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UNIVERSITY of CALIFORNIA BERKELEY

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We have completed an experiment at the Berkeley 184-inch cyclotron set up to study radiative capture of pions on nuclei, i.e., the process $\pi^- N(A, Z) \rightarrow \gamma N^*(A, Z-1)$.

This process is believed to be theoretically well understood, and a number of authors have made very detailed predictions, mainly making use of the close relation of the matrix elements governing this process with the ones appearing in muon capture. The analogy with the latter process should manifest itself in the excitation of collective states in the residual nucleus, namely $\Delta T_3 = -1$ analogous states to the giant resonances in the parent nucleus, as observed in inelastic electron scattering.[1] The lack of experimental information, however, did not allow, until now, to check these models in detail. The expected fine structure in the energy spectrum requires a high resolution and, therefore, low efficiency detector, which in connection with the low pion intensities available make the experiment rather time consuming.

Our experimental set up, as shown in Figure 1, included a large size 180°-pair-spectrometer. It consisted of two 18"×36" C-magnets with a common poletip of 18"×86" and a 13" gap, allowing a maximum field of 10 kG, known to an accuracy of 0.2% throughout the volume. The γ-rays were converted in a 0.0045" thick gold foil, inserted between two sets of four-gap, thin (0.0005") aluminum plate spark chambers to detect the electron position pairs. The trigger signal was given by a stopped pion, a neutral particle entering the spectrometer and the electron positron pair detected in two of the six trigger counters in front of the magnet. The tracks are recorded optically and the pictures are being measured on semi-automatic scanning machines. We were able to obtain 10,000 events showing a pair for each of the elements, ^{4}He, ^{6}Li, ^{12}C, ^{16}O, ^{24}Mg and ^{40}Ca. In addition, the properties of the spectrometer were studied extensively using a liquid hydrogen target. The reaction $\pi^- p \rightarrow n\gamma$ with pions at rest allows a measurement of the resolution and provides, also, an independent calibration of the energy scale. The spectrum from mesonic capture $\pi^- p \rightarrow \pi^0 n$ serves as a check on the low energy cut off in our efficiency curve. The resulting spectrum is shown in Figure 2 together with the energy dependent efficiency of our spectrometer as given from a Monte Carlo calculation. Our energy resolution is 2 MeV (FWHM). The Panofsky ratio obtained from these data by use of the calculated relative efficiency agrees with the known value within our statistical errors. The same holds for the total capture rate on hydrogen. Including the efficiency our total solid angle was 3.8×10^{-4} sterradians, resulting in an event rate of 50 - 100 per hour. We obtained the following rates for radiative pion capture with the emission of a γ-ray with energy greater than 50 MeV relative to the total capture rate: ^{4}He 1.40%, ^{6}Li 2.07%, ^{12}C 1.68%, ^{24}Mg 2.74%, and ^{40}Ca 2.20%. The estimated systematic error is 10%. While our value for carbon agrees with the one given by Davies et al.[2] of 1.6 ± 0.1%; we disagree with their value for ^{6}Li of 3.3 ± 0.2%.

