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Br^{82m} and Its Decay Scheme*

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The discovery of a new activity of bromine is reported and is assigned to a $2(-)$ isomeric state of Br^{82} . The new activity is chemically identified as bromine and shown to be the short-lived parent of Br^{82} . It decays primarily by a highly converted $M3$ transition ($\alpha=382\pm 75$) of 46 keV to the $5(-)$ ground state of Br^{82} . Two weak branches in the proposed decay scheme lead by beta emission to the 0.78-MeV level (0.15%) and the 1.48-MeV level (0.024%) of Kr^{82} . Time-dependent gamma spectra, obtained with a large anti-coincidence counter, demonstrate the growth of the 2.65-MeV sum peak of Br^{82} after thermal-neutron activation of NH_4Br . Short-lived gamma peaks at 46 keV, 0.78 MeV, and 1.48 MeV were observed in the gamma spectra of an activated sample of enriched NH_4Br (99.32% Br^{81}). X-ray spectra of activated NH_4Br taken with an argon-methane proportional counter provide evidence that the short-lived component is a thermal-neutron activation product. One-component decay curves of the $\text{Br } K$ x rays over more than 6 half-periods define the half-life of Br^{82m} as 363 ± 2 sec.

INTRODUCTION

THE existence of a metastable state of Br^{82} can be postulated from the shell model of atomic nuclei.¹ An indication for the existence of such an activity presented itself for the first time in the course of a systematic study of the time-dependent gamma spectra obtained after 5-min thermal-neutron activations of pure elements.² It was observed that for the activated bromide samples the higher energy peaks, generally attributed to Br^{82} , grew in with time initially and decayed later with the characteristic 36-h half-life of Br^{82} , rather than decaying uniformly with this half-life as expected from the known nuclear data.

Another discrepancy with the available information was encountered in an investigation of the decay characteristics of Br^{79m} . It was observed that there existed a short-lived component of more than 2 min and less than 12-min half-life in the x-ray spectrum of ammonium bromide samples activated with thermalized neutrons.³

When several attempts to determine the isotopic abundances in bromide samples by short-time neutron-

activation techniques resulted in excessive errors and the previously observed discrepancies were remembered, it appeared of interest to further investigate the situation and identify the interfering activity.

INSTRUMENTAL

The source of neutrons available in this laboratory is a 2-MV Van de Graaff accelerator producing neutrons of < 6 -MeV energy in a water-cooled beryllium target by the reaction $\text{Be}^9(d,n)\text{B}^{10}$. The target is surrounded by a cube of paraffin 2 ft on an edge to provide a flux of up to 4×10^8 n/cm^2 sec of thermal neutrons at the sample position.

A rather well-suited tool for the present purpose is a large anti-coincidence counter which has been built in the laboratory. It consists of a 5-in. well-type $\text{NaI}(\text{Tl})$ crystal in the center of a 65-gal tank of liquid scintillator. The signal from the two 16-in. multiplier phototubes viewing the liquid scintillator are coupled to the anti-coincidence gate of a RIDL 400-channel analyzer. For some of the work described the anti-coincidence feature of this counter was not employed and the signal from the 5-in. crystal alone processed through the analyzer. For some experiments a single-channel analyzer was used which, in turn, provided a triggering signal for the multichannel analyzer operating in its multi-scaler mode.

X-ray spectra were collected with a 4-in.-diam, 12-in.-long x-ray proportional counter filled with 2 atmos-

* This paper was presented in part at the 148th national meeting of the American Chemical Society in Chicago, Illinois, on 1 September 1964.

¹ M. G. Mayer and J. H. Jensen, *Elementary Theory of Nuclear Structure* (John Wiley & Sons, Inc., New York, 1955).

² O. U. Anders, *Gamma Ray Spectra of Neutron Activated Elements* (The Dow Chemical Company, Midland, Michigan, 1960).

³ O. U. Anders, *Anal. Chem.* **34**, 1678 (1962).

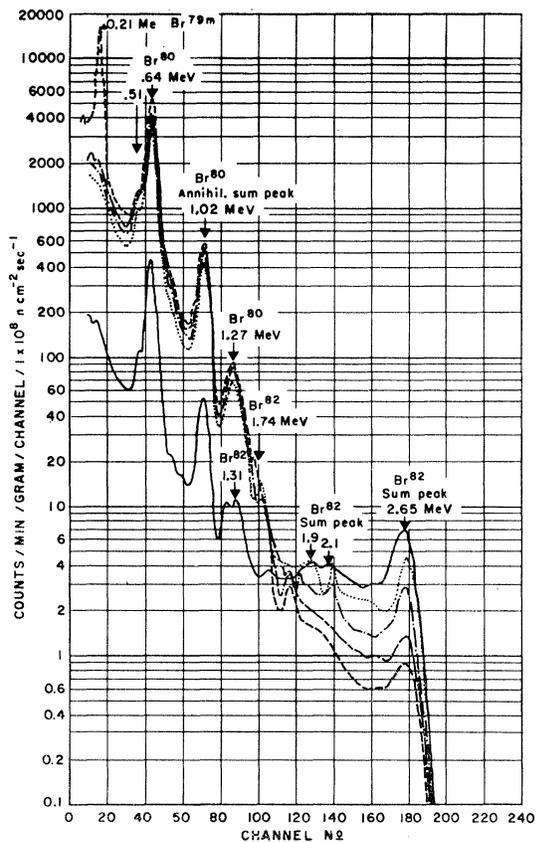


FIG. 1. Time-dependent gamma spectra of neutron-activated bromine. A sample of ammonium bromide was activated for 10 sec with thermalized neutrons and spectra were collected with the anticoincidence counter for 1 min each, beginning: ---- 0.1 min after end of irradiation, -.- 1.1 min after end of irradiation, 3.5 min after end of irradiation, 8.5 min after end of irradiation, and ——— 70 min after end of irradiation.

pheres of a mixture of 10:1 argon-methane.⁴ Its output, after suitable amplification, was also processed by the multichannel analyzer.

