Letters to the Editor.

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The Mass-Spectrum of Uranium Lead and the Atomic Weight of Protactinium.

It will be recalled (NATURE, Aug. 13, 1927) that the identification of the isotopes of ordinary lead was made by means of a sample of its tetramethide kindly supplied to me by Mr. C. S. Piggot, of the Geophysical Laboratory, Washington. He has since succeeded in the much more troublesome task of preparing the similar compound of a rare uranium lead from Norwegian bröggerite. His reasons for this work have already been published (C. S. Piggot, "Lead Isotopes and the Problem of Geologic Time," *Jour. Wash. Acad. Sci.*, May 19, 1928). The first tube of uranium lead methide despatched to me a year ago was unfortunately broken in transit, but the second reached Cambridge safely last summer. At that time I was endeavouring to work out a photometric method of measuring the relative abundance of isotopes. This work is by no means complete, but has recently reached a stage which justified an attempt on the mass-spectrum of this very precious material. The procedure was the same as with ordinary lead methide, but the general conditions of the discharge tube, etc., were not so favourable, so that the spectra obtained are weaker.

The mass-spectrum consists of a strong line at 206, a faint one at 207, and a still fainter one at 208. The last is barely visible to the eye, but easily distinguishable on the photometer curves. The impossibility of eliminating mercury limits the search for lighter isotopes, but there is not the least indication of 203 or 205. Unfortunately, the experimental conditions all conspire to make the determination of the true relative intensities of the lines from the curve of photometer wedge readings too complex to be really trustworthy. Calling the intensity of the strong line 100, the mean of the best plates gives 10.7 ± 3 and 4.5 ± 2 for 207 and 208 respectively. As the only curve available for transforming wedge readings into intensities is one derived from krypton, these figures are probably both too high. They correspond to percentages 86.8:9.3:3.9, and as the packing fraction is indistinguishable from that of mercury (0.8×10^{-4}), the mean atomic weight deduced is 206.19, rather higher than that determined chemically for other uranium leads. These figures have been communicated to Mr. Piggot, and when combined with the analyses of the mineral should enable its age to be fixed with considerable certainty.

There is, however, another point of view from which these results are of fundamental interest in connexion with the radioactive elements. The line 207 is of peculiar significance. It cannot be due to the presence of lead as an impurity, for in ordinary lead 208 is about twice as strong as 207, neither can it be the product of radium or thorium. It is difficult to resist the natural conclusion that it is the end product of the only other known disintegration, namely, that of actinium. If this is so it settles the mass numbers of all the members of this series, that of protactinium being 231. Extrapolation of the packing fraction curve suggests an atomic weight on the oxygen scale of 231.08.

F. W. ASTON.

Cavendish Laboratory,
Cambridge, Feb. 16.

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Origin of Actinium and Age of the Earth.

By the kindness of Dr. Aston, I have had the opportunity of inspecting his photographs showing the isotopes of lead obtained from the radioactive mineral bröggerite. As he concludes, it seems highly probable that the isotope of mass 207 is mainly due to actinium lead, and that the actinium series has its origin in an isotope of uranium—a suggestion independently put forward by several investigators on other evidence. Since six α particles are emitted in the successive changes from protactinium to the end product actinium lead, the atomic weight of protactinium should be 231. The direct determination of the atomic weight of this element number 91 now in progress in the laboratory of Prof. Hahn in Berlin should afford a crucial test of the accuracy of this deduction.

In the light of this new knowledge and of the measurements made by Dr. Aston of the relative intensities of the lead isotopes in the mineral, it may be of interest to consider its bearing on the origin of actinium and other problems. We shall first discuss the probable mass of this new isotope, which for convenience will be called actino-uranium. It seems simplest to suppose that its mass is 235, and that it undergoes first an α and then a β ray transformation into protactinium. The β ray body is probably to be identified with uranium Y, discovered by Antonoff, which has generally been regarded as the immediate parent of protactinium. On this view, the successive transformations follow the order $\alpha\beta\alpha\beta$, where the α and β changes alternate, and differ in this respect from the main uranium series which follow the order $\alpha\beta\beta\alpha$. It is of course possible to assume that actino-uranium has a mass 239 and number 92, and is converted into a mass 235 of number 92 in consequence of an α ray change followed by two β ray transformations, but no evidence has been obtained of the existence of such β ray bodies, although a careful search has been made for them by Hahn and others.

An estimate of the period of transformation of the new isotope of uranium can be deduced on certain probable assumptions. The ratio K' of the number of atoms of actinium lead to those of uranium lead can be deduced approximately from Aston's measurements, and we also know the ratio K —about $3/100$ —of the number of atoms delivered in a mineral into the actinium series compared with the number passing into the radium series. If λ_1, λ_2 are the constants of transformation of actino-uranium and the main uranium isotope respectively, it can easily be deduced

that $K'/K = \frac{\lambda_2 \cdot e^{\lambda_1 t} - 1}{\lambda_1 \cdot e^{\lambda_2 t} - 1}$, where t is the age of the

mineral from which the lead is derived. We shall suppose for the purpose of calculation that t is 10^9 years—an average estimate of the age of old primary uranium minerals. Taking as a low estimate that $K' = 7/100$, it can be deduced from the equation that $\lambda_1/\lambda_2 = 10.6$. Since the half-value period of transformation of uranium is 4.5×10^9 years, it follows that the period of actino-uranium is 4.2×10^8 years. A larger value of K' lowers the period, while a higher value for the age of the mineral raises it.

Taking the period as 4.2×10^8 years, it is seen that the amount of actino-uranium is only about 0.28 per cent of the main uranium isotope—an amount too small to influence appreciably the atomic weight of uranium as ordinarily measured. The amount of actino-uranium at the time of its formation taken as 10^9 years age comes out to be 1.44 per cent.

There is another interesting deduction that can be made from these estimates. It is natural to suppose that the uranium in our earth has its origin in the sun,