the cross section at 5 Mev for neutrons, the corresponding proton cross section at this energy was found to be approximately 0.18 b. The error here is very large, approximately a factor of two.

Charged particle groups.

Energy considerations indicated the charged particles were protons. The proton groups showed, in addition to the ground state transition, excited states at 1.15 ± 0.05, 1.99 ± 0.05, 3.12 ± 0.1, 3.59 ± 0.1, and 4.24 ± 0.2 Mev in the residual nucleus $C^{14}$. The energy calibration could not be performed using an alpha particle source, and was obtained by noting the change in channel number for a given peak, as shown in Figure 4, as the alpha particle energy was increased. The gradient of the curve can also be used to distinguish protons from deuterons and tritons.

These levels in $C^{14}$ have not previously been identified, and in order to try to eliminate the conclusion that they arose from impurities the following facts were ascertained.

1) The protons could not arise from the most likely impurity, $B^{10}$ - the energy of the protons, and the known cross section for $B^{10}$ for alpha particles, forbade this, since the $B^{11}$ was known to be 98% pure.

2) No other light element had a suitable ( $\alpha$, p) reaction.

3) The levels could not arise from ( $\alpha$ , p) or ( $\alpha$, T) reactions, since, apart from other considerations, the deuterons and tritons would have insufficient energy.

4) Allowing for energy loss in the aluminum foil, the pulse height gave the most energetic protons to be 7.3 Mev, for 10 Mev alpha particles, in good agreement with the calculated value for the

ground state transition of 7.39 Mev for $B^{11}(\alpha,p_0)$.

This seems to indicate the new levels are real.

## Ratio of proton groups with energy and angle.

The curves of Figures 5 and 6 show the ratio to the first excited state at 90° of the proton groups from the various levels. Since spectra were only taken at intervals of twenty kilovolts, the detailed resonance structure is not well seen. It will be seen that, relative to the other groups, there is a peak at 9.2 Mev in the first excited state at 90°, one at 8.2 Mev for the first and second excited states at 160°, and a peak at 9.0 Mev for the first and third excited states at 160°.

## Conclusion.

Although no direct conclusion can be reached about the spins and parities of the states, it is obvious that this region of the compound nucleus $N^{15}$ is complex, but the resonance structure and level widths show that the compound nucleus still appears to be a good approximation here. The new levels in $C^{14}$ are still open to discussion.

I am indebted to Dr. A. B. Whitehead for the loan of much of the apparatus with which this experiment was performed, and to Mr. W. D. Harrison for his invaluable assistance in performing this experiment. Also, I am indebted to Dr. T. Lauritsen for the hospitality extended to me at the California Institute of Technology.

## Table 1

| Energy $N^{15}$ Mev | Energy Mev | Particles | Other Workers | Particles |
|---|---|---|---|---|
| 15.86 | 6.8 | n | 15.99[4,6] | n, α |
| 16.04 | 7.04 | p | 16.04[4,6] | n, α |
| 16.08 | 7.09 | p | | |
| 16.18 | 7.22 | γ,n,p | | |
| 16.23 | 7.34 | p | | |
| 16.31 | 7.40 | n | | |
| 16.35 | 7.46 | γ,p | | |
| 16.42 | 7.54 | p | | |
| 16.53 | 7.70 | n | 16.47[15] | p |
| 16.60 | 7.80 | p | | |
| 16.69 | 7.91 | n | | |
| 16.74 | 7.98 | γ | 16.72[8,15,17,18] | n,p,d |
| 16.75 | 8.09 | p+γ | | |
| 16.91 | 8.21 | p,γ | 16.90[16] | n,d |
| 16.98 | 8.3 | n | | |
| 17.12 | 8.49 | p,n | 17.11[8] | d, α |
| 17.19 | 8.58 | γ | | |
| 17.29 | 8.72 | p,n | 17.24[8] | t,d |
| 17.35 | 8.8 | p | 17.37[8,16,19] | p,α,t,d,n |
| 17.50 | 9.0 | γ | | |
| 17.56 | 9.08 | p | | |
| 17.58 | 9.11 | p,n | 17.58[15] | t,d |
| 17.95 | 9.61 | p | | |

