S^{--} $3p$ as shown in Fig. 3. This indicates that the Zn $K\beta_5$ line which is usually regarded as due to a "forbidden" or quadrupole transition ($\Delta l = 2$) is due instead to a cross transition of a S^{--} $3p$ electron into a K-shell vacancy in the zinc ion. One can thus understand the relatively low intensity of this line and its anomalous variation with atomic number. The above applies to zinc sulphide and probably to all salts of elements in the iron group. The $K\beta_5$ line has also been observed in the x-ray emission spectrum of metallic zinc, in fact, accompanied by a weak and scarcely resolvable $K\beta_2$ line.[15] These lines show a breadth and lack of symmetry which is characteristic of the conduction band in metals. Their origin is discussed by Beeman and Friedman[16] in connection with their study of the structure of the K-absorption edges of compounds in the neighborhood of the iron group. They also give excellent reasons against the usual interpretation of $K\beta_5$ as a forbidden or quadrupole transition in those cases where there is conduction band formation in the solid. The present observations give support to a similar interpretation in regard to compounds.

The writer takes this opportunity to thank the Graduate School of the University of Minnesota for its support of this investigation, and to Mr. George Werner for his assistance in the laboratory.

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[15] J. A. Bearden and C. H. Shaw, Phys. Rev. **48**, 18 (1935).

[16] W. W. Beeman and H. Friedman, Phys. Rev. **56**, 392 (1939).

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An Accurate Measurement of the Energy Released in the Disintegration of Li^6 by Protons

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The energy release in the reaction $\mathrm{Li}^6(p,\alpha)\mathrm{He}^3$ has been determined by a comparison of the He^4 range with that of the alpha-particles from $\mathrm{Be}^9(p,\alpha)\mathrm{Li}^6$. The energy of the latter reaction is accurately known from electrostatic deflection measurements. The determination was carried out in a small, variable air pressure, absorption cell and ionization chamber, both being at the same pressure. The device had high dispersion, 1 mm of range corresponding to about 13 cm Hg. Calibration of the cell was carried out by a method which utilized this high dispersion. The Q value for the reaction was found to be 3.945 ± 0.06 Mev as compared to the previously accepted value due to Neuert of 3.72 ± 0.08. With the new Q value, H^3 is found to be unstable against β-decay by either 0.19 ± 0.09 or 0.10 ± 0.1 Mev depending on whether Bainbridge's or Aston's value for the deuterium-helium bracket is used. The mass of He^3 is found to be 3.01688 ± 0.00011 mass units.

INTRODUCTION

ONLY three nuclear reactions are known at the present time which lead to the formation of the He^3 nucleus. The one most studied has been $\mathrm{D}^2 + \mathrm{D}^2 \rightarrow \mathrm{He}^3 + n^1$, and this chiefly through measurement of the neutron energy;[1] the alternative being to measure a 4-mm range. Another reaction is the recently discovered[2] beta-radioactivity of H^3. The third is the reaction $\mathrm{Li}^6 + \mathrm{H}^1 \rightarrow \mathrm{He}^3 + \mathrm{He}^4$, which is the subject of this paper. These short range particles were first found by Oliphant, Kinsey, and Rutherford.[3] The best measurement of the energy release hitherto published is that of Neuert,[4] who measured the

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[1] T. W. Bonner and W. M. Brubaker, Phys. Rev. **49**, 19 (1936); T. W. Bonner, Phys. Rev. **52**, 686 (1937) and **53**, 711 (1938); E. Baldinger, H. Huber, and H. Staub, Helv. Phys. Acta **11**, [3] 245 (1938), and others.

[2] L. Alvarez and R. Cornog, Phys. Rev. **56**, 613 (1939) and **57**, 248A (1940).

[3] M. L. E. Oliphant, B. B. Kinsey, and Lord Rutherford, Proc. Roy. Soc. **141**, 722 (1933).

[4] H. Neuert, Physik. Zeits. **36**, 629 (1935).

range of the He^3 nuclei in a cloud chamber. This method is open to criticism chiefly because it depends directly on the range-energy curve in a region where it is not too well known. The method to be described here depends only on the slope of the range-energy curve over a narrow region. The percentage error in the Q value is 0.2 times the percentage error in the slope.

