Neutron-Deficient Activities of Holmium

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Proton bombardment of pure oxides of Dy, Ho, and Er has served to clear up some uncertainties concerning neutron-deficient activities of Ho. Two previously reported activities, 5.2 day and 65 day, were not found, and reassignment of the 5.0-hour activity to a mass of 162 is made. The gamma-ray spectrum of the 5.0-hour activity shows it to decay by electron capture with gamma energies of 0.19, 0.71, and 0.95 Mev. 41-minute Ho^{164} is shown to decay by electron capture and by β^- emission.

HOLMIUM-164

HOLMIUM-164 has been reported to decay by beta emission with a half-life of 39 minutes;[1–3] it was produced by Dy(p,n), Ho(n,2n), and Ho(γ,n). In the present investigation, a 41-minute activity was produced by Dy(p,n), Ho(p,pn), and Er(p,α), and the assignment of element and mass number were both confirmed. To aid in the assignment, ion exchange methods[4] were used in the separations following bombardment.

The emission of a 0.9-Mev beta particle was determined from measurements of absorption in aluminum. In addition, an x-ray peak of 0.043 Mev was evident in the gamma-ray spectrum as measured with a NaI(Tl) scintillation spectrometer. No other more energetic gamma rays were identified. Decay of the x-ray activity was followed with the scintillation spectrometer, and decay of the 0.9-Mev β^- was followed with an end-window GM tube. No significant difference was found between the two measurements; the average value for the half-life was 41 minutes. It is possible, of course, that the 0.043-Mev peak is not the x-ray but a very weak gamma or secondary radiation from self-bombardment. However, since the energy is that of the x-ray in this region, it is very likely to be due to electron capture.

HOLMIUM-163

A 5.2-day activity has been reported[1] for Ho^{163}, supposedly produced by Dy(p,n), Dy(d,n), and Dy(d,2n), with ion-exchange methods being used for chemical identification. However, as previously reported,[5] this activity was not observed as the daughter of 75-minute Er^{163}. Previously, a limit of <30 minutes or >1 year was placed on the half-life of the daughter of 75-minute Er^{163}. An improvement in ion-exchange techniques[6] has made it possible to place the upper limit on the half-life of the daughter of Er^{163} as <10 minutes. The 5.2-day activity was not observed as a product of the bombardment of Dy_2O_3 with 20.5-, 14.0-, and 8.5-Mev protons, followed by ion-exchange separation for chemical identification. Energy of the incident proton beam was adjusted by use of appropriate aluminum absorbers. To place further limits on the half-life of Ho^{163}, the following experiments were performed.

In separate experiments, Dy_2O_3 was bombarded with 20.5-, 14.0-, and 8.5-Mev protons and, the products were separated by ion exchange. The entire holmium fraction was collected and adjusted to a known volume, and aliquots were taken for counting. These were counted, at the x-ray peak by means of a scintillation spectrometer and on an end-window GM tube, for a sufficient time to allow the 5.0-hour activity of Ho^{162} (see below) to decay. The decay curve did not indicate the presence of any activity with a half-life longer than 5.0 hours. From these decay curves, extrapolations were made to the end of the bombardment to determine the amount of 5.0-hour activity produced. A scavenger carrier was then added to the entire original holmium fraction and recovered by precipitation with oxalate. To determine the maximum amount of activity produced with a half-life $\gg$5.0 hours, this precipitate was counted in the same manner as the aliquots, after waiting, of course, a sufficient time for the 5.0-hour activity to decay. Since the 5.0-hour and 5.2-day activities would be produced with approximately the same cross sections and from isotopes of approximately the same abundance, it is possible to calculate, with corrections for the time of bombardment, dilution factor, and chemical yields, the maximum half-life of activities longer than 5.0 hours. From these results it can be said that no holmium activity (between masses 158 and 164 inclusive) deficient in neutrons exists with a half-life between 5.0 hours and 20 years.

The 5.2-day activity was not observed as a product of proton bombardment of erbium followed by ion-exchange separation; it would be expected to result from the nuclear reaction $Er^{166}(p,\alpha)Ho^{163}$. In summation, the reported 5.2-day activity definitely does not belong to Ho^{163}; limits placed on the half-life of Ho^{163} indicate that it is not between 10 minutes and 20 years.

[1] G. Wilkinson and H. G. Hicks, Phys. Rev. **79**, 815 (1950).
[2] M. L. Pool and J. D. Kurbatov, Phys. Rev. **63**, 463 (1943).
[3] H. Waffler, Helv. Phys. Acta **23**, 239 (1950).
[4] B. H. Ketelle and G. E. Boyd, Am. Chem. Soc. **69**, 2800 (1947).
[5] Thomas H. Handley and Elmer L. Olson, Phys. Rev. **92**, 1260 (1953).
[6] Thomas H. Handley and Elmer L. Olson, Phys. Rev. **94**, 968 (1954).

