Biedenharn and Rose) shows that $\delta=2.3\pm0.3$ for the 1200-kev transition.

The angular correlation function obtained for the 535 kev-1400 kev cascade was

$$P(\theta)=A[1+(0.108\pm0.010)P_2(\cos\theta)]. \quad (3)$$

The function obtained for the 535 kev-1200 kev cascade was

$$P(\theta)=A[1-(0.10\pm0.01)P_2(\cos\theta)]. \quad (4)$$

An analysis of the last two functions gives a value of $\delta=-3\pm1$ for the 1200-kev transition; i.e., the sign of δ is different from that obtained from the angular correlation measurement of the 1200 kev-200 kev cascade.

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Radiative Capture of Protons in Be^9†

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Measurements have been made on the proton-capture gamma rays in Be^9 at proton bombarding energies of 662 kev and 998 kev. Branching ratios for various levels in B^{10} are given.

INTRODUCTION

As part of a survey of the gamma rays produced in proton-capture reactions in light nuclei, the gamma rays from Be^9+p reaction were studied. Mass 10 is in the middle of $1p$ shell and has been used as a good testing point[1] for the validity of the intermediate-coupling nuclear shell model. It was part of our interest to examine the branching ratios from the various energy levels carefully to see how they compared with the theoretically computed values. Another phase of this investigation was to examine the decay of the 7.48-Mev level (2^-, $T=1$) of B^{10}. This level has been reported[2] to decay equally by $E1$ and $M2$ or $E3$ radiations to the ground state.

EXPERIMENTAL PROCEDURE

Targets of approximate thickness 100 $\mu g/cm^2$ were made by evaporating spectrochemically pure beryllium on 0.02-in. thick copper backing. They were bombarded with proton beams of 60 microamperes from a Cockroft-Walton H. T. Set. The gamma rays produced were detected with a 5 in.$\times$6 in. sodium-iodide crystal mounted on an E.M.I. photomultiplier tube. The pulses, after amplification and shaping, were recorded on a 100-channel Hutchinson-Scarrott Kicksorter. The spectra were analyzed in the manner described in earlier papers.[3]

EXPERIMENTAL RESULTS

Two resonances were found in the gamma-ray yield at proton bombarding energies of 662 kev and 998 kev. Pulse-height spectra were studied in detail at both these resonances. The results are given below.

662-kev Resonance.—The presence of a nearby 669-kev resonance in the $F^{19}(p,\alpha,\gamma)$ reaction has made the spectrum analysis rather difficult (see Fig. 1), though the γ rays from the fluorine reaction are well known and can be subtracted. The results are given in Table I.

998-kev Resonance.—The spectrum observed at this

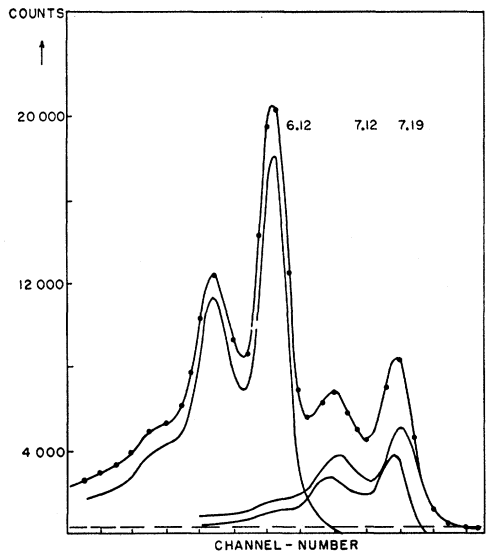

FIG. 1. The pulse-height spectrum observed at the 662-kev resonance.

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[1] D. Kurath, *Proceedings of the Rehovoth Conference on Nuclear Structure, 1957* (Interscience Publishers, Inc., New York, 1958), p. 46.

[2] S. Devons and G. Goldring, Proc. Phys. Soc. (London) **A67**, 413 (1954).

[3] Green, Singh, and Willmott, Phil. Mag. **46**, 982 (1955).

TABLE I. Gamma rays observed at the 662-kev resonance in Be^9+p.

Gamma-ray energy (Mev)	Relative intensity	Gamma-ray energy (Mev)	Relative intensity
7.19	9.00	1.42	0.30
3.58	2.4	1.25	0.44
2.86	0.26	1.00	0.80
2.32, partly $C^{12}(p,\gamma)$	0.12	0.71	2.00
2.10	0.80	0.51	3.40
1.84	0.10	0.41	1.00
1.62	0.80		

TABLE II. Gamma rays observed at the 998-kev resonance in $Be^9(p,\gamma)$.