In this work the He^4 range from $Li^6(p,\alpha)He^3$ was compared by an absorption cell and ionization chamber method with that of the He^4's emitted in $Be^9(p,\alpha)Li^6$. The energy of the latter had been accurately determined in this laboratory by electrostatic deflection,[5] and since the expected difference in range was only of the order of a millimeter, it was felt that the measurements would be of high precision. The ranges were expected to be about 7 and 8 mm for the beryllium and lithium reaction, respectively. Thin targets were used in both cases.

Apparatus

The high voltage set used was the Cockcroft-Walton type circuit described by Hatch.[6] A low voltage ion source designed by Allison furnished the protons. The beam was magnetically separated and passed through two circular apertures 0.54 cm in diameter and 10 cm apart before striking the target. The disintegrations were observed at 90°. Figure 1 is a drawing of the target assembly and range measuring apparatus. The latter is seen to consist of two sections. The region from B to A acted as a variable air pressure absorption cell, that from A to the collecting electrode farther to the right as a parallel plate ionization chamber. The target spot and the opening A were the limiting apertures, each 0.54 cm in diameter. The screen B was covered on the higher pressure side by a collodion window with an air equivalent of about 3.5 mm. This was the only window in the apparatus. There was a fine perforated screen over A also, but nothing else, so that the pressures in the ionization chamber and absorption cell were the same. The screen had 26 holes per sq. cm, each hole being about 0.02 cm in diameter. The depth of the absorption cell was 0.54 cm and of the ionization chamber 0.45 cm. The collecting voltage for the latter was applied to the outside brass case of the entire device.

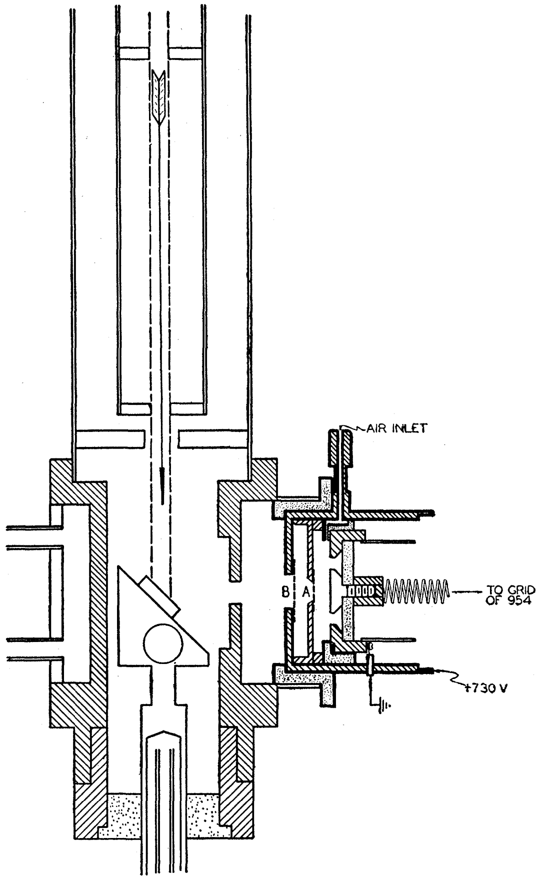

FIG. 1. Target assembly and range measurement apparatus. There was a collodion window on the right-hand side of screen B.

Performance of the Variable Pressure Range Comparison Device

The performance of the variable pressure ionization chamber will depend on the biasing of the counting circuit, that is, on the minimum number N_0 of ion pairs which must be formed between the plates to record a count. Preliminary trials showed that acceptable number-pressure curves of the short range particles from beryllium could be produced with a bias of 9 volts on the first stage of the vacuum-tube scale-of-sixteen counting circuit. By a method described later it

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[5] S. K. Allison, L. S. Skaggs, and N. M. Smith, Jr., Phys. Rev. **54**, 171 (1938); L. S. Skaggs, Phys. Rev. **56**, 24 (1939); S. K. Allison, L. S. Skaggs, and N. M. Smith, Jr., Phys. Rev. **57**, 550 (1940).

[6] G. T. Hatch, Phys. Rev. **54**, 165 (1938).