EXPERIMENTAL

The first objective of the present study was the verification of the growing-in of Br^{82} after the activations. Several samples of B & A reagent grade NH_4Br were activated for 10 sec each, and gamma spectra collected with the anticoincidence counter over the range between 0-3 MeV at different times after the activation. A typical series of time-dependent spectra is seen in Fig. 1. While the lower energy region of the spectra decay as expected from the presence of Br^{79m} (0.21 MeV), Br^{80} and Br^{80m} (0.62, 1.03 MeV), the high-energy parts, especially the 2.65-MeV sum peak of Br^{82} , are clearly seen to grow in during the 70-min interval elapsed between the first and the fifth spectrum of Fig. 1.

⁴ O. U. Anders, Phys. Rev. **120**, 2114 (1960), and U. S. Atomic Energy Commission unclassified report AECU-3513 (unpublished).

It was now attempted to measure the half-period for the growth of this 2.65-MeV peak. This was accomplished by again activating NH_4Br samples for 10 sec each, but counting them with the 5-in. crystal and a single-channel analyzer. The window of the analyzer was set to pass only pulses in the 2.65-MeV peak range. The pulses from the single-channel analyzer were collected with the multichannel analyzer working in its multiscaler mode with a channel advance period of 12.5 sec per channel. A typical curve obtained in this manner is seen in Fig. 2. The growth period was calculated from these data to be 5.0 min. A careful analysis of these curves revealed that only about 90% of the equilibrium counting rate of Br^{82} is accounted for by the growth, while $\approx 10\%$ of the Br^{82} is apparently produced directly during the activation of the sample.

If one activity grows in, in a sample, another must decay and, when the daughter is very long lived with respect to the parent, the growth occurs with practically the same half-period as the decay of the parent.

It was now suspected that the parent activity might be an isomeric state of Br^{82} , and chemical identification was in order. It is possible that an unknown activity is induced in the Br samples by the fast-neutron component of the neutron flux via the (n,p) or (n,α) reactions, yielding isotopes of Se⁵ and As, respectively. Selenous acid was thus added to a freshly activated sample and the selenium metal precipitated with SO_2 . After thorough centrifuging the growth of the 2.65-MeV peak was found to stay with the supernate. Similar results were obtained with other samples to which a HCl solution of AsCl_3 had been added as carrier after the

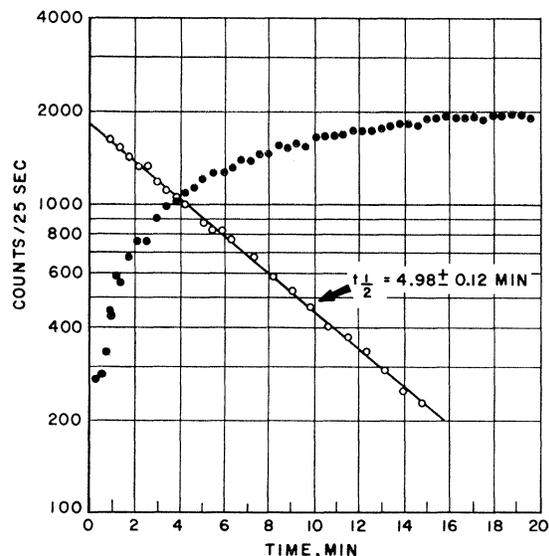


FIG. 2. ●-●-● Growth of the 2.56-MeV sum peak of Br^{82} gamma spectrum of ammonium bromide sample activated with thermalized neutrons. ○-○-○ Associated decay of parent (maximum count rate minus instantaneous count rate).

⁵ A. Flammersfeld and W. Herr, Z. Naturforsch. **5a**, 569 (1950).

activation and from which As₂S₃ was precipitated with H₂S. Again the growing-in 2.65-MeV gamma-ray sum peak remained with the supernate. These experiments excluded Se and As as the chemical assignment of the new activity.

Finally a highly purified solution of carbon tetrabromide in benzene was irradiated and the water soluble recoil fragments from the Szilard-Chalmers reaction extracted with a very dilute solution (≈ 500 mg/l) of NH₄Br in water. The aqueous phase was backwashed twice with benzene until the separated organic phase did not contain any activity. The aqueous phase was then placed into a separatory funnel containing an aqueous solution of sodium hypochlorite and ≈ 7 ml benzene. The mixture was acidified with a few ml HCl to liberate Cl₂ and the Br₂ from the reaction $2\text{Br}^- + \text{Cl}_2 \rightarrow \text{Br}_2 + 2\text{Cl}^-$ was extracted into the benzene layer. The organic phase was then backwashed twice with distilled water and transferred to the anticoincidence counter. The growth of the 2.65-MeV sum peak of Br⁸² was again observed in this sample which thus identified the new activity as an isotope of bromine.

