the four types of integrals that enter G^2, calculated from some of our potentials, for momentum transfer up to $q=8$ f^{-1}.

Note added in proof. We are indebted to Dr. H. P. Noyes for informing us that the triplet scattering length is now known much more accurately than indicated by the sources we quoted. Based on a very careful study of the experimental data, R. Wilson in a book on nucleon-nucleon scattering [Interscience Publishers, Inc., New York (to be published)] reports a value of the n-p cross section at a few ev of 20.400 ± 0.060 barns and a coherent scattering length of -3.744 ± 0.010 f. Therefore the triplet and singlet scattering lengths are: $a_t=5.4043\pm0.0122$ f and $a_s=-23.7009\pm0.0332$ f. Hence potential No. 8 is the only one which now fits the experimental data.

The deuteron binding energy is also known more accurately now and the weighted mean of the experimental values is 2224.68 ± 0.196 kev.

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One of us (G.K.) expresses his appreciation to Professor I. Perlman and Professor J. O. Rasmussen for their hospitality. An IBM 709 computer at this laboratory was used to perform the calculations.

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Gamma Rays Resulting from Lithium Bombardments of Lithium*

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Lithium beams of mass 6 and 7 were used to bombard thick targets of Li^6F and Li^7F. Reactions leading to Li^7, Be^7, Be^{10}, B^{10}, B^{11}, B^{12}, C^{11}, C^{12}, and C^{13} were identified from direct observation of gamma rays, residual target radiation, and the presence of neutrons.

I. EXPERIMENTAL APPARATUS

THICK targets of Li^6F and Li^7F were bombarded by 2.5–2.75-Mev Li^6 and Li^7 beams obtained from the State University of Iowa Van de Graaff accelerator. The ion source is of the hot filament type and is similar to one described by Norbeck[1] and Allison and Littlejohn.[2] Gamma rays from these reactions were

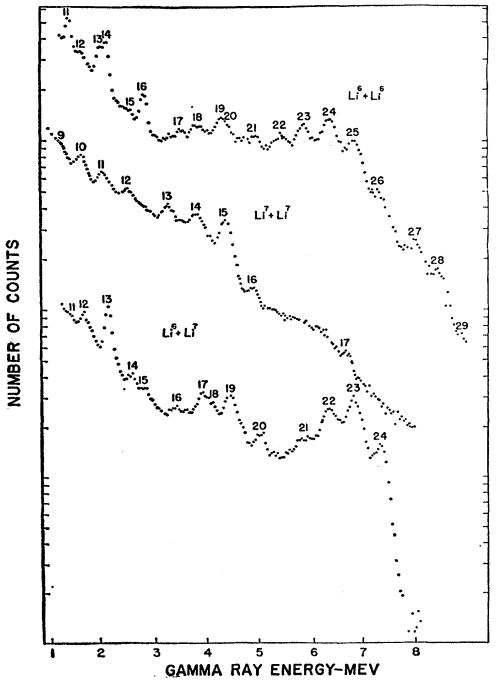

FIG. 1. High-energy spectra. Most peaks contain more than 10^3 counts per point. Ordinates are arbitrary and different for each of the three curves.

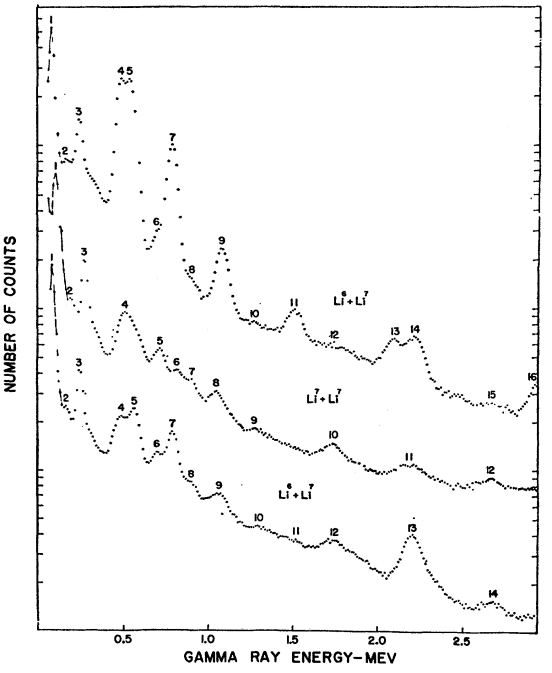

FIG. 2. Low-energy spectra. Most peaks contain more than 10^3 counts per point. Ordinates are arbitrary and different for each of the three curves.

* Supported in part by the U. S. Atomic Energy Commission.

[1] E. Norbeck, Jr., Phys. Rev. **105**, 204 (1957).