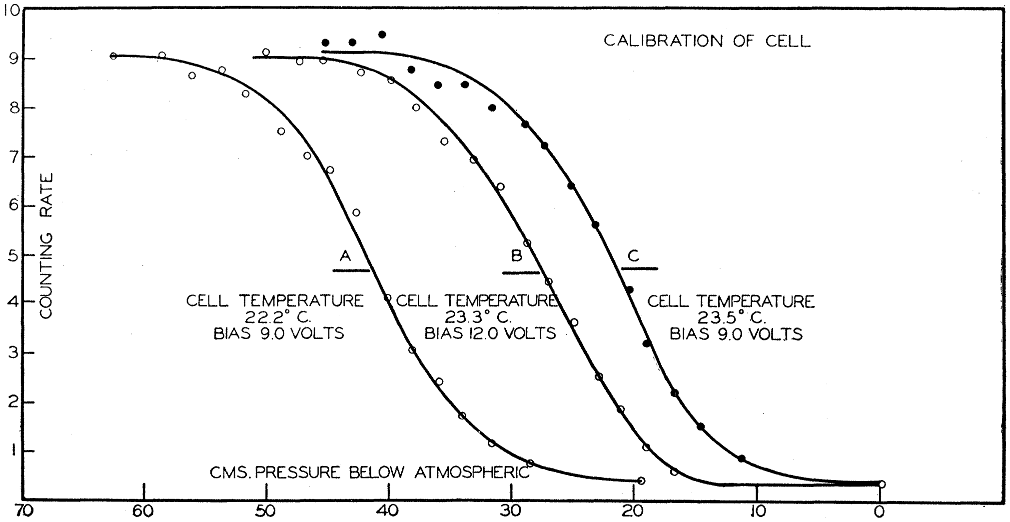

FIG. 2. Calibration of the cell with polonium alpha-particles. Curves A and C are separated by 1.5-mm motion of micrometer at the prevailing barometric pressure and at the temperatures indicated in the drawing. Curves B and C represent the effect of changing the bias three volts for groups of the same residual range. The ordinate 10 represents 1000 counts in 70 seconds.

was shown that this corresponded to the collection of 1900 ion pairs.

The range of a particle measured in the cell is a sum of three terms. The first is the air equivalent of the collodion window. This is assumed to be independent of the temperature and of the energy of the particle. The second term refers to the range expended in the first compartment of the device, i.e., the absorption cell proper. This will be the product of the cell length L with the air density ρ. In order to conform to the standard practice in range work, the unit of density is taken to be the density of dry air under 76 cm Hg pressure at a temperature of 15°C. The third term is the product of the penetration δ into the ionization chamber required to register a count with the corresponding air density. In the device used here, the latter is also ρ. Then for the difference in range of two separate groups of particles we have

$$R_1-R_2=L(\rho_1-\rho_2)+(\delta_1\rho_1-\delta_2\rho_2).$$

If now neither δ_1 nor δ_2 is greater than the ionization chamber depth D $(=0.45 \text{ cm})$, the difference $(\delta_1\rho_1-\delta_2\rho_2)$ is zero since δ_1 and δ_2 are the linear path lengths required to produce N_0 ion pairs before losing ionizing power and these lengths vary inversely as the density. The device now acts like the conventional type in which the ionization chamber is at constant pressure. Then

$$R_1-R_2=\frac{288L}{76.0}\left[\frac{P_1}{T_1}-\frac{P_2}{T_2}\right], \qquad (1)$$

where P is the pressure and T the absolute temperature.

There is a certain critical pressure P_c, however, below which formula (1) becomes invalid. This is the pressure at which an alpha-particle will not produce enough ionization to record a count before reaching the end of the ionization chamber. It may be computed from:

$$N_0=\int_0^{D_c} I(x)dx$$

with $D_c=DP_c/76$. The abscissa $x=0$ corresponds to residual range zero in the specific ionization *versus* range curve $I(x)$. If it is assumed that $I(x)$ has the form of Fig. 9 in the paper of Holloway and Livingston,[7] and that the maximum ordinate represents the creation of 60,000 ion pairs per cm, one gets $P_c=17$ cm Hg for $N_0=1900$ ion pairs. Since none of the number-pressure curves started dropping off until somewhat above this pressure, formula (1) was applicable.

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[7] M. G. Holloway and M. S. Livingston, Phys. Rev. **54**, 18 (1938).

