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PRELIMINARY REPORT ON THE ABSOLUTE EXCITATION CURVE FOR THE $C^{12}(p,pn)C^{11}$ REACTION FROM THRESHOLD TO 350 MEV

L. Aamodt, V. Peterson and R. Phillips

November 21, 1949

Berkeley, California

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The formation of C^{11} from C^{12} by protons above 20 Mev has been widely used at this and other laboratories as a radioactive monitor and detector. The high threshold of the reaction discriminates against low energy background, and the pure C^{11} activity (0.95 Mev β^+, 20.5 min.) is convenient for short activation and counting periods. For these reasons, and in order to study the reaction itself, considerable effort has been taken to establish the excitation curve of the $C^{12}(p,pn)C^{11}$ reaction with absolute values for the cross-sections.

Fig. 1 shows the results obtained to date, which are to be regarded as preliminary. The data are obtained by three different methods, over the low, intermediate and high energy regions of the curve. A detailed study(1) of the threshold of the reaction (18.5 $\pm$ 0.3 Mev), and the variation of the cross-section with energy up to 32 Mev is being carried out using the Berkeley linear accelerator. The data above 100 Mev to a maximum proton energy of 350 Mev has been obtained using the deflected proton beam of the 184-inch cyclotron with copper absorbers to degrade the energy of the protons. Below about 100 Mev this method is inaccurate due to excessive range

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(1) W. K. H. Panofsky and R. Phillips, Phys. Rev. 74, 1732 (1948)

straggling of the protons, and also a direct connection with the 32 Mev linear accelerator data is impossible. Fortunately, the previous work of Chupp and McMillan[2] using the internal cyclotron beam of stripped protons formed when 190 Mev deuterons strike a target covers this range of energies. Chupp and McMillan obtained a relative excitation curve using a stack of carbon discs. Finally, McMillan and Miller[3] have made an absolute determination of the cross-section using the internal stripped protons of 62 Mev.

In the case of the data up to 32 Mev, a stack of carefully molded polystyrene foils .0025 in. to .010 in. thick were bombarded in the beam of the linear accelerator and then counted under an end window Geiger-Müller counter. The counter efficiency for counting beta particles of approximately the same energy as C^{11} betas was determined by counting beta-standards under identical geometrical conditions with equivalent target half-thicknesses on either side of the standard to compensate for scattering and absorption. Three standards were employed: Na^{24} and Au^{198}, which were calibrated by beta-gamma coincidences, and RaE, whose absolute disintegration rate was determined by counting the alphas from RaF. All three standards gave agreement within three percent.

Absolute values were given to the above relative points by bombarding a thin foil with 32 Mev protons and collecting the proton current in a Faraday cup. The charge was integrated on low leakage condensers and the voltage measured by an electrometer circuit. Investigations of the effects of secondary emission electrons apparently show that the loss of charge by this means is small when a high-potential suppressing cylinder is used in front of the Faraday cup. However, these results are still inconclusive and therefore the absolute value at 32 Mev cannot be regarded as final.

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(2) W. W. Chupp and E. M. McMillan, Phys. Rev. 72, 873 (1947)

(3) E. M. McMillan and R. D. Miller, Phys. Rev. 73, 80 (1948)

Essentially the same method is used at the higher proton energies using the deflected proton beam, with several important exceptions. The range of 350 Mev protons in matter is such that both the Faraday cup and the copper absorbers used to degrade the beam energy have dimensions of the order of 6 inches. In this case the absorptions of protons in copper (or carbon) is sufficiently high so that a "stacked foil" technique is of little value. Instead each point was measured absolutely using a Faraday cup and "bad" geometry. Considerable care was taken to make sure that the effects of nuclear and Coulomb scattering in the copper absorbers were not sufficient to allow protons to activate the foil and yet escape the Faraday cup. The neutron background (neutrons above 20 Mev) has been found to be less than one percent in terms of C^{11} activity by counting a foil placed beyond the range of the protons in copper. Secondary emission effects appear to be negligible at these proton energies, and loss of protons from the 6 in. diameter brass cup has been found to be less than 0.1 percent of the beam by placing nuclear photographic plates around the cup during a run. The .005 in. polystyrene foils were counted in the same manner as described above. With increased beam current recently available and improved electrometer circuits, it is planned to fill in several gaps in the curve at higher energies and reduce the errors in current and activity measurement.

Straggling in energy of 350 Mev protons in the copper absorbers is sufficiently great at energies below 100 Mev to render data obtained with the deflected beam in this region of little value. Hence to bridge the gap between 32 Mev and 100 Mev the relative excitation curve of Chupp and McMillan has been corrected for absorption of protons in carbon and fitted to the absolute points already obtained. In making this absorption

correction, rough value of 0.5 barns for the absorption cross-section was assumed, based on a preliminary measurement of the reduction of 350 Mev proton beam current in passing through carbon absorbers ("bad" geometry). The extrapolation to low energies from 350 Mev protons was made on the basis of the ratio of neutron total cross-section at 275 Mev and 90 Mev (a factor of 2). The accumulated absorption correction is approximately 40 percent for the 140 Mev point relative to the 32 Mev point. Measurements are now underway to determine the absorption of protons in carbon more accurately and at lower energies than are now available. In spite of these rough corrections, the absolute value at 62 Mev measured by Chupp and McMillan, when corrected for a more reliable value of the uranium beta-standard which they used, is in fortuitous agreement with the fitted relative excitation curve.

