Decay of 6.3-Min Br^{78}†

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The nuclide 6.3-min Br^{78} has been made by the reactions (γ,n), $(n,2n)$, (p,n), $(d,2n)$, and (α,n), and its decay properties have been investigated by positron decay-curve analysis, by application of a standard chemical isomer-separation procedure, by searching for conversion electrons, and by studying the gamma-ray and positron-gamma-coincidence spectra. The early portion of the positron decay curve exhibited a single 6.25±0.2-min component, and no active daughter of this species was chemically separable from active CBr_4. Conversion electrons were not found, and soft gamma rays were shown to be absent. There are 12-kev x rays, of intensity about 0.05 relative to the positrons and therefore presumed to be K x rays of Se resulting from electron capture. These results show that 6.3-min Br^{78} has no daughter isomer and probably no >10-sec parent isomer. There is a 615-kev gamma ray, in coincidence with positrons, and of intensity 0.139 that of all positrons, representing decay of Br^{78} to Se^{78} in the 615-kev 2+ state. However, no evidence for decay to Se^{78} in the 1.32-Mev state could be found. From these data it was deduced that 6.3-min Br^{78} decays 81% by positron emission and 6% by electron capture to ground-state Se^{78}, 11% by positron emission and 2% by electron capture to Se^{78} in the 615-kev state, and <1% to Se^{78} in the 1.32-Mev state. The disintegrations of Br^{78} to Se^{78} in the ground state and 615-kev state have log ft values of 4.8 and 5.2, respectively, indicating that the spin of ground-state Br^{78} is 1, with even parity. The absence of isomerism is discussed in terms of the locations of expected energy levels, with reference to the known locations of these levels in Br^{80}.

INTRODUCTION

SINCE the first characterization[1] of Br^{78} as a nuclide emitting 2.3-Mev positrons with a half-period of 6.4 min, there have been reports of conversion electrons[2] and Br K_α x rays[3] emitted in its decay. On the basis of these reports, and in analogy with the known decay properties of Br^{80}, a decay scheme for Br^{78} has been proposed by Way *et al.*[4] This decay scheme postulates that the 6.4-min species is an isomer of spin 5−, decaying via a 108-kev ($M3$)−49-kev ($E1$) cascade to a <6-min ground state of spin 1+, which in turn emits a 2.2-Mev positron to Se^{78} in the ground state. The proposal is supported by the calculation[4] that the half-period for a 100-kev $M3$ transition is 8 min based on the 4.5-hr 49-kev transition in Br^{80}. The ground-state isomer in this decay scheme would be expected to have a half-period of at least 1 min.

The present study was made in an effort to clarify the nature of the decay process. It was found that the ground state of Br^{78} is the 6.4-min species discovered by Snell,[1] a conclusion which has been reached independently by Goodman and Schardt.[5] This species decays 87% to ground-state Se^{78} and 13% to Se^{78} in the 615-kev level, and the spin appears to be 1+. The conversion electrons[2] and x rays[3] ascribed to Br^{78m} are not found in the decay of Br^{78}, and they are undoubtedly associated with the recently discovered[6] 4.2-min Br^{77m}. It seems quite probable that the expected 5− isomer is the newly found 120-μsec species,[5,7] and it is postulated that its short half-period is due to a 3+ level intervening below the 5− level.

EXPERIMENTAL AND RESULTS

I. Decay Curve Experiments

If Br^{78} should exhibit isomerism, with an upper state of disintegration constant λ_1 (corresponding to 6.4-min half-period) decaying in fraction p_1 by positron emission and in fraction q_1 by isomeric transition to a short-lived lower state, the positron activity from the quantity A_1^0 produced in a short bombardment would be:

$$A_1(\beta^+)=p_1A_1^0e^{-\lambda_1 t}. \quad (1)$$

If the lower state should decay in fraction p_2 by positron emission, the positron activity from the quantity A_2^0 produced in the one short bombardment plus that growing from the upper isomer would be:

$$A_2(\beta^+)=A_2^0p_2\,e^{-\lambda_2 t}+\frac{\lambda_2p_2q_1A_1^0}{\lambda_2-\lambda_1}(e^{-\lambda_1 t}-e^{-\lambda_2 t}). \quad (2)$$

The activity of the lower state would in time come to equilibrium with the activity of the upper state to give the asymptotic positron decay rate

$$A_2(\beta^+)_{\text{asympt.}}=\frac{\lambda_2p_2q_1A_1^0}{\lambda_2-\lambda_1}e^{-\lambda_1 t}. \quad (3)$$

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[1] A. H. Snell, Phys. Rev. **52**, 1007 (1937).

