γ-Rays from the Decay of N^{16}

C. H. Millar, G. A. Bartholomew, and B. B. Kinsey
Atomic Energy Project, National Research Council of Canada, Chalk River, Ontario, Canada

November 6, 1950

Sommers and Sherr[1] observed that γ-radiation of about 6 Mev is emitted in the β-decay of N^{16}; and more recently, Millar, Cameron, and Glicksman[2] have demonstrated that this radiation consists of at least two components. Since a direct and accurate measurement of these γ-rays is of interest in connection with the levels of O^{16}, we have studied them with the aid of a pair spectrometer.

The N^{16} is produced in the cooling water from the Chalk River pile by the fast neutron reaction $O^{16}(n, p)N^{16}$. Since the half-life of this isotope is only 7.35 sec, it was necessary to maintain a continuous flow of the active water through a reservoir in front of the spectrometer.

In a survey of the γ-ray spectrum between 5.8 and 9.8 Mev only two γ-rays were found. These have energies of 6.133 ± 0.011 and 7.10 ± 0.02 Mev, which are in good agreement with the values 6.136 ± 0.030 and 7.111 ± 0.030 Mev recently reported by Chao, Tollestrup, Fowler, and Lauritsen[3] for the energies of two of the excited states of O^{16}. The ratio of the intensity of the 7.10-Mev γ-ray to that of the 6.133-Mev γ-ray is 0.08 ± 0.02.

No definite evidence was obtained for a γ-ray with an energy corresponding to that of the 6.91 Mev excited state of O^{16}. Since we determine the energy of a γ-ray by measuring the end point of its coincidence spectrum, the most energetic component of a partially resolved doublet can always be observed and measured, while the existence of the lower energy component is difficult to establish. For this reason, a γ-ray of 6.91 Mev with an intensity not much less than that of the 7.10-Mev γ-ray might have escaped detection, especially since the coincidence counting rates obtained were extremely low.

Recent independent measurements by Barnes, French, and Devons,[4] and Arnold[5] have shown that the γ-ray emitting level of O^{16} excited by the bombardment of F^{19} with 340-kev protons has a spin of 3 units and is of opposite parity to that of the ground state of O^{16}. Under these conditions of bombardment, the 6.133-Mev level of O^{16} is the one most frequently produced,[6] and assuming that the ground state of O^{16} is of even parity, it follows that the excited level has a spin of 3 and odd parity. Bleuler, Scherrer, Walter, and Zünti[7] showed that β-decay of N^{16} to the ground state of O^{16} is a first-forbidden transition, while decay to the γ-ray emitting levels is allowed. From these results it may be deduced that the N^{16} ground state has a spin of 2 and odd parity, and from our measurements it follows that the 7.10-Mev level of O^{16} has odd parity.

[1] H. S. Sommers and R. Sherr, Phys. Rev. **69**, 21 (1946).
[2] Millar, Cameron, and Glicksman, Phys. Rev. **77**, 742 (1950), and Can. J. Research **A28**, 475 (1950).
[3] Chao, Tollestrup, Fowler, and Lauritsen, Phys. Rev. **79**, 108 (1950).
[4] Barnes, French, and Devons, Nature **166**, 145 (1950).
[5] W. R. Arnold, Phys. Rev. **80**, 34 (1950).
[6] W. E. Burcham and J. M. Freeman, Phys. Rev. **75**, 1756 (1949).
[7] Bleuler, Scherrer, Walter and Zünti, Helv. Phys. Acta. **20**, 96 (1947).

Precise Determination of the $Li^7(p, \alpha)He^4$ and $Be^9(d, \alpha)Li^7$ Q-Values[*]

Ward Whaling[†] and C. W. Li
Kellogg Radiation Laboratory, California Institute of Technology, Pasadena, California

October 26, 1950

A magnetic spectrograph of the double-focusing 180° sector type has recently been constructed in this laboratory and used to measure the energy released in the $Li^7(p, \alpha)He^4$ reaction. This 16-in. spectrograph follows closely the design of the 10.5-in. instrument used previously but has an extended energy range and a larger aperture (0.007 steradian). The angle θ between the direction of the proton beam incident on the target and the direction in which alpha particles leaving the target enter the spectrograph was measured by two independent methods: (1) by the ratio of the energies of monoenergetic protons elastically scattered from Be and Ta targets; (2) by means of a stop with a narrow slit in it which could be rotated about the target to intercept first the incident protons and then the particles entering the spectrograph. The angle through which the slit turned was read from a dividing head fixed to it. Both methods agree within 0.1° and show the angle of observation to be 89.3°; we assign a probable error of 0.2°.

