(6) On June 21 the diurnal variation at $\lambda_m = 60°$ would amount to 4 percent or 5 percent or the mean total intensity (if all the particles had the same sign). In view of the mixed composition of the radiation the actual variation must be several times smaller.

(7) The annual variation at $\lambda_m = 60°$ is about 0.75 percent of the total intensity with its maximum on July 1 and its minimum on January 1.

At present variations of this magnitude are within the experimental error or just on its verge, but in a few years they may fall outside its range.

JUNE 1, 1938 PHYSICAL REVIEW VOLUME 53

The Loss of Neutrons by Neutron Bombardment and the Radioactive Isotopes of Scandium

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(Received April 20, 1938)

The bombardment of lithium by deuterons of 6.3 Mev energy yields neutrons of energy up to 20 Mev. These neutrons are in turn able to produce disintegrations by the ejection of two neutrons from bombarded nuclei. In the case of scandium there has been evidence that the process corresponding to the ejection of three neutrons also occurred thus producing Sc^{43} of half-life 4 hours and Sc^{44} of half-life 53 hours from the stable Sc^{45}. By varying the energy of the incident neutrons and observing the ratio of the two radioactivities produced, it now appears that these two activities are due to isomers of Sc^{44}. Hence there is no definite evidence as yet for the loss of three neutrons from the excited nucleus. Although scandium has but one stable isotope (Sc^{45}) there appears to be eight radioactive periods, six of which can be assigned with reasonable certainty to various scandium isotopes. The excitation function for the ejection of two neutrons is studied by observing the radioactivity produced at various energies of the incident neutrons. There is evidence of anomalous behavior for certain elements.

IT has been shown[1] that most elements when bombarded by the energetic neutrons from lithium, yield isotopes corresponding to the ejection from the excited nucleus of two neutrons $(n, 2n)$. The beta-activity of isotopes so formed is usually positive in sign due to their position with respect to the stable isotopes. The energy required for this process might reasonably be expected to be in excess of 8 Mev. This follows from the equation representing the reaction:

$$ {}_zA^N + n \rightarrow {}_z{}^*A^{N-1} + 2n \rightarrow {}_{z-1}A^{N-1} + {}_{+1}e + 2n. $$

Since ${}_zA^N$ and ${}_{z-1}A^{N-1}$ often differ by almost one mass unit, the energy of the positron and that corresponding to the excess mass of the second neutron (i.e. 0.0089 mass unit or 8.4 Mev) must be carried into the nucleus by the incident particle. The identification of the radioactive isotopes can be made reasonably certain by producing them by alternative methods in conjunction with the chemical analyses.

In certain elements, notably fluorine, copper and scandium radioactive isotopes lighter than the lightest stable isotope both by one and by two mass units have been identified. Thus in fluorine the stable isotope is F^{19} and the radioactive isotopes F^{17} and F^{18} have half-lives respectively of 1.2 min. and 109 min. In copper the lightest stable isotope is Cu^{68} and the radioactive Cu^{66} and Cu^{67} have half-lives of 3.4 hr. and 10 min. Scandium has a single stable isotope Sc^{45} and radioactive Sc^{43} and Sc^{44} of half-lives 4 hr. and 53 hr., respectively. The identification of these radioactive isotopes offers the possibility of detecting a process in which three neutrons are ejected from the nucleus excited by neutron bombardment $(n, 3n)$.

Positive results of this nature in the case of scandium have been reported.[2] This conclusion was based upon the correctness of the assignment of the radioactive periods of this element by Walke.[3] Table I shows the stable and radioactive

[1] Pool, Cork and Thornton, Phys. Rev. **52**, 239 (1937).

[2] Pool, Cork and Thornton, Phys. Rev. **52**, 41 (1937).

[3] H. Walke, Phys. Rev. **52**, 669 (1937); **52**, 777 (1937).