[2] G. E. Valley and R. L. McCreary, Phys. Rev. **56**, 863 (1939).

[3] P. Marmier and P. Preiswerk (unpublished); described by P. Stähelin and P. Preiswerk, Nuovo cimento **10**, 1235 (1953).

[4] *Nuclear Level Schemes, A=40−A=92*, compiled by K. Way, R. W. King, C. L. McGinnis, and R. van Lieshout, Atomic Energy Commission Report TID-5300 (U. S. Government Printing Office, Washington, D. C., 1955).

[5] A. Goodman and A. W. Schardt (private communication). Also, from their measurement of the threshold for the $Se^{78}(p,n)Br^{78}$ reaction, one deduces a positron end point of 2.57±0.01 Mev for the main decay branch in Br^{78}, and we have used this figure in our decay scheme (Fig. 3) and in our calculations.

[6] A. Goodman and A. W. Schardt, Bull. Am. Phys. Soc. 4, 56 (1959).

[7] R. B. Duffield and S. H. Vegors, Jr., Phys. Rev. **112**, 1958 (1958).

The difference $\Delta(\beta^+)$ between the observed curve, which should be the sum of Eqs. (1) and (2), and the asymptotic curve, which should be the sum of Eqs. (1) and (3), is:

$$\Delta(\beta^+)=\left(A_2{}^0p_2-\frac{\lambda_2p_2q_1A_1{}^0}{\lambda_2-\lambda_1}\right)e^{-\lambda_2t}. \quad (4)$$

The difference $\Delta(\beta^+)$ of the decay curve from a simple exponential decay of 6.4-min half-period should then be a positive exponential if $A_2{}^0>\lambda_2q_1A_1{}^0/(\lambda_2-\lambda_1)$, and a negative one (growth of activity) if the reverse inequality should hold.

By using various kinds of bombarding particles at various energies and for various lengths of time, one should be able to find a set of conditions such that $\Delta(\beta^+)$ is an observable positive or negative contribution, and thus determine λ_2. For equal cross sections for forming Br^{78m} and Br^{78} and for short bombardments, $A_2{}^0/A_1{}^0$ would be equal to λ_2/λ_1. It can be said that if λ_2 should be, say, $5\lambda_1$, the ratio of initial $\Delta(\beta^+)$ to the asymptotic activities of Eq. (3) extrapolated to zero time would be 3 for equal cross sections and unit values for p_2 and q_1.

The Br^{78} was produced by the following reactions: (1) $Br^{79}(\gamma,n)Br^{78}$; (2) $Br^{79}(n,2n)Br^{78}$; (3) $Se^{78}(p,n)Br^{78}$; (4) $Se^{78}(d,2n)Br^{78}$; and (5) $As^{75}(\alpha,n)Br^{78}$. Bombardment conditions for these experiments were, respectively, as follows:

(1) CBr_4 target, 15-sec and 1-min irradiations with 17.0-Mev and 15.3-Mev electrons at the MIT Linear Accelerator;

(2) CBr_4 target, 30-sec irradiation with neutrons from reaction of 15-Mev deuterons with Be at the MIT Cyclotron;

(3) Se target, 1- to 7-sec irradiations with 6.4-Mev protons;

(4) Se target, 1- and 5-sec irradiations with 15-Mev deuterons; and

(5) As target, 2- and 30-sec irradiations with 10-Mev alpha particles, and a 30-sec irradiation with 8.9-Mev alpha particles.

The alpha particles were degraded from 30 Mev to the desired energies[8] by means of foils of Dural and Ta, the latter being used to prevent contamination of the target by 2.55-min P^{30} formed by the $Al^{27}(\alpha,n)P^{30}$ reaction.

Three alternative arrangements were employed for selectively counting the positrons:

(1) A 3 in.×3 in. or 2 in.×2 in. NaI(Tl) crystal for detecting the annihilation radiation, a single-channel analyzer with the baseline set at 511 kev, and associated equipment;

(2) Two 2 in.×2 in. NaI(Tl) crystals at 180° relative to the source, two single-channel analyzers set at 511 kev, a coincidence circuit, and a motorized tape-punch readout system for recording the coincidence rates; and

(3) A gas-flow proportional counter.