Gamma-ray energy (Mev)	Relative intensity	Gamma-ray energy (Mev)	Relative intensity
7.48	199.00	2.12	1.10
5.71	2.20	1.85	0.60
5.34	5.40	1.54	3.00
5.10	0.34	1.42	1.70
4.44	0.31	1.25	1.00
3.88	0.50	1.00	4.5
3.56	0.40	0.71	10.00
2.86	0.40	0.51	10.7
2.35, partly $C^{12}(p,\gamma)$	3.00	0.41	5.0

resonance is shown in Fig. 2. The relative intensities of various γ rays are given in Table II.

DISCUSSION OF PROPOSED DECAY SCHEMES

All the γ rays observed at these two resonances can be fitted in terms of the known energy levels of B^{10} as seen from the proposed decay scheme shown in Fig. 3.

662-kev Resonance.—Besides a transition to the ground state, gamma rays arising from transitions to the levels at 5.93 Mev, 5.58 Mev, 5.11 Mev, and 3.58 Mev are also observed. Part of the weak 2.32-Mev γ ray could be due to a transition from the 5.93-Mev state to the 3.58-Mev state even though the 5.93-Mev state is known to have large α-width.[4] The intensity of the 3.58-Mev γ ray is too large compared with those of other γ rays originating from this state and it thus appears that part of this γ ray is due to a transition between the 5.58-Mev and 2.15-Mev levels. Such a γ ray, of energy 3.44 Mev, cannot be resolved from the 3.58-Mev γ ray. This also agrees with the population of the 2.15-Mev level as required by the intensities of the γ rays originating from it. From the known[4,5] branching ratios for the 2.15-Mev level, it appears that part of the observed 2.10-Mev γ ray arises from a transition between the resonance level and the 5.11-Mev state. The 5.11-Mev state then decays entirely by alpha emission, in agreement with other investigations.[4] A weak 1.84-Mev γ ray suggests a possible transition from the 3.58-Mev state to the 1.74-Mev state. Such a transition, if of normal strength, should have a branching ratio of about 8%.[6]

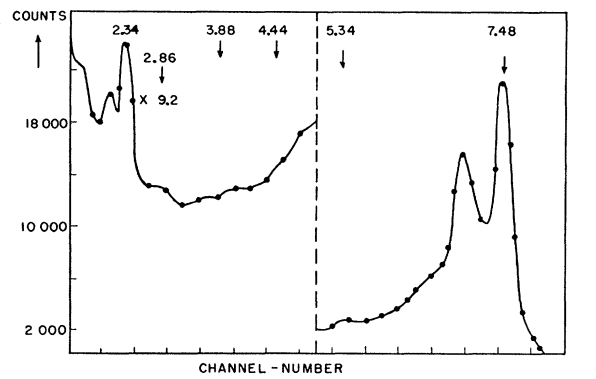

FIG. 2. The pulse-height spectrum observed at the 998-kev resonance. The γ rays were collimated with a lead cylinder having a $\frac{1}{2}$-in. diameter hole along its axis.

998-kev Resonance.—Besides a strong ground-state transition, there are γ rays arising from transitions to the levels at 1.72 Mev, 2.15 Mev, 3.58 Mev, 5.16 Mev, 5.58 Mev, and 5.93 Mev. The 5.16-Mev γ ray could be due to a transition between the 5.93-Mev and 0.72-Mev states. But the presence of a 4.44-Mev γ ray and the fact that the 5.93-Mev level has a large particle width suggest that the 5.16-Mev level is fed directly from the resonance level even though this transition will be forbidden by isotopic spin selection rules for $E1$ radiation. Besides decaying to the ground state and the 720-kev state, the 5.16-Mev state may also be weakly coupling with the 3.58-Mev state. No γ ray corresponding to a transition from 5.16-Mev state to the 2.15-Mev state was observed. A strong 510-kev γ ray, which appears at both resonances, cannot be fitted in the proposed decay scheme. It could be due to a reaction in carbon 12.

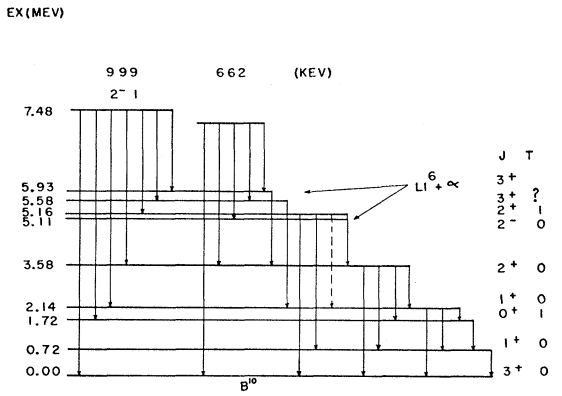

FIG. 3. Energy levels of B^{10} and corresponding gamma-ray transitions.