A comparison of the activities of the original activated CBr₄ solution after the extraction with the dilute aqueous NH₄Br solution, and the combined aqueous phases and counting sample proved that the method employed had been 56% efficient in extracting the Br activation products from the benzene solution into the aqueous phase.

If the new activity is indeed Br^{82m} decaying by emission of a low-energy gamma ray to the 36-h ground state, much of this decay may be internally converted, and one should observe the corresponding Br K x rays decay with the short half-life.

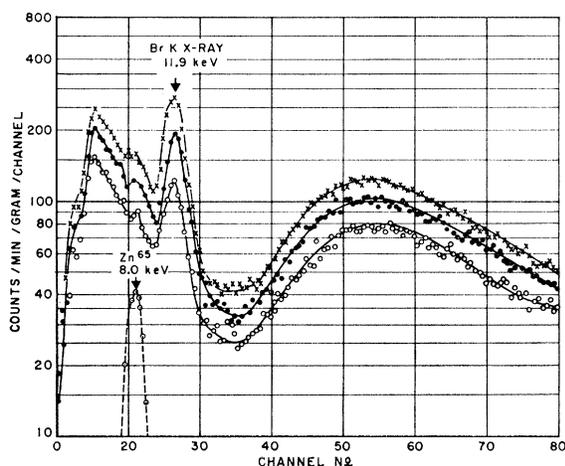


FIG. 3. Time-dependent x-ray spectra of neutron-activated bromine. A sample of ammonium bromide was activated with thermalized neutrons for 1 min and spectra collected with a proportional counter for 1 min each beginning: x-x-x 0.3 min after end of irradiation, ●-●-● 5.3 min after end of irradiation, and ○-○-○ 12.3 min after end of irradiation. The x-ray spectrum of Zn⁶⁵ is shown for comparison.

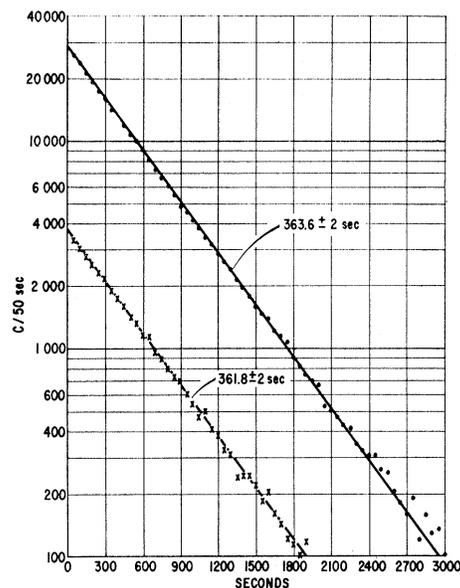


FIG. 4. ○-○-○ Decay of 11.9-keV bromine K x-ray peak in an enriched NH₄Br⁸¹ sample (99.32% Br⁸¹) activated for 1 min with thermalized neutrons. x-x-x Decay curve of the same sample activated in the same manner and the same neutron source yield inside a cadmium box.

X-ray spectra of the briefly activated NH₄Br samples were now taken with the x-ray proportional counter over a period of about 5 h (Fig. 3) and the corresponding decay curves plotted for the 11.9-keV photopeak of the spectra. A computer program using least-squares techniques was able to resolve one such curve into a 4.5-h component from Br^{80m} of 700-count/min initial counting rate, a clean 17.5-min component due to Br⁸⁰ counting 11000 counts/min and finally a rather prominent component decaying with the 5.1-min half-period of the new activity which counted 10500 counts/min at the end of the bombardment.

There existed yet a possibility that the short-lived x-ray emitter might be a different product than the parent of Br⁸², e.g., Br^{81m} from an (*n,n'*) reaction due to the fast-neutron component of the flux. The experiment was thus repeated using the same deuteron beam on the target of the Van de Graaff accelerator, but both target and sample were enclosed in a box of $\frac{1}{32}$ -in.-thick Cd sheet. In a previous study (3) it had been shown that under similar circumstances the fast neutron product Br^{79m} showed a 20% increase in yield, when irradiated inside the Cd box as compared to the irradiation inside the paraffin cube, while the yield of the thermal neutron products Br⁸⁰ and Br^{80m} had been reduced by more than a factor of 10. The result of the present experiment also indicated an ~ 10 -fold reduction in count rate proportional to the reduction of the thermal neutron component of the flux. This proved that the new short-lived component of the x-ray decay curve is not a fast neutron reaction product and left only Br^{82m} as its assignment.