Counting of electron-irradiated CBr_4 began about 10 sec after bombardment; counting of other samples began 50 to 110 sec after bombardment.

The data obtained in all cases could be fitted by a single exponential of 6.3±0.2-min half-period for 4 or more half-periods (up to 12 half-periods in the case of activity produced by alpha bombardment of As). Figure 1 shows a treatment of the coincidence counting data for annihilation radiations on two runs for the reaction $Br^{79}(\gamma,n)Br^{78}$. No evidence is present for growth or short-lived decay. It is felt that if 6.3-min Br^{78} decayed to a short-lived daughter isomer of half-period >10 sec, this would have been detected by such experiments.

The results of the (γ,n) experiments also exclude the possibility of formation, with equal cross section, of a short-lived isomer of half-period of 5 sec or more decaying to the 6.3-min Br^{78}. The upper limit on the cross section for the formation of such an isomer falls inversely with the half-period assumed for it.

From the best of the $As^{75}(\alpha,n)Br^{78}$ and $Br^{79}(\gamma,n)Br^{78}$ experiments, a half-period of 6.25±0.2 min was determined for Br^{78}.

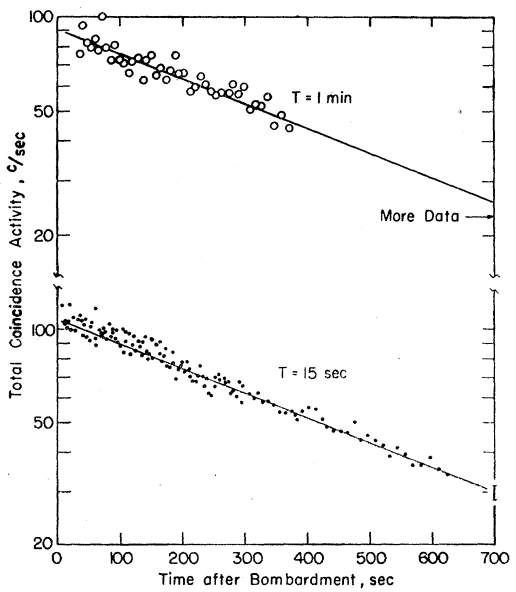

FIG. 1. Positron decay of CBr_4 irradiated with 15.3-Mev electrons for 1 min (top curve) and with 17.0-Mev electrons for 15 sec (bottom curve). Drawn lines are for 6.4-min half-period. There is no evidence for a $\Delta(\beta^+)$ effect.

[8] W. A. Aron, and B. G. Hoffman, *Range-Energy Curves, Second Revision, 1949*, Atomic Energy Commission Report AECU-663 (Technical Information Service, Oak Ridge, Tennessee, May 28, 1951),

II. Chemical Separation of Isomers

The next set of studies involved efforts to extract chemically any Br^{78} isomer that might be formed by isomeric transition of 6.3-min Br^{78}. The chemical separation of the lower-state isomer depends on the rupture of covalent bonds as a consequence of internal conversion.[9,10] The chemical procedure is based on those of DeVault and Libby,[10] using the Br^{78} retained in chemical combination as, say, CBr_3Br^{78}, in solid CBr_4 samples after irradiation with fast neutrons, the Br^{78} having been produced by the reaction $Br^{79}(n,2n)Br^{78}$. After the bombardment, the active CBr_4 is dissolved in pentane, and the bromine (Br^{78}, Br^{80}, and Br^{82}) which has not been chemically retained is removed by extraction with aqueous bisulfite solution, using a small amount of Br_2 carrier. The Br^{78} daughter isomer, if any, then may be extracted by bisulfite after allowing a short period for growth in the presence of a trace of Br_2.