TABLE I. *Stable and radioactive isotopes as proposed by Walke.*

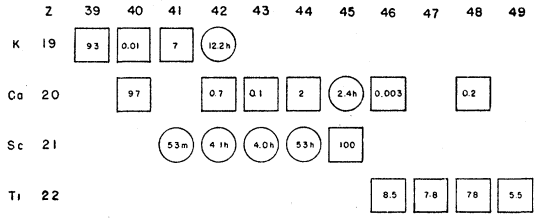
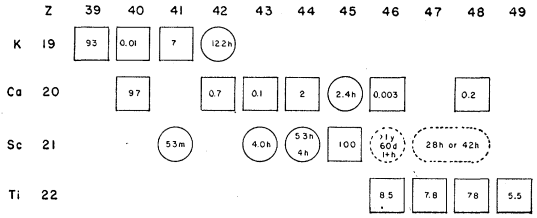


TABLE II. *Proposed arrangement of stable and radioactive isotopes.*



isotopes for elements in this part of the periodic table as proposed by Walke.

The evidence for the assignment of the periods to Sc^{41}, Sc^{42}, Sc^{43} and Sc^{44} is based upon the results obtained when calcium is bombarded by deuterons and by alpha-particles and on the bombardment of potassium by alpha-particles. In the latter case the scandium precipitate yielded the two periods 4.1 hr. (Sc^{42}) and 53 hr. (Sc^{44}). Since there are two abundant stable isotopes of potassium K^{39} and K^{41} it seemed reasonable to suppose that each entered into the reaction (α, n) thereby contributing the two periods. Since it is now known that isomeric isotopes are not uncommon it is evident that both of the observed periods in scandium may equally well be explained as due to either Sc^{42} or Sc^{44}. It will be shown that this is undoubtedly the case and that the isomers are associated with Sc^{44}.

In order to check this possibility and at the same time learn more about the existence or nonexistence of multiple neutron ejection the following experiments were carried out. Samples of chemically pure scandium oxide were successively exposed to neutron radiation of varying energy and the radioactivity produced in each case observed. Neutrons of different energies were obtained in two ways. Deuterons of 6.3 Mev energy striking on lithium[4] yield neutrons in the direction of the incident particle of energy up to 20 Mev. Now if the energy of the deuterons be reduced by allowing them to pass through an appropriate absorbing foil before striking the lithium the neutron energy may be reduced to about 15 Mev. This reduced energy of course reduces the yield of radioactivity but the essential observation to make is the ratio of the activity of half-life 4 hr. to that of half-life 53 hr. If the assignment of Table I is correct then the yield of the 4-hr. activity, being due to triple neutron ejection, should decrease with reduced energy much more rapidly than the activity of 53-hr. half-life which is due to double neutron loss.

Another method of obtaining neutrons of lower energy is to allow the 6 Mev deuterons to bombard other elements such as beryllium, deuterium or copper. The upper limits for the energy of these neutrons is not known with certainty but is probably about 10 Mev for beryllium,[5] about 8 Mev for deuterium[6] and slightly less for the copper.

For scandium bombarded by neutrons of 20→15 Mev from lithium and also by the 10 Mev neutrons from beryllium, some activity of both the 4-hr. and the 53-hr. periods is obtained. Although the activity of the 53-hr. half-life, in arbitrary units, changes from 0.980 at 20 Mev to 0.016 at 10 Mev, the corresponding change in the 4-hr. activity is such that the ratio of the two is constant within the limits of the accuracy of the observation. For a 2-hr. exposure this ratio of intensities at the end of bombardment is that $I_{4\text{ hr}}/I_{53\text{ hr}}=14/1$. When corrected for infinite bombardment time, this gives for the branching ratio a value almost 1 : 1 or an equal probability for the production of the two isotopes. This could hardly be expected if the 4-hr. activity is due to Sc^{43} hence it must be concluded that the shorter period is also associated with the active Sc^{44}, this being a case of isomeric isotopes. Such a conclusion is equally well supported by the evidence of Walke, who produced both activities by bombarding potassium with alpha-particles. This means that Table I should be modified to appear as Table II.

Further attempts to detect the 3.4-hr. period in copper corresponding to the loss of three neutrons, were made without success.

[4] W. E. Stephens, Phys. Rev. **53**, 223 (1938).

