PHYSICAL REVIEW C **74**, 027302 (2006)

Half-life of ^{120}Xe

A. A. Phillips,[1,*] C. Andreoiu,[1] G. C. Ball,[2] D. Bandyopadhyay,[1] J. A. Behr,[2] T. E. Chupp,[3] P. Finlay,[1] P. E. Garrett,[1] G. F. Grinyer,[1] G. Hackman,[2] M. E. Hayden,[4] B. Hyland,[1] S. R. Nuss-Warren,[3] M. R. Pearson,[2] M. A. Schumaker,[1] M. B. Smith,[2] C. E. Svensson,[1] E. R. Tardiff,[3] J. J. Valiente-Dobón,[1,†] and T. Warner[4]

[1]*Department of Physics, University of Guelph, Guelph, Ontario, Canada N1G 2W1*

[2]*TRIUMF, 4004 Wesbrook Mall, Vancouver, British Columbia, Canada V6T 2A3*

[3]*Focus Center, University of Michigan, Ann Arbor, Michigan 48109, USA*

[4]*Physics Department, Simon Fraser University, 8888 University Drive, Burnaby, British Columbia, Canada V5A 1S6*

(Received 19 June 2006; published 10 August 2006)

We have measured the half-life of ^{120}Xe using a high-purity germanium (HPGe) detector to monitor the 176, 178, and 762 keV γ rays from ^{120}Xe β^+ decay. The result, 46±0.6 min, differs significantly from the value 40±1 min reported by Andersson *et al*. [Ark. Fys. **28**, 37 (1964)]. We have also measured the half-lives of ^{120}Cs and ^{120}I to be 60±0.7 s and 82.1±0.6 min, respectively, both of which are consistent with previous measurements.

DOI: 10.1103/PhysRevC.74.027302 PACS number(s): 21.10.Tg, 27.60.+j

An atomic electric-dipole moment (EDM) measurement program using odd-*A* Rn isotopes to search for new CP-violating fundamental interactions is being planned at the TRIUMF Isotope Separation and Acceleration (ISAC) facility in Vancouver, Canada. The first step in the EDM search was to determine the efficiency of transferring a noble gas from a collection foil to a measurement cell. In anticipation of Rn beams from a new ISAC actinide production target, preliminary experiments were performed using the radioactive isotope ^{120}Xe to test the collection and transfer techniques. Experiments were performed by implanting a 30-keV ^{120}Cs beam in various stopper foils, after which the ^{120}Cs rapidly decayed to ^{120}Xe. The diffusion of ^{120}Xe was observed and characterized when the foil was heated [1], and the efficiency of ^{120}Xe gas transfer from the foil to the measurement cell [2] was determined via data obtained from HPGe detectors located at the foil and cell. During the analysis of data from these experiments, the accuracy of a previously reported measurement of the ^{120}Xe half-life was questioned. To address this, half-lives were extracted from data in a separate run of the experiment where a Zr stopper foil was not heated. A single HPGe detector observed the activity of the foil. The half-lives of ^{120}Cs and ^{120}I were also measured to provide a consistency check from the β^+-decay chain of ^{120}Cs → ^{120}Xe → ^{120}I → ^{120}Te (stable). Previous measurements of half-lives for these decay processes are summarized in Table I.

The experiments were performed using a CAMAC-based data-acquisition system to derive an energy and time stamp for each γ ray. An Ortec AD413A 8k ADC extracted the energies, whereas a precision 100-kHz Stanford Research Systems model DS335 synthesized function generator was used to determine the timing of γ-ray events relative to the start of the run. The raw data were binned in a 4096 × 4096 channel energy-time matrix, using 0.5 keV/ch on the energy axis and 5 s/ch on the time axis. Activity-time curves for each nuclide were created using gates on the ^{120}Cs 322-keV, ^{120}Xe 762-keV, and ^{120}I 560-, 641-, and 1523-keV γ rays. A wide gate on the 176- and 178-keV peaks was set to generate another independent decay curve for ^{120}Xe. The observed γ-ray energy spectrum, with the location of these gates indicated, is shown in Fig. 1. Background subtraction was performed only for the ^{120}Cs 322-keV activity-time curve by subtracting a scaled activity-time curve from gates on channels surrounding the peak. The scaling was set so that the background subtracted decay curve averaged to zero at long times. Before the decay curves were fit, rate-dependent corrections for deadtime and pileup were applied [9], typically amounting to ~5% and ~0.5% at the beginning of the time analysis region, respectively.

