Electrostatic Analysis of Nuclear Reaction Energies*

R. M. WILLIAMSON,† C. P. BROWNE,‡ D. S. CRAIG, AND D. J. DONAHUE
University of Wisconsin, Madison, Wisconsin

(Received August 6, 1951)

Electrostatic analyzers for incident and product particles of nuclear reactions have been employed to measure the following ground-state Q values: $Li^6(p, He^3)\alpha$ (4.024±0.005 Mev), $Li^7(d, p)Li^8$ (−0.192±0.001 Mev), $Be^9(p, d)Be^8$ (0.558±0.002 Mev), $Be^9(p, \alpha)Li^6$ (2.123±0.004 Mev), $Be^9(d, Li^7)\alpha$ (7.159±0.009 Mev). Absolute energy calibration was based on a $Li^7(p, n)Be^7$ threshold of 1.882±0.002 Mev. No systematic differences appear between these data and other measurements employing magnetic analysis and other absolute energy calibrations. Data taken on the inelastic scattering of both protons and deuterons from Li^7 result in a value of 0.4780±0.0012 Mev for the first excited level of lithium. This figure overlaps previous gamma-ray measurements based on the 411.2-kev gamma from Au^{198}. The yield of alphas from deuteron bombardment of tritium absorbed in zirconium showed that the number of absorbed tritium atoms decreased rapidly near the surface of the zirconium. From this data, a lower limit of 17.578−0.030 Mev may be given the $T(d, \alpha)n$ Q value.

I. INTRODUCTION

RECENT refinements in the energy analysis of nuclear reaction particles have made it possible to obtain reaction Q values accurate to a few kilovolts. Ground-state Q values may be compared with mass spectrographic doublets, which are measured to the same order of accuracy for stable light atoms. Sufficient nuclear data is now published[1–4] to establish a table of nuclear masses[2] based on O^{16} for all elements lighter than neon. A comparison of this table with the most recent mass spectrographic data of Nier[5] and Roberts[6] indicates differences several times quoted errors.

Most of the previously reported nuclear data has been obtained by magnetic analysis based on absolute alpha-particle energy measurements,[7,8] the F^{19} $(p, \alpha\gamma)$ resonance energy,[9] and the proton moment.[10] Equipment developed at Wisconsin, consisting of a cylindrical electrostatic analyzer[11] for incident particles and a spherical electrostatic analyzer[12] for product particles, has been used to remeasure ground-state Q values of lithium and beryllium reactions in order to check for the presence of systematic errors in the nuclear data. In this work, absolute energy calibration was based on a $Li^7(p, n)Be^7$ threshold of 1.882±0.002 Mev.[9,13,14]

As a further comparison of absolute energy calibrations, the 478-kev excited level[15] in Li^7 was investigated by inelastic scattering of protons and deuterons. Gammas from this level to the ground state have been measured in several laboratories relative to the 411.2 ±0.1-kev gamma from Au^{198}, measured absolutely by DuMond.[16]

II. PROCEDURE

Incident beam energies (T_1) were obtained by calibrating the cylindrical electrostatic analyzer against the $Li(p, n)$ threshold. The spherical analyzer[12] was then calibrated using particles of known energy (T_2) elastically scattered from thick platinum. Product particle yields from thick targets of lithium, beryllium, and tritium then gave T_2 for the various reactions. Q is calculated from T_1, T_2, and θ, which is a known constant of the spherical analyzer.

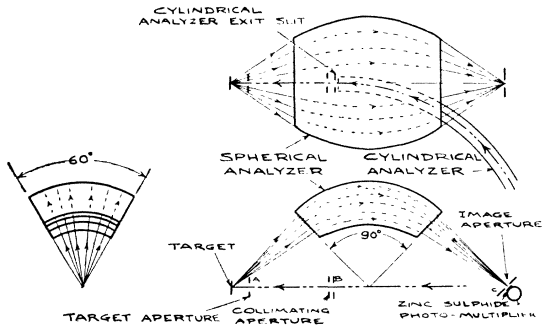

FIG. 1. Schematic drawing showing the arrangement of the two analyzers and the paths of the particles.

* Supported by the Wisconsin Alumni Research Foundation and the AEC.