[5] Bonner and Brubaker, Phys. Rev. **50**, 308 (1936).

[6] Bonner, Phys. Rev. **52**, 685 (1937).

Other radioactive isotopes of scandium are known to exist. Slow neutron activation leading to Sc^{46} was reported[7] by Hevesy to yield a period of several years and later by Hevesy and Levi to give two periods one of two months half-life and another of more than a year. Walke observed a period of 84 days. On samples bombarded here both by deuterons and by slow neutrons strong activities are observed of very long half-life. Over a period of three months a half-life in close agreement with Walke, namely 88 days, is observed. However, this is not a sufficiently long time to draw final conclusions and should this ultimately go into a much longer period as found by Hevesy then the subtraction of the end activity might reasonably reduce the period to 60 days. Without carrying out the chemistry as it seemed unnecessary in this case, since the end products in other elements are either stable or known, another period slightly greater than one hour is always observed in the scandium This can be evaluated later when the final periods are more definitely established. Also the scandium precipitate from titanium bombarded by fast neutrons has been shown to yield activity in the scandium. Pool observed periods of 1.7 hr. and 28 hr. while Walke reports periods of 42 hr. and 84 days. If the 1.7-hr. period is the activity here observed as about 1.1 hr. and the analysis of Hevesy and Levi is ultimately substantiated then Sc^{46} must consist of three isomeric isotopes. The period reported as 28 hr. and 42 hr. is tentatively placed as Sc^{47} although it might be due to Sc^{48} except that a shorter half-life would be expected for this element. It thus appears that although scandium has but a single stable isotope there are probably eight radioactive isotopes.

Double Neutron Loss

An attempt has been made to study the excitation function for the process of double neutron ejection. It has already appeared above that in scandium the yield dropped by a factor of twenty as the energy of the neutrons varied from 20 Mev to 10 Mev. Such observed yields are uncertain since in these experiments the deuteron exposure is controlled and the neutron yield from the different targets and the geometry of the specimen might vary. It is therefore considered more significant to observe the ratio of the intensity of the activity associated with the double neutron emission to some other standard activity in the same substance.

The 2.1-min. period in oxygen due to O^{15} appears to give almost the same yield for beryllium neutrons as for lithium neutrons. That this should be the case seems incompatible with energy-mass relationships since the mass 15.0049 indicates that at least 13 Mev should be necessary. However, if this oxygen activity be taken as a standard then other activities can be measured with respect to it. Thus if NH_4NO_3 be exposed to fast neutrons of varying energies then there results the nitrogen period of 10 min. due to N^{13} and the oxygen 2.1-min. period. The ratio of intensities for these activities observed is as follows:

Li neutrons (0.560), Be neutrons (0.145), deuterium neutrons (0.099), copper neutrons (0.045). Other substances are being studied in this way. In some cases there is evidence of anomalous behavior of certain elements. Thus if copper oxide be treated similarly to the ammonium nitrate mentioned above and the ratio of the intensities of Cu^{67} (10 min.) to O^{15} (2.1 min.) formed, then a uniform decrease as obtained with NH_4NO_3 is not observed. The value of the ratio indicates that while the yield of Cu^{67} is about one-tenth as great for beryllium neutrons as for lithium neutrons, the neutrons from copper are more effective than the neutrons from beryllium. Further work must be done to establish more definitely these energy limits.

The chemical separations of the activated scandium were carried out by Mr. D. W. Stewart. It is a pleasure to acknowledge the fact that this work was made possible by a grant from the Horace H. Rackham Trust Fund. This opportunity is taken to express our thanks to Professor B. S. Hopkins of the University of Illinois, Professor L. L. Quill of Ohio State University and Professor C. M. Mason of the University of New Hampshire for their kindness in loaning samples of scandium.

[7] Hevesy, Nature **135**, 1051 (1935); Hevesy and Levi, Det. Kgl. Danske Videnskabernes Selskab. Mathfys. **14**, 5 (1936).

Note added in proof: Burcham, Goldhaber and Hill, Nature **141**, 510 (1938), have arrived at a similar conclusion regarding the assignment of the scandium isotopes.