H_2SO_4, diluted with water, and allowed to stand to separate out lead as $PbSO_4$. After filtering out the $PbSO_4$, about 50 mg of indium, dissolved in H_2SO_4, was added as a carrier, and the acidity was adjusted to $1N$ in H_2SO_4. Cadmium sulfide was precipitated from this solution by H_2S, washed with water, and dried at 105°C.

APPENDIX II

Separation of Indium from the Purified Cadmium

After completion of the measurements on CdS, this same precipitate was dissolved in HCl; 30 mg of indium was added, and the acid concentration was adjusted to $0.3N$. Cadmium sulfide was precipitated with H_2S, removed by filtration, and the acidity of the filtrate was adjusted to $0.05N$. Indium sulfide was then precipitated with H_2S, washed with water, and dissolved in HNO_3. From this solution, $In(OH)_3$ was precipitated with an excess of ammonia. The precipitate was washed with a 2 percent NH_4NO_3 solution, dried, and ignited to In_2O_3.

APPENDIX III

Chemical Procedure for the Purification of Hafnium

Three hundred milligrams of Hf_2O_3 were fused with borax, and the melt was dissolved in $2N-HCl$. The hydroxide was precipitated with ammonia in slight excess and washed with water. After dissolving the precipitate in $N-H_2SO_4$, about 20 mg of copper (as a carrier for Ag, Sn, Pb, and Cu) and about 20 mg of iron (as a carrier for Fe, Ni, and Zn) were added in solution. The solution was diluted to $0.3N$, and H_2S was passed into the cold solution until the copper was completely precipitated.

Tartaric acid was added to prevent precipitation of hafnium and, without filtering, the solution was made alkaline, with ammonia and saturated with H_2S, until the iron was precipitated. This precipitate was filtered out and discarded. After neutralizing the filtrate with H_2SO_4, 10 percent by volume was added in excess, and the H_2S was boiled off. About 20 mg of erbium were added, in H_2SO_4 solution, as a carrier for rare earths. Hafnium was precipitated from the cold solution by cupferron reagent; the precipitate was washed with $N-HCl$ and ignited to the oxide. This was dissolved in hydrafluoric acid, evaporated to a small volume, and diluted with ten volumes of water. The hafnium, in solution, was separated by decantation and filtration from carbon and fluorides of the rare earths.

To the filtrate containing the hafnium was added a few milliliters of H_2SO_4, after which the solution was evaporated to expel HF. Water and H_2SO_4 were added to the solution to bring the volume to 300 ml and the acid concentration to 10 percent by volume. Hafnium was again precipitated with cupferron. After washing, the precipitate was ignited to HfO_2.

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The Radiations from Hf^{181}

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The beta-spectrum and photoelectron spectrum of Hf^{181} have been studied with a semicircular focusing beta-ray spectrograph of 2 percent resolving power. In addition to the continuous beta-spectrum, four partially converted gamma-rays were found. An estimate of the relative intensities of the two higher energy gamma-rays can be made from the Compton and photoelectron intensities. Data have also been obtained from $\beta-\gamma$- and $\beta-e^-$-coincidence measurements. An energy level diagram is discussed.

INTRODUCTION

THE beta- and conversion electron spectrum of Hf^{181} has previously been studied by Cork, Shreffler, and Fowler,[1] Voigt and Thamer,[2] and by Beneš, Ghosh, Hedgran, and Hole.[3] Coincidence work on the radiations of Hf^{181} is also discussed in the preceding paper by Mandeville, Scherb, and Keighton.

BETA-SPECTRUM OF Hf^{181}

We have studied the beta-spectrum of Hf^{181}, using a semicircular focusing spectrograph of 2 percent resolving power. The spectrograph was calibrated from the 0.400-Mev line[4] of Au^{198}. The

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* Rackham Predoctoral Fellow, 1948–49.

[1] J. M. Cork, R. G. Shreffler, and C. M. Fowler, Phys. Rev. 72, 1209 (1947).

[2] A. F. Voigt and B. J. Thamer. Phys. Rev. 74, 1254 (1948).

[3] J. Beneš, A. Ghosh, A. Hedgran, and N. Hole, Nature 162, 261 (1948).

[4] K. Siegbahn, Proc. Roy. Soc. 187, 527 (1947).

sources were of hafnium oxide mounted on 0.2-mil sheet Nylon. A Geiger counter was used as a detector. Two types of counter windows were used, one of mica which transmitted electrons of energies above 38 kev; the second was of Nylon which had a cut-off at about 12 kev.

