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# The Half-Lives for $^{24}$Na, $^{72}$Ga and $^{140}$La*

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## Summary

THE HALF-LIVES of $^{24}$Na, $^{72}$Ga and $^{140}$La were determined by counting neutrons from D($\gamma$, n) and Be ($\gamma$, n) reactions. The radionuclide samples were encapsulated in aluminum shells to form the gamma-ray emitting core of spherical photoneutron sources. Half-lives were determined by unfolding the activation and decay of $^{56}$Mn in a manganese sulfate bath. Half-lives were determined to be 15.010 ± 0.028, 13.945 ± 0.005 and 40.232 ± 0.067 hr for $^{24}$Na, $^{72}$Ga and $^{140}$La, respectively. The value for $^{72}$Ga is 1% lower than previously published values.

## Introduction

PHOTONEUTRON sources have been used at the University of Michigan to measure the absolute fission cross-sections for $^{235}$U and $^{239}$Pu in the energy range of 0.1–1.0 MeV.[1,2] The neutron sources were calibrated using a manganese sulfate bath. The absolute source calibration also yielded values of the half-lives of the gamma-ray emitting isotopes used in the sources. Supplementary measurements of the primary isotope half-lives are reported here using the manganese bath as a neutron detector. This method avoids the usual requirement for high-purity samples, since one need only be concerned with gamma-ray emission above the photodisintegration threshold energies of deuterium (2.225 MeV) or beryllium (1.662 MeV).

## Experimental Method

The half-lives were determined by following the decay of photoneutron sources in a manganese bath system. The sources consist of sealed aluminium spheres packed with reagent grade $Ga_2O_3$, NaF or $La_2O_3$. Photoneutrons are produced by surrounding these gamma-ray emitting cores with interchangeable beryllium or deuterated polyethylene shells. Figure 1 shows the deuterated polyethylene shells and mold used to form them. The gamma-ray emitting core is also seen in this figure.

These sources were placed in the University of Michigan manganese bath system, which has been described previously.[1] The $^{56}$Mn activity, produced in the $^{55}$Mn(n, $\gamma$) $^{56}$Mn reaction, was followed over a three-day period. Data were recorded in 400 intervals throughout the bath activity build-up, saturation and decay following removal of the source. Residence time in the manganese bath was corrected to account for activation during transfer of the source to and from the bath within the experimental area.

The manganese activity was measured using a NaI crystal and a specially selected photomultiplier tube (gain being insensitive to count rate). Extremely stable, low-noise, counting electronics were used, and the gain of the system was checked periodically using a $^{60}$Co gamma-ray source. A background counting rate was determined prior to placing the source in the bath, but its contribution to the total count rate at saturation was negligible. The dead time of the system was determined by placing in the bath a californium source emitting $10^8$ neutrons/sec and allowing the manganese activity to saturate. The source was then removed and the decay of the manganese followed. As the decay proceeded, the dead-time effect lessened and from the counting data and an assumed value for the $^{56}$Mn half-life, the dead time of the system was readily obtained.

Several steps were taken to detect any perturbation from the true half-life due to the presence of impurities in the core. Bath runs were repeated and berylium and deuterium shells were interchanged for a given core to show that there was no measurable change in the half-life above statistics. A lithium-drifted germanium detector was used to monitor the gamma-ray spectrum above the photodisintegration threshold during each source residence period. Allowing 3 weeks for decay, a spectral analysis was performed again to detect long-lived impurities. Short-lived impurities were checked by low-level irradiations in the Ford Nuclear Reactor for 2–3 hr periods followed by spectral analysis using Li–Ge gamma-ray spectrometer. Traces of Fe, Se, Zn and Co were observed, but their gamma-ray energies are far below threshold energies to produce neutrons.

## Data Analysis and Residual Errors

Data were obtained for both the growth of $^{56}$Mn activity and its decay following the removal of the source from the bath. Typical results for the total number of $^{56}$Mn nuclei as a function of time are shown in Fig. 2. For a non-decaying source, the $^{56}$Mn concentration grows until a point of saturation is reached at which its rate of decay is equal to its rate of formation. On removing the source, the manganese decays. This behavior is illustrated by the solid line. The shape of the growth and decay portions of such data depend, of course, on the $^{56}$Mn half-life, and analysis of large numbers of runs using $^{252}$Cf and Ra–Be sources indicates that the value of 2.5764 ± 0.0004 hr given by MERRITT[4] is entirely satisfactory. For a decaying source, no steady-state saturation occurs, but a "decay saturation" period is reached when the manganese activity decreases as a function of the half-lives of $^{56}$Mn and the source itself. This is illustrated by the dashed curve. If each of the data points obtained during the saturation period is corrected by $\exp(st_n)$, where $t_n$ is the time of the $n$th counting interval since source insertion and $s$ is the decay constant of the source, then ideally a straight line of zero slope should be obtained. Using this fact, the value of the source decay constant which gave zero slope to the least-squares fitted line through the data points in the saturation period was determined. Each data point was corrected first