Coincidence measurements were made at the 998-kev resonance to verify some of the suggested cascades. The following γ rays appear to be in coincidence with the 720-kev γ ray: 6.74 Mev, 5.71 Mev, 5.34 Mev, 2.86 Mev,

[4] W. E. Meyerhof and L. F. Chase, Phys. Rev. **111**, 1348 (1958).

[5] S. M. Shafroth and S. S. Hanna, Phys. Rev. **95**, 86 (1954).

[6] G. Morpurgo, Phys. Rev. **110**, 721 (1958).

1.42 Mev, 1.00 Mev, and 0.41 Mev. The 6.74-Mev γ ray, which arises from a transition between the 7.48-Mev and 0.72-Mev states, was too weak to be observed under the strong 7.48-Mev γ ray in the general spectrum. The coincidence spectrum is shown in Fig. 4.

ANGULAR DISTRIBUTIONS

The angular distribution of the 7.48-Mev γ ray at 998-kev resonance has been measured (see Fig. 5). It is of the form $1-0.08\pm0.01P_2(\cos\theta)$, in good agreement with the value reported elsewhere.[7,8] Assuming the γ ray to be $E1$, about equal contributions from S- and D-wave protons are required to explain its observed anisotropy.

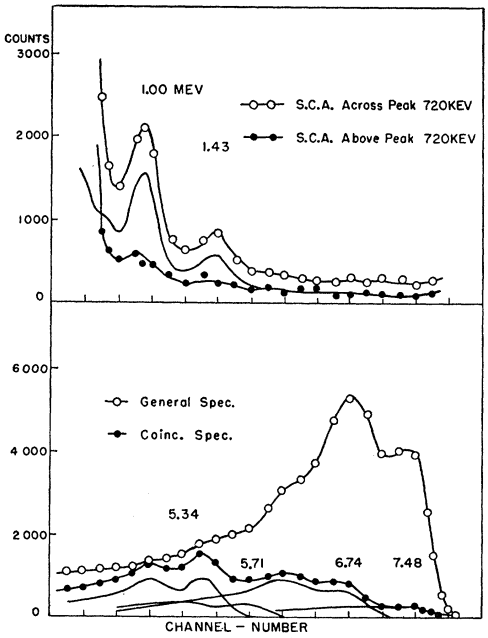

FIG. 4. Gamma rays coincident with the 720-kev radiation. To allow for the portion of higher energy γ rays under the 720-kev peak, the lower limit of the single-channel analyzer was raised by an amount equal to the width of the window and the coincidences were counted for the same number of incident protons. The differnce between these two spectra gave genuine coincidences.

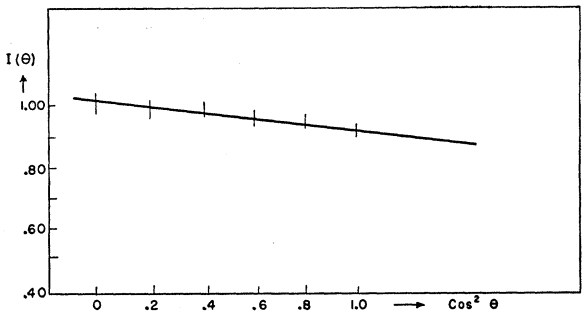

FIG. 5. Angular distribution of the 7.48-Mev gamma ray at the 998-kev resonance. The errors on various points are purely statistical.

CONCLUSIONS

The 5.93-Mev level may be decaying partly ($\leqslant 10\%$) by gamma emission to the 3.58-Mev level in spite of its large alpha-width. The 5.58-Mev level decays mainly by γ emission to the 2.15-Mev level. No γ transition originating from the 5.11-Mev level has been observed. The 3.58-Mev level decays to the 1.74-Mev state with a branching ratio of about 10%.

It is found that the angular distribution of the 7.48-Mev γ ray is weak and that there is no other intense gamma ray of comparable energy at the 998-kev resonance. In other words, our results are consistent with those of Devons[2] *et al.* Mozer[9] has recently suggested another resonance at 980 kev proton energy (leading to a 2^+, $T=0$ level). A 2^+, $T=0$ level at about this energy of excitation has also been predicted by Kurath.[1] A polarization measurement on the 7.48-Mev γ ray is being planned to distinguish between the two alternative explanations of the experimentally observed[2] angular correlation function between internally converted e^+e^- pairs from this gamma ray.

ACKNOWLEDGMENTS

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[7] S. Devons and M. G. N. Hine, Proc. Roy. Soc. (London) **A199**, 56 (1949).

[8] E. B. Paul and H. E. Gove, Proc. Roy. Soc. (Canada) **47**, 145A (1953).

[9] F. S. Mozer, Phys. Rev. **104**, 1386 (1956).