A typical spectrum obtained with a Nylon window is shown in Fig. 1. This spectrum is not corrected for window absorption. It is seen that conversion lines from four distinct gamma-rays are superimposed on the continuous beta-spectrum. The energies of the gamma-rays giving rise to these lines are 0.130, 0.134, 0.337, and 0.471 Mev. The two lowest energy lines are clearly shown in the enlarged section of Fig. 1. (Some of the experimental points have been omitted from the main diagram to avoid overlapping.) These two lines had first been observed on a photographic plate by Cork *et al.*,[1] and ascribed to conversion electrons and photoelectrons arising from a single gamma-ray. From a study of the intensity of this group we feel that two separate gamma-rays of nearly the same energy are emitted in the decay of Hf^{181}. In fact, the total conversion coefficient in the low energy groups (i.e., $N_{K_1+K_2+L_1+L_2+M_1+M_2}/N_\beta$) is found to be 0.7, even if no correction is made for window absorption. If the number of conversion electrons is corrected for window absorption and the number of beta-particles is obtained by extrapolating the Fermi plot to zero energy, the total conversion coefficient for the low energy

TABLE I. The conversion coefficients listed are the ratio of the number of conversion electrons in the group to the total number of beta-particles.

Line	Energy in Mev	Conversion coefficient
K_1	0.130	~0.56
K_2	0.134	~0.22
L_1+L_2		~0.425
M_1+M_2		~0.089
K_3	0.337	0.019
L_3		0.0053
K_4	0.471	0.021
L_4		0.0071

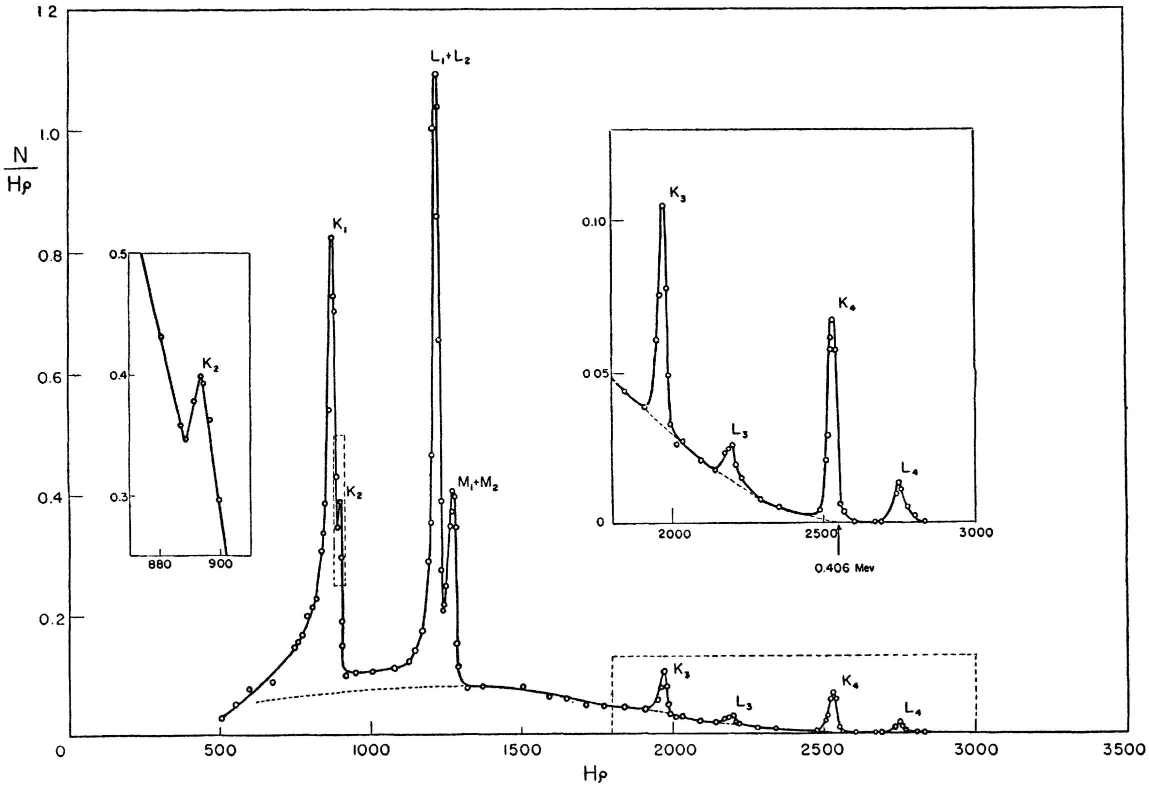

FIG. 1. Beta-spectrum of Hf^{181}. The K conversion lines of the low energy components can be clearly distinguished.

groups is ~1.3. Therefore, it seems clear that two distinct gamma-rays are present.**

The conversion coefficients for the various lines are listed in Table I.

