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EVIDENCE FOR A p,d REACTION IN CARBON

by

Wolfgang K. H. Panofsky and Robert Phillips

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EVIDENCE FOR A p,d REACTION IN CARBON

by

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Berkeley, California

July 21, 1948

The reaction $C^{12}(p,pn)C^{11}$ has been investigated at proton energies up to 140 m.e.v. in the 184" cyclotron by Chupp and McMillan(1) and McMillan and Miller(2), both as to excitation and absolute cross section. The high energy behavior of this reaction is taken as evidence for the ideas of Serber(3) explaining these processes by a direct knockout, rather than a compound nucleus process.

In this experiment excitation curves of this reaction were obtained in the region from threshold to 32 m.e.v. using the Berkeley linear accelerator. Stacks of polystyrene (C_nH_n) foils were bombarded in the beam of the accelerator; specially molded 10 mil (25 mg/cm^2) foils were used from 32 m.e.v. to 21 m.e.v., commercial 5 mil and 2.5 mil foils were used from 21 m.e.v. to 16 m.e.v. All foils were weighed and calibrated for uniformity. The β^+ from C^{11} were counted in standard geometry in a thin window G.M. counter and compared with a UO_2 standard sample. The resultant curve is shown in Figure 1. The absolute cross sections were obtained by bombarding a foil at 32 m.e.v. in vacuo and collecting the protons in a Faraday cup. The beam passed through an open cylinder maintained at 8,000 volts in going from the sample to the collector cup. The current to the cup was integrated on a low leakage condenser and the voltage read on a balanced electrometer. The entire electrometer

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(1) Chupp and McMillan, Phys. Rev. 72, 873, 1947
(2) McMillan and Miller, Phys. Rev. 73, 80, 1948
(3) R. Serber, Phys. Rev. 72, 1114, 1947

apparatus is in vacuo. Bombardments were also made with the sample located directly in the collector cup and gave results in agreement with the results obtained when bombarding in the beam ahead of the secondary electron suppressing cylinder. The result is

$$\sigma_{32\text{ m.e.v.}} = (.075 \pm .02) \times 10^{-24}\ \text{cm}^2$$

The probable error is entirely due to the problem of absolute evaluation of the β-ray standard. Further work on improving the precision of the absolute β^+ count is planned. The internal consistency is ± .0004 barns over 8 runs.

The energy scale in Figure 1 was established by the use of a range-energy relation in polystyrene as computed by Mr. Henrich of this laboratory. To check the correctness of this relation, a run was made substituting Al absorbers[(4)] to energies down to 20 m.e.v. and using polystyrene absorbers below this point. The resultant points, shown by X in Figure 1, are indistinguishable from the polystyrene absorber points. The range-energy relation was checked also by absorbing the 32 m.e.v. beam down to the threshold of the $B^{11}(p,n)C^{11}$ reaction which was found to be 2.97 ± .1 m.e.v. by Haxby, Shoupp, Stephens and Wells[(5)]. We obtain 3.0 ± .3 m.e.v. indicating that the accuracy at the end point of the $C^{12} \rightarrow C^{11}$ reaction is of the order of ± .1 m.e.v. The output energy of the linear accelerator is inferred from frequency and drift tube dimensions to be 32.0 ± .1 m.e.v., an extrapolated range measurement in Al gave 32.1 ± .1 m.e.v.

If we assume that the threshold of the reaction is sharp, then the threshold can be located from the maximum of the second derivative curve.

- -

(4) J. H. Smith, Phys. Rev. 71, 32, 1947

(5) Haxby, Shoupp, Stephens and Wells, Phys. Rev. 58, 1035, 1940

(Figure 1) We place the threshold of the reaction at

$$18.5 \pm .3 \text{ m.e.v.}$$

If we take the mass of C^{11} to be 11.01498 (in agreement with the threshold[5] of 2.97 m.e.v. for $B^{11}(p,n)C^{11}$, and the β^+ end-point[6] from C^{11} of .95 m.e.v.) the calculated threshold of the reaction $C^{12}(p,pn)C^{11}$ corrected for recoil, is 20.2 m.e.v. The earlier values given by Livingston and Bethe and Barkas[7] for the C^{11} β^+ end-point and the mass of C^{11} are about .3 m.e.v. higher but are based on earlier measurements[8] probably affected by N^{13} contamination. This means that the reaction $C^{12} \rightarrow C^{11}$ must be a (p,d) reaction, rather than a (p,pn) reaction, at least near the excitation threshold. The only other instance of a specific deuteron yielding reaction known is the reaction $Be^9(p,d)Be^8$[9]. Cosmic ray evidence in photographic plates[10] makes it appear that such an event is also possible in high energy processes without breakup of the deuteron.

If the incoming proton were captured by the C nucleus, the resultant excited N^{13} would strongly favor energetically the re-emission of a proton over the emission of a deuteron or neutron. The cross section of the p,d reaction by a compound nucleus process should therefore be much smaller than the values observed. The process is therefore likely to take place by a direct interaction, e.g. by direct ejection of a deuteron and subsequent decay of proton unstable N^{12}.