The rate-corrected data were fit using a Levenberg-Marquardt χ^2 minimization algorithm [10] to simultaneously deduce the half-lives of ^{120}Xe and ^{120}I. The χ^2 function was defined by a maximum likelihood approach using the Poisson distribution [11] for the ^{120}Xe and ^{120}I gates, whereas the Gaussian distribution was used for the ^{120}Cs gate because background subtraction was performed. The ^{120}Cs fit region was delayed by approximately 30 s after the beam was turned off and the fit function was defined as a single exponential. The ^{120}Xe and ^{120}I fit regions were delayed by 14 min from the time the beam was turned off (approximately 14 ^{120}Cs half-lives) to eliminate the need for a grow-in component ^{120}Xe curve; the contribution of the remaining ^{120}Cs (only ~0.006% of the collected ^{120}Cs) to the ^{120}Xe decay was negligible compared to the statistical uncertainty of the measurement. The ^{120}Xe and ^{120}I fit function was defined as the sum of two exponentials, characterizing the primary nuclide in a gate, and the background due to the other nuclei under the γ-ray peak. All of the ^{120}Xe and ^{120}I decay curves were fit simultaneously. Fits for each decay are shown in Fig. 2. The results of this work are shown in column 4 of Table I.

Systematic effects were examined by varying a number of parameters: (i) γ-ray energy gate width, (ii) removing data

*Electronic address: aphillip@physics.uoguelph.ca

†Present address: INFN, Laboratori Nazionali di Legnaro, I-35020, Legnaro, Italy.

TABLE I. β^+ decay chain for ^{120}Cs to stable ^{120}Te: ^{120}Cs is believed to have two states that undergo β^+ decay with similar lifetimes. ^{120}I is known to have an isomeric state.

β^+ decay	Dominant γ-ray energies (keV)	Previous $T_{1/2}$ measurements	$T_{1/2}$ from this work
$^{120}\mathrm{Cs} \rightarrow {}^{120}\mathrm{Xe}$	322 [3]	64 ± 3 s [3]	$\}$ 60.0 ± 0.7 s
$^{120m}\mathrm{Cs} \rightarrow {}^{120}\mathrm{Xe}$	322 [3]	57 ± 6 s [3]	
$^{120}\mathrm{Xe} \rightarrow {}^{120}\mathrm{I}$	176, 178, 762 [4]	40 ± 1 min [5]	46.0 ± 0.6 min
$^{120}\mathrm{I} \rightarrow {}^{120}\mathrm{Te}$	560 [6]	81.0 ± 0.6 min [7]	82.1 ± 0.6 min
$^{120m}\mathrm{I} \rightarrow {}^{120}\mathrm{Te}$	560, 615 [8]	53 ± 4 min [7]	Not observed

from the beginning of the decay curve, and (iii) removing data from the end of the decay curve. No significant changes in the half-lives of the nuclides were observed when the γ-ray gate width was changed. Eliminating data from the start and end of the decay curve likewise did not significantly influence the half-lives extracted for each nuclide.

Our ^{120}Cs half-life of 60.0±0.7 s agrees with the half-lives previously reported for both the ground and metastable