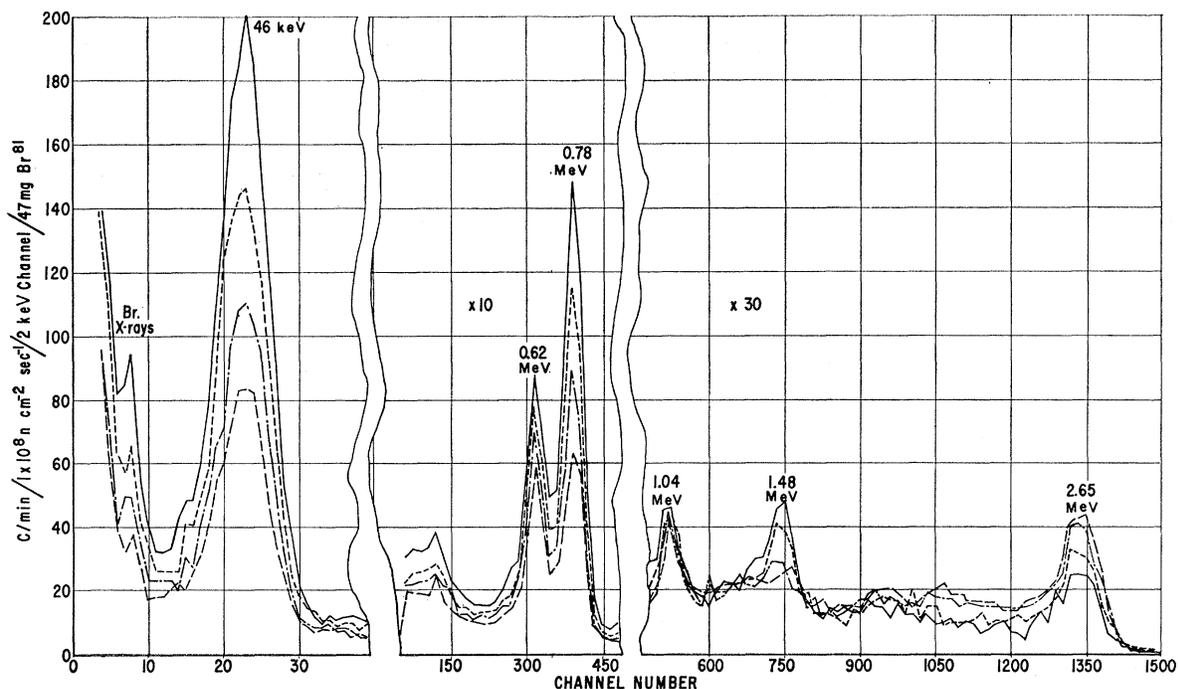


FIG. 5. Time-dependent gamma spectra of enriched ammonium bromide sample 99.32 Br^{81} . Sample activated for 5 min with thermalized neutrons. Spectra collected with anticoincidence counter for 2.5 min each at: — 1 min after end of activation, - - - 3.5 min after end of activation, - · - · 6 min after end of activation, - - - - 8.5 min after end of activation.

To verify these results the two experiments were repeated again at a later time using an enriched $\text{NH}_4\text{Br}^{81}$ sample, 99.32% Br^{81} . The resulting decay curves seen in Fig. 4 are single-component curves over more than six half-periods. A computer program using a least-squares fit calculated the half-lives of these curves as 363.6 and 361.8 sec, respectively.

If the new activity indeed decays by a highly converted internal transition, it may be possible that some of its gamma rays are not converted and should be identifiable in the gamma spectra of the activated bromine. It was impossible, however, to see any peaks of corresponding half-life in the gamma spectra of the activated nonenriched NH_4Br samples due to the strong

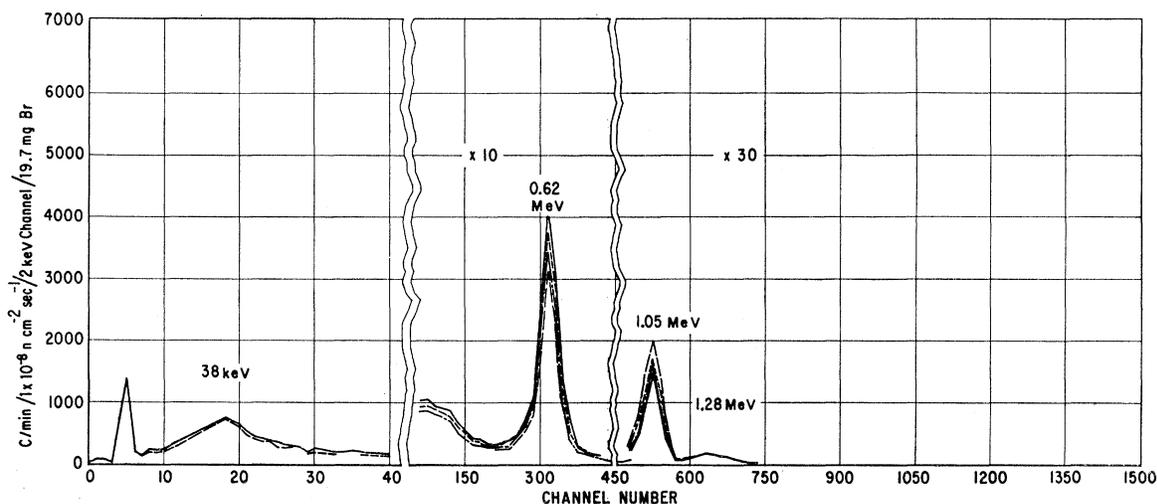


FIG. 6. Time-dependent gamma spectra of nonenriched ammonium bromide sample. Sample activated for 5 min with thermalized neutrons. Spectra collected with anticoincidence counter for 2.5 min each at: — 1 min after end of activation, - - - 3.5 min after end of activation, - · - · 6 min after end of activation, - - - - 8.5 min after end of activation.

