known and is difficult to estimate since it involves shower theory. Williams' calculations indicate an uncertainty of about 30 percent for his results but unfortunately the suggested range of possible values extends upward from the curve. His calculations would agree moderately well with those of T–B if the more exact cross section for production of knock-on electrons were used.

Large changes in mesotron mass would be required in order to remove the discrepancy, e.g., an increase in mesotron mass from 200 to $250m_e$ results in only a 12 percent decrease in the predicted number of secondaries. Large changes in the mesotron spectrum also produce only small alterations in the expected number of secondaries.

We have greatly appreciated instructive conversations with Dr. David Bohm concerning the shower theory.

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Disintegration Schemes of Radioactive Substances IX. Mn^{52} and V^{48}

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The radiations emitted in the decay of $_{25}Mn^{52}$ (6.5 day) and of $_{23}V^{48}$ have been investigated by spectrometer and coincidence methods. Mn^{52} decays with the emission of positrons of maximum energy 0.582 ± 0.015 Mev, followed by three gamma-rays in cascade, of energies 0.734 ± 0.015 Mev, 0.940 ± 0.02 Mev, and 1.46 ± 0.03 Mev, respectively. These energies are the multiples 3, 4, and 6 of 0.240 Mev, within the experimental errors. The orbital electron capture by Mn^{52} leads to the same excited state of Cr^{52} as the positron emission with which it competes. The positrons of V^{48} are emitted with a maximum energy of 0.716 ± 0.015 Mev, with successive emission of two gamma-rays of 1.33 ± 0.03 Mev and 0.980 ± 0.02 Mev energy. These gamma-ray energies are in the ratio 4:3. From the disintegration schemes one finds the mass differences between neutral atoms: $Mn^{52}-Cr^{52}=5.10\pm0.15\times10^{-3}$ a.m.u. and $V^{48}-Ti^{48}=4.37\pm0.12\times10^{-3}$ a.m.u. Some evidence is also presented concerning the disintegration of V^{52} and of Sc^{48}. The energy levels of Cr^{52} and Ti^{48} identified in the radioactive processes are compared with those found by other methods. The disintegration energies of several nuclei studied are examined with a view to their dependence on atomic weight. It is shown that beta-ray theory explains consistently the lifetimes, the shapes of the positron spectra, and the ratio of electron capture to positron emission if one assumes tensor interaction, angular momentum change $\Delta I=0$ or $\Delta I=\pm1$ (not $0\rightarrow0$) without parity change in the case of Mn^{52} and with parity change in the case of V^{48}.

INTRODUCTION

IN paper VII of this series[1] we called attention to some apparent similarities between the energy levels of certain nuclei in the same region of the periodic table. It seems desirable to study the excited states of several nuclei which might be expected to differ in some regular fashion in their internal structure. The most desirable method for such a study would be—in many respects—the measurement of the energies of secondary heavy particles from transmutation or inelastic scattering processes. When this method is developed to the ultimate precision of which it is capable, it should prove to be as powerful a tool for the analysis of energy levels in light nuclei as the study of spontaneously emitted alpha-particles has been for the levels of very heavy nuclei. However, the contemporary techniques are such that the resolution obtained is less than some known level spacings, even in rather light nuclei, such as Fe^{56} (paper VI). Therefore a study of the radiations emitted in radioactive disintegrations appears to be the most hopeful approach at present. This method has yielded reliable and rather precise information concerning the energy levels of a number of nuclei, but its extension to the study of any selected sequence or group of nuclei presents certain inherent difficulties. Each of the nuclei to be investigated must be the product of one or, preferably, two or three radioactive processes of sufficiently long period to permit thorough study, and involving several excited states. Furthermore there must be some practical method to produce the radioactive species in-

[1] Reference to the first five papers will be found in paper VI: Phys. Rev. **64**, 321 (1943); papers VII and VIII appeared in Phys. Rev. **65**, 211 (1944) and **68**, 193 (1945).

volved either free from other activities of the same element or at least free from such activities as might interfere with the unambiguous assignment of the radiations. Few groups of nuclei which might exhibit structural similarities satisfy these conditions with the techniques available.