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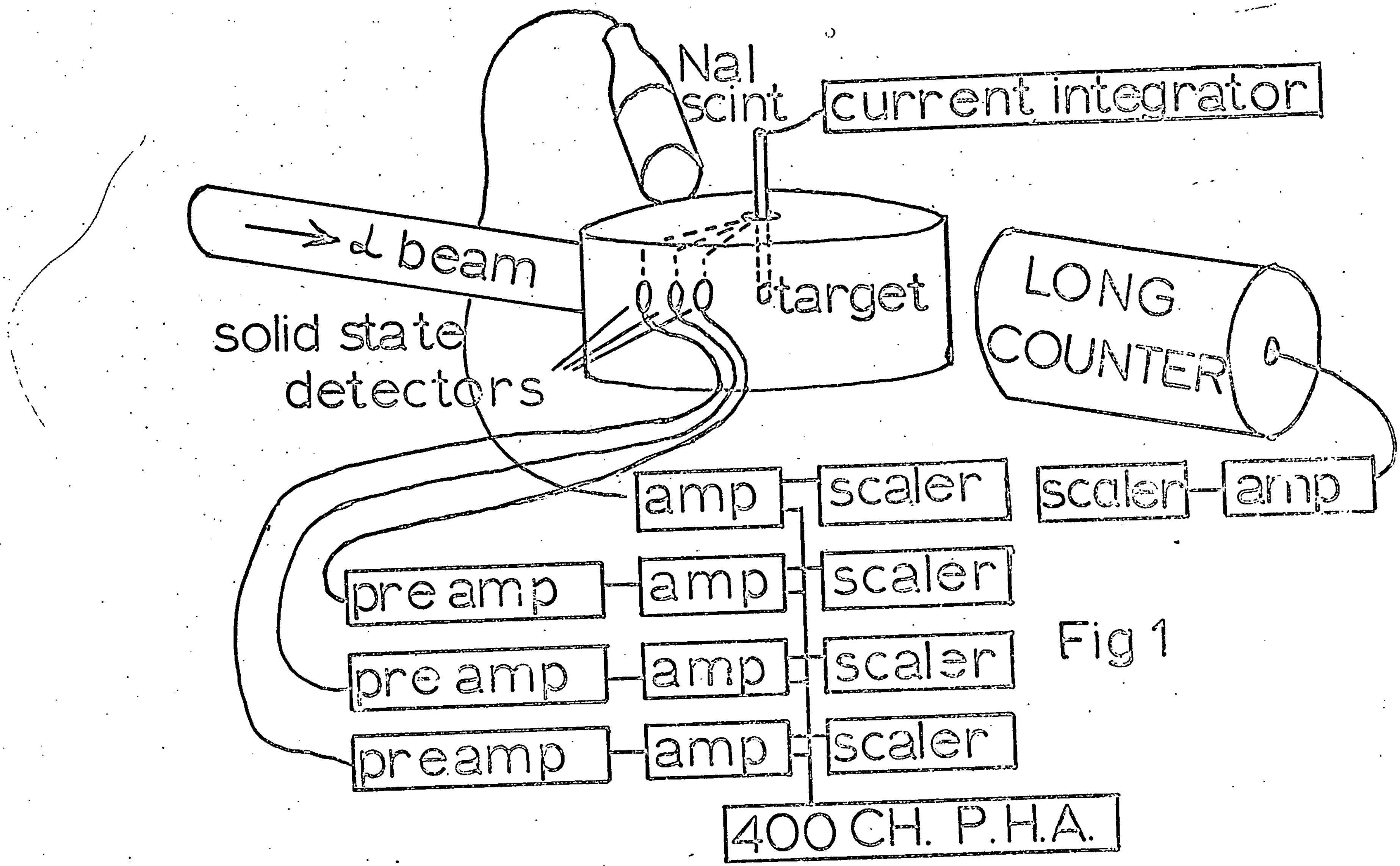



