

lines no intense converted radiation is observed, the presence of the Tc  $\alpha$ -radiation proves that the 33.4-keV transition is an isomeric one of the Tc nucleus. The half-life (53 minutes) is in good agreement with the value derived from a semi-empirical energy-lifetime relation<sup>2</sup> for 33.4 keV and an angular momentum change  $\Delta L=4$ .

We hope to succeed in determining, by means of an isomer separation, the shorter lifetime, caused by the ground state of Tc, from which the positron emission and electron capture result.

A more extensive report on these measurements will appear in *Helv. Phys. Acta*.

<sup>1</sup> P. C. Gugelot, O. Huber, H. Medicus, P. Preiswerk, and R. Steffen, *Helv. Phys. Acta* **20**, 240 (1947).

<sup>2</sup> M. L. Wiedenbeck, *Phys. Rev.* **69**, 567 (1946).

### On the Radioactivity of $K^{40}$

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SEVERAL recent papers in this journal<sup>1-3</sup> have dealt with the decay of  $K^{40}$  by following Bleuler and Gabriel<sup>4</sup> in assuming  $(7 \pm 1) \times 10^8$  years for the beta-decay period,  $(2.4 \pm 0.5) \times 10^8$  years for the total period, and a branching ratio corresponding to 1.9 capture processes per beta-decay. It should be pointed out that the interpretation Bleuler and Gabriel gave of their experimental observations does not agree with the following:

A branching ratio of 1.9 would mean a yield of argon sufficiently large to make it easily detectable in old rocks and gaseous exhalations.<sup>5,6</sup> No excessive abundance of argon, however, has yet been reported in such cases. A careful investigation of two samples of sylvine and one of carnallite has been carried out recently<sup>7</sup> in order to reach a final conclusion on this question. From the data of Bleuler and Gabriel a content of at least  $1.5 \times 10^{-2}$  cm<sup>3</sup> argon per gram sylvine, was to be anticipated, as the sylvine's age exceeded  $2 \times 10^8$  years. Analysis of the gases collected from the samples, however, gave an upper limit of  $0.02 \times 10^{-2}$  cm<sup>3</sup> argon. The carnallite analysis gave a similar result. These results indicate that only a few percent of the decaying  $K^{40}$  can yield  $A^{40}$ . This, as well as geochemical evidence as a whole, makes it seem most unlikely that more than 10 percent of the decaying  $K^{40}$  is converted into argon.

From the general systematics of the abundance of nuclei in the universe<sup>8</sup> it is possible to estimate the concentration of  $K^{40}$  at the time of its formation. It can in that way be estimated that the  $K^{40}$  content of potassium hardly exceeds the  $Lu^{176}$  content of lutetium, which is 2.5 percent. The age of the elements is certainly greater than  $33 \times 10^8$  years, the figure given by Holmes<sup>9,10</sup> for the age of the earth. A total period of  $2.4 \times 10^8$  years leads to an improbable value of more than 60 percent  $K^{40}$  in potassium at the time specified. A total period of  $7 \times 10^8$  years, however, leads to 1 percent  $K^{40}$  in potassium  $45 \times 10^8$  years ago; both these values do not seem far wrong for the original concentration of  $K^{40}$  and the age of the elements, respectively.

By considering the fact that the large concentration of  $A^{40}$  in the atmosphere has undoubtedly originated from  $K^{40}$ , we find from the present amount of atmospheric argon<sup>11</sup> and the present amount of  $K^{40}$  in the earth<sup>12</sup> and assuming a total period of  $7 \times 10^8$  years, that approximately 0.5 percent of the total amount of the decay products produced during the last  $33 \times 10^8$  years is now present in the atmosphere in the form of argon. The major part of  $A^{40}$  is probably left occluded in the earth's interior; yet the proportion of atmospheric to occluded argon is not necessarily as small as assumed previously<sup>6,13</sup> because a large part of the earth's surface was probably in a molten liquid state during the long period extending from  $33 \times 10^8$  until  $20 \times 10^8$  years ago. We can thus take 0.5 percent as a lower limit for the branching ratio for the decay of  $K^{40}$ .

The conclusion from geochemical evidence, that more than 0.5 percent and less than 10 percent of the decaying  $K^{40}$  is converted into  $A^{40}$ , seems to make it most probable that, as in the case of  $Lu^{176}$ ,<sup>15</sup> the full number of capture processes is accompanied by the emission of hard gamma-quanta known to be emitted by excited  $A^{40}$  nuclei<sup>1,14</sup>. The hard quanta are emitted at a rate of 3 quanta according to Gray and Tarrant,<sup>16</sup> or at a rate of  $7 \pm 1.5$  quanta according to Gleditsch and Gráf,<sup>3</sup> per 100 beta-rays. Geochemical evidence seems to make the lower value appear slightly more probable. A value of  $5 \pm 2$  percent for the branching ratio might be considered to be within the limits of error if all the data concerned.

The suggested scheme (Fig. 1) makes it necessary to regard the soft radiation with an approximate intensity

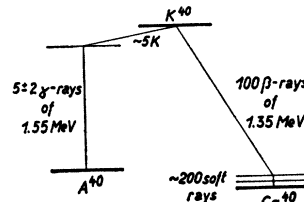


FIG. 1. Disintegration scheme of  $K^{40}$ . Total half-life period  $7 \times 10^8$  year.

of 2 quanta per beta-ray<sup>4,5</sup> as connected with the beta-process. Haxel and Houtermans<sup>17</sup> have recently observed a soft radiation of similar quality from  $Rb^{87}$  coinciding with the beta-emission. It seems reasonable to assume a similar process to occur in the beta-process of  $K^{40}$ .

<sup>1</sup> H. A. Meyer, G. Schwachheim, and M. D. de Souza Santos, *Phys. Rev.* **71**, 908 (1947).

<sup>2</sup> E. Gleditsch and T. Gráf, *Phys. Rev.* **72**, 640 (1947).

<sup>3</sup> E. Gleditsch and T. Gráf, *Phys. Rev.* **72**, 641 (1947).

<sup>4</sup> E. Bleuler and M. Gabriel, *Helv. Phys. Acta* **20**, 67 (1947).

<sup>5</sup> F. C. Thompson and S. Rowlands, *Nature* **152**, 103 (1943).

<sup>6</sup> F. G. Houtermans and P. Jordan, *Zeits. Naturforsch.* **1**, 125 (1946).

<sup>7</sup> P. Harteck and H. Suess, *Naturwiss.* **34** (1947).

<sup>8</sup> H. E. Suess, *Zeits. Naturforsch.* **2a**, 322 (1947).

<sup>9</sup> A. Holmes, *Nature* **157**, 680 (1946).

<sup>10</sup> F. G. Houtermans, *Zeits. Naturforsch.* **2a**, 322 (1947).

<sup>11</sup> F. Paneth, *Nature* **139**, 180 (1937).

<sup>12</sup> V. M. Goldschmidt, *Videnskapsakad. Oslo* (1938).

<sup>13</sup> C. v. Weizsäcker, *Physik. Zeits.* **38**, 623 (1937).

<sup>14</sup> H. Wäffler and O. Hirzel, *Helv. Phys. Acta* **19**, 216 (1946).

<sup>15</sup> A. Flammersfeld, *Zeits. Naturforsch.* **2a**, 86 (1947).

<sup>16</sup> L. H. Gray and G. T. P. Tarrant, *Proc. Roy. Soc. A* **143**, 681 (1934).

<sup>17</sup> O. Haxel and F. G. Houtermans, lecture held at the meeting of the German Physical Society at Göttingen, September, 1947.