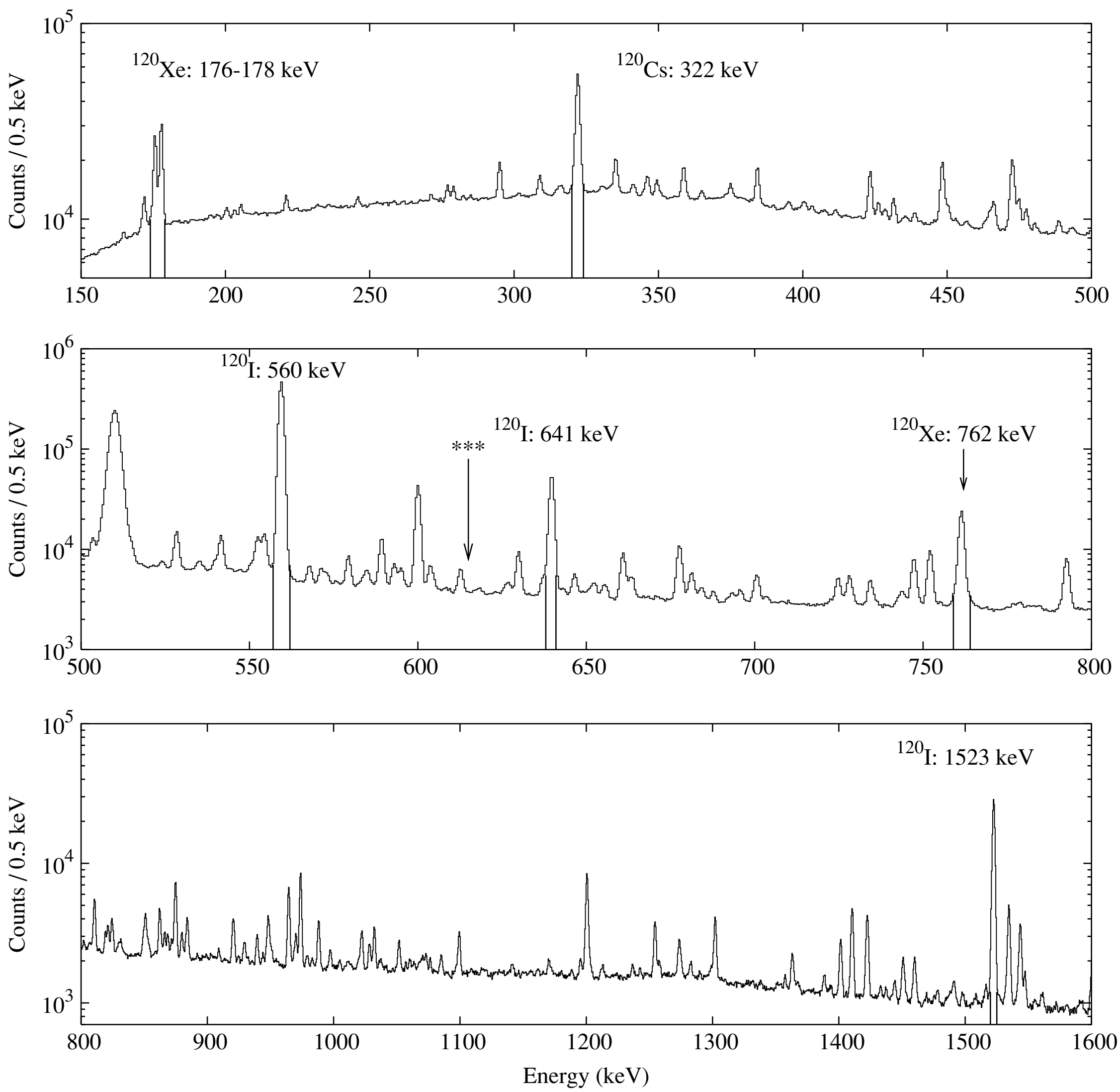

FIG. 1. The γ-ray energy spectrum from the half-life measurement run. Activity-decay curves were generated by gating on γ-ray energy peaks of 322 keV for ^{120}Cs; 176–178 keV and 762 keV for ^{120}Xe, and 560, 641, and 1523 keV for ^{120}I. The stars indicate the absence of a peak centered at 615 keV (∗∗∗), which suggests that the isomeric state of ^{120}I was not populated in our experiment.

