isotopes U^{231}, U^{229}, and U^{228} are all unstable in the latter sense.) This effect may be visualized from an energy surface diagram in which pairs of elements differing by $Z=2$ can be compared if it is assumed that a fairly constant difference in packing fraction exists between pairs of nuclear species on the two contours separated by 5–6 mass units. Since alpha-decay proceeds between points on the two contours differing by four mass units, the energy differences between such pairs of points increase with decreasing mass number.

In the lower elements a different phenomenon appears. Although the heaviest isotopes of each show the trend noted above, the alpha-energies begin to decrease with decreasing mass number beyond a particular point. The isotopes showing maxima in alpha-energy are, for the respective elements, Bi^{211}, Po^{212}, and At^{214} or At^{213}, the latter being unknown. This trend was noted some time ago for polonium isotopes.[3] However, at still lower mass numbers for each element the initial trend of increase in alpha-energy with decrease in mass number is resumed. The exact trend cannot be followed in the case of bismuth as it can for polonium and astatine since no alpha-activity has yet been observed over the mass number range 202–210, with the possible exceptions of Bi^{208} and Bi^{210}. However, the reappearance of alpha-activity at lower mass numbers leaves little doubt that bismuth shows the same behavior as polonium and astatine.

In order to explain the course of those curves of Fig. 1 that go through maxima, and minima it is necessary to modify the smoothly varying energy surface by replacing in it a depression or ridge (or both), but the exact shape and position of the irregularity cannot be determined without more data including that of beta-decay energies in this region. It is of interest to speculate whether or not this irregularity becomes smoothed out above the region around lead or extends to the higher elements. It may be pointed out that Bi^{209}, Po^{210}, and At^{211}, which are situated at or near the minima of their respective curves, contain 126 neutrons, possibly an especially stable configuration.[4]

The difficulty of observing this effect for higher elements is apparent from the relative positions of the curves for each element with respect to the region of beta-stability. In the cases of bismuth and polonium it is seen that the peak in alpha-energy occurs either in the region of beta-stability or on the β^--unstable side. It is, therefore, possible to prepare and observe isotopes of considerably lower mass number. In the cases of the higher elements the regions of beta-stability occur at relatively higher mass numbers, and the alpha-decay energies are still increasing for isotopes which become difficult to prepare and which are on the neutron deficient side of beta-stability. However, there is some hope for preparing more highly neutron deficient isotopes of emanation and francium as decay products of highly neutron deficient isotopes of the heaviest elements in the same manner in which At^{214} results from an alpha-decay chain starting with Pa^{226}.

It is not possible to discuss in this communication a number of other correlations which can be made regarding alpha-decay energies and half-lives and regions of beta-stability. These will be dealt with in a later paper.

Besides the measured alpha-particle energies, some others can be calculated for cases in which the alpha-decay completes an otherwise known decay cycle of two alpha- and two beta-emissions. A few of these have been entered in Fig. 1 for those cases in which indirect evidence for alpha-emission has been obtained by observing the growth of the daughter.

This work was done under the auspices of the U. S. Atomic Energy Commission.

[1] For similar treatment of alpha-decay data see, for example: K. Fajans, *Radioelements and Isotopes* (McGraw-Hill Book Company, Inc., New York, 1931); J. Schintlmeister, Oesterr. Chem. Z. **41**, 315 (1938); A. Berthelot, J. phys. rad. (Series VIII) **3**, 17 (1942).
[2] G. T. Seaborg and I. Perlman, Rev. Mod. Phys. **20** (October 1948 issue).
[3] For discussion of early work see: K. Fajans, *Radioelements and Isotopes* (McGraw-Hill Book Company, Inc., New York, 1931).
[4] Maria G. Mayer, Phys. Rev. **74**, 235 (1948).

Evidence for a *p,d* Reaction in Carbon

WOLFGANG K. H. PANOFSKY AND ROBERT PHILLIPS
Radiation Laboratory, Department of Physics, University of California, Berkeley, California
October 19, 1948

THE reaction $C^{12}(p,pn)C^{11}$ has been investigated at proton energies up to 140 Mev in the 184-inch 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 Mev 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) foils were used from 32 Mev to 21 Mev, commercial 5 mil and 2.5 mil foils were used from 21 Mev to 16 Mev. 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 Fig. 1. The absolute cross sections were obtained by bombarding a foil at 32 Mev in vacuum and collecting the protons in a Faraday cup. The beam passed through an open cylinder maintained at 8000 volts in going from the sample to the collector cup, in order to suppress secondary electrons. The current to the cup was integrated on a low leakage condenser and the voltage read on a balanced electrometer. The entire electrometer apparatus is in vacuum. 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

$$\sigma_{32\ \mathrm{Mev}}=(0.075\pm0.02)\times10^{-24}\ \mathrm{cm}^2.$$

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 ± 0.0004 barn over 8 runs.