About 5 g CBr_4 was irradiated for 60–70 sec with fast neutrons from the (Be+d) reaction (about 40 μa of 15-Mev deuterons). The target was then dissolved in 30 ml pentane and about 2 drops Br_2 added. This solution was shaken with 15 ml aqueous solution of 0.1M $NaHSO_3$ and 0.6M $NaHCO_3$; more Br_2 was added and the extraction was repeated. Finally, the organic solution was washed with 15 ml water containing a drop or two of Br_2. The preparation was then permitted to stand for 3.8–4.0 min in order to allow time for the growth of any possible ground-state Br^{78}. Two or three drops of Br_2 were added and the solution was shaken with 15 ml $NaHSO_3$-$NaHCO_3$ solution. The aqueous layer was drawn off rapidly and counted immediately (about 25 sec after the separation). The counting arrangement incorporated a 2 in.$\times$2 in. NaI(Tl) crystal with a single-channel analyzer set for 511 kev in order to count selectively annihilation radiation of positrons from ground-state Br^{78}.

The activity observed in the extract was chiefly 6.3-min Br^{78}, in the amount (a few percent of the total activity) to be expected, on the basis of exploratory experiments, from contamination. The organic layer exhibited the same components as the aqueous layer, in about the same relative amounts, showing that no observable enrichment in any species had been achieved by the separation.

The effectiveness of this isomer separation was tested on the Br^{80} isomeric pair. It was found that 35–40% of the 18-min Br^{80} grown in from 4.5-hr Br^{80m} after the clean-up operation was extracted. The 18-min half-period persisted in the aqueous extract for about 3 half-periods. Assuming the same chemical separation efficiency in the Br^{78} experiments, the activity of 6.3-min Br^{78} in the organic layer in these experiments was such that a $\geq$15-sec Br^{78} daughter of 6.3-min Br^{78} would have been detected.

III. Conversion Electrons

Experiments were designed to detect the 95.5-kev conversion electrons reported by Valley and McCreary[2] and interpreted by them to be associated with a 108-kev isomeric transition in the decay of 6.3-min Br^{78}. The Br^{78} activity was produced by the reaction $As^{75}(\alpha,n)Br^{78}$, by bombardment of As metal with alpha particles of about 10 Mev. The target was dissolved in hot concentrated HNO_3 and the Br activity was isolated by a chemical procedure similar to that employed by Brady and Campbell[11] for separating Br out of the fission products. This procedure involved addition of carrier Br^-, oxidation to Br_2 in the aqueous phase by means of $KMnO_4$, extraction with CCl_4, then reduction and extraction with aqueous $NaHSO_3$ solution, from which AgBr was then precipitated. The thin AgBr source prepared in this way contained substantial activity despite losses incurred in dissolving the target. The activity decayed with the 6.3-min Br^{78} half-period for the duration of the experiments.

The AgBr was pressed directly onto the surface of a disk of Pilot B scintillation plastic (Pilot Chemicals, Incorporated, Watertown, Massachusetts) 0.3 cm thick$\times$1.9 cm diameter. The detector, light pipe, and phototube cathode were then covered with a conical cap of Dural foil which acted as a light seal and reflector; this made it possible to avoid having material between the source and the detector.

Conversion-electron spectra were obtained with a 256-channel analyzer[12] (Radiation Counter Laboratories, Incorporated, Skokie, Illinois). No conversion-electron peak was seen. Sources of 4.5-hr Ru^{105} studied by the same technique showed plainly the 107-kev conversion electron[13,14] ($\alpha\approx3$, $\alpha_K/\alpha_L\approx1.5$) from the 130-kev isomeric transition of the daughter 42-sec Rh^{105m}, even in the presence of the 1.15-Mev betas of Ru^{105}. From this, it was estimated that we must have $\alpha_K<1$ for any possible isomeric transition of 6.3-min Br^{78}, an unlikely situation.

IV. X Rays and Gamma Rays

For the experiments on x rays and gamma rays, the NaI(Tl) detector was located inside a Cu-lined thick Pb shield, 17½ in.$\times$19½ in.$\times$22 in. inside dimensions, and a 1.0-cm Be absorber was located between source

[9] E. Segrè, R. S. Halford, and G. T. Seaborg, Phys. Rev. **55**, 321 (1939).

[10] D. DeVault and W. F. Libby, Phys. Rev. **55**, 322 (1939); **58**, 688 (1940); J. Am. Chem. Soc. **63**, 3216 (1941).

[11] E. L. Brady and G. W. Campbell, *Radiochemical Studies: The Fission Products*, edited by C. D. Coryell and N. Sugarman (McGraw-Hill Book Company, Inc., New York, 1951), Paper No. 231, National Nuclear Energy Series, Plutonium Project Record, Div. IV, Vol. 9.