A Fermi plot obtained from the continuous spectrum is shown in Fig. 2. It appears to be linear down to energies at which window absorption becomes appreciable. The end point of the beta-spectrum is 0.404 Mev.

The decay of a Hf^{181} source was followed in the spectrograph over a period of sixty days. Within the experimental uncertainties, all components decayed with the same lifetime.

PHOTOELECTRON SPECTRUM OF Hf^{181}

The photoelectron spectrum obtained by using a lead radiator is shown in Fig. 3. It is seen that the photo-lines of the two higher energy gamma-

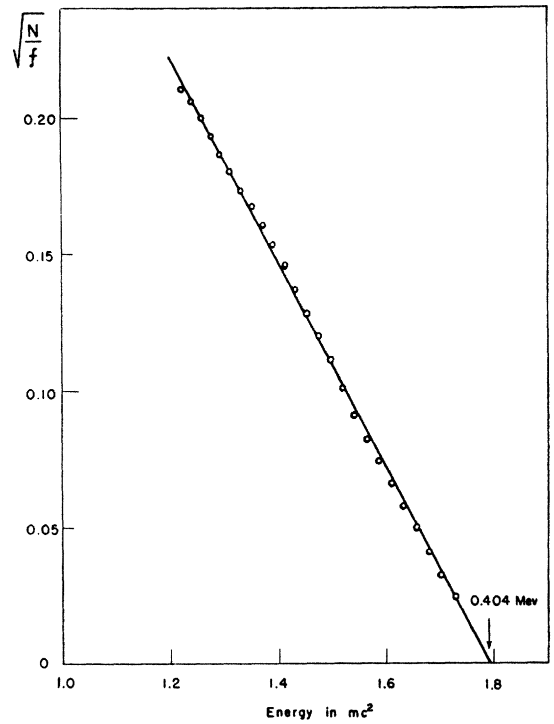

FIG. 2. Fermi plot of the Hf^{181} beta-spectrum.