[2] S. K. Allison and C. S. Littlejohn, Phys. Rev. **104**, 959 (1956).

viewed by a 3 in.×3 in. NaI(Tl) crystal mounted at 90° to the beam in a lead collimated geometry subtending a solid angle of 0.17 sr. Using standard electronics, gamma-ray energy spectra were obtained with a 256-channel pulse-height analyzer. The response of the crystal to several known single gamma rays were taken in the energy range of the lithium-lithium spectra. The standard response shapes of the crystal were used as guides in effecting a spectral decomposition of the data by inspection. Starting with the assumption that the highest energy peak is entirely due to a gamma ray, the standard shapes and suitable interpolations were subtracted from the data beginning at the highest energy peak and working down.

II. RESULTS

The low-energy (<2 Mev) regions of these spectra display a striking similarity. For the most part these low-energy gamma rays do not originate in the target chamber but are principally due to levels excited by inelastic scattering of reaction neutrons in the NaI crystal. Assignments of reactions and gamma-ray intensities were complicated by the triple peak response of thea NI crystal above 1.02 Mev.

TABLE I. Li^6+Li^6.

Number	Gamma energy[a] (Mev)	Relative intensity[b]	Assigned transition (energies in Mev)
1	0.062		[c]
2	0.135		[c]
3	0.211		backscatter[c]
4	0.441		$Na^{23}(n,n'\gamma)$[c]
			Be^7, 0.431 → 0
5	0.484		Li^7, 0.481 → 0
6	0.648		[c]
7	0.726		B^{10}, 0.717 → 0
8	0.846		[c]
9	1.02		B^{10}, 1.74 → 0.717
10	1.22		[c]
11	1.44		B^{10}, 2.15 → 0.717
			B^{10}, 3.58 → 2.15
12	1.67		escape[d]
13	2.02	0.4	C^{11}, 1.99 → 0
14	2.14	0.4	B^{11}, 2.13 → 0
			B^{10}, 2.15 → 0
15	2.62	0.2	$Pb^{208}(n,n'\gamma)$
16	2.85	0.4	B^{10}, 3.58 → 0.717
			B^{11}, 7.30 → 4.46
			B^{11}, 5.03 → 2.13
17	3.58	0.2	B^{10}, 3.58 → 0
18	3.85		escape[d]
19	4.34	0.7	escape[d]
20	4.48		B^{11}, 4.46 → 0
21	4.95	0.4	B^{11}, 5.03 → 0
22	5.44		escape[d]
23	5.90	0.3	B^{11}, 7.99 → 2.13
24	6.40	0.8	C^{11}, 6.50 → 0
			B^{11}, 8.57 → 2.13
25	6.81	0.6	B^{11}, 6.81 → 0
			B^{11}, 6.76 → 0
26	7.3	1.0	B^{11}, 7.30 → 0
27	7.98	0.2	B^{11}, 7.99 → 0
28	8.44	0.2	B^{11}, 8.57 → 0
29	8.9	0.2	B^{11}, 8.93 → 0

[a] Gamma ray energies are determined to 1%.
[b] Intensities are measured with respect to the 7.3-Mev peak and corrected for crystal efficiency. The error is ±60%.
[c] $I^{127}(n,n'\gamma)$.
[d] Only peaks identified wholly as escape peaks are so labeled.

TABLE II. Li^6+Li^7.

Number	Gamma energy[a] (Mev)	Relative intensity[b]	Assigned transition (energies in Mev)
1	0.062		[c]
2	0.138		[c]
3	0.212		backscatter[c]
4	0.435		$Na^{23}(n,n'\gamma)$[c]
5	0.515		annihilation γ (C^{11})
6	0.645		[c]
7	0.724		B^{10}, 0.717 → 0[c]
8	0.840		[c]
9	1.02		B^{10}, 1.74 → 0.717[c]
10	1.23		[c]
11	1.44		B^{10}, 2.13 → 0.717
12	1.66		B^{12}, 1.67 → 0
13	2.15	0.5	B^{11}, 2.13 → 0
			B^{10}, 2.15 → 0
14	2.62		$Pb^{208}(n,n'\gamma)$
15	2.84	0.4	B^{11}, 7.30 → 4.46
			B^{11}, 5.03 → 2.13
16	3.45		escape[d]
17	3.97		escape[d]
18	4.06		escape[d]
19	4.47	0.4	B^{11}, 4.46 → 0
			C^{12}, 4.43 → 0
20	5.03	0.3	B^{11}, 5.03 → 0
21	5.88		escape[d]
22	6.36		escape[d]
23	6.81	0.4	B^{11}, 6.76 → 0
			B^{11}, 6.81 → 0
24	7.3	1.00	B^{11}, 7.3 → 0

[a] Gamma-ray energies are determined to 1%.
[b] Intensities are measured with respect to the 7.3-Mev peak and corrected for crystal efficiency. The error is ±60%.
[c] $I^{127}(n,n'\gamma)$.
[d] Only peaks identified wholly as escape peaks are so labeled.

TABLE III. Li^7+Li^7.