So far, we have been able to scan only a small sample of our data, concentrating on hydrogen and carbon. The carbon spectrum, including 25% of our total data for this element, is shown in Figure 3a. We compare our result to a simple phase space calculation, assuming a ^{11}B + n + γ final state and a prediction by use of a Fermi gas model. Both calculations give no representation of our data, the Fermi gas model has already been shown to give too high absorption rates by Anderson et al.[3] Finally, we compare our result with the predictions of the giant resonance model by Kelly and Uberall.[1] We have folded the spectrum, which they obtained for 1s-capture using the model of Kamimura et al.[4] and which includes the widths of the contributing states, with our experimental resolution, as given by the hydrogen line. The result is displayed in Figure 3b. The relative strengths of the states appearing in 2p-capture from the same model is indicated, also. We have omitted their calculations based on an alternative model by Lewis and Walecka.[5] The detailed nature of the experimental spectrum is not described too well by this model, the general features, however, besides the relative strength of the matrix elements for the different states, seem to be present. The 3 MeV broad structure centered around 122 MeV corresponds to excitation energies between 2.7 and 5.7 MeV in ^{12}B, and including a shift due to Coulomb energy of 1.7 MeV to 18 - 21 MeV in ^{12}C. This group probably corresponds to the strong resonance seen in inelastic electron scattering at 19.6 MeV (together with two smaller excitations around 20.4 and 18.1 MeV.)[6] Both the Kamimura and the Lewis model require a strong 2^- spin-isospin resonance in this region. The two peaks at 118 and 116 MeV correspond to about 25 and 23 MeV excitation energy in ^{12}C and can be associated with the giant dipole resonance at 22.8 MeV seen in photoabsorption and its inverse reaction $^{11}\text{B}(p, \gamma_0)^{12}\text{C}$,[7] and the peak at 25.5 MeV, also, seen in the latter process and in the reaction $^{11}\text{B}(p, \gamma_1)^{12}\text{C}$.[7] Both states are well explained by the Kamimura model. This model as well as the Lewis model does not give any account of a dominant structure around 112 MeV (28 MeV in ^{12}C). There is, also, no evidence in any of the reactions mentioned before including inelastic electron scattering. If we follow Kelly and Uberall's speculation, we can attribute this to a positive parity state, arising from spin-isospin oscillation in a giant quadrupole mode. Positive parity states are expected[8] to contribute even stronger to pion capture than the negative parity states. With our full data sample available we hope to arrive at more definite conclusions. We then will also be able to shed light on the question, whether there is any structure visible around 105 MeV, were both models place a $J = 1^-(p_{1/2}s_{1/2})$- state. This energy region has not yet been investigated by the other reactions. At present, however, the conclusion is allowed, that radiative pion capture as muon capture proceeds mainly through the excitation of collective states.

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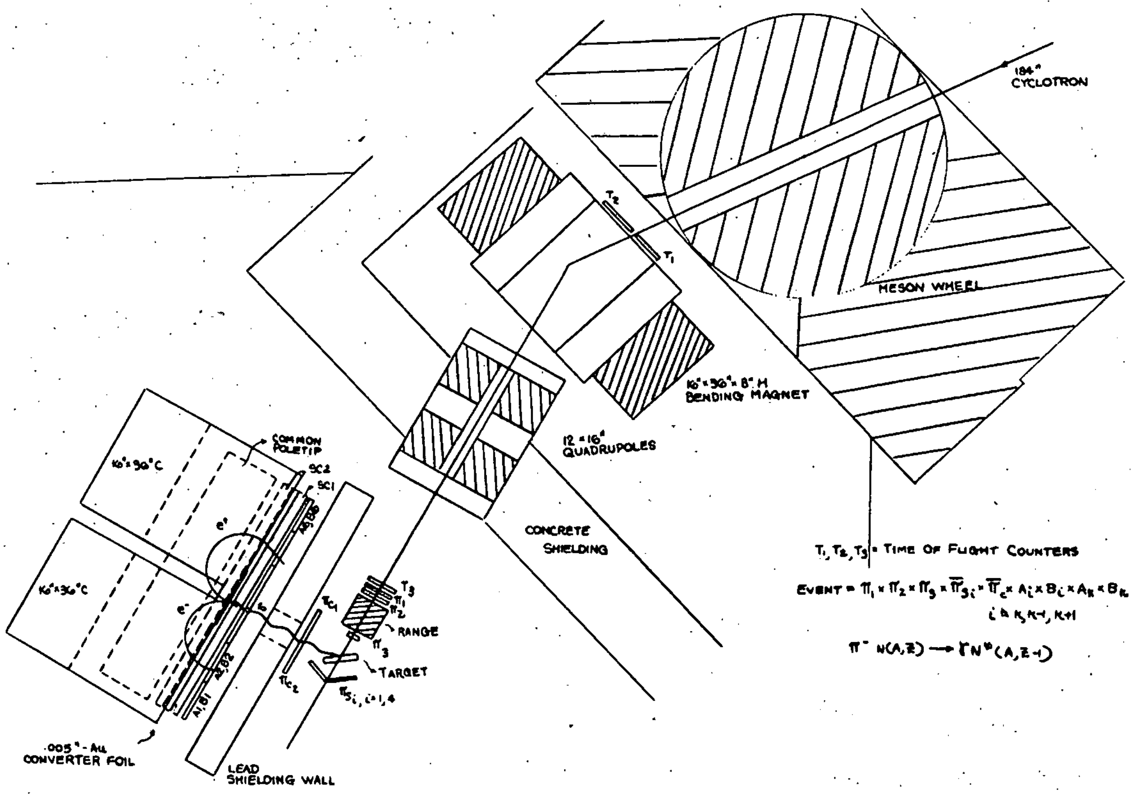