The quantity N_0 was determined in the following way. A thin polonium source was placed so that its alpha-particles passed through the absorption compartment and entered the ionization chamber near the end of their range. The pressure was then reduced in the two-compartment device and the diminishing pulse heights on the oscillograph observed. (In order to reduce the pressure without rupturing the collodion film, a vacuum was created in an auxiliary chamber, temporarily attached.) The pressure was lowered until this rough evidence indicated that the particles traversing the ionization compartment were producing approximately the critical number of ion pairs corresponding to the selected bias. With the pressure held at this value, the distance of the polonium source was readjusted until the pulses showed a maximum height. Then an accurate measurement of the critical pressure was made by counting with the biased circuit and varying the pressure in this reduced region until the sharp low pressure cut-off of the number-pressure curve was found. Let the pressure at which the cut-off occurs be P_0. If the linear depth of the ionization chamber is D, then its equivalent depth at P_0 is $P_0D/76=D_0$. The critical number of ion pairs N_0 corresponding to the given bias may then be found from:

$$N_0=\left[\int_{\alpha}^{\alpha+D_0} I(x)dx\right]_{\max},$$

where α is to be chosen to give the greatest value for the integral. For the 9-volt bias, P_0 was measured to be 5.5 cm Hg. For $D=0.45$ cm D_0 becomes 0.033 cm, and graphical integration gives $N_0=1900$ ion pairs.

CALIBRATION

Since the difference in range of two groups of particles as measured with an absorption cell is proportional to the product of the cell length by the pressure difference between the two number-pressure curves, the dispersion of the device may be made extremely large by choosing a short enough cell. Such was the case in the present measurements, each mm of range in standard air corresponding to about 13 cm difference in pressure. Now measurement of the cell dimensions is complicated by such things as the bulge of the screens, and the uncertainty of the boundary between absorption and ionization compartments. It is clear that a small absolute error in this measurement produces a large error in the range difference. Therefore the measured cell dimensions were given no weight in the calibration. Instead a method suggested to the author by Dr. N. M. Smith of this laboratory was employed. A thin polonium source was mounted on an accurate metric micrometer. The axis of the range measuring device was placed along the screw axis and the micrometer adjusted until particles ended their range in the cell at some particular pressure. The evacuated chamber mentioned previously was used to avoid rupturing the cell window.A number pressure curve was taken for a given position of the source. The micrometer was then turned an integral number of times and another number-pressure curve taken. In Fig. 2 curves A and C are separated by 1.5 mm motion of the micrometer at the prevailing barometric pressure. Table I gives the data of several such calibration runs suitably corrected for variations in temperature and barometric pressure during the run. The mean value is seen to be 12.95±0.2 cm Hg difference in pressure at 15°C for each mm difference in range in air at 76.0 cm Hg and 15°C.

This method of calibration gives directly the range difference of two groups of alpha-particles measured with the cell. It automatically takes into account the irregularities of the screens, the variation of the air equivalent of window with the alpha-particle energy, any deviation from uniformity of the collecting field in the ionization chamber, the protruding of the collodion window through the screen apertures and any variation of this with pressure, and finally it minimizes any correction to the range difference due to change in obliquity of the two groups,—for although the geometry for the calibration was not

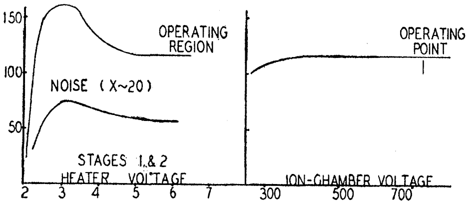

FIG. 3. Some operating characteristics of the amplifier and ionization chamber.

identical with that for the reactions investigated, it was not very different.

The geometry for the experiment was "good" according to the criteria of Livingston and Bethe[8] whose notation is used below. The ratio of the limiting aperture widths to the separation between them (one of them being the target spot) was $a/b=0.12$ while the quantity $\cos\theta_0$ was equal to 0.26 and 0.18 for the lithium and beryllium reactions, respectively. The obliquity correction was found to be less than 0.01 mm and was neglected. The angle straggling should be symmetrical and therefore not affect the mean range.

Pressure in the cell was measured with an open-tube mercury manometer. Atmospheric pressure was measured with an aneroid barometer frequently checked against the standard barograph at the U. S. weather bureau observatory a few hundred yards away. The temperature of the cell was read from a thermometer pressing against it. This temperature was usually about 2°C higher than that of the room because of heat conduction from the target chamber. Diffusion of cooler air into the cell was impeded by making the pressure lead of small bore.