Number	Gamms energy[a] (Mev)	Relative intensity[b]	Assigned transition (energies in Mev)
1	0.062		[c]
2	0.138		[c]
3	0.210		[c]
4	0.446		$Na^{23}(n,n'\gamma)$[c]
5	0.633		[c]
6	0.738		[c]
7	0.840		[c]
8	1.02		[c]
9	1.25		[c]
10	1.64		B^{12}, 1.67 → 0
11	2.13	1.2	B^{11}, 2.13 → 0
12	2.55	0.7	$Pb^{208}(n,n'\gamma)$
13	3.37	0.5	Be^{10}, 3.37 → 0
14	3.93		escape[d]
15	4.35	2.	C^{12}, 4.43 → 0, B^{11}, 4.46 → 0
16	5.03	1.00	B^{11}, 5.03 → 0
17	6.75		Li^6 contamination

[a] Gamma-ray energies are determined to 1%.
[b] Intensities are measured with respect to the 5.03-Mev peak and corrected for crystal efficiency. The error is ±60%.
[c] $I^{127}(n,n'\gamma)$.
[d] Only peaks identified wholly as escape peaks are so labeled.

A. Li^6+Li^6

The spectrum appears in Fig. 1 and the data are summarized in Table I. Higher-gain spectra are reproduced here in Fig. 2 and are summarized in the appropriate tables. C^{11} and Be^7 were detected with the beam off from the residual target radiation in amounts which give rough agreement with the yields for these reactions measured by Norbeck.[3] The neutrons responsible for excitation of levels in I^{127} and Na^{23} come from the reaction producing C^{11} and have energies up to 9 Mev.

B. Li^6+Li^7

The spectra appear in Figs. 1 and 2 and the data are summarized in Table II. The presence of C^{11} was again detected from the residual radiation with yields in rough agreement with Norbeck's measurements. The neutron sources are now $C^{12}+n+20.9$ Mev and $C^{11}+2n+2.2$ Mev.

[3] E. Norbeck, Jr., Phys. Rev. **121**, 824 (1961).

C. Li^7+Li^7

The spectra appear in Figs. 1 and 2 and the data are summarized in Table III. No residual radiation was detected. The neutron sources are $C^{13}+n+18.6$ Mev and $C^{12}+2n+13.7$ Mev. B^{12} and B^{13} contribute a high-energy β spectrum. B^{13} has been observed from $Li^7(Li^7,p)$ by Norbeck.[1] No evidence for B^{13} can be adduced from these data.

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Isobaric States in Nonmirror Nuclei*

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The 14.8-Mev protons from the Livermore variable-energy cyclotron have been used to study (p,n) spectra from 13 selected target nuclei with mass numbers from 48 to 93 for a laboratory angle of 23°. Neutron energies were determined using standard time-of-flight techniques. All spectra show one strong neutron group at an energy corresponding in excitation in the final nucleus to the isobaric counterpart (analog state) of the target ground state, i.e., the Q value is the usual Coulomb energy displacement. The strong forward peaking of the angular distribution of the neutrons corresponding to the analog state in $V^{51}(p,n)Cr^{51}$ confirms the direct nature of the reaction. Although it is tempting, on the basis of the narrow width of the isobaric states (<300 kev), to imply some validity to isotopic spin as a quantum number for masses up to $A=93$, Lane and Soper have shown that isobaric states in adjoining nuclei can occur even in mass regions where isotopic spin is not a good quantum number.

INTRODUCTION

MEASUREMENTS of neutron spectra emitted from (p,n) reactions in the energy region below 20 Mev have been carried out by several investigators.[1–3] Results of these measurements have been compared with theoretical calculations derived from the compound statistical model[4] of the nucleus. Direct reaction neutrons are observed as an excess of high-energy neutrons over that predicted by statistical models of the compound nucleus[1] and by the anisotropy (forward peaking) of the high-energy neutrons.[2] No structure was resolved in medium-A nuclei because of poor counting statistics and only gross features were observed. In the present experiment, standard time-of-flight techniques, together with an 8.7-m flight path, provided adequate energy resolution to resolve a prominent neutron group in all the observed neutron spectra.

The resolved neutron group is interpreted as being due to a direct reaction which leads to a particular final state of the residual nucleus, i.e., the isobaric counterpart of the target ground state. Evidence for the existence of an isobaric state in Cr^{51} from proton bombardment of V^{51} has been presented in a previous letter.[5] This reaction is assumed to go as follows: The incoming proton reacts with an $f_{7/2}$ neutron, exchanges its charge, and is emitted as a neutron. In the initial state there are eight $f_{7/2}$ neutrons available and three $f_{7/2}$ protons. Since, by definition of an isobaric state, all the nuclear interactions within the initial and final nucleus are the same, the Q for the (p,n) reaction between V^{51} and its

* Work was done under the auspices of the U. S. Atomic Energy Commission.

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[2] D. M. Thomson, Proc. Phys. Soc. (London) **A69**, 447 (1956).
[3] R. D. Albert, J. D. Anderson, and C. Wong, Phys. Rev. **120**, 2149 (1960).
[4] J. Blatt and V. F. Weisskopf, *Theoretical Nuclear Physics* (John Wiley & Sons, Inc., New York, 1952).
[5] J. D. Anderson and C. Wong, Phys. Rev. Letters **7**, 250 (1961).