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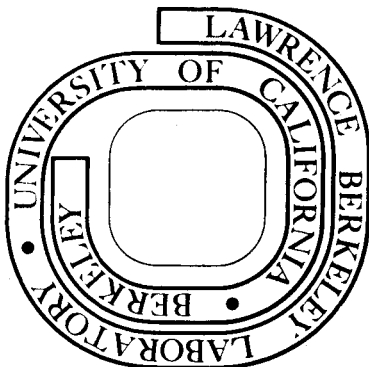
Alan R. Smith and Ralph H. Thomas

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THE PRODUCTION OF ^{11}C BY THE INTERACTION
OF 375 MeV/AMU Ne^{10+} IONS WITH
CARBON*

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ABSTRACT

We have measured the reaction cross section for production of ^{11}C from ^{12}C in a polystyrene target with incident 375-MeV/amu Ne^{10+} ions at the Lawrence Berkeley Laboratory's Bevalac. We used a broad beam irradiation, and determined both beam profile and absolute particle fluence with LiF thermoluminescent dosimeters, which had been calibrated by track counting in nuclear emulsions; the induced target activity was measured with a NaI(Tl)-crystal, γ -ray spectrometer. The reaction cross section was 75 ± 7 mb.

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The interactions of heavy ions with matter are of fundamental interest, as in understanding the interaction of the galactic cosmic radiation with interstellar matter and the Earth's atmosphere. The interaction of the cosmic-ray components of these heavy ions with spacecraft materials and human passengers is of practical importance. Energetic heavy ion beams of intensities usable for both physics and radiobiological experiments have recently become available at the Lawrence Berkeley Laboratory Bevalac facility.¹ The beam intensity available decreases with ion mass, but intensities of 10^7 to 10^8 Ne^{10+} ions/sec have been produced at energies up to ~ 2 GeV/amu. At present the available intensity of Ar^{18+} is only about 10^4 ions/sec, but plans are underway to increase the intensities of Ar^{18+} one to two orders of magnitude.

Interpretation of results in many physical and radiobiological experiments requires knowledge of the absolute number of beam particles that impinge upon the experimental apparatus. The response characteristics of ionization chambers and secondary-emission chambers, the traditional beam-monitoring instruments for high-intensity beams of singly-charged particles, are not yet well known for the high dE/dx heavy ions now produced by the Bevalac. Thus the determination of reaction cross sections, of fundamental interest in itself, is also of great value in providing techniques for absolute determination of ion beam intensities. This paper describes preliminary studies of the reaction cross section for the production of ^{11}C from the interaction of 375-MeV/amu Ne^{10+} ions with ^{12}C .

Experimental Technique

A beam of Ne^{10+} ions was extracted from the Bevalac at an energy of 400 ± 4 MeV/amu,³ and transported to a polystyrene target. From the known thickness of material in the beam path and specific energy losses,⁴ the beam energy at the target was computed to be 372 ± 6 MeV/amu.

The ions were focused into a broadly distributed beam designed for the irradiation of small mammals for radiobiological studies.⁵ The radial distribution of the beam was effectively Gaussian in form with a standard deviation, s , of 4.24 cm. Figure 1 shows the measured beam distribution using ^7LiF thermoluminescent dosimeters (Harshaw chips 1/8-in. \times 1/8-in. \times 0.035-in.; mass 25 mg.)

Two polystyrene discs, each 3.00-in. diam. by 0.250-in. thick, were irradiated in this beam with thermoluminescent dosimeters placed on the surface of the disc in which the ion beam entered. The dosimeters, which had been absolutely calibrated, were used to determine the incident particle fluence. Two

polystyrene discs were used to estimate the degree of activation buildup with thickness of target material. The irradiation time was 510 sec, at nominal total beam intensity of $\approx 2 \times 10^7$ ions/sec, of which $\approx 6 \times 10^6$ ions/sec were incident on the discs.

Activation Measurements

Each irradiated disc was counted five times in a period of 30 minutes using a NaI(Tl) scintillation crystal γ -spectrometer. The only radionuclide observed was ^{11}C , which decays by positron emission with a half-life of 20.34 min.; the counts in each target confirmed this half-life. Counting rates in the positron-annihilation γ -ray peak were 3 to 5×10^4 counts/min., to be compared with a background counting rate of 45 counts/min. Approximately 3.2×10^5 counts were obtained from each irradiated target, giving a standard deviation of $\pm 0.15\%$.