The energy scale in Fig. 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 Mev and using polystyrene absorbers below this point. The resultant points, shown by X in Fig. 1, are indistinguishable from the polystyrene absorber points. The range-energy relation was checked also by absorbing the 32-Mev beam down to the threshold of the $B^{11}(p,n)C^{11}$ reaction which was found to be 2.97 ± 0.1 Mev by Haxby, Shoupp, Stephens, and Wells.[5] We obtain 3.0 ± 0.6 Mev, indicating that the accuracy at the end point of the $C^{12}\rightarrow C^{11}$ reaction is of the order of ± 0.15 Mev. The output energy of the linear accelerator is inferred from frequency and drift tube dimensions to be 32.0 ± 0.1 Mev, an extrapolated range measurement in Al gave 32.1 ± 0.1 Mev. The test by means of the $B^{11}(p,n)C^{11}$ reaction would show up both errors in the accelerator energy, absorber, or range-energy curve.

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 (Fig. 1). We place the threshold of the reaction at

$$18.5\pm 0.3 \text{ Mev},$$

where the probable error includes possible errors in the energy scale. If we take the mass of C^{11} to be 11.01498 (in agreement with the threshold[5] of 2.97 Mev for $B^{11}(p,n)C^{11}$, and the β^+-end point[6] from C^{11} of 0.95 Mev) the calculated threshold of the reaction $C^{12}(p,pn)C^{11}$ corrected for recoil, is 20.2 Mev. 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 0.3 Mev 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 N^{12} with emission of a proton.

We are indebted to Messrs. Heckrotte and Martinelli, 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.

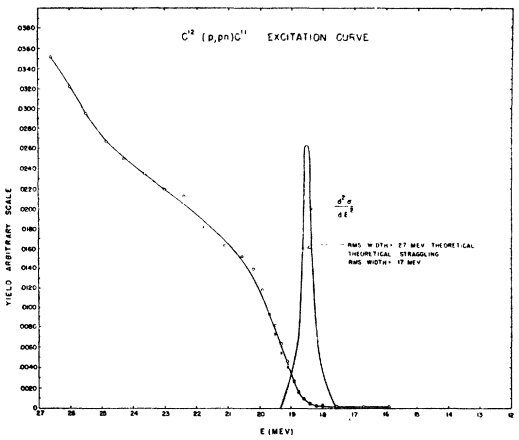

FIG. 1. The excitation curve for the reaction $C^{12}(p,pn)C^{11}$.

[1] W. W. Chupp and E. M. McMillan, Phys. Rev. **72**, 873 (1947).
[2] E. M. McMillan and R. D. Miller, Phys. Rev. **73**, 80 (1948).
[3] R. Serber, Phys. Rev. **72**, 1114 (1947).
[4] J. H. Smith, Phys. Rev. **71**, 32 (1947).
[5] Haxby, Shoupp, Stephens, and Wells, Phys. Rev. **58**, 1035 (1940).
[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.

Some New Radioactive Isotopes of Tb, Ho, Tm, Lu, Ta, W, and Re

GEOFFREY WILKINSON AND HARRY G. HICKS
Radiation Laboratory and Department of Chemistry, University of California, Berkeley, California
October 13, 1948

IN order to allow quantitative interpretation of the reactions of high energy particles from the 184-inch cyclotron with tantalum and heavier elements, a systematic survey is being made of radioactive isotopes of the rare earth elements—hafnium, tantalum, tungsten, and rhenium. Bombardments of various elements are being made using 38-Mev and 20-Mev helium ions, 19-Mev deuterons and 10-Mev protons from the 60-inch Crocker Laboratory cyclotron. Chemical separation of the rare earth elements is made by ion-exchange resin columns. Table I summarizes present data; energies of radiations are determined from absorption measurements; positrons are observed using a "magnetic counter;" mass allocations are made on the basis of measured cross sections. The symbols used in the table are those employed by Seaborg.[1]

Detailed accounts of experimental techniques and of the isotopes will be published.

The allocation of the previously reported β-active