The group of stable nuclear species of even atomic number and isotopic number four which extends from S^{36} to Zn^{64} is one of the few available for our purpose. The members of this group may be thought of as built up from S^{36} by the addition of from one to seven alpha-particles. While there is no definite evidence that such a group could be considered a sequence of nuclear homologues, it appeared at least as a possible starting point, in view of our slight knowledge of the structure of any but the lightest nuclei. Two members of the group, Fe^{56} and Ni^{60}, have been discussed in papers VI and VIII of this series[1] while some evidence concerning other members has been reported by other authors. In this paper we present results concerning Cr^{52} and Ti^{48} in the light of the radioactive decay of their neighbors. The results are not as complete as might be desired because of the pressure of more urgent work. The beta- and gamma-ray spectrometer[2] and coincidence techniques have been described in earlier papers.[1]

A. Mn^{52}

The species of manganese with 6.5 day half-life has been assigned to mass number 52 by Livingood and Seaborg.[3] It appears to be isomeric with the 21-minute activity assigned to the same mass number. Hemmendinger[4] studied Mn^{52} and reported that the maximum energy of the positrons emitted by the 6.5-day species is 0.77 Mev. He also reported finding gamma-rays of 1-Mev and 2-Mev quantum energy and estimated that 95 percent of the disintegrations proceed by orbital electron capture.

PREPARATION OF SOURCES OF Mn^{52}

Mn^{52} was produced for our experiments by the reaction $Cr^{52}(d, 2n)Mn^{52}$. A water-cooled "probe" of the Massachusetts Institute of Technology cyclotron was chromium-plated and bombarded for two hours with an average current of 0.5 milliamperes of 13.5-Mev deuterons. The bombardment was concentrated on an area of about 0.5 cm^2 as indicated by a slight discoloration of the bright chromium plate. The plating was dissolved from this area in hydrochloric acid and 2 mg of Mn, 5 mg of V, and 5 mg of Cu were added to this solution as chlorides. Manganese and copper were precipitated with sodium peroxide; the precipitate was redissolved and the copper removed with H_2S. Finally MnO_2 was precipitated from concentrated HNO_3.

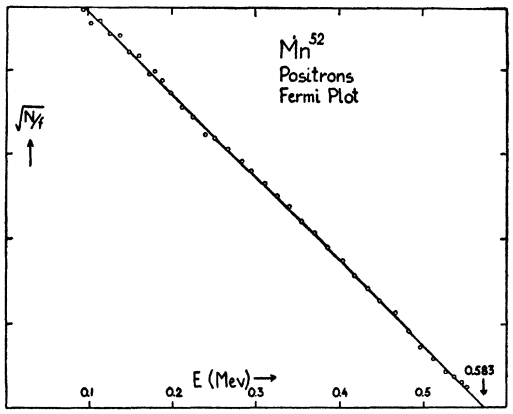

FIG. 1. Positron spectrum of Mn^{52} (6.5 day).

Sources for the study of the beta-rays were prepared as follows. A drop of a dilute solution of active $MnCl_2$ was deposited on a thin (about 0.25 mg/cm^2) aluminum leaf, mounted on a brass frame. This was then covered with an inverted watch glass on which a few drops of concentrated ammonium hydroxide had been deposited. This produced a hydroxide precipitate which, upon gentle warming, formed a very uniform and adherent film, probably with partial conversion to oxide. The thickness of this deposit was less than that of the supporting aluminum. Gamma-ray sources were prepared by sealing a small amount of the active oxide into a suitable copper capsule.

The intensity of the radiations due to the long-lived Mn^{54} (paper VII) was quite negligible during the first few weeks after bombardment. The 21-minute isomer of Mn^{52} had completely decayed before the measurements were begun.

[2] M. Deutsch, L. G. Elliott, and R. D. Evans, Rev. Sci. Inst. 15, 178 (1944).
[3] J. J. Livingood and G. T. Seaborg, Phys. Rev. 54, 391 (1938).
[4] A. Hemmendinger, Phys. Rev. 58, 929 (1940).

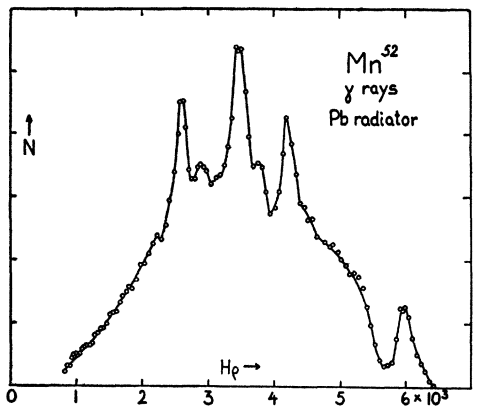

FIG. 2. Photoelectrons and Compton recoil electrons due to the gamma-rays of Mn^{52}.