GAMMA SPECTRA OF THE ACTIVATION PRODUCT OF Br⁸¹

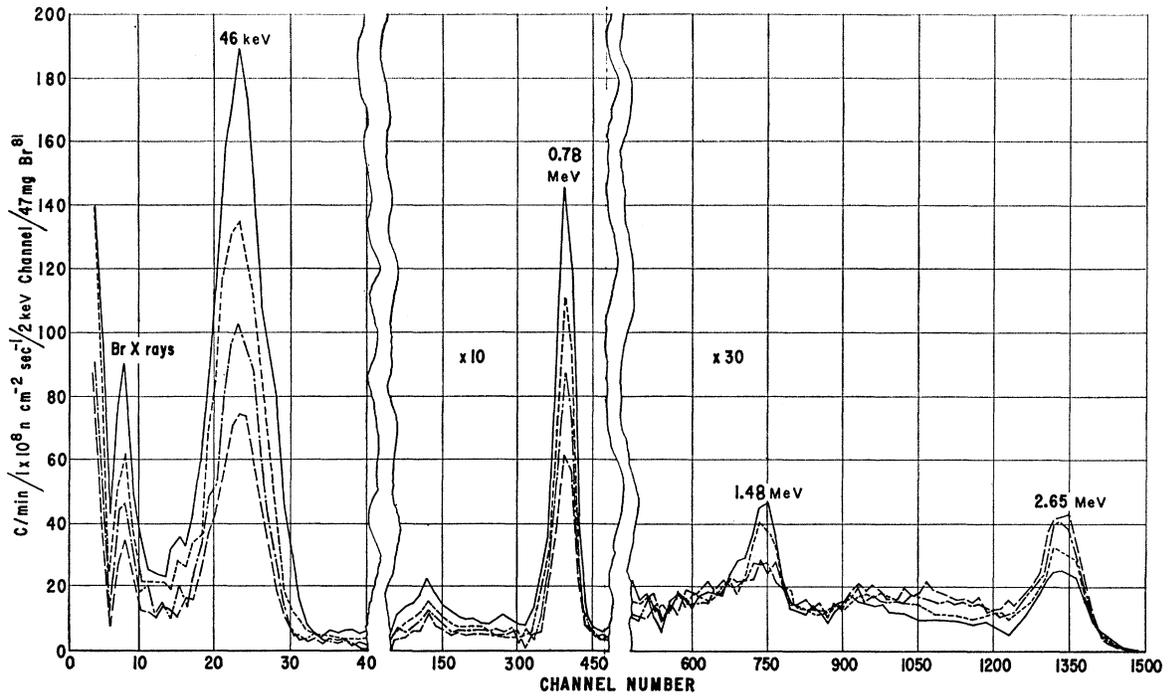


FIG. 7. Time-dependent gamma spectra of activated Br⁸¹. Data of Fig. 5 with the contribution of the Br⁷⁹ activation products subtracted out.

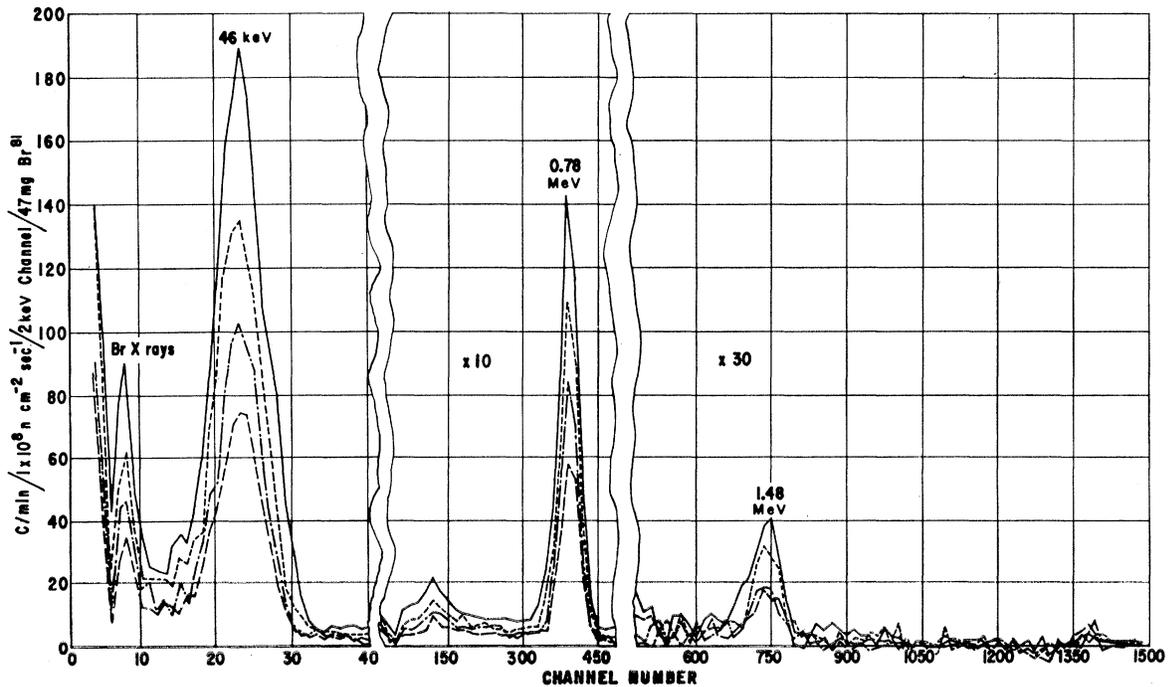


FIG. 8. Time-dependent gamma spectra of Br^{82m}. Data of Fig. 5 with the contributions of the Br⁷⁹ activation products and those of the growing in daughter activity Br⁸² subtracted out.