† Now at Duke University, Durham, North Carolina.

‡ Now at Massachusetts Institute of Technology, Cambridge, Massachusetts.

[1] Strait, Van Patter, Buechner, and Sperduto, Phys. Rev. **81**, 747 (1951).

[2] Li, Whaling, Fowler, and Lauritsen, Phys. Rev. **83**, 512 (1951); A. H. Wapstra, Phys. Rev. **82**, 756 (1951).

[3] L. del Rosario, Phys. Rev. **74**, 304 (1948).

[4] Collins, McKenzie, and Ramm, Nature **167**, 682 (1951).

[5] A. O. Nier, Phys. Rev. **81**, 624 (1951).

[6] T. R. Roberts, Phys. Rev. **81**, 624 (1951).

[7] W. B. Lewis and B. V. Bowden, Proc. Roy. Soc. (London) **A145**, 250 (1934).

[8] G. H. Briggs, Proc. Roy. Soc. (London) **A157**, 183 (1936).

[9] Herb, Snowdon, and Sala, Phys. Rev. **75**, 246 (1949).

[10] Thomas, Driscoll, and Hipple, Phys. Rev. **78**, 787 (1950).

[11] Warren, Powell, and Herb, Rev. Sci. Instr. **18**, 559 (1947).

[12] Browne, Craig, and Williamson, Rev. Sci. Instr. (to be published).

[13] Shoup, Jennings, and Jones, Phys. Rev. **76**, 502 (1949).

[14] W. J. Sturm, Phys. Rev. **83**, 542 (1951). Sturm has measured the energy of RaC′ and Po alphas in terms of the $Li(p, n)$ threshold.

[15] Brown, Snyder, Fowler, and Lauritsen, Phys. Rev. **82**, 159 (1951)—contains a complete summary of all data on Li^7*.

[16] DuMond, Lind, and Watson, Phys. Rev. **73**, 1392 (1948).

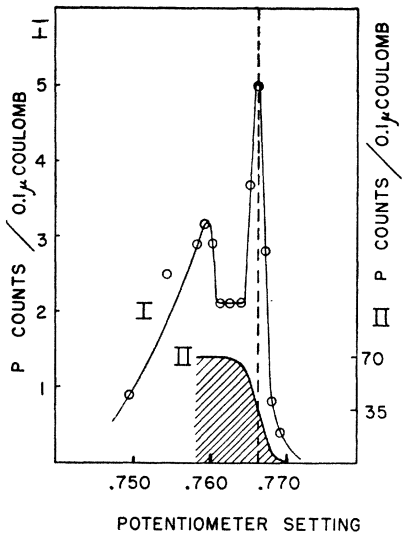

FIG. 2. Curve I shows protons scattered elastically from carbon in an evaporated beryllium target. The peak at 0.766 coincides with the half yield point of Curve II and represents surface carbon buildup. The peak at 0.759 is from carbon between the evaporation and the nickel backing foil. Curve II shows protons scattered elastically from thick soot. A potentiometer setting of 1.0 corresponds to about 1.0 Mev/charge in particle energy.

The path of the particles through the two analyzers is illustrated in Fig. 1. Bombarding particles from a pressure electrostatic generator emerged from the cylindrical analyzer with an energy spread of ± 0.06 percent. Spherical analyzer collimating and detector slit diameters of 1 and 2 mm, corresponding to resolutions of 0.15 percent and 0.24 percent in T_2, were used. Beam currents of 1/20 to 1/10 microampere were obtained. The mean angle θ between T_1 and T_2 was 134°31.5′, while the range of angle θ of particles accepted by the spherical analyzer was $\pm 12'$. The mean angle was obtained[12] by direct measurement and by observation of protons scattered from deuterons, since the scattering energy is very angle sensitive in this reaction. Particles in a solid angle of 0.0025 steradian were accepted by the spherical analyzer and energies up to 1.2 Mev/charge could be measured. A scintillation counter, consisting of an RCA 1*P*21 dusted with zinc sulfide, was used for detection of product particles —ranging from mass one to mass seven in the present data. Background counting rates were 1 to 2 counts per 100 microcoulombs above, and 5 to 40 per 10 microcoulombs below the elastically scattered groups from thin beryllium and nickel foils. Incident particles of degraded energy, probably resulting from slit edge scattering or inhomogeneities in the foils, were the cause of the higher counting background below elastically scattered groups.