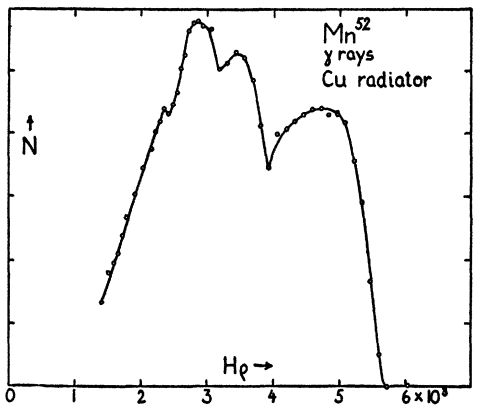

FIG. 3. Compton recoil electrons due to the gamma-rays of Mn^{52}.

THE POSITRON SPECTRUM OF Mn^{52}

Figure 1 shows a Fermi plot of the beta-ray spectrum of Mn^{52} obtained with the magnetic lens spectrometer.[2] The maximum energy, as found from the intercept on the axis, is 0.582 $\pm$0.03 Mev. The fact that the plot is a straight line indicates that the distribution agrees with that predicted by the Fermi theory for an allowed transition, within the experimental error. Below about 0.20 Mev the experimental points may be slightly shifted by instrumental effects. The shape of the upper two-thirds of the energy range should, however, be reliable. There can be no doubt that the spectrum is simple, i.e., there is only one mode of beta-decay, and there are no pronounced internal conversion lines, at least above 0.1 Mev.

THE GAMMA RAYS OF Mn^{52}

Figure 2 shows a typical secondary electron spectrum produced by the gamma-rays of Mn^{52} in a lead foil of 36 mg/cm^2-thickness and in the copper capsule containing the source, and observed in the magnetic lens spectrometer. There are pronounced photoelectron peaks due to four gamma-rays of energies 0.510$\pm$0.01 Mev, 0.734 $\pm$0.015 Mev, 0.940$\pm$0.02 Mev, and 1.46$\pm$0.03 Mev. Figure 3 shows the spectrum of Compton recoil electrons produced in a copper radiator, indicating the same four gamma-rays. The lowest energy gamma-ray is certainly due to annihilation radiation. The particular radiators and resolution used are not well suited for an estimate of the relative intensities of the gamma-rays.[2] It would seem, however, that all of the rays, including the annihilation radiation are of approximately equal intensity.

COINCIDENCE MEASUREMENTS OF Mn^{52}

Coincidences between positrons and gamma rays were studied in the standard arrangement (paper V). The number of such coincidences per recorded positron was $4.18\pm0.12\times10^{-3}$. This number did not change when some aluminum absorber was placed between source and beta-ray counter, indicating that the positron spectrum is simple, in agreement with the shape of the Fermi plot (Fig. 1). From the known efficiency curve for the gamma-ray counter in the geometry used (very similar to Fig. 6, paper V), we find that the efficiencies for detecting each of the three nuclear gamma-rays identified in the secondary electron spectrum (Fig. 2) are, respectively, 1.10×10^{-3}, 1.25×10^{-3}, and 1.80×10^{-3}, in order of increasing energy. It is seen that the sum of these three is just equal to the observed coincidence rate, within the experimental error. Since the positron spectrum has but a single component, we may conclude that the emission of a positron by Mn^{52} is always followed by three gamma-rays in cascade.

Coincidences between x-rays, emitted in the orbital electron capture process, and gamma-rays were also measured, by replacing the beta-ray counter in the standard geometry with an x-ray counter (paper VII). The number of x-ray-gamma-coincidences per recorded x-ray was the same as the number of coincidences per recorded

positron. This indicates that the K-electron capture process leads to the same level as the positron emission. Gamma-gamma-coincidences were not studied in the standard arrangement because the presence of the annihilation radiation makes the interpretation of such an experiment difficult.