Lithium targets were prepared by deposition of the fluoride from a flame upon a nickel button. For the beryllium targets, the fluoride was deposited from an oxygen flame. Because of the high yields from the beryllium reaction,[6] it was found necessary to rub the targets clean before the intensity was reduced enough to enable accurate measurement. A high intensity of particles produces an apparent shortening of the range as well as some straggling, due to particles crowding up on the "back-kick" of a given amplifier pulse.

Targets were heated after the fashion described by Hatch.[6] It is certain that the beryllium targets remained free of carbon. For the lithium ones, however, it was difficult to decide since alkali halides become discolored by bombardment with charged particles. It may have been the case that cohesive forces between the lithium fluoride and such organic materials as pump oil were stronger than those due to heat agitation. In such a case, a film of oil would be left, and would subsequently carbonize. This would reduce the measured range, and because of the irregularity of the carbonization, give increased straggling. To guard against this, no lithium target in the data reported was used for more than one run. However, bombardment of badly discolored targets showed no unidirectional shift of the mean range point, nor any appreciable change in the slope of the number-pressure curves.

The linear amplifier constructed for this research was of the usual resistance coupled type. A 954 acorn pentode was used in the first stage. There were two subsequent stages using 6J7 pentodes followed by two employing 6C5 triodes. Power for these was furnished by a power pack, except that the heater on the second stage was run in parallel with that on the first, a storage battery supplying the current. All stages but the last were self-biased. The power supplies for the amplifier and ionization chamber were of a simple sort, stabilization being achieved by a voltage regulator of the saturated core type placed on the a.c. line. Figure 3 gives some of the characteristics of the amplifier and ionization chamber. The curves on the left show the dependence of the gain and noise upon heater voltage of the first two stages. It is seen that there was a broad plateau in the neighborhood of 6 volts. This coincided with the discharge plateau of the storage battery, making stabilization automatic. The curve on the right shows that the ionization chamber was run at saturation. A scale-of-sixteen circuit similar to that described by Stevenson and Getting[9] was utilized. It was likewise stabilized by way of the a.c. line. The bias voltage was supplied by a battery and read with a good voltmeter.

MEASUREMENTS

All data were taken with the bombarding beam at 370 kv as measured with a high resistance voltmeter calibrated some time before. This was safely above the observed 330-kev resonance in F^{19}. The deflecting magnet was set on the maximum of the mass 1 spot. Considerations of the ripple in a Cockcroft-Walton type circuit show that most of the beam has the average voltage, so that the energy of the protons at the target could be assumed quite close to 370 kv.

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[8] M. S. Livingston and H. A. Bethe, Rev. Mod. Phys. **9**, 245 (1937).

[9] E. C. Stevenson and I. A. Getting, Rev. Sci. Inst. **8**, 414 (1937).