Lithium was evaporated in the target chamber onto 4 micro-inch nickel foils.[17] Both 10 micro-inch beryllium foils (obtained from Dr. Hugh Bradner, University of California) and beryllium evaporations on 4 micro-inch nickel foils were used. Platinum foils were found to be very stable targets and were used for most of the calibration data. Targets were constantly heated to 200°C to prevent condensation of oil vapor. One water-cooled and one liquid-air-cooled baffle between the oil diffusion pump and the system reduced the amount of vapor present.

The use of thin nickel target backings allowed the observation of elastically scattered particles from carbon as one check on taget contamination. A thick soot target was used to check the carbon scattering cross section at 135° for 1-Mev incident protons (see Fig. 2). The value $d\sigma/d\Omega = 2.2\times 10^{-25}$ cm²/steradian was the basis for the calculations of amounts of carbon contamination. All contamination checks were made near this bombarding energy, which is in a nonresonant region of the scattering yield curve.[18]

Both lithium and beryllium evaporations showed a constant distribution of carbon through the evaporations (see Fig. 1, Curve I). The surface carbon buildup was easily discernable as a superimposed thin target yield whose peak corresponded to the mean energy of scattering from pure carbon.

Prolonged bombardments of bare nickel foil showed that oxygen buildup was small compared to carbon. The oxygen scattering cross section at 165° may be obtained from the data of Laubenstein *et al.*[19] Lithium targets were found to oxidize almost immediately after evaporation in the target chamber and beryllium targets contained small amounts of oxygen distributed through the thickness of the evaporation.

The position of the elastic scattering edges from lithium and beryllium also served as a check on the surface condition of these targets. In the case of lithium targets, the half yield point of either the product particle edge or the elastic scattering edge could be observed before and after re-evaporation for shift due to contamination.

Our experience was that the rate of contamination buildup was not a predictable function of bombarding time. The buildup seemed to be greater for the 4-micro-inch foils than for the 0.002″ platinum. The scattering edge from 0.002″ platinum showed no contamination shift greater than 0.03 percent during 6-hour bombardment with 1-Mev protons. No data from targets evaporated on 4-micro-inch nickel showed more than 3×10^{16} carbon atoms/cm² after four hours bombardment. This corresponds to 0.1 percent energy loss in one traversal of a 300-kev proton. Most of the particle edges were taken in two hours or less and none of our light particle data required contamination correction, while the corrections to heavy particle data were considerably less than calibration uncertainties. Much of

[17] S. Bashkin and G. Goldhaber, Rev. Sci. Instr. **22**, 112 (1951).

[18] G. Goldhaber and R. M. Williamson, Phys. Rev. **82**, 495 (1951).

[19] Laubenstein, Laubenstein, Koester, and Mobley, Phys. Rev. **84**, 12 (1951).

the data reported by other laboratories[1,2,15] contain contamination corrections greater than calibration errors.

The choice of target thickness lay between targets either thick or thin compared to the spherical analyzer resolution. T_2, the mean product particle energy, is the "half yield" point of a thick target edge and the peak of a thin target yield curve. Platinum scattering data showed that thin target peak yields less than $\frac{1}{4}$ of the thick target yield coincided with the half yield point of the thick target edge. Because of the higher counting rates involved, thick targets were used for most of the reactions. Further advantages are: evaporation thickness is noncritical, re-evaporation leaves the shape of the edge unchanged, survey points need not be as closely spaced, and unbacked foils may be used.

For some reactions, the change in product particle energy over the $\pm 12'$ acceptance angle of the spherical analyzer was sufficient to decrease the slope of the thick target edge. Both scattering data and line shape calculations[20] showed the $Li^7(d, d)Li^7$ edge slope to be $\frac{3}{4}$ that of the platinum scattering edge. Calibrations based on half yield points of these edges were in good agreement. An analysis of line shape showed that all other sources of line width which depend on the source of the observed particles have a negligible effect on the shape of the edges. Extrapolated end points could be used in calibration if the scattering data and the reaction data involved the same $dT_2/d\theta$. This procedure was followed for Li^{7*} and $T(d, \alpha)n$.