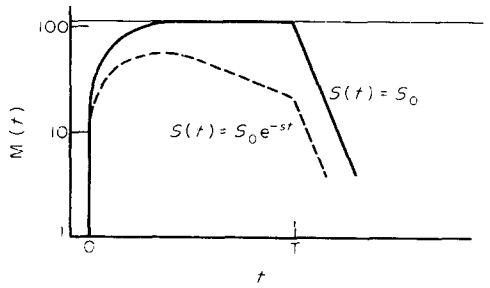


FIG. 2. Time dependence of $^{56}$Mn activity. $s$ is the half-life of the neutron source. $S_0$ is the initial source strength, and $T$ is the time of source withdrawal from the manganese bath.

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TABLE 1. Summary of errors for the Ga–D case

| Error source | Magnitude (%) |
|---|---|
| Counting statistics | 0.03 |
| Background measurement | 0.01 |
| Mn half-life | 0.004 |
| Detector deadtime | 0.02 |
| Timing of bath activations | 0.005 |
| Gain shifts | Negligible |
| Mixing delays | Negligible |
| Quadrature sum = 0.038% | |

for background and dead-time losses. By using only the data collected during the saturation period, the mixing delay uncertainties associated with the initial counting intervals following source insertion were avoided.

The sources of error using the Ga–D source are listed in Table 1. In calculating the error due to the individual contributors, each was changed by one standard deviation, and the effect on the half-life was obtained. Similar error contributions for Na and La varied only slightly with counting statistics from the manganese decay, thus accounting for the differences in the magnitude in the final reported error.

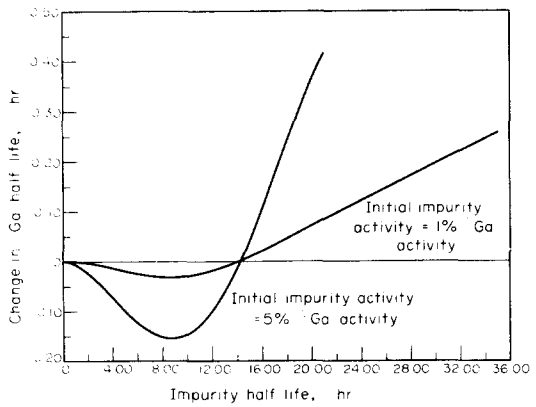


FIG. 3. Effect of an impurity on the calculated $^{72}$Ga half-life.

To further illustrate the method's insensitivity to impurities, the analysis was repeated assuming a 1 and 5% gamma emission contribution from an impurity and calculating the perturbation on the observed half-life. It is seen in Fig. 3 that even a 5% impurity with a half-life of 8.5 hr lowers the observed gallium half-life by only 0.15 hr.

## Results and Discussion

The half-lives were determined to be 15.010 ± 0.028, 13.944 ± 0.007., 13.945 ± 0.005 and 40.232 ± 0.067 hr for $^{24}$Na–D, $^{72}$Ga–Be, $^{72}$Ga–D, and $^{140}$La–Be sources, respectively. The weighted-average half-life of $^{72}$Ga was observed to be significantly shorter than that previously reported, as can be seen by studying Table 2. The result was supported by the fact that measurements of the $^{24}$Na and $^{140}$La half-lives, made in the same way, are in excellent agreement with previous values. The discrepancy cannot be traced to impurities. The advantage of the method used is that only high-energy gamma rays exceeding the energy threshold for photoneutron production from beryllium and deuterium could affect the result. The method could easily be applied to measure the half-life of any nuclide emitting a gamma ray of energy greater than the $(\gamma, n)$ threshold for beryllium or deuterium and whose half-life is comparable with that of $^{56}$Mn.