Gamma-Ray Spectrometer

The γ -ray spectrometer used here has previously been described by Radin et al.⁶ The detector, an 8-in. diam., 4-in. thick NaI(Tl) crystal, is coupled through a linear pulse amplifier to a 1600-channel pulse height analyzer. Measurements were made in the Lawrence Berkeley Laboratory low-background facility,⁷ in which the background counting rate is constant to within 2%. These small fluctuations in background rates have been observed to correlate with cosmic-ray muon intensity, and therefore can be corrected if required.

The linear amplifier system employs double delay-line clipping to accommodate very large overload pulses (e.g. from cosmic-ray muons) and very high counting rates. The pulse height analyzer has digital gain-stabilization ensuring that γ -ray spectra are measured on a constant energy scale, even at counting rates as high as 10^7 counts/min. Gamma-ray spectra in the energy range 0.1 to 4.1 MeV are accumulated in 400 channels, at a nominal energy calibration of 10 KeV/channel.

In the measurements reported here, the β^+ annihilation peak was stabilized at channel 51, and the integrated count in the 140-KeV-wide interval comprising channels 45 through 59 was taken as the measure of the quantity of ^{11}C present in the sample. This technique is reliable when no other γ -emitting radionuclides are present in the sample—as was the case during these measurements.

Under these conditions, and making a small correction for the distribution of activity across the sample, the efficiency of the γ -spectrometer has been calculated to be $45.0 \pm 0.5\%$, based on the work of Radin and Smith.⁸ Small corrections were applied to the data for dead time and counting loss. Stability of the γ -spectrometer has been periodically checked over the last 4 years; no statistically significant

change in relative detection efficiency as great as 0.1% has been detected over that period.

Measurement of Incident Fluence

The radial distribution of ion fluence across the target was shown to be given by (Fig. 1):

$$\phi(r) = \phi_0 \exp(-r^2/2s^2) \quad (1)$$

where ϕ_0 is the maximum fluence occurring at $r = 0$, and s is the standard deviation of the distribution.

The standard deviation may be determined from the beam profile shown in Fig. 1 and has the value $s = 4.24$ cm.

The thermoluminescent dosimeters were first calibrated in terms of incident neon ion fluence by exposing them simultaneously with Kodak nuclear track films (NTA). Packages of two dosimeters were placed at the center of the film and exposed at 45° to the beam direction. The ions registered clearly-identifiable tracks readily distinguished from tracks produced by particles of lower ionization. The track densities in the emulsions, as determined by two different scanners, were in agreement within the statistical accuracy of their measurements, and the accuracy of the final calibration was $\pm 4.8\%$.

The absolute value of $\phi(r)$ was determined by placing ^7LiF thermoluminescent dosimeters across the upstream face of the irradiated target. Table 1 summarizes measurements of $\phi(r)$ and the calculated value ϕ_0 obtained was $(6.40 \pm 0.09) \times 10^7$ ions cm^{-2} . The statistical uncertainty in this value for maximum fluence is calculated to be $\pm 5\%$, but it is possible that systematic errors in the techniques used could lead to an absolute error as high as $\pm 10\%$.

Determination of Buildup Correction

The ratio of the ^{11}C activities in the two polystyrene discs was used to determine the magnitude of ^{11}C activity buildup with target thickness. The ratio of disc activities, taken in the sense (rear disc)/(front disc), was found to be 1.152 ± 0.002 . We assumed a linear buildup of ^{11}C activity with target thickness; therefore, the front disc activity was decreased by the factor 0.928 for purposes of reaction cross-section calculation.

Calculation of Reaction Cross Section

The reaction cross section, σ , is given by:

$$\sigma = \frac{T}{2\pi\phi_0 s^2 (1 - e^{-R^2/2s^2})} \cdot \frac{M}{\rho L} \cdot \frac{B(t) C_0}{\epsilon [1 - \exp(-\lambda T)]}$$

where C_0 is the counting rate due to ^{11}C observed in the sample at the end of the irradiation.