First-order relativistic corrections, $(1+T/2E)$, were applied to the calibration of both analyzers so that T_1 and T_2 were relativistically correct (E is the rest mass of the particle). These then have to be converted to relativistic momenta, P_1 and P_2, in order to solve for P_3, the momentum of the recoil nucleus, and hence T_3 and Q. The difference between classical and relativistic treatment at this step is more than academic for the $T(d, \alpha)n$ reaction, being -133 kev in Q. This correction for the $Be^9(d, Li^7)\alpha$ Q is -3.4 kev, while the remaining reactions are changed less than 1-kev. This same consideration enters into the calculation of elastic scattering ratios. The effect is negligible for 1-Mev protons scattered from platinum, but is $-1/2000$ in the scattered energy of 2.5-Mev deuterons on Li^7. When the bombarding particles were HH^+ ions, a correction of 1/3674 (energy of the H) was made for the fraction of the kinetic energy carried by the electrons.

III. ERRORS

The following sources of systematic errors and the bases for their estimated magnitudes are considered.

(*A*) *Absolute energy calibration of both analyzers* is based on the value 1.882 ± 0.002 Mev for the $Li(p, n)$ threshold.[9] The effect on Q is always 0.1 percent of Q.

(*B*) *Analyzer angle* (θ) is $134°31.5' \pm 3'$.[12] This uncertainty has no effect on the spherical analyzer calibration since the elastic scattering ratio of protons and deuterons on platinum is insensitive to changes in angle. The effect of the $3'$ angle uncertainty is calculated for each Q.

(*C*) *The relative calibration of the spherical analyzer with respect to the cylindrical analyzer* was determined by a series of 30 platinum scattering edges taken at various bombarding energies over the course of 24 days. The extreme fluctuation of calibration points over this period was ± 0.1 percent. However, no points adjacent in time to a reaction differ by more than ± 0.05 percent. Both electrical tests of the high voltage power supply control circuits and checks on the position of the platinum edge showed no systematic sources of irreproducibility greater than ± 0.02 percent in test periods of several hours. Proton scattering tests between 1 and 2 Mev in T_1 and $\frac{1}{2}$ and 1 Mev in T_2 showed the combined effects of analyzer magnetic fields and power supply nonlinearity to be less than 0.02 percent. The source of the long period instability was not located and a systematic calibration uncertainty of 0.07 percent is attached to T_2 and ± 0.03 percent to T_1. Since Q is more sensitive to errors in T_2 than to errors in T_1, this is a safe assignment.

(*D*) *Uncertainties in nuclear mass values*[2,5,6] are negligible in all of the reactions reported.

The following statistical errors are considered.

(*E*) *Product particle edge.* The uncertainty in the graphical location of the center of the product particle edges is given for each reaction in Results.

(*F*) *Calibration particle edges.* Statistics on these edges are small compared to the total systematic calibration uncertainty.

Two methods of combining estimated errors are commonly quoted in current literature. The term "probable error" generally refers to the practice of taking the square root of the sum of the squared statistical and systematic errors. The term "limit of error" or "uncertainty" generally implies addition of the magnitudes of the systematic errors and the total statistical error. Current ground-state Q values[1,2] are generally quoted with "probable errors." This convention seems most consistent with the least squares treatment of ground state Q values used in calculating a table of masses.[2] "Limit of error" would appear to be the more useful convention when measurements of the same quantity are compared in order to locate discrepancies greater than quoted errors. In order that data from a large number of sources may be treated consistently, it is desirable to consider treatment of errors in some detail.

Table I shows the magnitude of the errors involved in one of the runs of the $Be^9(p, \alpha)Li^6$ reaction. The total limit of error minus the error of absolute calibration is given as the "limit of error of measurement"—dQ_m. This allows the comparison of our data with other data

[20] R. M. Williamson, thesis, University of Wisconsin (1951).

TABLE I. Calculation of errors for $Be^9(p, \alpha)Li^6$. For this run $T_1 = 2.5554$, $T_2 = 1.9280$, $Q = 2.1239$. All energies are given in Mev.