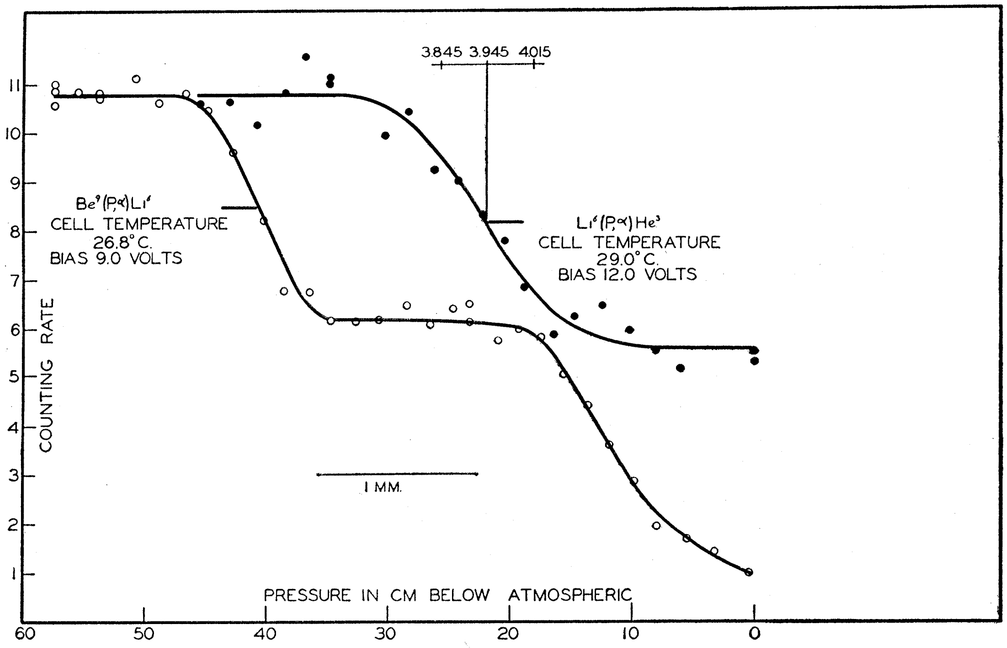

FIG. 4. Data for the computation of the Q value in $Li^6(p,\alpha)He^3$. Both the beryllium and lithium curves as plotted are corrected for barometric variation. Correction for the change in bias of the two curves has not been made. The extreme right of the beryllium curve shows the deuteron cut-off from $Be^9(p,d)Be^8$. The line marked 1 mm is from the calibration data of Table I. The numbers above the lithium curve indicate where the mean range point would have to occur to give various Q values if the alpha-particle energy from $Be^9(p,\alpha)Li^6$ is known exactly.

Care was taken to keep the magnet current constant during a run, and both the magnet and the generator supplying it were allowed to warm up for more than an hour before data were taken. Beams of between two and fifteen microamperes of protons were used, the measurement being made with a current integrator.

A considerable amount of adjustment of the absorption cell constants and the amplifier gain had to be made. Because of the high dispersion of the cell, and because it ran at pressures below atmospheric, only a small range interval could be measured. This interval had to be chosen to include the curves of interest and to exclude scattered protons (range$\sim$4 mm). It was also necessary that the deuterons from $Be^9(p,d)Be^8$ should have a threshold pressure sufficiently low that they might all be counted with the alphas from beryllium. It was found (Fig. 4) that the deuterons had more range in the cell than the alpha-particles and contributed more ionization at all pressures. Pains had then to be taken not to bias out the alphas. A satisfactory solution was achieved by increasing the amplifier gain and decreasing the bias as much as could be done safely. The curve of Fig. 4 marked Be shows the alpha-particles and the deuterons. This is taken at such a bias that at least 1900 ion pairs must be produced to record a count. The yield from the beryllium targets was so great that incidental noise had a negligible effect on these curves. For the lithium reaction, however, the situation was quite different. The only isotopic Li^6 target available was found to be too thick. The yield from the thin fluoride targets was quite small and comparable to the number of small disturbances. It was therefore necessary to count at a higher bias. The bias could not be made too much higher or the low pressure cut-off for the long range alpha-particles from Li^7 might fall in the pressure range being investigated and produce a rapid change in the background. A bias three volts higher (i.e., 12 volts) was found to be suitable. With this the He^3 particles and long range He^4's were counted at all pressures. Since the scaling circuit counted pulses of zero height for a 5.5-volt bias and 9.0 volts corresponded to 1900 ion pairs, 12 volts corresponds to

$1900(12.0-5.5)/(9.0-5.5)$ or 3500 ion pairs. For this the critical pressure P_c is computed to be 25 cm Hg, which is safely below the region of interest.

In Fig. 4 both the beryllium and lithium curves are shown. The mean range of the lithium had to be corrected for the three-volt change in bias. This was done with the calibration apparatus, curves being taken at both biases without moving the micrometer. *B* and *C* of Fig. 2 are such a pair. Two runs judged to be of equal weight gave 5.80 and 6.00 cm Hg difference in pressure at 15°C for a three-volt bias change when suitable corrections were applied. The mean is then 5.90 ± 0.04.

An interesting point concerning the lithium reaction is that there were not as many He^3 as He^4 particles observed. This is explicable if the reaction does not have spherical symmetry; for 90° in the laboratory system corresponds to different angles in the center of mass system for the two kinds of particles. A curve taken by varying the bias showed that there were about as many He^3's from Li^6 as long range He^4's from Li^7 and about as many short range He^4's as both together. A curve published by Neuert[4] shows the same inequality. This circumstance was quite helpful in that it reduced the probable error of the base-line on the number-pressure curves.