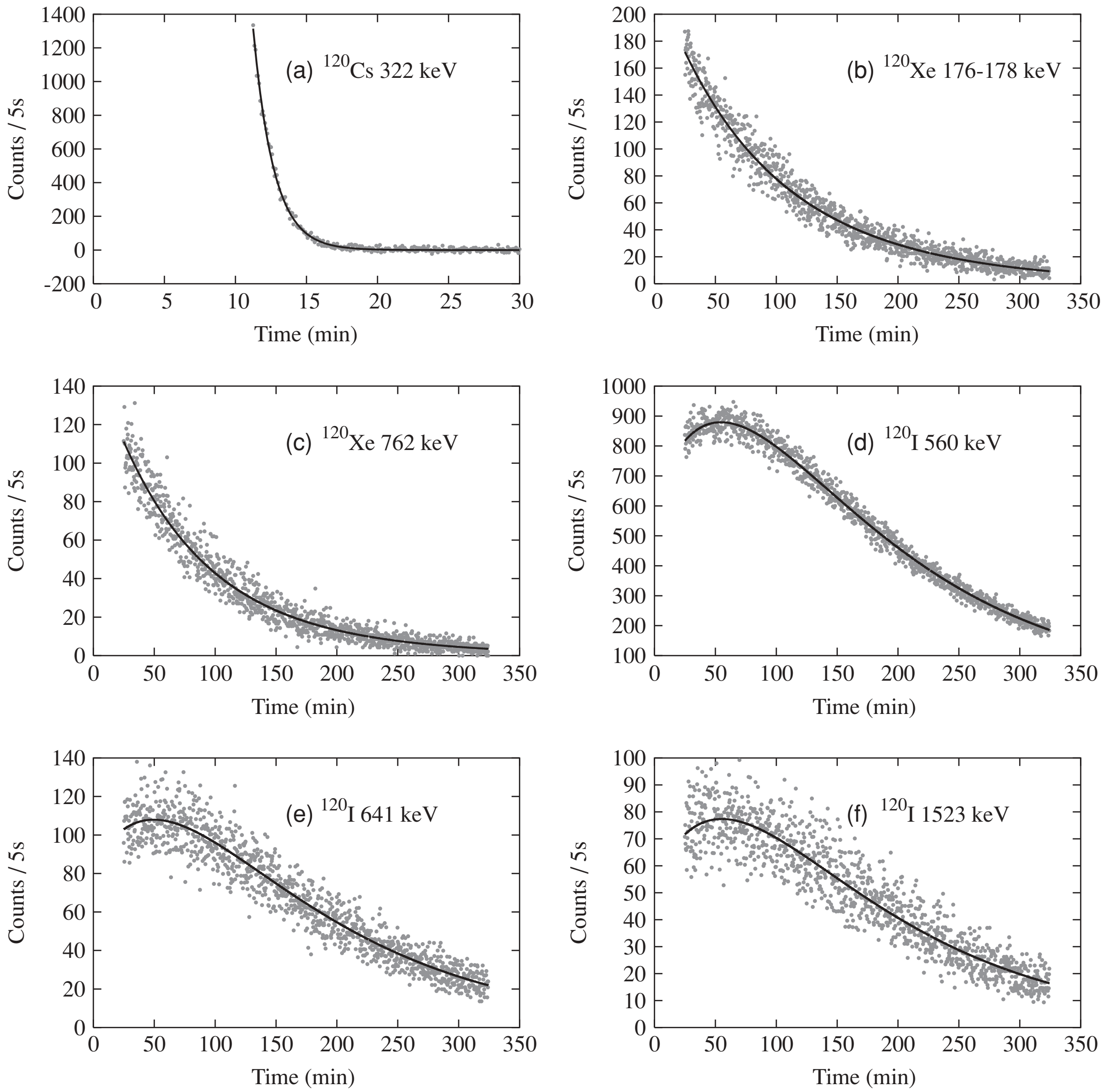

FIG. 2. Fits of activity decay data generated from (a) ^{120}Cs 322-keV, (b) ^{120}Xe 176- to 178-keV, (c) ^{120}Xe 762-keV, (d) ^{120}I 560-keV, (e) ^{120}I 641-keV, and (f) ^{120}I 1523-keV γ-ray peaks. The points represent the rate-corrected counts as a function of time in 5-s bins. The solid line represents the region over which the data were fit. The ^{120}Cs beam was turned off at $t \approx 10$ min. For display purposes, only every third data point is shown in panels (b) through (f). The best-fit half-lives are 60.0±0.7 s, 46.0±0.6 min, and 82.1±0.6 min for ^{120}Cs, ^{120}Xe, and ^{120}I, respectively.