[12] Provided by the Office of Scientific Research, U. S. Air Force, to the Laboratory for Nuclear Science.

[13] P. Axel and R. B. Duffield, private communication to the authors of reference 14.

[14] D. Strominger, J. M. Hollander, and G. T. Seaborg, Revs. Modern Phys. **30**, 585 (1958).

and detector. For this as well as all other work in which phototubes were employed, μ-metal magnetic shields were used. The spectra were obtained with the 256-channel analyzer[12] and decomposed into the component gamma rays after correction for Bremsstrahlung and annihilation in flight, by fitting previously determined single gamma-ray spectra, taken under identical conditions, to the resultant curve, starting at the high-energy end.

Metallic As was bombarded with 10-Mev alpha particles and the Br^{78} activity was separated as AgBr by the procedure described above.[11] The precipitate was mounted on a 1.88-mg/cm^2 plastic window and counted with a $\frac{1}{2}$ in. thick$\times 1\frac{1}{2}$ in. diameter NaI(Tl) crystal and DuMont 6292 phototube (resolution about 39% for the composite K x rays of Ba). The spectra showed an x ray of energy about 12 kev, half-period about 6 min, and intensity about 0.025 ± 0.002 that of the 511-kev positron annihilation radiation. Taking the K-shell fluorescence yield for $Z\approx 35$ to be[15] about 0.60, this means that the intensity of Br and/or Se K capture plus conversion is about 0.083 ± 0.007 relative to the total positron emission. It is not possible to determine, with the equipment used for this experiment, whether the x rays are those of Br or Se. However, the K/β^+ ratio for Br^{78} has been estimated in connection with work reported later in this section, and the expected ratio is about 0.075 ± 0.01. Thus, the x rays that were seen can all be attributed to Se resulting from electron capture.

At the same time, the low-energy (<200 kev) region of the gamma-ray spectrum was examined in an effort to detect the 47-kev and 108-kev gamma rays which would be expected on the basis of the conversion-electron work of Valley and McCreary.[2] No gamma rays were found; with the help of experiments with standard sources, it was estimated that 47-kev and 108-kev gamma rays would have been detected if they were emitted in more than 0.5% and 0.7%, respectively, of the disintegrations of 6.3-min Br^{78}.

As the energy of the alpha particles bombarding the target was increased to 16–19 Mev and higher, the induced activity of the As targets began to show a 110-kev gamma ray of half-period about 3 or 4 min. The alpha bombarding energy at which this new activity appears is about that expected for the $As^{75}(\alpha,2n)Br^{77,77m}$ reaction. The same gamma ray was produced by bombardment of Se with 6.4-Mev protons, and therefore it presumably is associated with the decay of the recently reported[6] 4.2-min Br^{77m}, formed from Se by the reaction $Se^{77}(p,n)Br^{77m}$. Since the 6.3-min Br^{78} activities studied by Valley and McCreary[2] and by Marmier and Preiswerk[3] were obtained by proton bombardment of Se, the conversion electrons[2] and x rays[3] observed by them and attributed to 6.3-min Br^{78} were undoubtedly from 4.2-min Br^{77m}.

[15] C. D. Broyles, D. A. Thomas, and S. K. Haynes, Phys. Rev. **89**, 715 (1953).

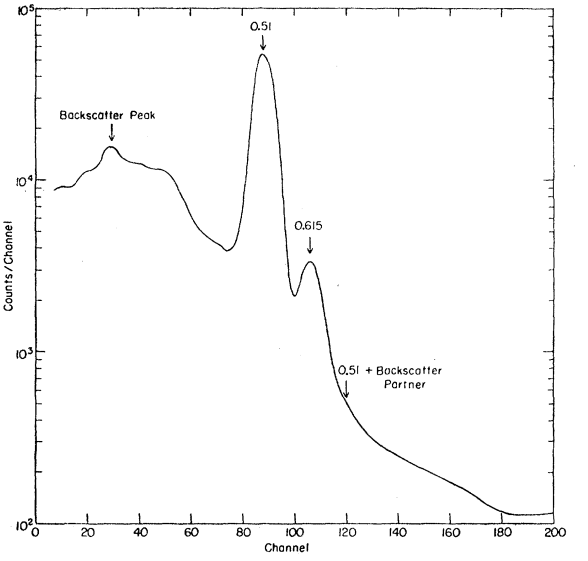

FIG. 2. Gamma-ray spectrum of 6.3-min Br^{78}. Activity produced by bombardment of As with 10-Mev alpha particles. Source 9.3 cm from window of 3 in.$\times$3 in. NaI(Tl) crystal and surrounded by Plexiglas (above) and Be (below) absorbers. Energies indicated are in Mev.