The energy of the alpha-particles from beryllium was computed from the 1940 revision of the electrostatic analyzer data of Allison, Skaggs, and Smith.[5] With a Q value of 2.115 ± 0.04 Mev, the Be alpha-particle energy becomes 1.455 ± 0.024 Mev at 370 kev proton energy. From Table II the pressure separation of the lithium and beryllium curves is 17.75 ± 0.4 cm Hg. The bias correction is 5.90 ± 0.04 cm Hg and addition to the uncorrected separation gives a true separation of 23.65 ± 0.4 cm Hg. Table I gives the cell calibration as 12.95 ± 0.4 cm Hg/mm range whence the true difference in range of the two groups is 1.83 ± 0.04 mm in standard air. From the 1938 Cornell range-energy curve based, presumably, upon the work of Holloway and Livingston[7] the slope at 1.6 Mev is 0.190 Mev/mm. If we estimate a 2 percent uncertainty in this value we get the energy separation to be 0.347 ± 0.009 Mev, the alpha-particles from Li^6 being more energetic. This gives 1.802 Mev for the lithium alpha-particles at 370-kv bombardment voltage. If a 10-kv uncertainty is assumed in both bombarding voltages, and exact masses are used in the computation, the Q value for the reaction becomes 3.945 ± 0.06 Mev, practically the entire error being due to the quoted uncertainty of the electrostatic deflection determination of the beryllium reaction, an uncertainty which is probably not as large as assumed.

TABLE I. *Calibration of the absorption cell.*

Trial	Motion of Source (cm)	$\Delta P/\Delta R$ cm Hg per mm range	Weight
1*	0.100	12.65	10
2	0.150	12.45	10
3	0.100	14.40	3
4	0.150	13.38	8

Weighted average result: 12.95 ± 0.2 cm Hg at 15°C is equivalent to 1-mm range at 76 cm Hg and 15°C

* Fig. 2, Curves *A*, *C*.

Application of Results

From the present measurements and certain others some information of interest may be deduced.

H^3-He^3 mass difference

Consider the reactions:

$$Li^6+H^1 \rightarrow He^4+He^3+3.95 \pm 0.06, \tag{1}$$

$$D^2+D^2 \rightarrow H^3+H^1+3.98 \pm 0.02, \tag{2}$$

$$Li^6+D^2 \rightarrow He^4+He^4+22.20 \pm 0.04. \tag{3}$$

These three energies were determined with absorption cells, (1) and (3) were studied in this laboratory, (1) by the author and (3) by Smith.[10] Reaction (2) is described by Oliphant, Kempton and Rutherford,[11] and corrected by Livingston and Bethe.[8] From these three we get

$$(2D^2-He^4)-(2H^1-D^2) = (H^3-He^3)+22.23 \text{ Mev.}$$

TABLE II. *Pressure separation of alpha-particles from* $Li^6(p,\alpha)He^3$ *and* $Be^9(p,\alpha)Li^6$.

Trial	ΔP in cm Hg	Weight
1	17.35	10
2	17.85	8
3	19.5	2

Weighted average result: $\Delta P = 17.75 \pm 0.4$ cm Hg at 15°C

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[10] N. M. Smith, Jr., Phys. Rev. **56**, 548 (1939).

[11] M. L. E. Oliphant, A. E. Kempton, and Lord Rutherford, Proc. Roy. Soc. **149**, 406 (1935).

The quantities on the left in parentheses are well-known mass-spectrograph brackets. If we use Bainbridge's values we get $H^3-He^3=0.19\pm0.09$ while Aston's predict $H^3-He^3=0.10\pm0.1$. That is we may expect H^3 to emit a low energy beta-ray. Neuert's value of 3.72 for reaction (1) would make H^3 stable by 50 and 130 kev for the two cases above. In the second case H^3 would be stable within the experimental error. The radioactivity of H^3 was recently observed by Alvarez and Cornog[2] who estimated the energy of the beta-ray to be about 10 Kev. Still more recently O'Neal and Goldhaber[12] have given evidence for the reaction $Be^9+D^2\rightarrow Be^8+H^3$ and detected beta-rays of about the same energy.