HOLMIUM-162

An activity with a half-life of 65 days has been assigned[1] to Ho^{162}. It was reported to have been produced by $Tb(\alpha,n)$, $Dy(p,n)$, and $Dy(d,2n)$ and to decay by β^- emission and K capture. In the present investigation, a 5.0-hour activity is assigned to this mass. It was produced by proton bombardment of Dy_2O_3 and is presumed to be the same activity reported by Wilkinson and Hicks[1] as having a half-life of 4.6 hours and which they assigned to Ho^{161}. Here, again, the limits mentioned in the previous section of this paper apply. Based on the production of the 5.0-hour activity, no holmium activity deficient in neutrons exists with a half-life between 5.0 hours and 20 years, thus eliminating the 65-day activity previously reported.

The 5.0-hour activity was not observed as a product of proton bombardment of erbium, and if it were either 164 or 163 it would be expected to be observed as a product of (p,α) reaction on erbium. It was not produced by proton bombardment (up to 22.5 Mev) of holmium, which again eliminates masses 163 and 164 because it would be observed as the daughter of Er^{163} or by (p,pn) on holmium. It was not observed by milking Er^{161} and could not be isomeric with 2.5-hour Ho^{161}, daughter of 3.5-hour Er^{161}. It was observed as a product of bombarding dysprosium with 8.5-Mev protons; this would eliminate all mass assignments lower than 160. From the relative amounts of the 5.0-hour and 2.5-hour activities, it could not be produced from Dy^{160}, therefore its mass could not be lower than 161. A gamma-ray spectrum, Fig. 1, as measured with a NaI(Tl) scintillation spectrometer, shows it to decay by electron capture, with the x-ray peak at 0.044 Mev and with gammas of 0.19, 0.71, and 0.95 Mev. There is no evidence for 0.51-Mev annihilation radiation; positrons, if present, constitute a small fraction of the total radiation.

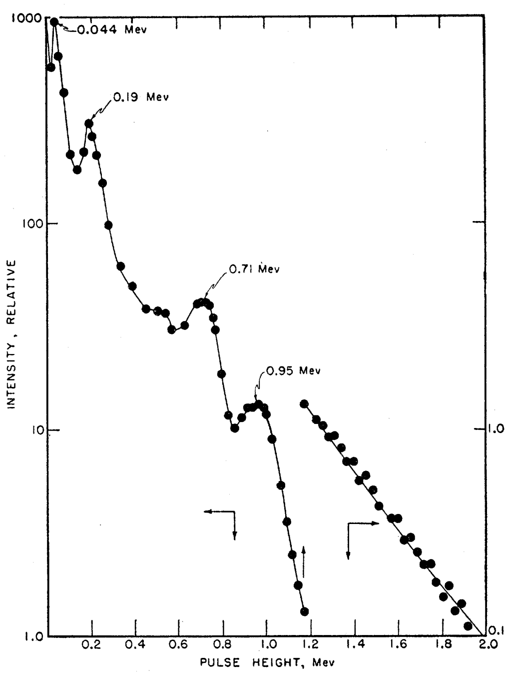

FIG. 1. Gamma-ray spectrum of Ho^{162}.

HOLMIUM-161

Previously, a 4.6-hour activity was assigned to Ho^{161}; however, this activity has not been confirmed, and it is presumed to be the same as the 5.0-hour activity which is assigned to Ho^{162} in the previous section. As reported earlier,[7] a 2.5-hour activity assigned to this mass was obtained from the decay of 3.6-hour Er^{161} which was produced by bombarding erbium with 24-Mev protons and separating by ion exchange. The erbium fraction was milked after an elapse of five hours to permit the Ho^{161} to grow in. A half-life of 2.5 hours was then observed. In the present work, the 2.5-hour activity is also produced by bombarding Dy_2O_3 with 20.5, 14.0, and 8.5-Mev protons. As reported previously, it was found to decay by electron capture, with possible gammas of 0.090 and 0.17-Mev energy.

HOLMIUM-160

An activity with a half-life of 22 minutes has been assigned[1] to Ho^{160}. In the present investigations, proton bombardment of Dy_2O_3 followed by ion-exchange separations gave a half-life of this order with the holmium elution peak. Due to the complexity of radiation from other holmium activities, it was not possible to obtain a gamma-ray spectrum. However, the 22-minute activity was not observed as a result of proton bombardment (up to 22.5 Mev) of either Ho or Er, which would eliminate its assignment to masses higher than 162. It was observed as a result of bombarding Dy_2O_3 with 8.5-Mev protons, which eliminates a mass assignment lower than 160. It was not observed as a daughter of Er^{161}, thus eliminating Ho^{161}. With these restrictions, it is tentatively assigned to a mass of 160.

[7] Thomas H. Handley and Elmer L. Olson, Phys. Rev. 93, 524 (1954).