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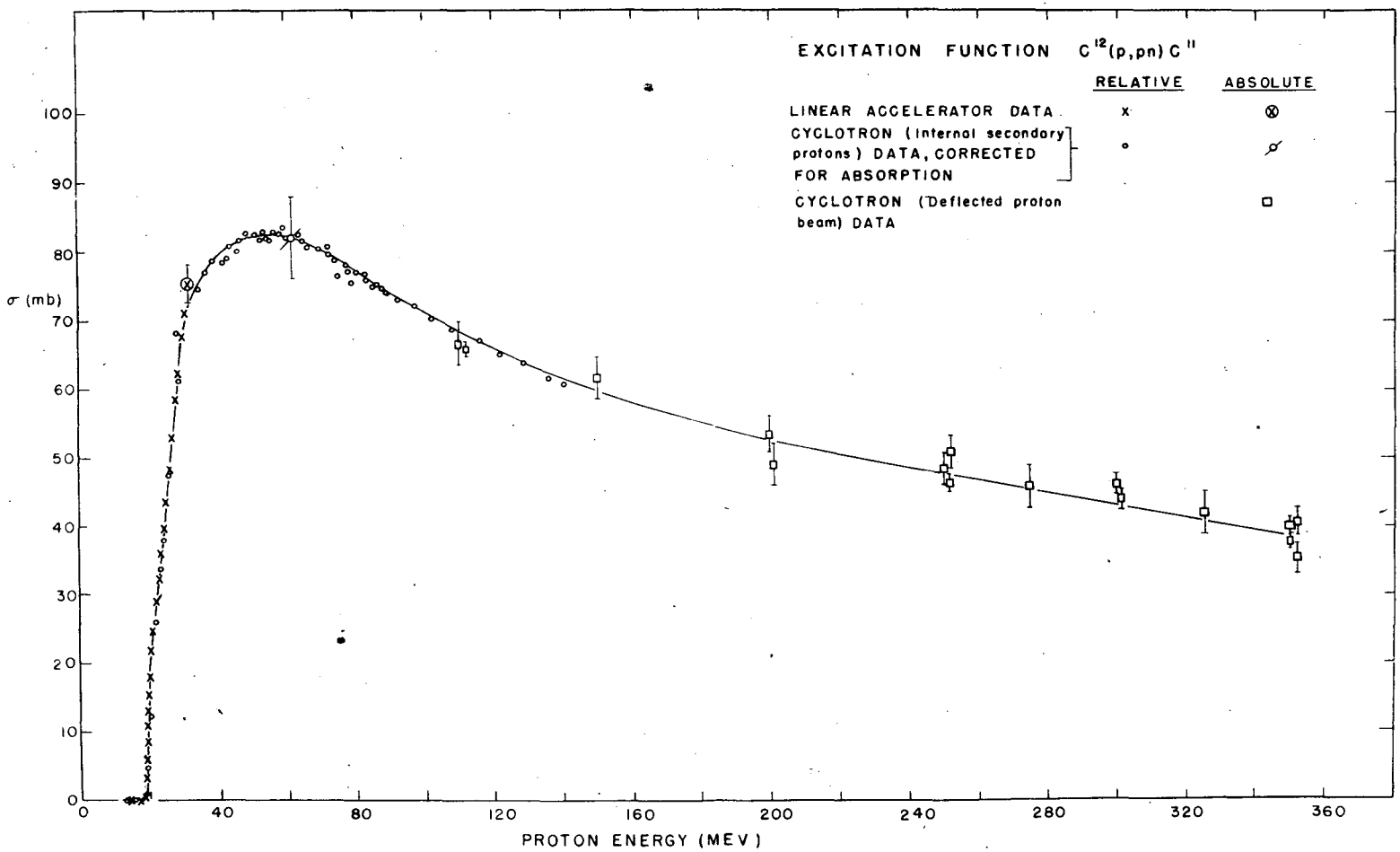
EXCITATION FUNCTION $C^{12}(p,pn)C^{11}$
RELATIVE
ABSOLUTE
LINEAR ACCELERATOR DATA
CYCLOTRON (Internal secondary protons) DATA, CORRECTED FOR ABSORPTION
CYCLOTRON (Deflected proton beam) DATA
σ (mb)
0
10
20
30
40
50
60
70
80
90
100
0
40
80
120
160
200
240
280
320
360
PROTON ENERGY (MEV)

FIG. I