TABLE 2. Comparison of half-life measurements

| Nuclei | Half-life (hr) | Reference |
|---|---|---|
| $^{24}$Na | 15.010 ± 0.028 | This work |
| | 15.09 ± 0.06 | 5 |
| | 15.06 ± 0.039 | 6 |
| | 15.05 ± 0.02 | 7 |
| $^{72}$Ga | 13.945 ± 0.005 | This work |
| | 14.08 ± 0.02 | 8 |
| | 14.2 | 9 |
| | 14.12 ± 0.02 | 10 |
| $^{140}$La | 40.232 ± 0.067 | |
| | 40.22 ± 0.02 | 11 |
| | 40.27 | 12 |
| | 40.31 ± 0.06 | 13 |
| | others | 3 |

*Departments of Nuclear Engineering, The University of Michigan, Ann Arbor, MI* 48104, *U.S.A.*

M. C. DAVIS*
W. C. BOWMAN
J. C. ROBERTSON

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* Present address: Department of Engineering Sciences and Applied Mathematics, Northwestern University, Evanston, IL 60201, U.S.A.

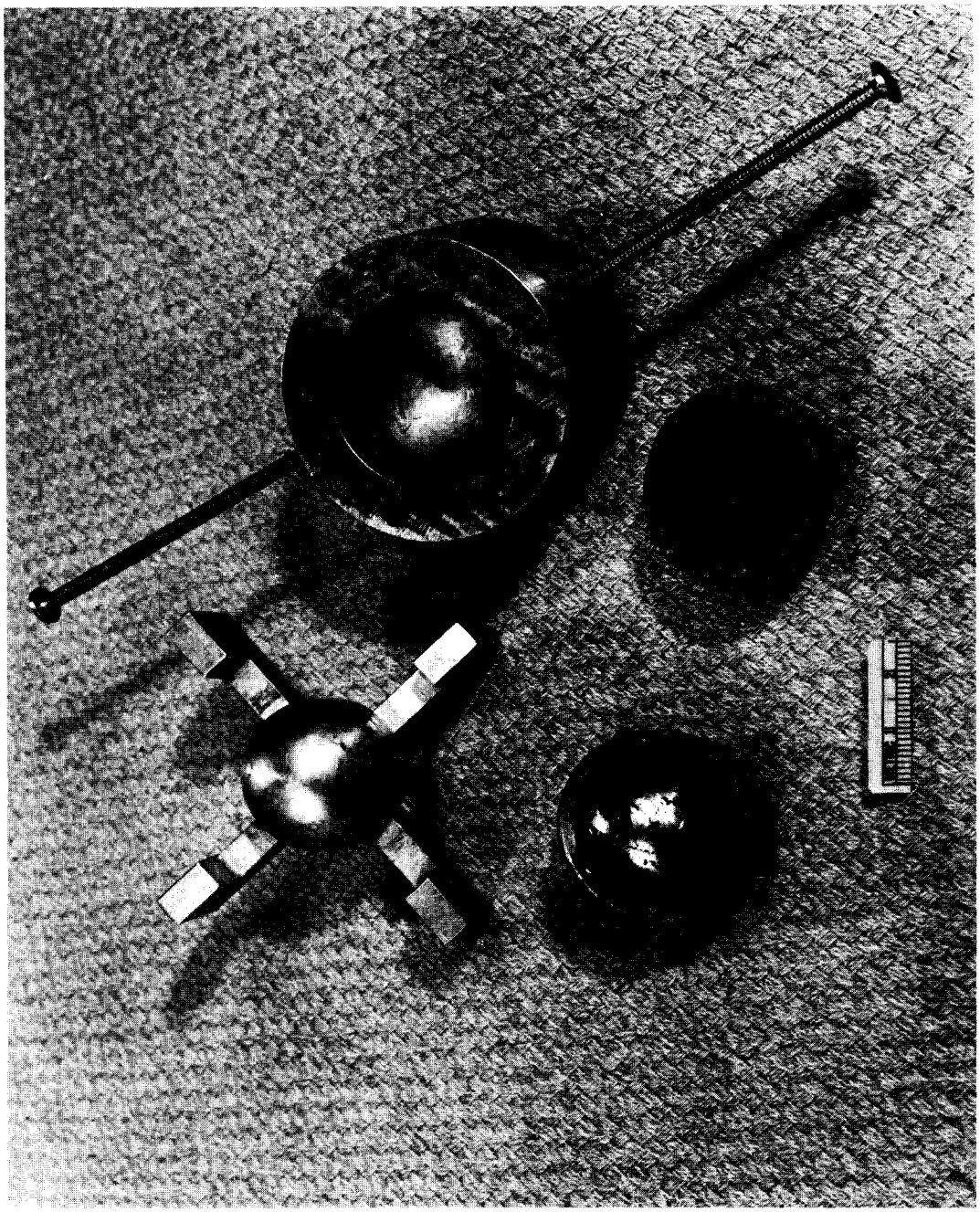

FIG. 1. Deuterated polyethylene shells and mold used for fabrication, along with gamma-ray emitting core.