Source of error	Magnitude	Error in Q Mev
Relative calibration of analyzers	±0.03 percent T_1 ±0.07 percent T_2	0.0005 0.0025
Analyzer angle	±3′	0.0009
Alpha-edge statistics (Fig. 2)	±0.0008 Mev	0.0015
Absolute calibration	±0.1 percent Q	0.0021
limit of error of measurement (dQ_m)		0.0054
total limit of error		0.0075
total probable error		0.0037

employing the same absolute calibration. Also, since the error in Q due to uncertainty in angle is small compared to the relative calibration errors of our data, dQ_m is a good measure of our estimates of statistical and relative calibration uncertainties when different runs of the same reaction are compared. Our final values are a weighted average of the runs taken and the final errors are the errors of the best runs.

IV. RESULTS

For each reaction reported, the following paragraphs give; bombarding energies, observed particles and edge statistics, target condition, Q values resulting from each run, average Q, error of measurement (dQ_m), and total errors. Figures 3, 4, 5, and 6 show some of the reaction data and the counting rates and backgrounds involved. The bases of the triangles in the upper right corner of these plots represent twice the spherical analyzer resolution. A potentiometer setting of 1.0 corresponds to about 1.0 Mev/charge in product particle energy.

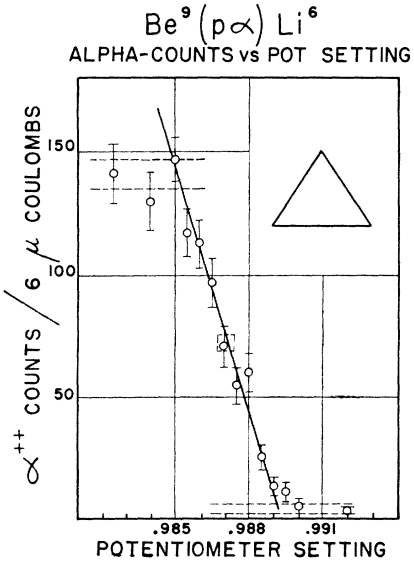

FIG. 3. Doubly ionized alphas from $Be^9(p, \alpha)Li^6$. The bombarding energy is 2.555 Mev.

$Li^6(p, \alpha)He^3$

The yield of He^{3++} from natural lithium targets was sufficient to locate edges to ±3/10,000 in about 2 hours bombarding time. Further evaporation of lithium at the end of this time caused no appreciable change of counting rate at the center of the He^3 edge. The scattering yield from carbon also showed the effect of contamination to be less than the uncertainty of the edge.

No. of runs	T_1 Mev	Q Mev	dQ_m
2	0.939	4.0220	0.0051
1	0.601	4.0265	0.0048

Average Q 4.024±0.009 limit of error
±0.005 probable error.

$Li^7(d, p)Li^8$

One proton edge was located to ±4/5000 when lithium was bombarded with 1.291-Mev deuterons. Deuterons scattered from Li^7 were observed in their calculated position at the end of the bombarding period and further evaporation of lithium did not shift this edge. Since the (d, p) reaction is less sensitive to contamination than elastic scattering, no correction to the Q values is required. The limit of error in the resulting Q of −0.192 Mev is ±0.0016 Mev; the probable error is ±0.001 Mev.

$Be^9(p, d)Be^8$

Data from both beryllium evaporations and beryllium foil targets are given below. No contamination corrections were necessary.

No. of runs	T_1 Mev	Q Mev	dQ_m
4	0.600	0.5587	0.002
1	0.732	0.5582	0.002
1	0.850	0.5584	0.002
2	1.100	0.5563	0.002

Average Q 0.558±0.0025 limit of error
±0.002 probable error.

$Be^9(p, \alpha)Li^6$

Doubly charged alphas were observed from beryllium bombarded at widely differing proton energies. The Q's resulting from observation of doubly and triply ionized Li^6 are increased 0.002 Mev because of contamination observed by scattering from carbon; the correction to the alpha-edges is negligible. Statistics on the alpha-edges were ±5/10,000, on the Li^6 edges ±15/10,000.