The present measurements give greater consistency than Neuert's with another series of reactions, suggested by Rumbaugh, Roberts, and Hafstad.[13] These reactions are

$$\begin{aligned}
&D^2+D^2\rightarrow H^1+H^3+Q_1,\\
&D^2+D^2\rightarrow n^1+He^3+Q_2,\\
&Li^6+n^1\rightarrow He^4+H^3+Q_3,\\
&Li^6+H^1\rightarrow He^4+He^3+Q_4.
\end{aligned}$$

From these we get

$$(Q_2+Q_3)-(Q_1+Q_4)\equiv f(Q)=0.$$

Table III gives various values of the discrepancy $f(Q)$ for different determinations of the Q's. It is seen that the value $Q_4=3.95\pm0.06$ given by the author is in better agreement with all the different combinations chosen than that of Neuert. The smallest discrepancy (0.03 Mev) is obtained with Bonner's latest value of the energy of the neutrons from the D on D reaction, and with Livingston and Hoffman's earliest value of the Li^6 plus neutron reaction.

TABLE III. *Values of the discrepancy* $f(Q)=(Q_2+Q_3)-(Q_1+Q_4)$ *for various combinations of the values of* Q *from the reactions* $D(d,p)H^3$, Q_1; $D(d,n)He^3$, Q_2; $Li^6(n,\alpha)H^3$, Q_3; $Li^6(p,\alpha)He^3$, Q_4.

REACTION	Q	ERROR QUOTED	COMBINATION	$f(Q)$ MEV
†Q_1	3.98	0.02	$(Q_1Q_2Q_3Q_4')$	−0.08
†Q_2	3.18	0.13	$(Q_1Q_2Q_3'Q_4')$	+0.11
Q_2'	3.29	0.08	$(Q_1Q_2Q_3''Q_4')$	+0.22
†Q_3	4.67	0.05	$(Q_1Q_2'Q_3Q_4')$	+0.03
Q_3'	4.86	0.04	$(Q_1Q_2'Q_3'Q_4')$	+0.22
Q_3''	4.97		$(Q_1Q_2'Q_3''Q_4')$	+0.33
†Q_4	3.72	0.08	$(Q_1Q_2Q_3Q_4)$	+0.15
Q_4'	3.95	0.06	$(Q_1Q_2Q_3'Q_4)$	+0.34
			$(Q_1Q_2Q_3''Q_4)$	+0.45
			$(Q_1Q_2'Q_3Q_4)$	+0.26
			$(Q_1Q_2'Q_3'Q_4)$	+0.45
			$(Q_1Q_2'Q_3''Q_4)$	+0.56

† Corrected by Livingston and Bethe.[8]

Q_1, M. L. E. Oliphant, A. E. Kempton, and Lord Rutherford, Proc. Roy. Soc. **149**, 406 (1935).

Q_2, T. W. Bonner and W. M. Brubaker, Phys. Rev. **49**, 19 (1936).

Q_2', T. W. Bonner, Phys. Rev. **53**, 711 (1938).

Q_3, M. S. Livingston and J. G. Hoffman, Phys. Rev. **50**, 401 (1936).

Q_3', M. S. Livingston and J. G. Hoffman, Phys. Rev. **53**, 227 (1938).

Q_3'', L. H. Rumbaugh, R. B. Roberts and L. R. Hafstad, Phys. Rev. **54**, 657 (1938).

Q_4, H. Neuert, Physik. Zeits. **36**, 629 (1935).

Q_4', Present measurements.

Mass of He^3

In the absence of a good measurement of the upper limit of the β-ray spectrum from H^3, the best method of computing the mass of He^3 appears to be the following:

$$\begin{aligned}
&Li^6+H^1\rightarrow He^4+He^3+3.95\pm0.06\text{ Mev},\\
&Li^6+D^2\rightarrow He^4+He^4+22.20\pm0.04\text{ Mev},\\
&H^1=1.00812\pm0.000,02,\\
&D^2=2.01472\pm0.000,02,\\
&He^4=4.00388\pm0.000,07.
\end{aligned}$$

From this we obtain $He^3=3.01688\pm0.000,11$ mass units. This is to be compared with the value $3.01701\pm0.000,12$ quoted in the paper by Barkas.[14]

The 1.9-Mev excited state in He^3 reported by Bonner[1] would result in particles of too short range to be detected in this experiment.

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