The higher-energy region (>100 kev) of the gamma-ray spectrum was examined by means of a 3 in.$\times$3 in. NaI(Tl) crystal mounted on a DuMont 6363 phototube. The resolution of this assembly was 8.0% for the 661-kev gamma ray of Cs^{137}. Sources were either Se bombarded with 6.4-Mev protons, or As bombarded with 10-, 16-, 19-, and 22-Mev alpha particles. In all cases the only gamma rays observed which were associated with 6.3-min Br^{78} were 511 kev (annihilation radiation) and 615 kev; As bombarded with 10-Mev alpha particles, since it produced an essentially pure 6.3-min Br^{78} activity, gave only these two gamma rays. With the source close to the crystal, a sum peak at 1.13 Mev (511 kev plus 615 kev) was observed, indicating that the 615-kev gamma ray has positrons in coincidence with it. This gamma ray therefore represents the transition from the first excited state[16] of Se^{78}, a 2+ state at 615 kev, to the ground (0+) state.

High-energy spectra taken for analysis were obtained with the source completely surrounded by enough low-Z absorber to stop all the positrons, thereby assuring positron annihilation essentially at the location of the source, so that accurate gamma-ray intensities relative to the positron could be obtained. Such a spectrum is shown in Fig. 2; analysis of this spectrum yielded the ratio 0.139 for intensity of the 615-kev gamma rays to the intensity of all positrons. Since conversion of the $E2$ 615-kev gamma ray[16] may be neglected, this is equivalent to saying that

$$a/b=0.139, \tag{5}$$

[16] G. M. Temmer and N. P. Heydenburg, Phys. Rev. **104**, 967 (1956).

where a=the total decays, both positron-emission and electron capture, to Se^{78} in the 615-kev state, and b=the total decays by positron emission only, to Se^{78} in all accessible states. Zweifel's[17,18] calculated K/β^+ ratios for allowed and first-forbidden transitions, and L/K capture ratios calculated by Brysk and Rose[18,19] were used to calculate the probability for $(K+L)$-electron capture relative to that for positron emission in decay of Br^{78} to Se^{78} in the lowest-lying states, with the following results: to ground state, 0.07; to 615-kev state, 0.16; and to 1.32-Mev[20] state, 0.70. With these figures and the measured gamma-ray intensities it was calculated that 0.129 of all disintegrations of 6.3-min Br^{78} go to Se^{78} in the 615-kev state. From the same information it was calculated that 0.075 ± 0.01 of all Br^{78} disintegrations should take place via electron capture.

V. Gamma-Gamma Coincidences

Since the gamma-ray spectra of 6.3-min Br^{78} did not show the expected 700-kev and 1.32-Mev gamma rays[20] from Se^{78} in the 1.32-Mev state, an attempt was made to detect them by studying the gamma-ray spectrum in coincidence with the positron annihilation radiation. This was done by means of a coincidence sorter,[21] which shows simultaneously, on an oscilloscope, all coincidences involved in the decay of a given source, and shows the approximate relative intensities of these coincidences. The two detectors were 3 in.$\times$3 in. NaI(Tl) crystals positioned at a right angle from the source, with a Pb shield between them. A time-exposure photograph of the presentation provided a permanent record of the coincidences accumulated over any chosen period of time. An output of the coincidence unit also was fed to a scaler which registered the total number of coincidences over the chosen time interval. The activity was produced by bombardment of As with 9.2-Mev alpha particles, and spectra were taken, adding to the source as time elapsed in order to keep the activity high. A picture exposed for 80 000 coincidence events showed only coincidences between the 511-kev positron annihilation radiation and the 615-kev gamma ray. This, together with experiments with various gamma-ray standards, sets an upper limit of 0.01 on the fraction of Br^{78} disintegrations that go to Se^{78} in the 1.32-Mev state.