Figure 1. Experimental set-up.

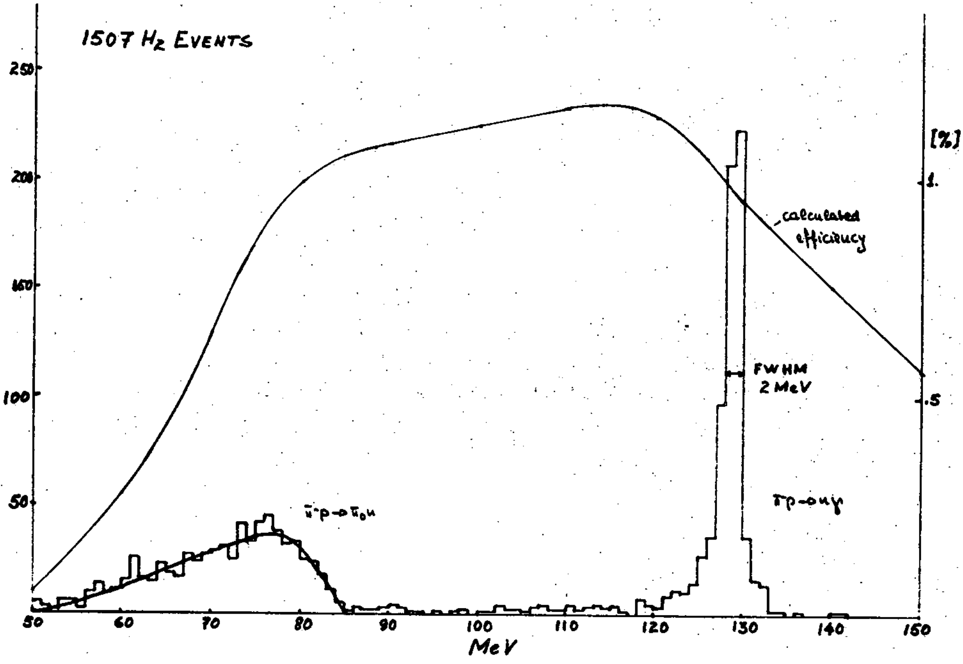

Figure 2. γ^- spectrum for pion-capture on hydrogen. Solid line: calculated spectrometer efficiency. The theoretical yield for mesonic capture has been calculated using the experimental resolution given by the radiative capture, the calculated efficiency and the Panophy ratio.