Both thick and thin targets of lithium, evaporated in vacuum on copper backings, were used. Figure 1 shows typical thin and thick target spectra, together with the alpha-spectrum from ThC′ source located in the target position. The energy scale is fixed by the peak in the ThC′ curve. For the thick target curve the energy of the alphas coming from the surface of the target was taken to be that of a point at 54 percent of the maximum thick target yield, indicated by the arrow in the figure. This value was chosen by consideration of the shape of the curve obtained by folding the spectrograph window into the spectrum for infinite resolution. For the thin target the peak in the curve shows the energy of the alpha-particles, which must be corrected for the finite target thickness. This correction was made by adding to the peak energy one-half the thickness of the target measured in units of alpha-particle energy.

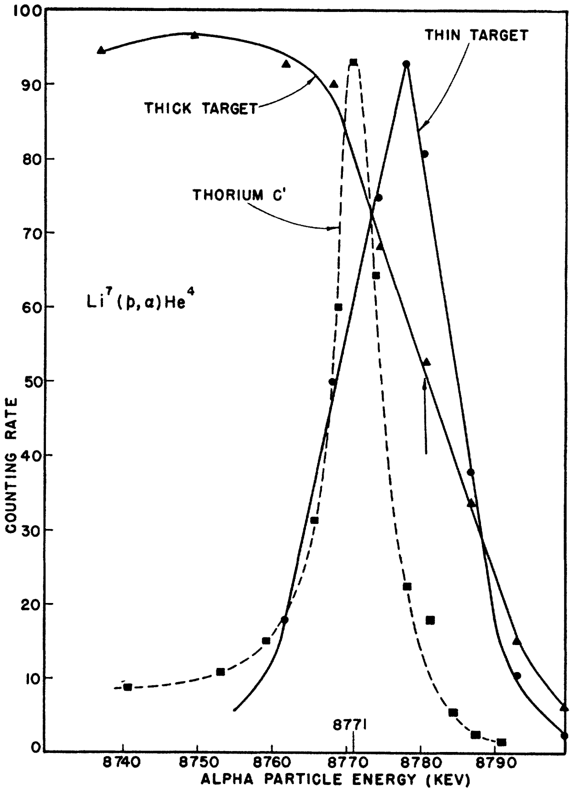

Fig. 1. Typical thin and thick target spectra of α-particles from $Li^7(p, \alpha)He^4$. Bombarding energy 336 kev. Angle of observation 89.3°. Energy scale fixed by peak in ThC′ spectrum.

The proton bombarding energy was held constant to within 0.1 percent with an electrostatic analyzer. Three determinations of Q were made at a bombarding energy of 1008 kev using H^+ ions and eight at 336 kev using HHH^+ ions. At the lower bombarding energy the Li alpha-particle energy is very close to that of the ThC′ alpha-particles, and by calibration of the fluxmeter with the ThC′ alphas, errors that might arise from inaccuracies in the field measurement are avoided. The values of Q at these two energies agreed to within 3 kev and have been averaged to give the final value of 17.338 ± 0.011 Mev. The 11-kev uncertainty is the probable error in Q arising from various experimental factors, of which the largest, $\Delta Q=7.5$ kev, is due to the 0.2° probable error in θ.

During a run the magnetic field was monitored continuously with a fluxmeter previously described[1] and controlled by varying the magnet current manually. To check on the stability of the fluxmeter the ThC′ spectrum was observed both before and after each Li run. The ThC′ source, prepared by the capture of recoils from the decay of thoron on a highly polished aluminum electrode, 1/16 in. in diameter, was mounted on the target holder so that it could be moved quickly into the target position without disturbing the apparatus. The energy of the alpha-particles from ThC′ is given by Briggs[2] as 8.7759 ± 0.0009 Mev. The energy of the alphas from our source will be less than this because the ThC′ atoms are imbedded in the source backing as a result of the recoil of the ThB nucleus into the source. After the method given by Rutherford[3] we calculate the range of the ThB recoil to be 0.136 mm air equivalent, and estimate the average alpha-energy loss in the source to be 4.4 kev, with a probable error of 25 percent. The peak in the ThC′ spectrum thus represents an energy of 8.7715 ± 0.0020 Mev.

The observed energy of the alpha-particles has been corrected for the energy loss of incident and emitted particles in the surface layers of carbon and oxygen that appear on the target surface during bombardment. The way in which these layers build up on a clean Li surface as a function of the bombarding charge was first determined, by measurement of the thickness of the layers by observing the protons elastically scattered from them. Then the surface layer on each target used was estimated from its total bombardment. The thickness of both C and O layers together usually amounted to about 1 kev (for 336-kev protons, measured normal to the surface), which requires a 4-kev correction to the measured Q-value.

Our value of Q is higher than the previously accepted value of 17.280 ± 0.030 Mev, determined from range measurements.[4] This discrepancy may be accounted for in part by the surface layers or possibly to an error in the measurement of θ, which seems difficult to know accurately in the earlier experiment. This new value is in excellent agreement with a similar magnetic measurement by Buechner,[5] whose value is 17.340 ± 0.014 Mev.