ϵ is the efficiency of the γ -spectrometer detector

M is the molecular weight of polystyrene

L is Avogadro's number

T is the irradiation time

λ is the decay constant for ^{11}C

R is the radius of the target

t is the target thickness

$B(t)$ is the buildup correction in a target thickness t , and the other symbols have already been defined. We substitute values in the above equation:

$$\phi_0 = 6.40 \times 10^7 \text{ ions cm}^{-2}$$

$$s = 4.24 \text{ cm}$$

$$\rho = 1.05 \text{ g cm}^{-3}$$

$$t = 0.635 \text{ cm}$$

$$\epsilon = 0.450$$

$$C_0 = 1.332 \times 10^3 \text{ counts sec}^{-1}$$

$$M = 13.01 \text{ grams/per mole}$$

$$L = 6.02 \times 10^{23} \text{ molecules/gram-mole}$$

$$\lambda = 5.68 \times 10^{-4} \text{ sec}^{-1} \text{ (half-life = 20.34 min)}$$

$$T = 510 \text{ s}$$

$$R = 3.81 \text{ cm}$$

$$B = 0.928$$

The chemical formula for polystyrene is $(\text{CH})_n$, and is therefore 92.3% carbon by weight. Elemental carbon is considered to be entirely ^{12}C , in accordance with the usual convention.⁹

We then obtain a value for the reaction cross section, σ :

$$\sigma = 75 \pm 7 \text{ mb,}$$

where uncertainty in the value arises mainly from the estimated inaccuracy of

the absolute fluence determination by the thermoluminescent dosimeter method. Improvements in this method should permit cross-section determinations to accuracies in the 3 to 5% range.

Summary

We have measured the reaction cross section for production of ^{11}C from ^{12}C in a polystyrene target with incident 375-MeV/amu Ne^{10+} ions, and find a value of 75 ± 7 mb. The absolute particle fluence in the broad beam incident on the targets was determined by thermoluminescent dosimeters which were calibrated by track-counting in nuclear emulsions. The thermoluminescent dosimeter monitor permitted the irradiation to be done at high beam intensity, which resulted in relatively large activation in the target. This high intensity insured that accuracy of the cross-section value would not be limited by measurement of target activity, as is often the case when particle counting is used as the absolute monitor at low beam intensity.

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References

- 1) H. Grunder, (Ed), Heavy-Ion Facilities and Heavy-Ion Research at Lawrence Berkeley Laboratory, Lawrence Berkeley Laboratory report, LBL-2090, October 1973.
- 2) Lawrence Berkeley Laboratory Staff, High-Intensity Uranium Beams From the SuperHilac and Bevalac, Proposal P-32, Lawrence Berkeley Laboratory, May 1975.
- 3) K.C. Crebbin (private communication) September 1974.
- 4) C. Richard-Serre, "Evaluation de la perte d'Energie Unitaire et du Parcours pour des Ions Lourds de 10 MeV/Nucleon jusqu'a 1000 MeV/Nucleon. CERN report 72-19, November 1972.
- 5) J.W. Patrick, L.D. Stephens, R.H. Thomas, and L.S. Kelly, The Design of an Experiment to Study Carcinogenesis and Hematological Effects in Mice Irradiated by Energetic Heavy Ions, Lawrence Berkeley Laboratory report, LBL-3071, July 1974. (Submitted to Radiat. Res.)
- 6) J.R. Radin, A.R. Smith, and N. Little, Alpha-Spallation Cross Sections at 920 MeV (230 MeV/N) in ^{27}Al , ^{16}O , ^{12}C , and ^9Be and Application to Cosmic-Ray Transport, Phys. Rev. C 9 (5), 1718 (1974).
- 7) H.A. Wollenberg and A.R. Smith, A Concrete Low-Background Counting Enclosure, Health Phys. 12, 53 (1966).
- 8) J.R. Radin and A.R. Smith, The ^{11}C Detection Efficiency in 3.81-cm Diameter Plastic Scintillators at 60 KeV γ , ^{241}Am Threshold, Lawrence Berkeley Laboratory report LBL-3864; and private communication, 1975.
- 9) J.B. Cumming, Monitor Reactions for High Energy Proton Beams, in Ann. Rev. Nucl. Sci., Vol. 13, edited by E. Segre (Annual Reviews, Inc., Palo Alto, Calif. 1963), p. 270.

Table 1. Absolute Determination of ϕ_0 .