states. It is possible that the ^{120}Cs beam was a mixture of these states. To compare our value for the ^{120}I half-life with previous reports, the particular state populated during our experiment had to be identified. When the isomeric state decays, a 615-keV γ ray is emitted [7,8]. As shown in Fig. 1, a peak at 615 keV was not observed in our γ-ray energy spectrum. Therefore, we conclude that the ^{120}Xe decay populated the ^{120}I ground state. The world average half-life of ^{120}I is 81.0±0.6 min (a value compiled in Ref. [7] from Refs. [6] and [12]). Our ^{120}I half-life of 82.1±0.6 min is in agreement with this world average.

However, the ^{120}Xe result we report here, 46.0±0.6 min, is approximately 6 min longer than the previously measured value [5], and the discrepancy is 5σ. It is unclear from Ref. [5] if their pioneering measurement, performed with a lower resolution NaI detector, could have been influenced by contaminating γ-ray transitions. It is likewise unclear if their experiment was influenced by diffusion of the radioactive ^{120}Xe gas on a time scale of several hours. Both effects might account for the shorter half-life reported in Ref. [5]. As discussed in Ref. [1], the diffusion of ^{120}Xe at room temperature was completely negligible during our half-life measurement. Furthermore, our longer ^{120}Xe half-life is accompanied by a half-life for ^{120}I that is consistent with other reports. Another previous measurement of 39.5±2.0 min for the ^{120}Xe half-life was reported [4]; however, the details for the measurement are not given so it is not possible to comment on the discrepancy. For these reasons, we favor the longer and more precise ^{120}Xe half-life of 46.0±0.6 min reported here.

We acknowledge J. Law (University of Guelph) and C. Pearson (TRIUMF) for discussions about data analysis. This work was partially supported by the Natural Sciences and Engineering Research Council of Canada and the United States National Science Foundation. TRIUMF receives federal funding through a contribution from the National Research Council of Canada. C.A. acknowledges the support offered by the Swedish Foundation for Higher Education and Research and the Swedish Research Council.

[1] T. Warner *et al*., Nucl. Instrum. Methods A **538**, 135 (2005).
[2] S. R. Nuss-Warren *et al*., Nucl. Instrum. Methods A **533**, 275 (2004).
[3] J. Genevey-Rivier, A. Charvet, G. Marguier, C. Richard-Serre, J. D'Auria, A. Huck, G. Klotz, A. Knipper, G. Walter (ISOLDE Collaboration), Nucl. Phys. **A283**, 45 (1977).
[4] F. Münnich, D. Lode, and H. Schrader, Nucl. Phys. **A224**, 437 (1974).
[5] G. Andersson, R. Rudstam, and G. Sörenson, Ark. Fys. **28**, 37 (1964).
[6] S. Gabrakov, Z. Zhelev, N. G. Zaitseva, I. Penev, and S. S. Sabirov, Bull. Acad. Sci. USSR, Phys. Ser. **34**, 1825 (1970).
[7] R. B. Firestone, *Table of Isotopes* (John Wiley & Sons, New York, 1996), 8th ed.
[8] P. Chowdhury, W. F. Piel Jr., and D. B. Fossan, Phys. Rev. C **25**, 813 (1982).
[9] V. T. Koslowsky, E. Hagberg, J. C. Hardy, G. Savard, H. Schmeing, K. S. Sharma, and X. J. Sun, Nucl. Instrum. Methods A **401**, 289 (1997).
[10] W. H. Press, S. A. Teukolsky, W. T. Vetterling, and B. P. Flannery, *Numerical Recipes in C: The Art of Scientific Computing* (Cambridge University Press, Cambridge, 1999), 2nd ed., p. 683.
[11] G. F. Grinyer *et al*., Phys. Rev. C **71**, 044309 (2005).
[12] J.-M. Lagrange, Ph.D. thesis, University of Paris, 1970.