Fig 1

DIAGRAM OF APPARATUS

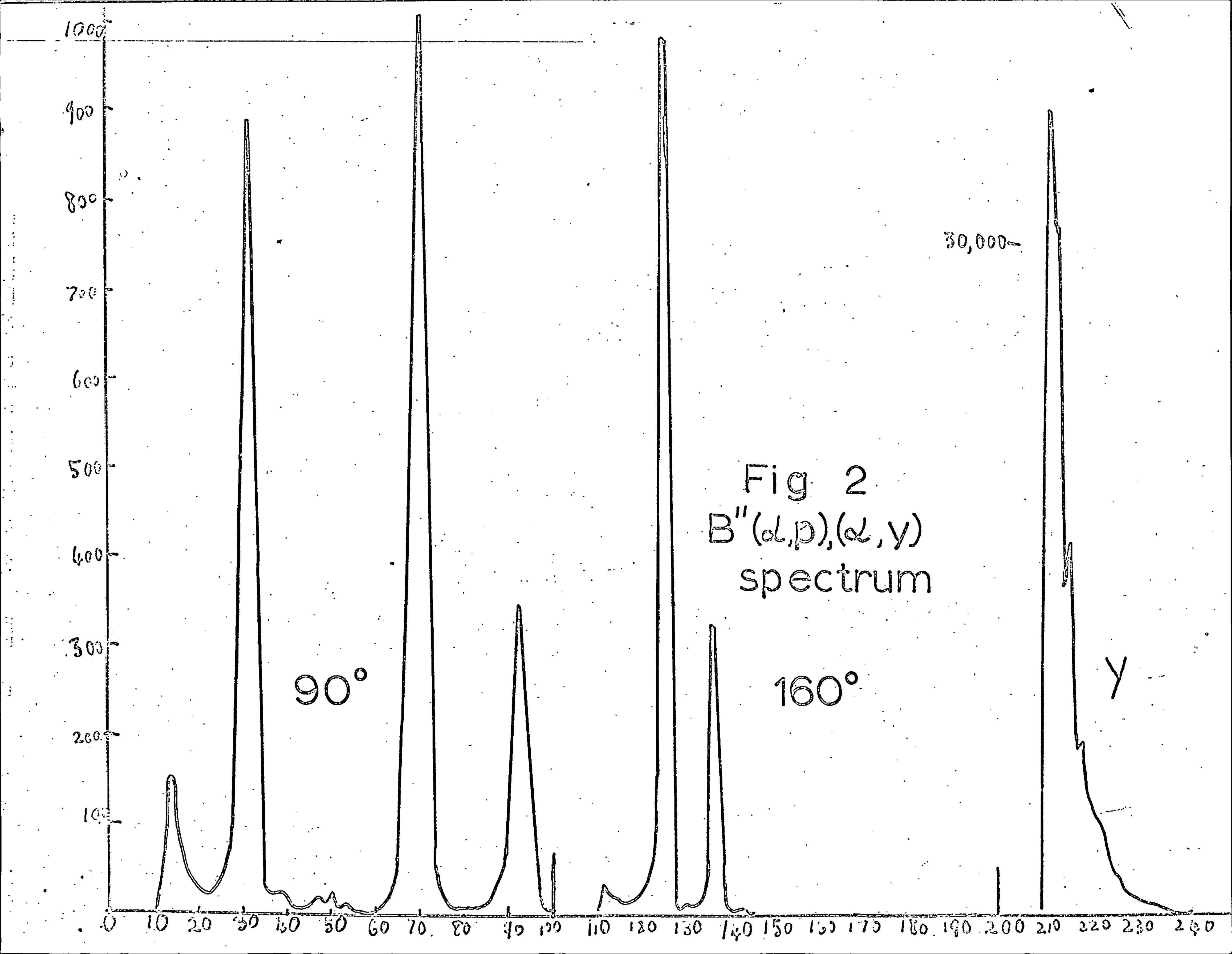



Fig 2
B''(α,p),(α,γ)
spectrum

