$^{12}C(p, pn)^{11}C$ cross section at 800 MeV†

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The $^{12}C(p, pn)^{11}C$ reaction cross section has been measured at 800 MeV by the method of activation analysis. The value of 32.0 ± 1.0 mb is about 8% greater than the normally used interpolated value of Cumming.

[NUCLEAR REACTIONS $^{12}C(p, pn)^{11}C$, measured σ at $E_p = 800$ MeV.]

The $^{12}C(p,pn)^{11}C$ activation cross section was measured in this work to provide future experiments with an additional proton beam monitor at 800 MeV. The Clinton P. Anderson Meson Physics Facility (LAMPF) external proton beam (EPB) presently has three monitors capable of measuring beam intensity, variable from 1 pA to 100 nA.[1] Because the beam at low intensities can be measured by only one of the three LAMPF monitors, the ion chamber, ^{12}C activation provides an additional monitor for future experiments. The $^{12}C(p,pn)^{11}C$ cross section can be interpolated from the existing data in the review paper by Cumming[2]; however, a shortage of data above 660 MeV limits the accuracy of this interpolation. Our results indicate that the cross section per ^{12}C nucleus, 32.0 ± 1.0 mb, is 8% greater than the 29.5 ± 1.5 mb interpolated value of Cumming.

The bombardment was made in the LAMPF external proton beam with the stripped H^+ beam at 800 MeV. The targets were located 1 m downstream of the beam focus, where the proton beam was approximately 1 cm full width at half maximum (FWHM) incident normal to the target. The targets were 5 cm $\times$ 5 cm $\times$ 0.181 g/cm^2 and 0.354 g/cm^2 NE 102 plastic scintillators and each were epoxied to a pair of 2.54 cm $\times$ 0.32 cm plexiglass light pipes. After bombardment the light pipes were optically coupled to an RCA 8575 photomultiplier tube. The 0.181 g/cm^2 target was bombarded for 590 sec at 75 pA and the 0.354 g/cm^2 target was bombarded for 1080 sec at 7.5 pA. The beam intensity was measured during bombardment by the LAMPF ion chamber (LION) located 6.5 m downstream from the target. LION has a calibrated gain of 143 ± 4 at a pressure of 58.9 cm of Hg and a temperature of 19 °C,[1] which was corrected for ambient conditions during bombardment. A consistency check of LION was performed by the Rice ion chamber (RION) which is an argon gas transmission ion chamber similar to LION located 3.5 m downstream of LION. The ratio of RION current to LION current was within 2% of the theoretically predicted value. The beam spot size and position was monitored by a Rice profile monitor[3] located immediately before RION, insuring that the beam passed within the active regions of the ion chambers. The spot size was observed to be approximately 2 cm FWHM making any space charge effect in the ion chambers negligible at these intensities. Each ion chamber was integrated by a calibrated current integrator and the dark current was measured to be approximately 3 pA (±1%) for LION and negligible for RION. Both beam current integrators were multiscaled allowing correction for a nonuniform beam intensity during bombardment.[4,5] The uncertainty in the gain of LION was the only significant error in calculating the cross section.

The ^{11}C activity, which is 100% β^+ decay to ^{11}B, was measured after bombardment using a $\beta^+\gamma\gamma$ coincidence technique. The targets were removed from the beam and placed into their counting positions, coaxial and midway between two 7.6 cm $\times$ 7.6 cm NaI(Tl) crystals separated by approximately 10 cm. This separation was not crucial but was chosen of such distance as to reduce the deadtime effects in the NaI. Thin light-tight shields and a 0.76 mm copper jacket were placed about the scintillator. The copper jacket stops positrons which escape the scintillator before annihilating. Approximately five minutes elapsed between the end of bombardment and the beginning of β^+ counting and allowed the disintegration of any short-lived activity.

Each NaI windowed the 0.511 MeV annihilation photopeak pulses. A $\gamma\gamma$ coincidence between the two indicated a β^+ decay in the scintillator. The ratio of the $\gamma\gamma$ coincidences coincident with a β^+ in the scintillator to the $\gamma\gamma$ coincidences measured the β^+ detection efficiency of the scintillator. The 0.181 g/cm scintillator had an efficiency of 96.4% and the 0.354 g/cm^2 scintillator had 92.8%. The thin scintillator had a higher efficiency which was probably due to its having better optical couplings. This seems reasonable since earlier measurements showed a sharply varying efficiency with pulse height threshold.[6] The β^+, $\gamma\gamma$, and $\beta^+\gamma\gamma$ counts were all multiscaled and fitted to a half-life curve with the ^{11}C 1224 sec half-life, and each had a χ^2/(degree of freedom) of approximately one.

The target thickness and time of bombardment were selected so as to keep the scintillator dead time for counting β^+ less than 1%. Accidental $\beta^+\gamma\gamma$ coincidences were subtracted in the hardware by using a time offset β^+ pulse to veto the $\beta^+\gamma\gamma$ coincidence. A second NE 102 scintillator located approximately 3 m from the activated scintillator multiscaled the counting area background, which was assumed linearly correlated to counter background. This technique allowed the data to be fitted to a ^{11}C half-life curve with a fluctuating background. Background was observed to be negligible except for the NaI $\gamma\gamma$ counter where it was on the order of 2%. Because the activation could be caused by other reactions such as $^{12}C(n,2n)^{11}C$ an additional Ne 102 target was placed approximately 15 cm above the activated targets during bombardment. No measurable ^{11}C activation was observed.

Results of the two bombardments yield cross sections of 32.0 and 32.1 mb for the thick and thin targets, respectively. Such agreement indicates that statistical errors are negligible, that the efficiences as calculated are reasonable, and that results of this method are reproducible. The cross section for the reaction $^{12}C(p,pn)^{11}C$ at 800 MeV is 32.0 ± 1.0 mb, where the error is based solely on the uncertainty in the ion chamber LION.

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