No. of runs	T_1 Mev	Q Mev	dQ_m
2	0.368	2.1238	0.004 alpha
4	0.601	2.1223	0.004 alpha
1	2.349	2.1231	0.0054 alpha
1	2.555	2.1239	0.0054 alpha (Fig. 3)
1	2.349	2.113	0.0075 Li^{6++} (Fig. 4)
1	2.349	2.117	0.0075 Li^{6+++}

Average Q 2.123±0.006 limit of error
±0.004 probable error.

$Be^9(d, \alpha)Li^7$

Doubly ionized Li^7 was counted from an evaporated beryllium target bombarded with 0.660-Mev deuterons. The alpha-edge was above the limiting energy of the spherical analyzer. Statistics on the Li^7 edge were $\pm 7/10{,}000$ and the position of elastically scattered deuterons indicated contamination effects to be negligible. Q was found to be 7.159 ± 0.017 limit of error, ± 0.009 probable error.

$T(d, \alpha)n$

Zirconium evaporated onto 0.010″ tungsten was loaded with tritium. (We are indebted to Dr. C. K. Bockelman for these targets.) Similarly shaped particle edges were obtained at bombarding energies of 0.800 and 1.000 Mev in the expected position for doubly

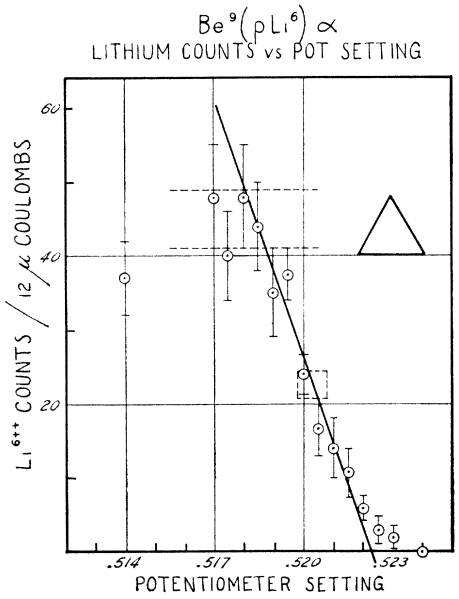

FIG. 4. Doubly ionized Li^6 from $Be^9(p, Li^6)\alpha$. The bombarding energy is 2.349 Mev.

charged alphas from the $T(d, \alpha)n$ reaction. The counting rate deep in the target was about that expected for the tritium/zirconium ratio of 1/1 which was indicated by tritium beta-activity. However, the number of tritium atoms was found to decrease rapidly near the surface of the zirconium. The maximum alpha-yield occurred 80 kev below cutoff instead of 8 kev, as expected for 2-Mev alphas from a uniform tritium target. Scraping the surface of the zirconium had no effect on the shape of the alpha-edge. Time was not available for further target development and the results of this data can only put a lower limit on the $T(d, \alpha)n$ Q value.

The extrapolated end point of deuterons elastically scattered from Li^7 was used in calibration. $dT_2/d\theta$ is the same for this scattering reaction as for the $T(d, \alpha)n$ reaction and the extrapolated cutoffs should bear the same ratio to the mean energies. Because of the non-uniform tritium target the experimental curve for the

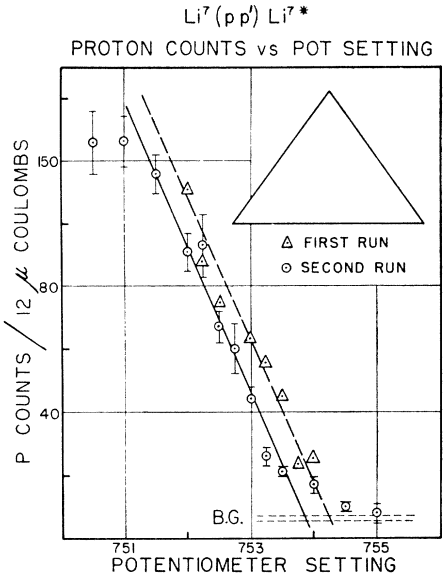

FIG. 5. Protons from $Li^7(p, p')Li^{7*}$ (478 kev). The bombarding energy is 1.812 Mev.