CONCLUSIONS

The positron decay-curve analyses and efforts at chemical isomer separation have set an upper limit of about 10 sec on the half-period of any Br^{78} daughter of 6.3-min Br^{78}, much shorter than would be expected for a 2.6-Mev allowed beta transition for $Z=35$. The absence of conversion electrons and the low intensity of x rays on the one hand, and the absence of soft gamma rays on the other, can only be explained by concluding that there is no isomeric transition in the decay of 6.3-min Br^{78}. These results constitute ample evidence that the 6.3-min species is the ground state of Br^{78}. Moreover it appears that this species has no >10-sec parent isomer.

One may ask why Br^{78} does not exhibit isomerism like that of Br^{80}, for there is good basis for expecting that the two nuclei should have similar properties.[22,23] We offer the following explanation: Of the four low-lying states predicted by the shell model[22] and by Nordheim's rules[23] for Br^{80}, namely $p_{3/2}p_{1/2}(1+)$, $f_{5/2}g_{9/2}(2-)$, $p_{3/2}g_{9/2}(\leq 6-$, probably $5-$; see pp. 84 and 85 of reference 22), and $f_{5/2}p_{1/2}(\leq 3+)$, only the $f_{5/2}p_{1/2}$ $(\leq 3+)$ cannot be said to have been observed.[24] The fact that the $5-$ state of Br^{80} has a half-period of 4.5 hr[25,26] indicates that in Br^{80} the $f_{5/2}p_{1/2}(\leq 3+)$ state lies above the $5-$ state. We postulate that in Br^{78} the $f_{5/2}p_{1/2}(\leq 3+)$ state lies below the $5-$ state, thus allowing Br^{78} nuclei in the $5-$ state to undergo a rapid $M2$ or $E3$ transition. This idea is reinforced by recent work by Duffield and Vegors[7] and Goodman and Schardt.[5] By bombarding Br with gamma rays, Duffield and Vegors[7] produced a 127-μsec Br activity, tentatively concluded from threshold measurements to be an isomer of Br^{78}, which decays by emission of a 149-kev gamma ray. On the basis of the half-period and energy, they suggest that the transition is $M2$. The only way an $M2$ transition in Br^{78} can be accommodated within the framework of the four predicted[23] low-lying levels is to postulate that the $f_{5/2}p_{1/2}(\leq 3+)$ level has a $3+$ configuration and that in Br^{78} it lies 149 kev below the $5-$ level. Goodman and Schardt[5] also have reported this isomer, of half-period 115 ± 5 μsec, emitting 150-kev and 32-kev gamma rays, and have established that the species is Br^{78}. Thus one is led to speculate that the 120-μsec isomer of Br^{78} is the expected $5-$ isomer, lying about 150 kev above a $3+$ level; the 32-kev transition might then be an $E1$ transition from the $3+$ state to the $2-$ state or from the $2-$ state to the $1+$ ground state, or it might be an $E2$ transition directly from the $3+$ state to the ground state.[18] A $3-$ or $4\pm$ state could have been invoked

[17] P. F. Zweifel, Phys. Rev. **107**, 329 (1957).
[18] A. H. Wapstra, G. J. Nijgh, and R. van Lieshout, *Nuclear Spectroscopy Tables* (Interscience Publishers, Inc., New York, 1959).
[19] H. Brysk and M. E. Rose, U. S. Atomic Energy Commission Report ORNL-1830, 1955 (unpublished).
[20] B. L. Schram, H. L. Polak, W. Schoo, R. K. Girgis, and R. van Lieshout, 1957 (unpublished); reported in reference 14.
[21] L. Grodzins, Rev. Sci. Instr. **26**, 1208 (1955).
[22] M. G. Mayer and J. H. D. Jensen, *Elementary Theory of Nuclear Shell Structure* (John Wiley & Sons, Inc., New York, 1955).
[23] L. W. Nordheim, Revs. Modern Phys. **23**, 322 (1951).
[24] K. Way, F. Everling, G. H. Fuller, N. B. Gove, R. Levesque, J. B. Marion, C. L. McGinnis, and M. Yamada, *Nuclear Data Sheets* (National Academy of Sciences—National Research Council, Washington, D. C., 1958 ff).
[25] E. Lipworth, H. L. Garvin, and T. M. Green, Bull. Am. Phys. Soc. **4**, 11 (1959).
[26] T. M. Green, University of California Radiation Laboratory Report UCRL-8730, June, 1959 (unpublished).