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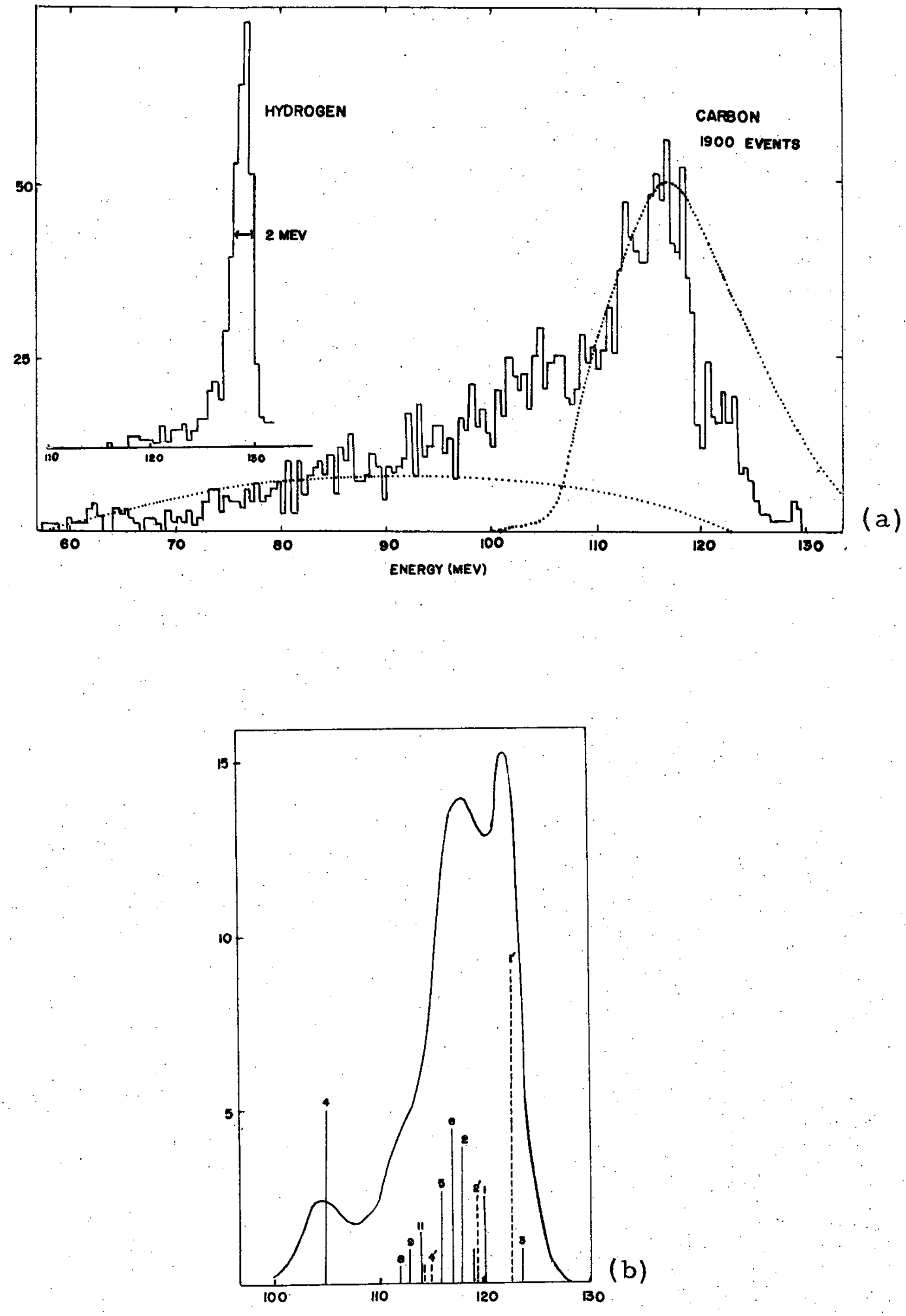

Figure 3. (a) γ^- spectrum from radiative pion capture in carbon. The two curves are a phase-space calculation assuming a $B^{11}n\gamma$ final state and a prediction from the Fermi gas model. For comparison, the experimental resolution is shown, also. (b) Theoretical predictions of Kelly and Uberall[1] folded with the experimental resolutions.

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