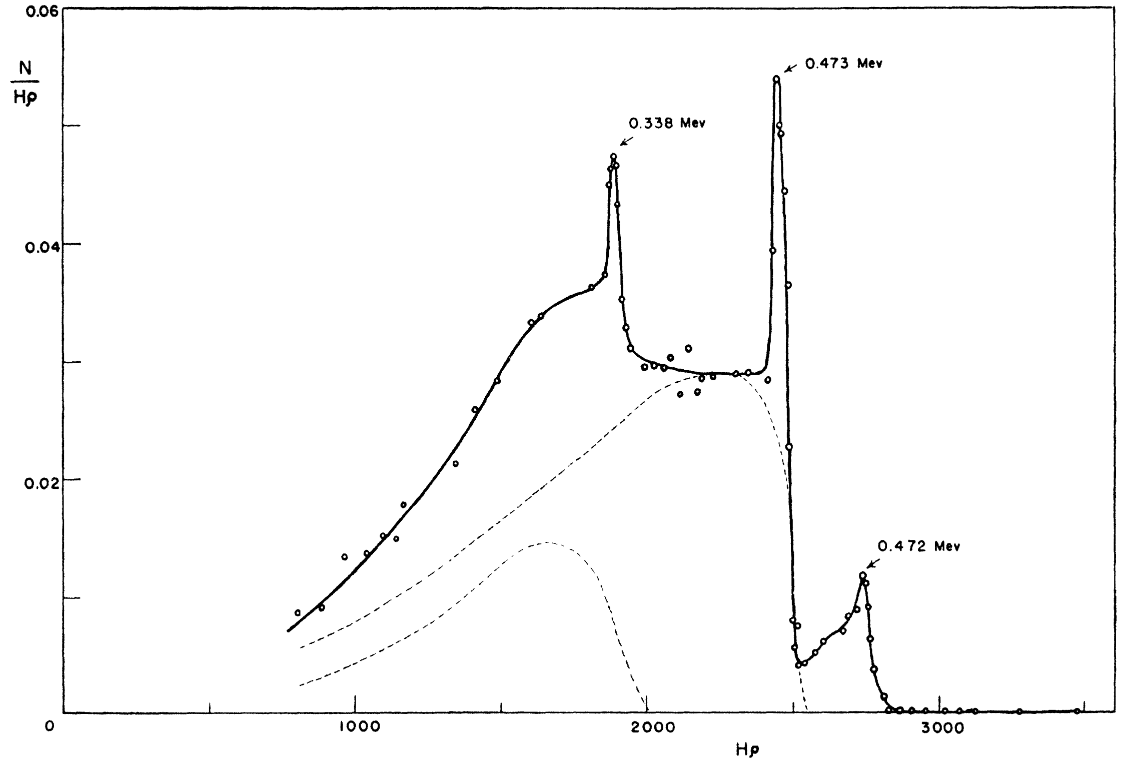

FIG. 3. Photoelectron spectrum of Hf^{181}, using lead as a radiator. The shapes of the Compton components were made to match that obtained for gold with the same spectrograph.

** *Note added in proof:* The beta-spectrum has been studied using a source which consisted of 50 percent active hafnium oxide mixed with 50 percent non-active hafnium oxide. The ratio of the peaks of K_1 and K_2 remained unchanged thus indicating conclusively that the photo effect plays no important role in the production of these peaks.

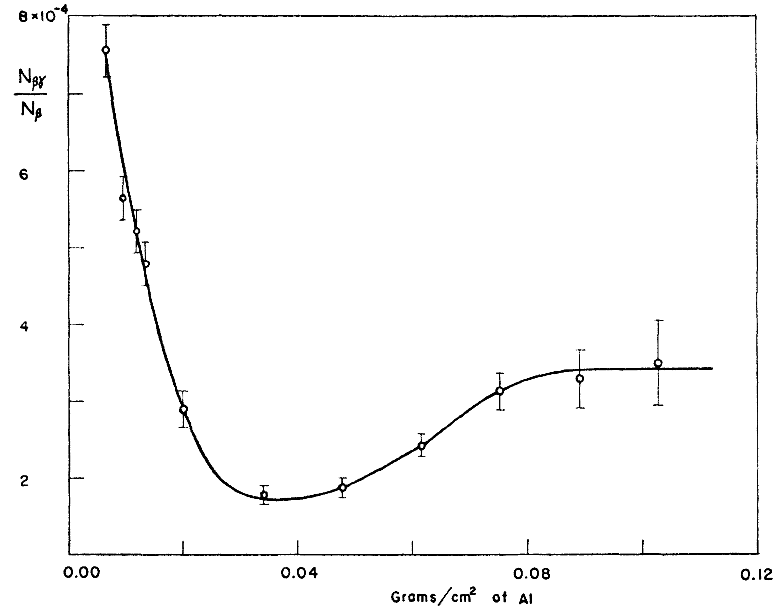

FIG. 4. Beta-gamma-coincidence rate as a function of beta-absorber thickness. The source used in obtaining this curve had been chemically separated.

rays are present, superimposed on the Compton spectra. There is no indication of a photo-line arising from the lowest energy gamma-ray, thus giving further evidence that the lines K_1 and K_2 in the beta-spectrum arise from highly converted gamma-rays.

The Compton spectra have been broken into two components as indicated. The shapes were made to match that of the spectrum of Au^{198}, which has a strong gamma-ray of energy 0.400 Mev.

From the intensities of the Compton components, one obtains a ratio of gamma-intensities $\gamma_3:\gamma_4=1:2$. The corresponding value as obtained from the K photo-lines (following the procedure of Deutsch, Elliot, and Evans[5]) is $\gamma_3:\gamma_4=1:2.8$.

It may also be noted that no additional lines occur in the photoelectron spectrum which had not been observed in the beta- and conversion spectrum. The photoelectron spectrum has been checked up to 0.8 Mev but has given no indication of activity beyond that of the L_4 photo-line.