DISINTEGRATION SCHEME OF Mn^{52}

In the light of the results reported in the preceding sections, it may be concluded that most, if not all, of the disintegrations of Mn^{52} (6.5 day) proceed according to the scheme shown in Fig. 4. Our experiments throw no light on the order of emission of the three gamma-rays, and the particular arrangement of the levels shown is rather arbitrary. Some indirect evidence supporting the assignment of an excitation energy of 1.46 Mev to the lowest level involved is presented in the next section. The relative probabilities of positron emission and orbital electron capture has been determined in this laboratory by W. M. Good[5] using a modification of the coincidence technique. He found $\lambda_+/\lambda_{cap.}=0.54\pm0.05$.

DISINTEGRATION SCHEME OF V^{52}

The negatron decay of V^{52} (3.9 min.) leads to the same product nucleus—Cr^{52}—as the decay of Mn^{52}. Martelly[6] reports as a result of very careful absorption experiments that the gamma-rays emitted by V^{52} consist of a single group of 1.47-Mev quantum energy. Preliminary observations of beta-gamma-coincidences carried out by us are consistent with the assumption that the beta-ray spectrum is simple, and that each beta-ray is accompanied by a single gamma-ray of about 1.5 Mev. Using the value 2.05 Mev for the maximum energy of the beta-rays, given by Davidson,[7] we have drawn a tentative decay scheme indicated by dotted lines in Fig. 4.

B. V^{48}

The species of vanadium with 16 day half-life has been assigned to mass number 48 by Walke.[8] He reported that it decays by positron emission and by orbital electron capture and gave a value of 1 Mev for the maximum energy of the positrons as observed in the cloud chamber. Richardson[9] by observation of recoil electrons in a cloud chamber found a gamma-ray of 1.05-Mev quantum energy. Recently, Hibdon, Pool, and Kurbatov[10] also investigated the decay of V^{48} and reported a maximum positron energy of 0.58 Mev, a gamma-ray of 1.50 Mev, and a relative probability of orbital electron capture eighteen times as great as that for positron emission.

PREPARATION OF SOURCES OF V^{48}

Vanadium was separated by precipitation with cupferron from the chromium targets used to prepare Mn^{52}. The cupferron precipitate was dissolved, freed of the hydrogen sulphide group and of elements precipitated by sodium peroxide. Finally the vanadium was re-precipitated with cupferron, and the precipitate ignited to the oxide.

Sources for beta-ray measurements were made by evaporating the oxide in vacuum from a platinum filament onto aluminum of 0.25 mg/cm² thickness. Gamma-ray sources were made by sealing the active oxide into a brass capsule. The shorter-lived activities of V^{50} and V^{51} were allowed to decay completely before measurements were started.

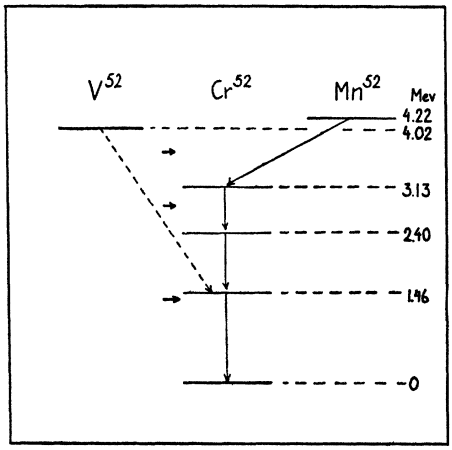

FIG. 4. Disintegration scheme of Mn^{52} (6.5 day). 35 percent of the disintegrations are by positron emission, the rest by orbital electron capture. Dotted line indicates a tentative decay scheme for V^{52}. Short arrows locate energy levels of Cr^{52} found by inelastic scattering of protons.

[5] W. M. Good, D. Peaslee, M. Deutsch, Phys. Rev. **69**, 313 (1946).
[6] J. Martelly, Comptes rendus **216**, 838 (1944).
[7] Quoted by G. T. Seaborg, Rev. Mod. Phys. **16**, 1 (1944).
[8] H. J. Walke, Phys. Rev. **52**, 669, 777 (1937); Proc. Roy. Soc. **171**, 360 (1939).
[9] J. R. Richardson, Phys. Rev. **53**, 124 (1938).
[10] C. T. Hibdon, M. L. Pool, and J. D. Kurbatov, Phys. Rev. **65**, 351 (1944).