$T(d, \alpha)n$ reaction has a slope much less than expected. Q can be given as $17.578 - 0.030$ Mev. This does not disagree with the mass value of Li and Whaling,[2] from which Q is 17.576 ± 0.018 Mev.

Li^{7*}

The 0.478-Mev level in Li^7 was investigated by the inelastic scattering of both protons and deuterons. Within the sum of the limits of error of the two measurements (± 0.0017 Mev), the two reactions involve the same level. Alternate edges of elastically and inelastically scattered particles were taken and found to reproduce to better than $\pm 4/10{,}000$ (see Figs. 5 and 6).

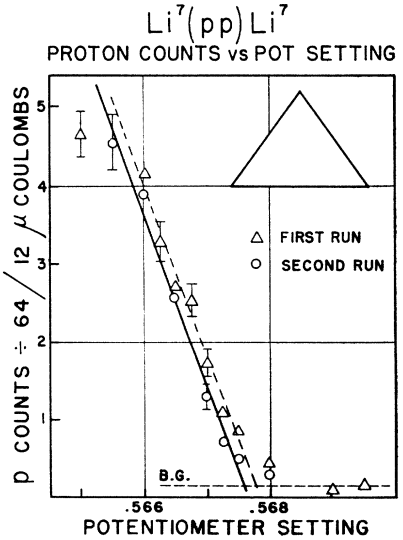

FIG. 6. Elastically scattered protons from Li^7 bombarded at 0.9051 Mev. The first and second runs follow the first and second runs, respectively, of Fig. 4.

TABLE II. Summary of ground-state Q values quoted with probable errors. References 1, 2, 3, and 4 give the publications of all data.

Reaction	Q(Mev)	Calibration	Laboratory
$Li^6(p, \alpha)He^3$	4.015±0.006[a]	proton moment	Birmingham[d]
	4.017±0.012	$F(p, \alpha\gamma)$	Cal. Tech[e]
	4.021±0.006	Po alpha	M.I.T.[f]
	4.024±0.005	$Li(p, n)$	Wisconsin
$Li^7(d, p)Li^8$	−0.192±0.001	$Li(p, n)$	Wisconsin
	−0.188±0.007	Po alpha	M.I.T.[f]
	−0.187±0.010[b]		Cambridge[g]
$Be^9(p, d)Be^8$	0.541±0.003	Abs.	Chicago[h]
	0.558±0.002	$Li(p, n)$	Wisconsin
	0.558±0.003	$F(p, \alpha\gamma)$	Cal. Tech.[e]
	0.560±0.004[c]	$Li(p, n)$	Wisconsin[i]
	0.562±0.004	Po alpha	M.I.T.[f]
$Be^9(p, \alpha)Li^6$	2.074±0.030	Abs.	Chicago[j]
	2.121±0.007	$F(p, \alpha\gamma)$	Cal. Tech.[e]
	2.123±0.004	$Li(p, n)$	Wisconsin
	2.142±0.006	Po alpha	M.I.T.[f]
$Be^9(d, \alpha)Li^7$	7.150±0.008	Po alpha	M.I.T.[f]
	7.151±0.010	ThC′ alpha	Cal. Tech.[k]
	7.159±0.009	$Li(p, n)$	Wisconsin

[a] Limit of error.
[b] Recoil angle of Li^8.
[c] From photodisintegration thresholds of D and Be^9.
[d] See reference 4.
[e] Tollestrup, Fowler, and Lauritsen, Phys. Rev. **76**, 428 (1949).
[f] See reference 1.
[g] E. B. Paul, Phil. Mag. **41**, 942 (1950).
[h] See references 3 and 13.
[i] R. C. Mobley and R. A. Laubenstein, Phys. Rev. **80**, 309 (1950).
[j] See references 3 and 20.
[k] See reference 2.

The elastic scattering edge was taken as the spherical analyzer calibration and the added fluctuations of the elastic and inelastic scattering edges was taken as the error in T_2. None of this fluctuation was attributed to the cylindrical analyzer. Since Q is more sensitive to dT_2 than to dT_1, this is a safe assignment. Extrapolated end points of the two edges could be compared since the slopes are theoretically equal. Errors due to both analyzer angle and target condition partially cancel in the calculation of Q. Carbon scattering and re-evaporation checks indicated negligible contamination effect.