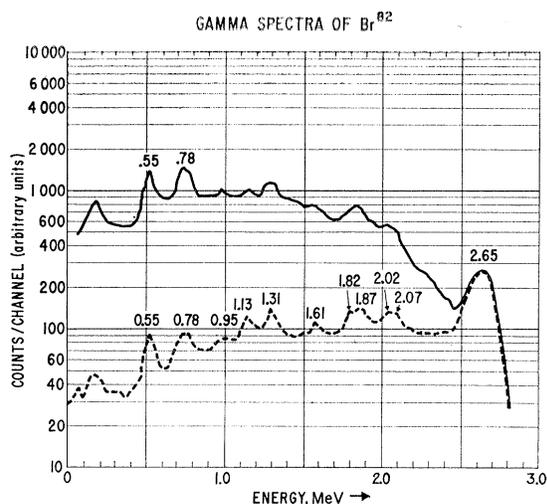


FIG. 9. Gamma spectra of Br^{82} taken with: ---- anticoincidence counter, ——— 5-in. well crystal counter, i.e. anticoincidence circuit inoperative.

interferences from Br^{80} and Br^{80m} in the lower energy range of the spectra (Figs. 1 and 6). It was thus necessary to continue the research with the aid of a sample enriched in Br^{81} . Fifty milligrams of an enriched sample containing 99.32% Br^{81} in the chemical form NaBr were thus purchased from the Oak Ridge National Laboratory.

Preliminary experiments with this NaBr^{81} sample indicated that its sodium content would interfere with the experiments, and it was thus deemed necessary to convert the sample chemically to NH_4Br . This was done by dissolving the enriched NaBr^{81} sample in a minimum amount of distilled water and applying it to a small column, 4 cm long and 0.4 cm diam, charged with DOWEX 50W X12 cation exchange resin (200–400 mesh) in its ammonium form. The eluted $\text{NH}_4\text{Br}^{81}$ sample was then used for the following experiments.

The $\text{NH}_4\text{Br}^{81}$ sample was repeatedly activated for 5-min periods and gamma spectra collected with the anticoincidence counter in 2.5-min intervals starting 1 min after the activations. For some of the experiments the gain of the analyzer was set to cover 2 keV per channel, in order to display the details of the low-energy range of the spectra; for the others the gain was set for 30 keV per channel to cover the range up to 3.0 MeV with 100 channels. The resulting normalized spectra are seen in Fig. 5. For comparison a small sample of nonenriched NH_4Br was treated in identical manner and the spectra of Fig. 6 obtained. The spectra from this NH_4Br sample were now normalized to the 0.62-MeV peak observed in the spectrum of the activated $\text{NH}_4\text{Br}^{81}$ sample and subtracted from Fig. 5 in order to reveal the spectrum of activated Br^{81} alone (Fig. 7). Three new gamma rays are readily identified in these spectra: at 46 keV, 0.78, and 1.48 MeV; all three decaying with a half-life of about 6 min. The remaining peak

in Fig. 7 is the sum peak of Br^{82} at 2.65 MeV which is seen to grow in. In order to ascertain the absence of additional small peaks due to Br^{82m} , the Br^{82} spectra (Fig. 9) were peeled from those of Fig. 7 and the pure gamma spectra of the decaying Br^{82m} obtained in Fig. 8.

If we compare these spectra with Fig. 1, it is readily seen why the new gamma rays could not be identified in samples of nonenriched bromide.

One of the characteristics of an anticoincidence counter is its ability to suppress pulses occurring from gamma rays forming a cascade in the decay scheme, while gamma rays not in coincidence with others, as well as the sum pulses adding up to the energy of the level from which the cascades start, are not affected.⁶ This is readily demonstrated for Br^{82} in Fig. 9 which represents the spectrum obtained with the anticoincidence counter as well as with the 5-in. well crystal alone, i.e., the anticoincidence circuit inoperative. It is seen in this figure that the 0.78-MeV, the 1.48-MeV peak, and all others are reduced in intensity by more than one order of magnitude by the anticoincidence circuit, while the sum peak at 2.65 MeV remains unaltered. This feature of the counter suppressed the growing-in contributions of Br^{82} to a sufficiently high degree during the above experiments to permit the clear identification of the rapidly decaying components of the 0.78- and the 1.48-MeV gamma-ray peaks, which were due to the new activity. Without this feature the growth of these two peaks due to Br^{82} might well have obscured their initial decay in these experiments.

This same feature of the counter permitted also the verification of the noncoincidence of the 46-keV and 0.78-MeV radiations, which was assumed from a suspected branching in the decay scheme of the new activity. An additional series of experiments proved that the count rate of the 46-keV gamma rays per neutron flux is reproduced within the experimental error of $\pm 3\%$ whether the anticoincidence circuit is in operation or not. Small gold foil monitors attached to the sample during these two experiments permitted the flux normalization of the counting data.

The half-life of 363 ± 2 sec obtained from the x-ray decay curves of the enriched sample mentioned above, is in disagreement with the values initially found for the growth of Br^{82} and the decay of the short-lived component in the x-ray spectrum of the activated nonenriched NH_4Br . It is, however, assumed that the earlier values were less accurate due to statistics and the strong interferences from Br^{80} and Br^{80m} which had been copiously present in the activated nonenriched NH_4Br samples used.

The remaining fact still needed for the establishment of the decay scheme of the new Br^{82m} activity was the internal conversion coefficient α of the transition to the ground state. This could be calculated from the absolute disintegration rates of the nuclei emitting 46-keV

⁶ P. R. Bell, Science **120**, 625 (1954).

gamma rays and the Br⁸² ground-state activity after it had grown in.