For this value of Q one can calculate the mass of the α-particle from the mass of the deuteron and the Q values of the three reactions: (1) $Be^9(d,\alpha)Li^7$, (2) $Be^9(p,d)Be^8$, (3) $Be^8(\alpha)He^4$. Q_2 and Q_3 have been measured previously with a magnetic spectrograph.[6] We have checked the value of Q_1 listed in reference 6 following exactly the procedure described above for the $Li^7(p,\alpha)\alpha$ reaction. The average of 6 determinations with both thick and thin Be targets is 7.151 ± 0.010 Mev in good agreement with Buechner's value[5] of 7.150 ± 0.008. Using 2.226 ± 0.003 Mev for the binding energy[7] and 2.014723 for the mass of the deuterium, and the "adopted" values of Q_2 and Q_3 listed in reference 6, we find for the He^4 mass 4.003840 ± 0.000018, where the error is the root square average of the probable errors in the Q-values entering in the calculation including an 0.004-mmu error in the deuteron mass. Ewald's[8] recent mass spectroscopic measurement of the He^4 mass from the $2D-He^4$ doublet also gives the value 4.003840 ± 0.000012, based on a D^2 mass of 2.014722 ± 0.000006.

* Assisted by the joint program of the ONR and AEC.

† AEC Post-Doctoral Fellow.

[1] C. C. Lauritsen and T. Lauritsen, Rev. Sci. Instr. **19**, 916 (1948).

[2] Holloway and Livingston, Phys. Rev. **54**, 18 (1938).

[3] Rutherford, Chadwick, and Ellis, *Radiations from Radioactive Substances* (Macmillan Company, 1930), p. 155.

[4] N. R. Smith, Phys. Rev. **56**, 548 (1939).

[5] W. W. Buechner, private communication.

[6] Tollestrup, Fowler, and Lauritsen, Phys. Rev. **78**, 372 (1950).

[7] Mobley and Laubenstein, Phys. Rev. **80**, 309 (1950).

[8] H. Ewald, Z. Naturforsch. **5A**, No. 1, 5 (1950).

The Inverse Voltage Characteristic of a Point Contact on *n*-Type Germanium

Lloyd P. Hunter
Westinghouse Research Laboratories, East Pittsburgh, Pennsylvania

November 10, 1950

The purpose of this letter is to suggest a qualitative picture of the effect of self-heating on the inverse voltage characteristic of a point contact. The typical inverse voltage characteristic of *n*-type germanium shown in Fig. 1 has never been satisfactorily explained in detail. Benzer[1] and others have reported that the form of the high voltage breakdown portion depends strongly on temperature. The low voltage portion has not been well accounted for by the diffusion and diode theories[2] of rectification, but seems to be explained by the theory of Aigrain.[3]

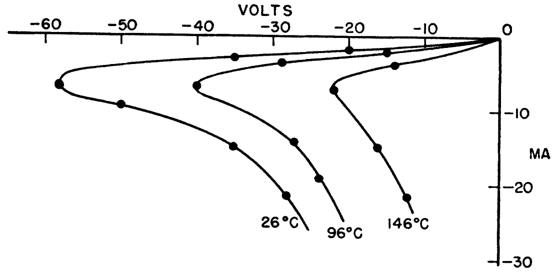

FIG. 1. Typical inverse voltage characteristic for *n*-type germanium point contacts.

The high voltage breakdown portion may be explained entirely on the basis of self-heating if one assumes: (1) that the isothermal characteristics are straight lines (as shown in Fig. 2); (2) that Newton's law of cooling holds, so that the difference between the temperature immediately beneath the point and the ambient temperature is directly proportional to the power dissipated; (3) that the conductivity of the isothermal characteristic shows a thermal activation energy of the order of one electron volt; then one can generate a thermal equilibrium characteristic as follows. In Fig. 2, the isothermal characteristics are laid out from the origin as straight lines. The one representing the ambient temperature being assumed, and the others calculated using the activation energy (0.76 ev in this example). On top of these isothermal characteristics are drawn several hyperbolas of constant

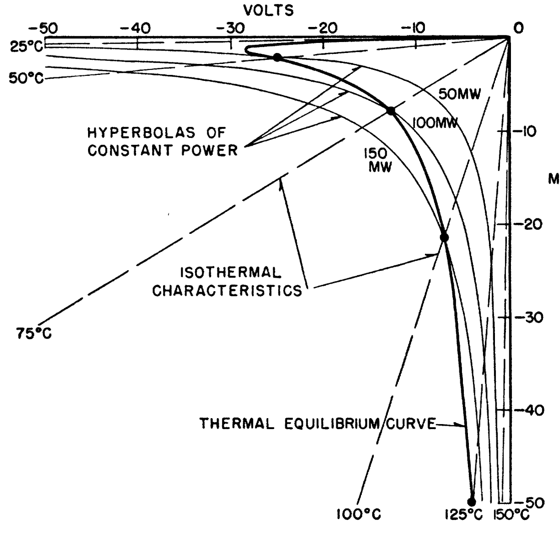

FIG. 2. Method of generating a thermal equilibrium characteristic.