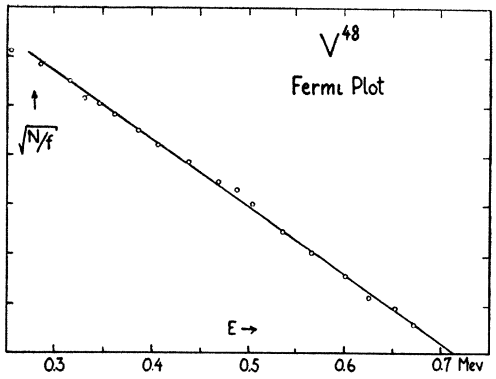

FIG. 5. Positron spectrum of V^{48}.

THE POSITRON SPECTRUM OF V^{48}

Figure 5 shows a Fermi plot of the positron spectrum of V^{48}. The fact that the points fall nearly on a straight line indicates that the spectrum is simple above 0.25 Mev. The deviation from the theoretical distribution for an allowed transition is small and could be due to instrumental effects. The intercept on the axis yields a value 0.716 ± 0.015 Mev for the maximum energy of the spectrum. The energy range between 0.18 Mev and 0.25 Mev also showed no unusual features. The relatively low specific activity of the material made it impossible to prepare sources which were sufficiently thin and at the same time small enough to permit the use of a very thin window. Therefore the data below 0.25 Mev were definitely distorted by instrumental effects and are not included in Fig. 5.

THE GAMMA RAYS OF V^{48}

The secondary electron spectrum from a 36 mg/cm²-lead radiator shown in Fig. 6 indicates photoelectron peaks and Compton recoil groups due to three gamma-rays. The one of lowest energy, 0.51 Mev, is again undoubtedly annihilation radiation while the other two are nuclear gamma-rays of quantum energies 0.980 ± 0.02 Mev and 1.33 ± 0.03 Mev, respectively. As in the case of Mn^{52} only a rough estimate of the relative intensities can be made. The three gamma-rays seem to be of approximately equal abundance.

COINCIDENCE MEASUREMENTS OF V^{48}

Coincidences between the positrons and nuclear gamma-rays emitted in the decay of V^{48} were observed in the standard arrangement (paper V). $2.93\pm0.09\times10^{-3}$ beta-gamma-coincidences per recorded positron were observed. The known efficiency curve of the gamma-ray counter indicates that the sum of its efficiencies for a gamma-ray of 0.98 Mev and one of 1.33 Mev is $3.04\pm0.08\times10^{-3}$. This agreement with the observed coincidence rate shows that each positron is accompanied by the emission of two gamma-rays in cascade. Introduction of a thin (30 mg/cm²)-aluminum absorber between source and beta-ray counter did not affect the coincidence rate per recorded particle. This shows that the positron spectrum is simple also at low energies. As in the case of Mn^{52}, gamma-gamma-coincidences were not studied because of the presence of annihilation radiation.

Unfortunately the x-rays of titanium, emitted in the orbital electron capture process, are so soft that they are almost completely absorbed in a beryllium absorber thick enough to eliminate the positrons when one wishes to observe x-ray-gamma-coincidences. Absorbers of lithium metal, which should make the experiment possible, are rather inconvenient to handle and were not available at the time this study was made. Therefore no direct evidence concerning the excited states involved in orbital electron capture by V^{48} was obtained.

DISINTEGRATION SCHEME OF V^{48}

The evidence presented in the preceding sections leaves little doubt that the positron emission by V^{48} is followed by the successive emission of two gamma-rays of 0.98 Mev and 1.33 Mev,

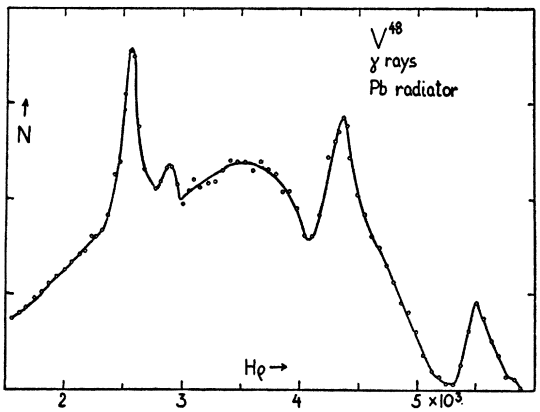

FIG. 6. Secondary electrons due to gamma-rays of V^{48}.

respectively, as shown in Fig. 7. The order of emission of the two gamma-rays is unknown.