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(6) Delsasso, White, Barkas and Creutz, Phys. Rev. 58, 586, 1940.
Siegbahn, Arkiv. Mat. Astr. Fysik 30A, No. 20, 1944.
30B, No. 3, 1944.

(7) Livingston and Bethe, Rev. Mod. Phys. 9, 245, 1937.
Barkas, Phys. Rev. 55, 691, 1939.

(8) Fowler, Delsasso and Lauritsen, Phys. Rev. 49, 561, 1936.

(9) Allison, Skaggs and Smith, Phys. Rev. 54, 171, 1938.
J. S. Allen, Phys. Rev. 51, 182, 1937.

(10) LePrince-Ringuet, Cosmic Ray Conference, Pasadena, June 1948.

We are indebted to Messrs. Heckrotte, Martinelli, and Professor Serber for theoretical discussions and to the linear accelerator personnel for making bombardments. The integrating chamber was constructed by Mr. Lee Aamodt. This work was carried out under the auspices of the Atomic Energy Commission.

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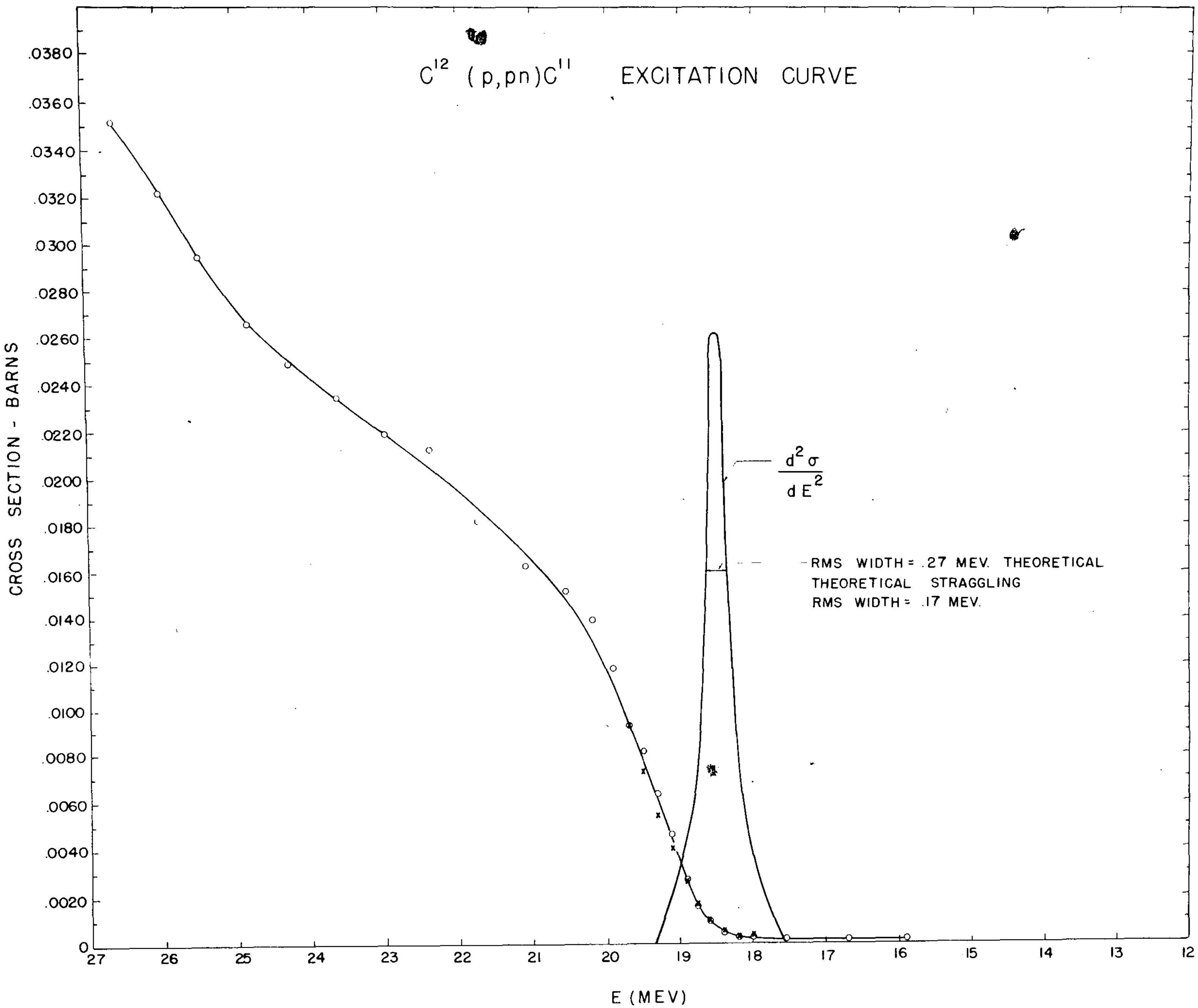

C^{12} (p,pn)C^{11} EXCITATION CURVE
CROSS SECTION - BARNS
E (MEV)
$\frac{d^2\sigma}{dE^2}$
RMS WIDTH = .27 MEV. THEORETICAL
THEORETICAL STRAGGLING
RMS WIDTH = .17 MEV.

FIG. 1

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