For this purpose the NH₄Br⁸¹ sample was again activated for 5 min and anticoincidence spectra taken in the low-energy range starting 1 min after activation. Thirty-six hours later the sample was again counted with the anticoincidence circuit inoperative and pulses collected in the range from 4 keV to 2.65 MeV.

The efficiency of the counter for x rays was then calibrated with a 1-ml Cs¹³⁷ source and found to be 50.2% for 32-keV radiation. (Ninety-five percent counting efficiency was assumed for the 660-keV gamma rays.) From this and the absorption coefficient for 32-keV radiation in an absorber of average atomic weight 23 (aluminum well lining, polyethylene vial and aqueous solvent) $\mu = 0.55 \text{ cm}^2/\text{g}$,⁷ the value 1.23 g/cm^2 sodium equivalent was calculated as the effective absorber for the samples. Using this value and the sodium absorption coefficient for 46-keV radiation, $\mu = 0.30 \text{ cm}^2/\text{g}$, an efficiency of 69% was estimated for counting the 46-keV gamma rays of the activated NH₄Br⁸¹ sample.

One hundred percent efficiency was assumed for the count of Br⁸², when the entire spectrum of the 5-in. well counter was used.

Using the 69% counter efficiency for 46-keV gamma rays and the 6.05-min value for the half-life of Br^{82m}, the number of gamma-ray emitting Br^{82m} nuclei present at the end of the 5-min activation was found to be $N^* = 118\,743$ nuclei. From the later count of Br⁸² it was calculated that the sample contained, at a time $T = 2165$ min after the end of the activation, $N_{\text{Br}^{82}} = 29\,803\,484$ Br⁸² nuclei, which had been formed as daughters of Br^{82m}. A ratio of 9:1 was assumed for the direct production rates of Br^{82m} and Br⁸² during the activation.

The following relationships govern the buildup and decay of the secondary product Br⁸² during the activation:

$$\frac{N_B}{N_S} = 1 - \left(\frac{\lambda_A e^{-\lambda_B t} - \lambda_B e^{-\lambda_A t}}{\lambda_A - \lambda_B} \right) \quad (1)$$

and

$$\frac{N_S}{\alpha} = \frac{\sigma N f}{\alpha \lambda_B} = \frac{\lambda_A N^*}{\lambda_B (1 - e^{-\lambda_A t})}; \quad (2)$$

and after the activation:

$$\frac{N_{\text{Br}^{82}}}{\alpha} = \frac{N_A}{\alpha} \frac{\lambda_A}{\lambda_B - \lambda_A} (e^{-\lambda_A T} - e^{-\lambda_B T}) + \frac{N_B}{\alpha} e^{-\lambda_B T}, \quad (3)$$

$$N_A/\alpha = N^*, \quad (4)$$

where α is the conversion coefficient, N_A is the number of Br^{82m} nuclei present at the end of the activation, N_B is the number of Br⁸² nuclei present at the end of the

activation, N_S is the number of Br⁸² nuclei present when saturation is reached, λ_A is the decay constant of Br^{82m}, λ_B is the decay constant of Br⁸², σ is the cross section of the reaction Br⁸¹(n, γ)Br^{82m}, N is the number of Br⁸¹ nuclei present in the sample, f is the neutron flux, t is the time of activation, and T the time after the end of the activation. It was thus possible to obtain $N_B/\alpha = 37\,377$ by substituting (2) into (1) and evaluating for

$$\begin{aligned} \lambda_A &= 0.114545 \text{ min}^{-1}, & t &= 5 \text{ min}, \\ \lambda_B &= 0.0003271 \text{ min}^{-1}, & T &= 2165 \text{ min}. \end{aligned}$$

Substituting this value, as well as (4), into the expression (3) yielded

$$\frac{N_{\text{Br}^{82}}}{\alpha} = 118\,743 \times 0.50042 + 37\,377 \times 0.4990 = 77\,947.$$

From this the internal conversion coefficient was obtained:

$$\alpha = \frac{N_{\text{Br}^{82}}}{N_{\text{Br}^{82}}/\alpha} = \frac{29\,803\,484}{77\,947} = 382.$$

This then identified the decay of Br^{82m} to the 5(-) ground state as an $M3$ transition involving a spin change of 3 and no change in parity. For such a transition an interpolation of Rose's tables⁸ yields a value of ~ 300 for α .

It was possible to also calculate the branching ratios of the direct decays to the 0.78- and 1.48-MeV levels of Kr⁸² to the 46-keV internal transition from the gamma spectra. Again 95% counting efficiencies were assumed for the 780- and 698-keV gamma rays and a resulting 90% efficiency for counting the peak at 1.48 MeV. It was thus found that, assuming no direct transitions to the ground state of Kr⁸², $\approx 99.8\%$ of the Br^{82m} decays to the ground state of Br⁸², while 0.15% decays to the 0.78-MeV level and 0.024% to the 1.48-MeV level of Kr⁸².⁹

The reported experiments were quite time consuming and stretched out over many weeks. Before each new activation the 36-h Br⁸² activity induced during the previous activation of the 50-mg NH₄Br⁸¹ sample had to be permitted to decay to a negligible count rate.

DISCUSSION

The results of the above experiments can be summarized briefly as follows: A new activity belonging to the element bromine has been observed decaying with a half-life of approximately 6.05 min. It decays via a highly converted 46-keV internal transition ($\alpha = 382$) to its daughter Br⁸² which grows in as the former de-

⁸ M. E. Rose, *Internal Conversion Coefficients* (North-Holland Publishing Company, Amsterdam, 1958).