No direct evidence is available concerning the levels involved in the orbital electron capture process. As in the case of Co^{56} (paper VI), some rather plausible considerations may be applied to this question. Although the theory of beta-decay is probably not in its final form, the main features of the process seem to be sufficiently well understood to make it very unlikely that abundant capture transitions could take place to the ground state or a low excited state without observable emission of high energy positrons. On the other hand, no gamma-rays due to de-excitation of a highly excited state other than the one at 2.3 Mev were observed. Thus it seems very likely that, as in the case of Mn^{52}, electron capture leads predominantly to the same state of Ti^{48} as positron emission. With this assumption, results of Good[5] indicate $\lambda_+/\lambda_{cap.} = 1.38 \pm 0.2$, for transitions to the 2.3-Mev level. If other excited states are involved in the capture process, this value is a lower limit for the branching to the 2.3-Mev state.

DECAY OF Sc^{48}

The negatron decay of Sc^{48} with a half-life of 44 hours also leads to the product nucleus Ti^{48}. Smith[11] reported a maximum energy of 0.644 Mev for the beta-ray spectrum emitted by this activity. Mandeville[12] reported a gamma-ray of 1.35 Mev emitted in the decay of Sc^{48} produced by the reactions Ti(n, p) and Ca$(d, 2n)$. We made a preliminary investigation of the gamma-rays of Sc^{48} produced by deuteron bombardment of calcium. Since the sample showed no observable positron emission after two days, we assume that the scandium fraction, separated chemically, was predominantly Sc^{48}, in agreement with the findings of Mandeville and of Hibdon, Pool, and Kurbatov.[13] Two gamma-rays, of 0.98 and 1.33 Mev were definitely identified. Their energies are the same as those of the gamma-rays from V^{48} to about ± 3 percent. There is a strong possibility of other gamma-rays of lower energy, but the sample proved too weak for a thorough investigation. The disintegration scheme indicated by dotted lines in Fig. 7 is, therefore, probably incomplete and serves only to summarize the known radiations.

A few hours after bombardment, the scandium samples showed a strong gamma-ray of 1.05 Mev

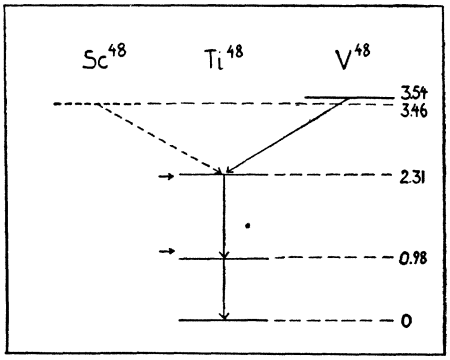

FIG. 7. Disintegration scheme of V^{48}. 58 percent of the disintegrations are by positron emission, the rest by orbital electron capture. The disintegration scheme indicated by the dotted lines is probably incomplete and serves only to summarize the known radiations. Short arrows indicate levels of Ti^{48} found by (α, p) reaction on scandium.

quantum energy, probably due to Sc^{43} in agreement with the results of Walke[14] and in disagreement with those of Hibdon, Pool, and Kurbatov.[13]

ENERGY LEVELS OF Cr^{52} AND Ti^{48}

The evidence concerning the nuclei Cr^{52} and Ti^{48} presented is incomplete even as far as the possibilities of our present methods are concerned. The disintegration schemes of the 21-minute isomer of Mn^{52}, of V^{52}, and of Sc^{48} should be investigated. Unfortunately the pressure of more essential work prevented the continuation of these studies except for the preliminary observations reported above.

The energy levels of Ti^{48} as found in the decay of V^{48} may be compared with those observed by Pollard[15] in the reaction $Sc^{45}(\alpha, p)Ti^{48}$. In Fig. 7 we have indicated the levels found by Pollard with short arrows. In view of the rather large experimental uncertainty of Pollard's results, all that can be said is that the levels found by the two methods may be identical. In the case of Cr^{52} we may compare our results with those of Dicke and Marshall[16] who observed groups of

[11] G. P. Smith, Phys. Rev. **61**, 578 (1942).
[12] C. E. Mandeville, Phys. Rev. **64**, 147 (1943).
[13] C. T. Hibdon, M. L. Pool, and J. D. Kurbatov, Phys. Rev. **63**, 462 (1943).
[14] H. J. Walke, Phys. Rev. **57**, 163 (1940).
[15] E. Pollard, Phys. Rev. **54**, 411 (1938).
[16] R. H. Dicke and J. Marshall, Jr., Phys. Rev. **63**, 86 (1943).