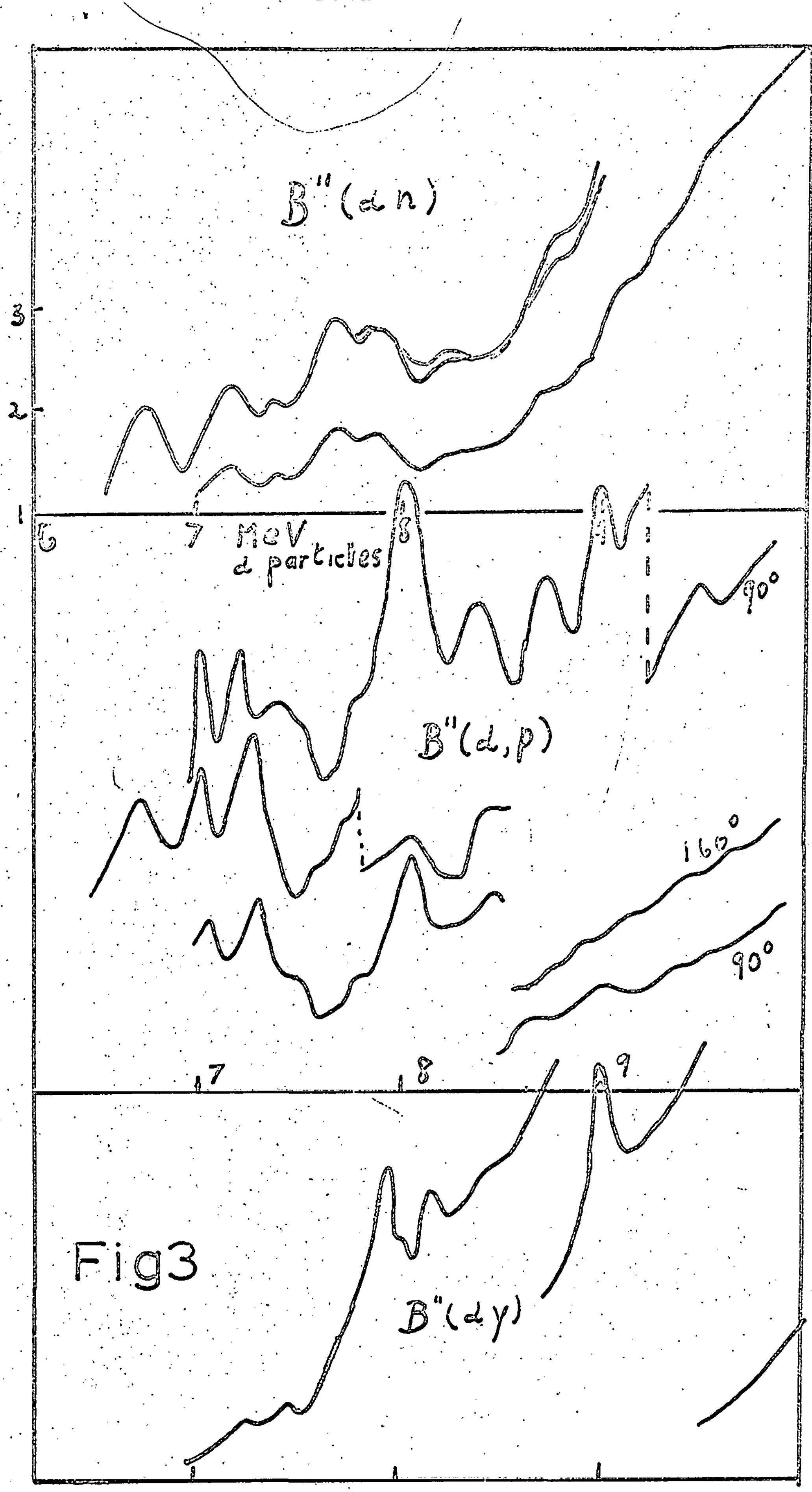
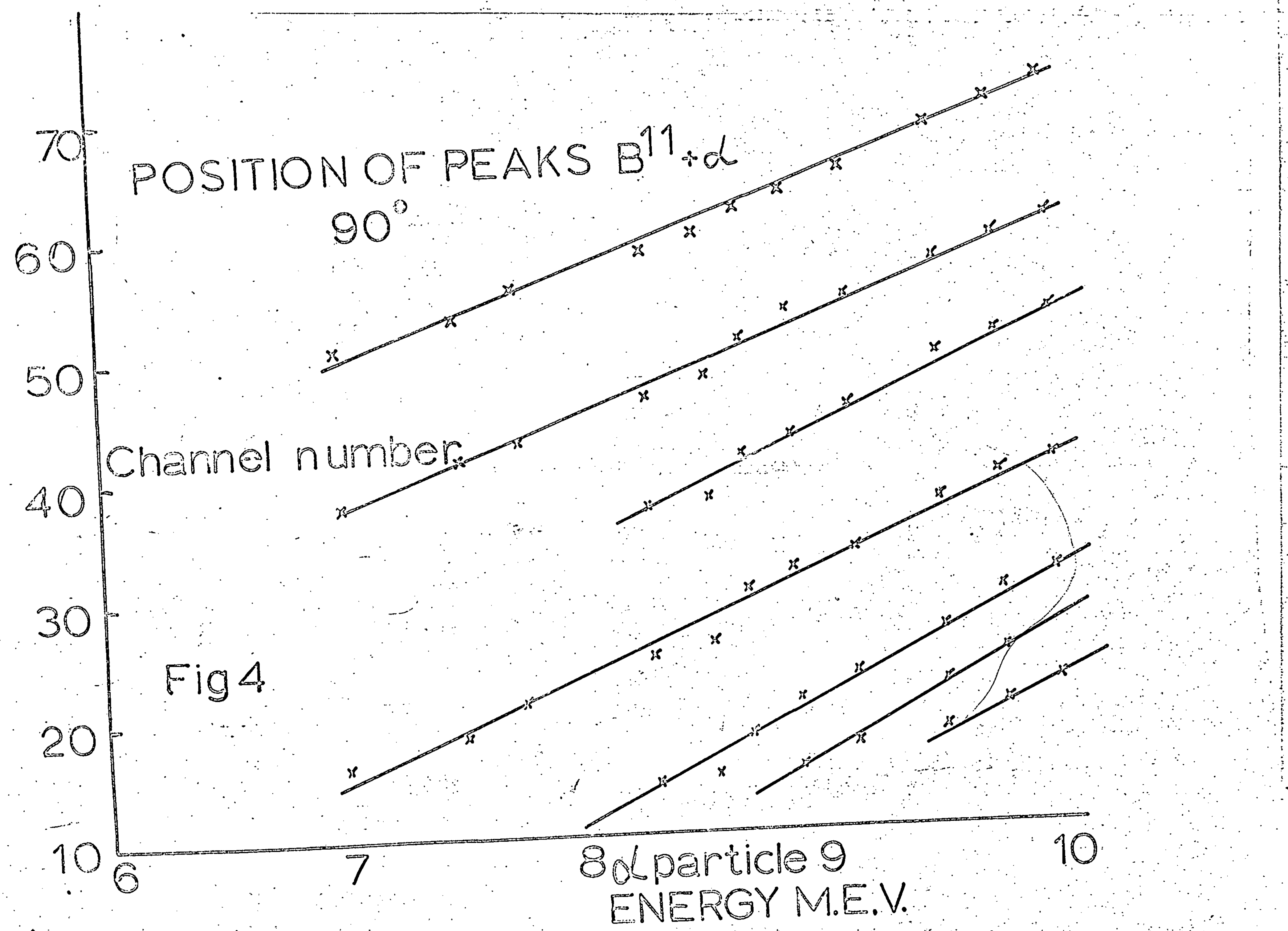
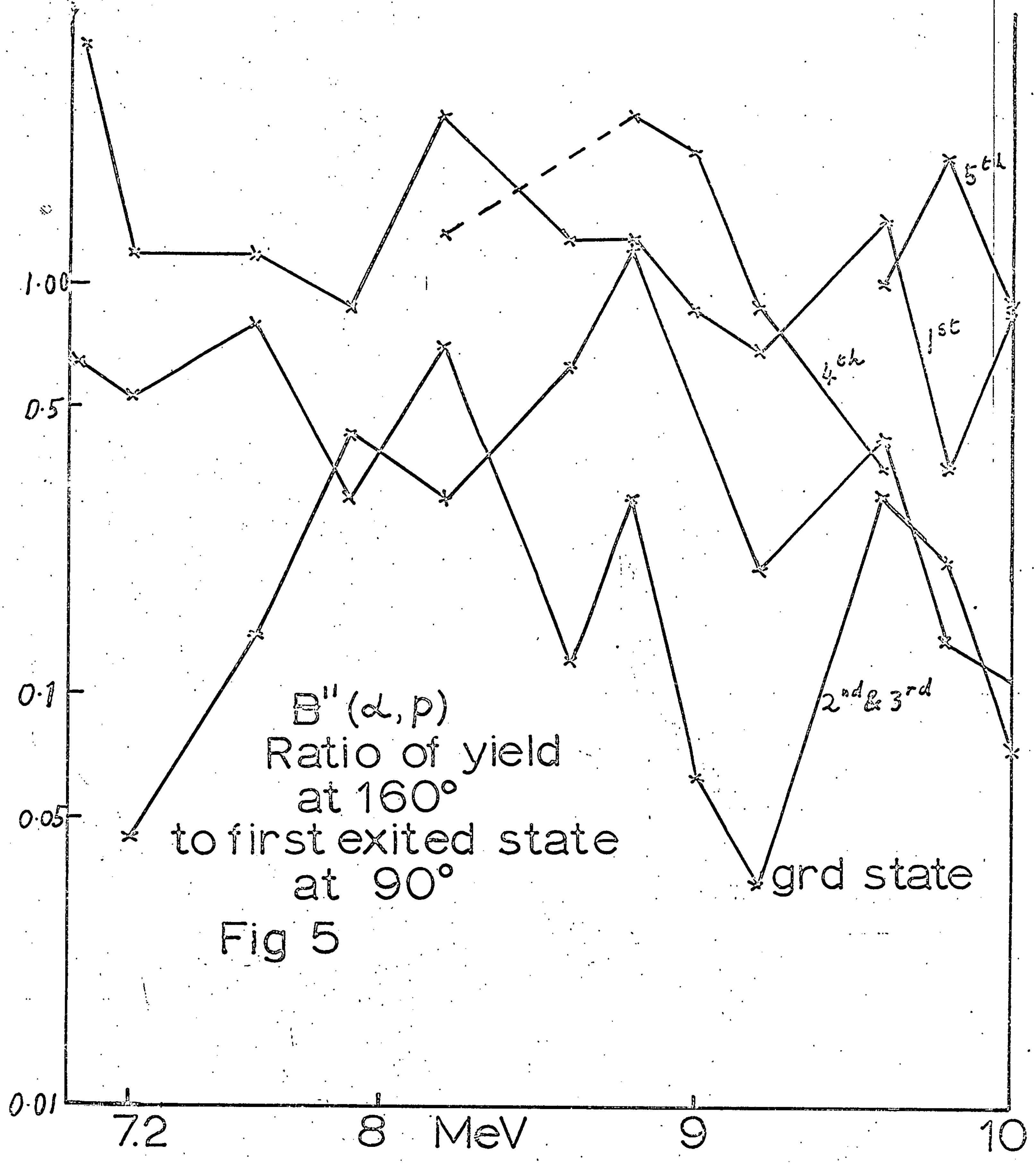



Fig3


POSITION OF PEAKS $B^{11}+\alpha$
90°
Channel number
70
60
50
40
30
20
10
6
7
8 α particle 9
10
ENERGY M.E.V.
Fig 4



1·00
0·5
0·1
0·05
0·01
7.2
8
MeV
9
10
5th
1st
4th
2nd & 3rd
grd state
B¹¹ (α, p)
Ratio of yield
at 160°
to first exited state
at 90°
Fig 5