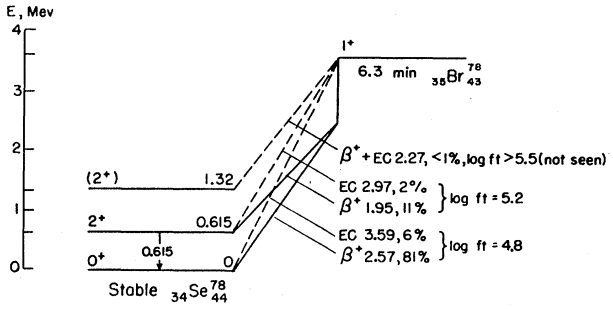

FIG. 3. Decay scheme of Br^{78}.

instead of a 3+ state in these arguments, but the data of Duffield and Vegors[7] and the predictions of the shell method[22,23] favor 3+.

In support of these speculations, Mayer[27] has pointed out the following: Se^{77} ($N=43$) has a ground-state spin[24,28] of $\frac{1}{2}$ (presumably $p_{1/2}$), and a state at 161 kev with a spin[24] of 7/2 [presumably $(g_{9/2}{}^5)_{7/2}$], whereas Se^{79} has a 7/2 ground state[24,29] [presumably $(g_{9/2}{}^7)_{7/2}$], and a spin $\frac{1}{2}$ state[24] at 96 kev. Therefore, imagining $Br^{78,80}$ as $Se^{77,79}$ plus a proton, a state with a $(g_{9/2}{}^{3,5,\text{or}7})_{7/2}$ neutron configuration might be expected to lie 257 kev higher in the case of Br^{78} than in Br^{80}, referred to some state with a $p_{1/2}$ neutron configuration. Similarly, Br^{79} is believed[24,30] to have a 5/2 state (presumably $f_{5/2}$), at 217 kev above the 3/2 (presumably $p_{3/2}$) ground state,[31] whereas in Br^{77} the $f_{5/2}$ state appears to be only 131 kev above the 3/2 ground state,[26] so that, imagining $Br^{78,80}$ as $Br^{77,79}$ plus a neutron, a state with a $f_{5/2}$ proton configuration might be expected to lie 86 kev lower in the case of Br^{78} than in Br^{80}, referred to some state with a $p_{3/2}$ proton configuration. Thus, relative to the $p_{3/2}p_{1/2}(1+)$ ground state, the $p_{3/2}g_{9/2}(5-)$ state[25,26,32] at 84 kev[33] in Br^{80} would lie 257 kev higher in Br^{78}; the $f_{5/2}p_{1/2}(3+)$ state would lie 86 kev lower in Br^{78} than in Br^{80}; the $f_{5/2}g_{9/2}(2-)$ state[32] at 36.3 kev[33] in Br^{80} would lie 171 kev higher in Br^{78}; and the separation between the $f_{5/2}g_{9/2}(2-)$ and $p_{3/2}g_{9/2}(5-)$ states would be 86 kev larger in Br^{78} than in Br^{80}. Of course the simple picture just drawn is quite crude, but it does serve to make plausible the idea that a 3+ state could lie well above the 5− state in Br^{80} and yet lie below the 5− state in Br^{78}, perhaps even below the 2− state.

It is not necessary to postulate the intervention of a 3+ state in Br^{78} if one makes the hypothesis that the separation between the 5− and 2− states is some 250–350 kev or more, which is perhaps a greater separation than one might expect. The half-period of the 5− isomer might then be 5 sec or less,[34,35] too short to have been detected by us. However, the data of Duffield and Vegors[7] and Goodman and Schardt[5] do not support this hypothesis.

Calculated log f values[36] and the branching ratios obtained in Secs. IV and V of the experimental work were used to determine log ft values for decay of 6.3-min Br^{78} to Se^{78} in the various levels: ground (0+) state, 4.8; 615-kev (2+) state, 5.2; and 1.32-Mev state, >5.5. This supports the 1+ assignment predicted[4] for the ground state of Br^{78}, and does not conflict with the 2+ assignment tentatively given[20] to the 1.32-Mev state of Se^{78}.

In accordance with the foregoing, the decay scheme shown in Fig. 3 is proposed.

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