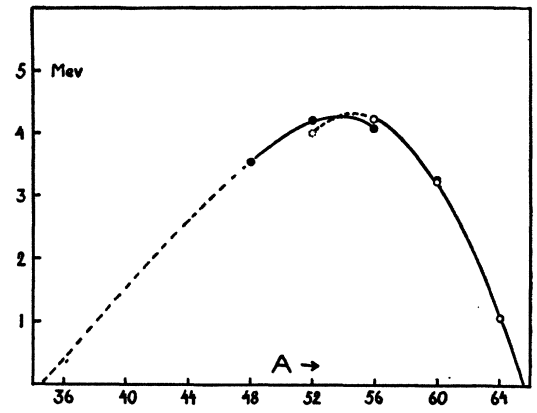

FIG. 8. Disintegration energies of the radioactive neighbors of nuclei with four excess neutrons. Open circles: Negatron emitters. Full circles: Positron emitters. The doubtful decay energy of V^{52} is indicated by a broken circle.

protons scattered inelastically by chromium. Their results are indicated by short arrows in Fig. 4. The agreement with the energies of the levels identified by us is rather less close than in the case of Pollard's results. The evidence favors the assumption that they observed a different set of levels than we did.

Consistent assignments of angular momenta and parity are possible for the decays of Mn^{52} and V^{48}. These assignments are, of course, in no way unique; e.g., the four levels in Cr^{52} might have angular momenta (in order of increasing excitation energy) of 0, 1, 2, and 3 with parity $+, -, -, +$, while the decaying state of Mn^{52} (6.5 day) could be $I=4$, parity $(-)$, similarly in Ti^{48} we might have I values of 0, 1, 2, parity $(+), (-), (+)$, with V^{48} having $I=3$, parity $(-)$.

It is interesting to note that, within the probable error, the gamma-ray energies in the decay of Mn^{52} (6.5 day) are the multiples 3, 4, and 6 of 0.240 Mev. The probability of finding such a combination by chance with an accuracy of two percent and involving no numbers greater than 6 is about one in fifteen. The gamma-rays emitted in the decay of V^{48} are the multiples 3 and 4 of 0.328 Mev. Although these relations are less striking than the one found in Fe^{56} (paper VI), the persistent occurrence of these whole number relationships appears to exceed chance expectance. We wish to call attention to the observations of Wiedenbeck[17] who observed six resonance levels in the nuclear excitation of silver by electrons. The six levels have excitation energies which are the multiples of 3, 4, 5, 6, 7, 8 of 0.392 Mev, with a mean deviation 0.8 percent and a maximum deviation of 1.5 percent which is well within the experimental error. The same author found resonance energies in cadmium which are multiples 3, 4, 5, 6, of 0.420 Mev with the same accuracy as those in silver. In the case of gold he found levels which are the multiples 3, 4, 5, 6, 7 of 0.422 Mev, with comparable accuracy. One should expect that such nuclear absorption spectra will show "series" of levels even more strongly than radioactive decay schemes.

[17] M. L. Wiedenbeck, Phys. Rev. 67, 92 (1945).

ENERGY BALANCE AND MASS DIFFERENCES

From the results presented in this paper we calculate the mass-differences between neutral atoms $Mn^{52}-Cr^{52}=5.10\pm0.15\times10^{-3}$ a.m.u. and $V^{48}-Ti^{48}=4.37\pm0.12\times10^{-3}$ a.m.u. Similarly we find the threshold for the reaction $Cr^{52}(p, n)Mn^{52}$ to be 5.55 ± 0.15 Mev, and that for $Cr^{52}(d, 2n)Mn^{52}$, 7.96 Mev. This takes into account the recoil energy and the mass difference between proton and neutron (1.35×10^{-3} a.m.u.). For the reaction $Ti^{48}(p, n)V^{48}$ we calculate a threshold value of 4.85 ± 0.15 Mev and for $Ti^{48}(d, 2n)V^{48}$ 7.25 Mev.