Distance of Dosimeter from Beam Axis (cm)	$\phi(r)$ ions cm^{-2}	ϕ_0 (ions cm^{-2})
0	6.15×10^7	6.15×10^7
0	6.63×10^7	6.63×10^7
1.70	5.88×10^7	6.37×10^7
1.70	6.05×10^7	6.56×10^7
3.30	4.50×10^7	6.09×10^7
3.30	4.85×10^7	6.57×10^7

Mean $(6.40 \pm 0.09) \times 10^7$ ions cm^{-2}

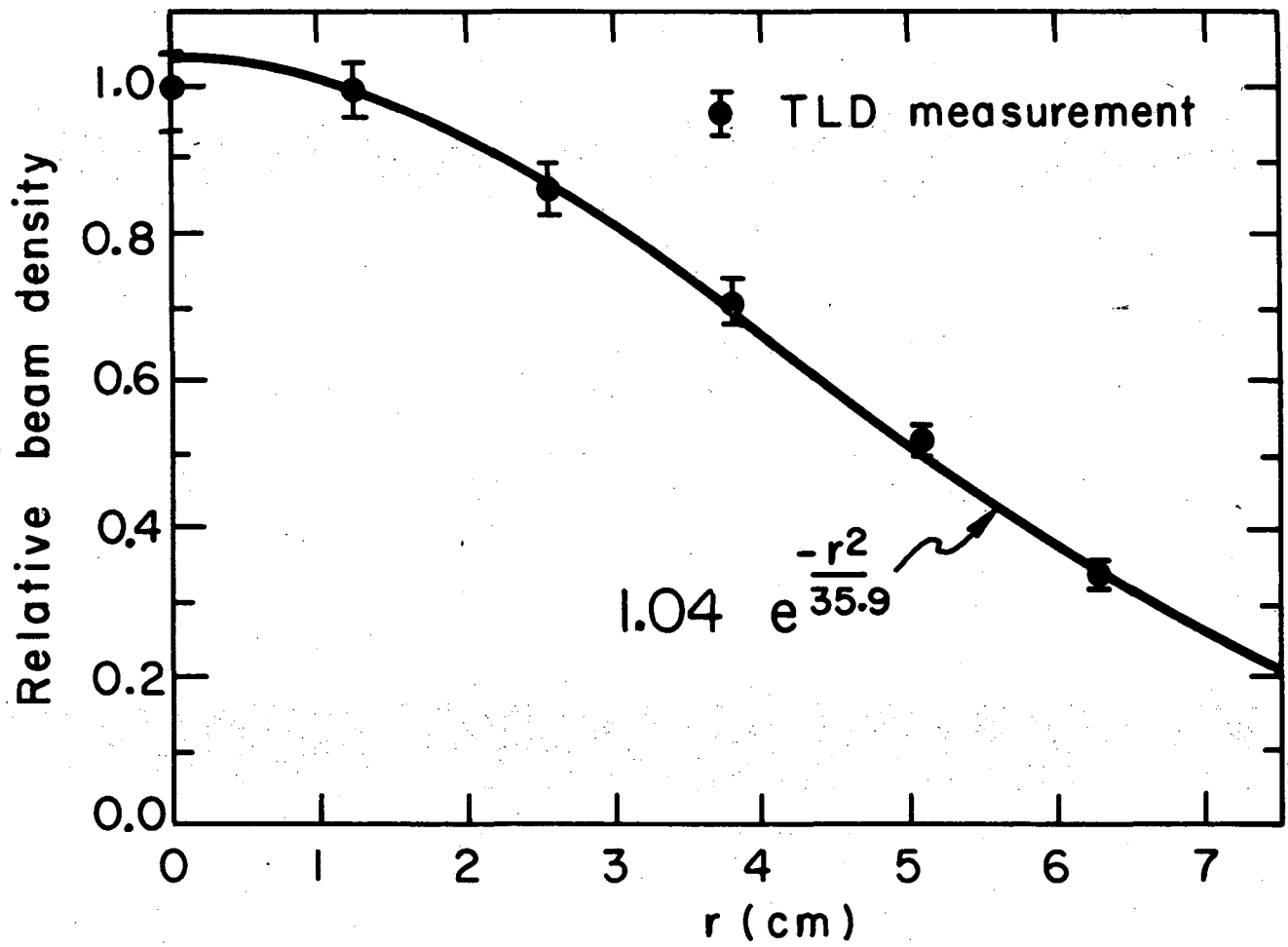


Fig. 1. Beam profile determined by thermoluminescent dosimeters showing experimental data and its Gaussian fit.

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