	Q Mev	dQ_m Mev	T_1 Mev
$Li^7(p, p')$	−0.4782	0.0007	1.812
$Li^7(d, d')$	−0.4775	0.0010	2.495

Average Q −0.4780±0.0012 limit of error.

V. DISCUSSION

From the reactions for which more than one edge was taken at comparable bombarding energies, it may be concluded that the estimated errors due to calibration uncertainty and edge statistics are comparable to the variations in Q values (see Results). Data on the $Be^9(p, \alpha)Li^6$ reaction taken over a wide interval of proton energy, 0.37 to 2.55 Mev, give a combined check on the correct measurement of angle, estimation of contamination, and choice of calibration point. The observation of Li^{6++} and Li^{6+++} from this same reaction serves to verify the above considerations and previous estimates[12] of spherical analyzer magnetic field. No closed cycles can be given from the present data as an internal consistency check.

TABLE III. Measurements of the excitation energy of Li^{7*} (478 kev).

Calibration	Reaction	Energy (kev)	Laboratory[b]
Au^{198} gamma	$Be^7(K)$	478.5±0.5	Wash. Univ.
Au^{198} gamma	$Be^7(K)$	476.6±0.8	Cal. Tech.
Au^{198} gamma	$Li^7(p, p')$	478.3±0.6[a]	Cal. Tech.
Au^{198} gamma	$Li^6(d, p')Li^{7*}$	478.5±1.0[a]	Cal. Tech.
Au^{198} gamma	$B^{10}(n, \alpha')Li^{7*}$	478.5±1.5	Chalk River
$Li(p, n)$	$Li^7(p, p')$	478.2±1.2	Wisconsin
$Li(p, n)$	$Li^7(d, d')$	477.5±1.5	Wisconsin
$F(p, \alpha\gamma)$	$Li^7(p, p')$	479.0±1.0	Cal. Tech.
Po alpha	$Be^9(d, \alpha')Li^{7*}$	482±3	M.I.T.

[a] No correction for Doppler shifts.
[b] Reference 15 contains a complete list of measurements of this level.

Table II gives all measurements of comparable accuracy of ground-state Q values and probable errors reported by various laboratories. Data reported from *MIT*[1] is from magnetic analysis of T_1 and T_2 based on the energy of polonium alphas.[7,8] Electrostatic analysis of T_1 and magnetic analysis of T_2 is used in the measurements reported from the California Institute of Technology.[2] Their data is based on ThC′ alpha-energy[7,8] or the $F^{19}(p, \alpha\gamma)$ resonance.[9] Measurements carried out at the University of Chicago[3] utilized one absolutely calibrated electrostatic analyzer for data on T_1 and T_2. The recent work of Collins *et al.*,[3] makes use of one annular magnet calibrated by the proton resonance method against the absolute proton moment given by Hipple.[10] Several of the Q values listed differ by more than twice the sum of the probable errors. However, the only indication of differences larger than quoted errors which are systematic with respect to type of absolute calibration are the Chicago measurements.[21]

Table III shows the most accurate observations[15] of the 478-kev level in Li^7. Here again the errors of comparison appear to mask hidden systematic errors in the comparison or absolute measurements involved. Hence it is not possible to decrease the $Li^7(p, n)$ quoted error[9] by a comparison of inelastic scattering data with gamma-ray data based on the absolute measurement by DuMond[16] of the Au^{198} gamma. Sturm[14] has measured the energies of Po and RaC′ alphas with a cylindrical analyzer[11] calibrated against the $Li^7(p, n)$ threshold. Collins[4] has measured Po and ThC′ alphas in an annular magnet calibrated with respect to the proton moment given by Hipple.[10] These more direct comparisons of absolute calibrations also suggest no errors greater than the present errors of measurements in reaction data.

We wish to thank Professor H. T. Richards for suggesting this work and for many helpful discussions of it, and Mr. R. E. Benenson and Mr. K. W. Jones for their help in the experimental work.

[21] More recent Chicago work reported at the Washington 1951 meeting gives values agreeing with those of the other laboratories.