⁷ C. M. Davison, in *Beta and Gamma Ray Spectroscopy*, edited by K. Siegbahn (Interscience Publishers Inc., New York, 1955), Appendix I.

⁹ C. L. McGinnis, *Nuclear Data Sheets, Br⁸²⁻²*, compiled by K. Way *et al.* (Printing and Publishing Office, National Academy of Sciences-National Research Council, 1959), NCR 59-1-71.

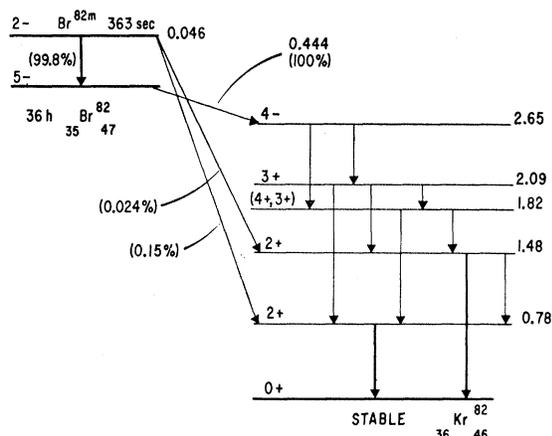


FIG. 10. Proposed decay scheme of the new activity Br^{82m} .

cays.¹⁰ The new activity emits gamma rays of 46 keV, and 0.78 and 1.48 MeV of which the first are not in coincidence with the latter two.

The fact that the growth curve of the 2.65-MeV peak of Fig. 3 indicates a uniform growth and no initial decay, proves the absence of a direct beta transition of Br^{82m} to the 2.65-MeV level.

The proposed decay scheme for the new activity is given in Fig. 10. It indicates the highly converted 46-keV internal transition to the ground state of Br^{82} and two weaker beta branches decaying directly to the 0.78- and 1.48-MeV levels of Kr^{82} .

The predicted spin and parity assignment of the new Br^{82m} based on the nuclear shell model is either $(2-)$ or $1(+)$.

In the bromine isotopes the odd proton is in a $p_{3/2}$ state.

The $2p_{1/2}$ and $1g_{9/2}$ levels for the odd neutrons of the unstable bromine isotopes are rather close in energy values and compete for the ground-state configurations.¹¹ They thus constitute close-lying energy levels

¹⁰ The existence of the new isomer as well as some of the decay properties reported here are in substantial agreement with the results of J. F. Emery, who presented his findings also at the meeting of the American Chemical Society on 1 September 1964, in Chicago, Illinois.

¹¹ M. Goldhaber and R. D. Hill, *Rev. Mod. Phys.* **24**, 179 (1952).

of large spin differences, a prerequisite for the existence of isomeric states. The $(g_{9/2})^{3,5,7}_{7/2}$ configurations constitute a rather stable anomalous coupling of several neutrons in $g_{9/2}$ orbits to a low-lying state of spin $\frac{7}{2}$ and even parity.¹

For ${}_{35}\text{Br}^{82}$ we thus have a proton configuration $(p_{3/2})^3$ with spin $\frac{3}{2}$ and odd parity and the neutron configurations: $(p_{1/2})^2(g_{9/2})^7_{7/2}$ with spin $\frac{7}{2}$ and even parity, or $(p_{1/2})^1(g_{9/2})^8$ with spin contribution $\frac{1}{2}$ and odd parity. The spins of the protons and neutrons in the first configuration add, according to Nordheim's weak rule,¹² to form the lower lying $5(-)$ which constitutes the ground state of Br^{82} .¹³ A higher lying state can be formed by the same proton and neutron configurations, when the respective spins add to a minimum total angular momentum in a $2(-)$ state. From the internal conversion coefficient of the 46-keV radiation ($\alpha=382$), and the fact that the ground state is $5(-)$, it is possible to show that in Br^{82m} the neutrons are indeed in this configuration resulting in a $2(-)$ state for Br^{82m} .

In the second possible arrangement the resulting states would be either $1(+)$ or $2(+)$, with the $1(+)$ state being the lower one according to Nordheim's strong rule.¹² For an assignment of Br^{82m} to this $1(+)$ state the α of the resulting $M4$ transition to the ground state would have to have been ~ 4400 instead of the 382 found.⁸

The fact that the Br^{82m} is formed primarily during the thermal-neutron activation of Br^{81} may also be explained from spin considerations. In thermal-neutron capture the spin of the compound nucleus differs from that of the target nucleus by $\frac{1}{2}$ and has the same parity. For the case of Br^{81} , which has a $\frac{3}{2}(-)$ ground state, the excited compound nucleus will be in a $1(-)$ or $2(-)$ state. The de-excitation of these states via the highly permitted dipole transitions to the $1(+)$ state and from there to the $2(-)$ level of Br^{82m} , or directly to the $2(-)$ level, are more favored than the $E4$ or $M3$ transition to the $5(-)$ ground state or their equivalent cascades.

¹² L. A. Nordheim, *Rev. Mod. Phys.* **23**, 322 (1951).

¹³ H. L. Garvin, T. M. Green, and E. Lipworth, *Bull. Am. Phys. Soc.* **2**, 344 (1957); and H. L. Garvin, T. M. Green, E. Lipworth, and W. A. Nierenberg, *Phys. Rev.* **116**, 393 (1959)