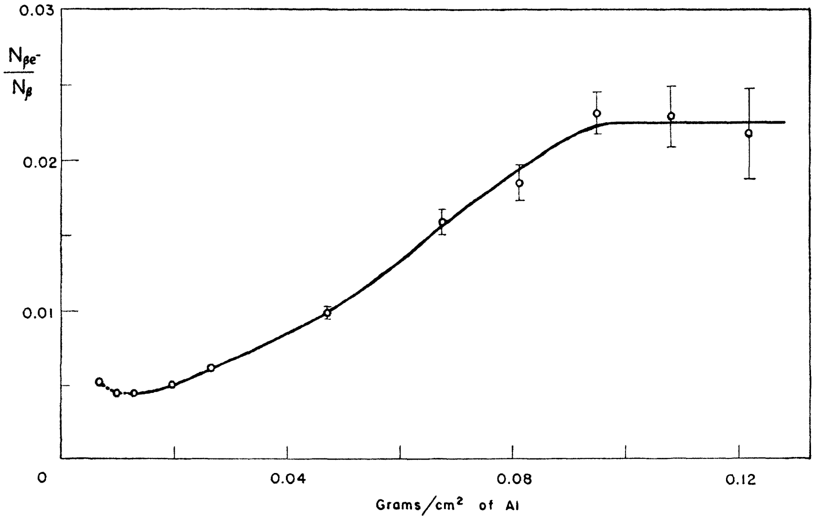

FIG. 5. Beta-beta-coincidence rate using a single absorber.

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[5] M. Deutsch, L. G. Elliot, and R. D. Evans, Rev. Sci. Inst. 15, 178 (1944).

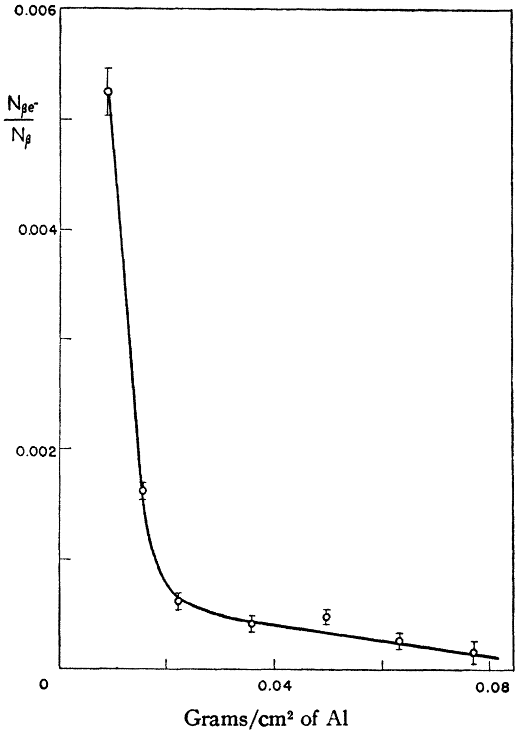

FIG. 6. Beta-beta-coincidence rate using absorbers before each counter.

COINCIDENCE MEASUREMENTS

Coincidence measurements on Hf^{181} can be extremely treacherous because of the complicated nature of the decay and the abundance of low energy electrons and gamma-rays. We have previously published a β-γ-coincidence curve[6] in which the coincidence rate was found to rise by a factor of three. Recently, we have had the opportunity to repeat these measurements and have obtained the curve in Fig. 4. This curve shows an initial sharp drop to a low value, followed by an appreciable rise which appears to be real. The sharp drop was not observed previously because of the absorption of the low energy electrons in the counter windows used at that time.

A beta-beta-coincidence rate curve is shown in Fig. 5. In obtaining this curve, an absorber was placed between the source and only one of the beta-counters. A curve showing the coincidence rate as a function of absorber thickness, using two equal absorbers, is shown in Fig. 6. It should be noted that the points at absorber thicknesses greater than 0.05 gram/cm^2 are difficult to obtain both for the beta-gamma- and beta-beta-coincidences with two absorbers.

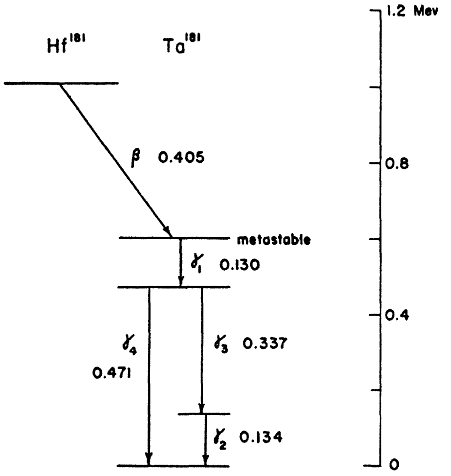

FIG. 7. Proposed energy level scheme.