The calculated value for the proton transmutation threshold of chromium must be compared with the value of 6.2 Mev for the production of the 21-minute isomer, found experimentally by Hemmendinger.[4] The discrepancy is larger than one might expect. It does not seem likely that the two isomers should have an energy difference of almost 0.7 Mev. Possibly selection rules favor the production of the 6.5-day isomer for low proton energies, thus making the apparent threshold for production of the 21-minute isomer higher than the true threshold.

The energy levels identified so far in the nuclei Ti^{48}, Cr^{52}, Fe^{56}, Ni^{60}, and Zn^{64} show no apparent regularity to indicate that these nuclei might be a series of homologues with respect to their level structure. However, if at least the ground states of the sequence of nuclei extending from S^{36} to Zn^{64} show any similar structure, the disintegration energies of their radioactive neighbors should at least show a regular behavior. One or two nuclei in the middle of the sequence

should be its "stablest" member, the disintegration energies of its two radioactive neighbors being about equal. Heavier members of the sequence will tend to have too high a charge for greatest stability so that the disintegration energy of the negatron-emitting neighbor will tend to be less as the mass increases, reaching zero at the end of the stable sequence. On the other hand the disintegration energy of the positron-emitting neighbor should increase as the mass increases. The reverse situation should hold on the low mass side of the "stablest" member of the sequence.

Figure 8 shows a schematic representation of the disintegration energies. It appears that the stablest mass number is 52 or 56. For heavier mass numbers the negatron energies fall off smoothly, reaching zero just beyond the known limit of stability. Less evidence is available concerning the positron-emitters on the light side of the maximum. One might expect their disintegration energies to follow the dotted line shown in Fig. 8. This curve indicates that the positrons emitted by Cl^{36} should be very soft. Also the electron capture process by K^{40} which leads to an excited state of A^{40} at about 2 Mev should have a very low transition energy, so that no positrons could be emitted. This seems to be in agreement with experimental evidence.

Unfortunately no experimental points are available beyond the point of greatest stability. The tentative disintegration scheme for V^{52}, shown in Fig. 7, would indicate a bending-over of the negatron branch, contrary to expectation. Some irregularities in the dependence of the disintegration energy on mass number may be introduced by the fact that the disintegrating state is not necessarily the ground state of the radioactive nucleus. Of the sixteen possible radioactive neighbors of the eight stable nuclei, eleven have been definitely identified.[18] Three of these, Sc^{44}, Mn^{52}, and Co^{60} have been found in two isomeric states. One might expect others to exist in low-lying, relatively long-lived states, and it is not known whether the radioactive states actually observed correspond to the higher or lower member of an isomeric pair.

We wish to thank Professor Robley D. Evans for his continued interest in these studies; Professor M. S. Livingston and the cyclotron crew for making the bombardments; and Professor John W. Irvine, Jr. for help with chemical procedures.

[18] G. T. Seaborg, Rev. Mod. Phys. 16, 1 (1944).

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Experimental Test of Beta-Ray Theory for the Positron Emitters Na^{22}, V^{48}, Mn^{52}, Co^{58}

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The positron branching ratio $\lambda_+/(\lambda_c+\lambda_+)$ has been measured by a coincidence counting method for four isotopes in which radioactive decay involves competition between positron beta-rays and orbital electron capture. The results are $_{11}Na^{22}$: 1.00 ± 0.05, $_{23}V^{48}$: 0.58 ± 0.04, $_{25}Mn^{52}$: 0.35 ± 0.02, $_{27}Co^{58}$: 0.145 ± 0.005. It is shown that these values, as well as the observed shapes of the beta-ray spectra, and the observed lifetimes are in agreement with predictions of the beta-ray theory for nuclear angular momentum changes $\Delta I=0$ or $\Delta I=\pm1$. The type of interaction remains uncertain, as does the parity change, except that the scalar interaction gives consistent results if one assumes the parity change in every case except Mn^{52}.

INTRODUCTION

A NUMBER of attempts have recently been made to refine the theory of beta-decay and to verify it experimentally.[1] In general the conclusion is drawn that the available experimental data can be explained by the Fermi theory which assumes an interaction between the nucleons and the electron-neutrino field depending

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[1] E. J. Konopinski, Rev. Mod. Phys. 15, 209 (1943).