PROPOSED LEVEL SCHEME

Two energy level schemes have been proposed thus far.[1,3] The cascade arrangement of Beneš *et al.*[3] does not take into account the presence of the two low energy gamma-rays. In addition, the photoelectron and Compton spectrum (Fig. 3) indicates that the 0.471-Mev gamma-ray is considerably more abundant than the 0.337-Mev gamma-ray. It would therefore seem that a level scheme similar to that shown in Fig. 7 might account for most of the observed facts. The beta-gamma-coincidence curve (including the apparent minimum) could clearly be fitted by such a scheme. The shape and magnitude of the β-γ-curve would not be appreciably affected by a change in the resolving time of the coincidence circuit since the conversion electrons would play the most important role, even at high energies. Likewise, the beta-beta-coincidence curves could be qualitatively accounted for by this scheme.

Unfortunately, coincidence measurements which are capable of distinguishing among various level schemes are extremely difficult to make. Clearly the level scheme proposed here should not give rise to coincidences between a non-delayed and a delayed gamma-ray. The work of DeBenedetti and McGowan[7] indicates that such

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[6] M. L. Wiedenbeck and K. Y. Chu, Phys. Rev. **72**, 1164 (1947).

[7] S. DeBenedetti and F. K. McGowan, Phys. Rev. **70**, 569 (1946).

coincidences do not occur, while Beneš *et al.*[3] report a small number of this type of coincidence. A second test would occur in the beta-beta-coincidence rate obtained with two absorbers. That portion of the curve *at great absorber thicknesses* should be due to coincidences between the beta-ray and delayed high energy conversion electrons, therefore this portion of the curve should be sensitive to the resolving time of the coincidence circuit. That portion of the curve obtained with small absorber thicknesses should not be sensitive to the resolving time.

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Evidence for a New Isotope of Potassium[*]

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A study of the potassium isotopes produced by the bombardment of argon with helium ions reveals the presence of a hitherto unknown isotope with a 22.4 hour half-life. The new potassium isotope has two beta-components of approximately 0.25-Mev and 0.8-Mev maximum energies. A gamma-component is present of roughly 0.4-Mev energy. The evidence strongly suggests that the isotope in question is K^{43} produced by the reaction $A^{40}(\alpha, p)K^{43}$.

I. INTRODUCTION

IN a recent communication by two of the authors[1] it was shown that bombardment of argon with 40-Mev helium ions resulted in the production of radio-potassium in exceptionally high yields (about one millicurie per microampere-hour). This bombardment subsequently has proven to be a very satisfactory method for the production of radioactive carrier free potassium, particularly for use as a tracer in the biological and agricultural sciences. Moreover, the apparatus used (See Fig. 1) which was designed by M. T. Webb of the Crocker Radiation Laboratory may be employed for the bombardment of other gases with protons, deuterons or helium ions. The reaction is carried out in a bell-jar constructed of 2*S* commercially pure aluminum so as to contain the beam and through which a slow stream of argon gas continuously flows. The outlet tube for the gas is approximately 20 feet in length and the end of the tube is immersed in a beaker of water. Also the outlet tube contains a glass wool plug adjacent to the bell-jar. The rate of gas flow and length of outlet tube are adjusted so as to prevent air being sucked back into the bell-jar as a result of cooling caused by momentary interruptions in the beam from sparking of the deflector, etc. The major portion of the radio-potassium settles out on the walls of the

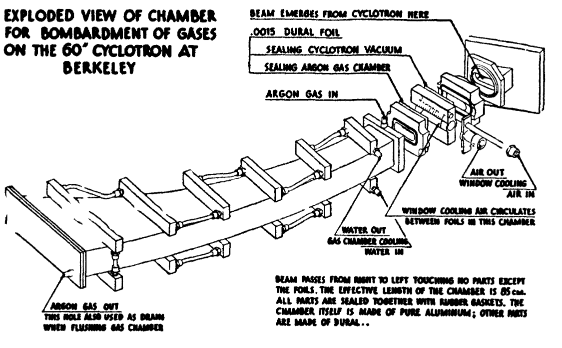

FIG. 1. Exploded diagram of aluminum bell-jar used for bombardment of gases with protons, deuterons, or alpha-particles.

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[1] Roy Overstreet and Louis Jacobson, Phys. Rev. **72**, 349 (1947).