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The Ground State Mass of ^{147}Gd from Single-Neutron Transfer Reactions

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Abstract

We used thin targets of radioactive ^{148}Gd to determine a precise value for the mass of ^{147}Gd. The (p,d), (d,t), and ^{3}He,α) reactions were used with high-resolution charged-particle spectrometry to determine Q-values for the ^{148}Gd target relative to several calibration targets having known Q-values. By combining the measured Q-value with the ^{148}Gd mass we get the mass defect, $\Delta M(^{147}Gd) = 75356 \pm 6$ keV, 149 keV less than the value in the 1977 mass tabulation.

The mass of ^{147}Gd is of key importance for shell-model analyses of nuclei in the region of the proton shell closure at Z = 64. The ^{147}Gd mass in the 1977 mass table[1] was based exclusively on early determinations of β-decay energies (Q_β). However, a recent more accurate result[2] gave a mass that is 144 ± 27 keV smaller than the tabulated value, and measurements[3] of the $^{144}Sm(^{12}C,^9Be)$ ^{147}Gd Q-value yielded a still smaller mass, 273 ± 40 keV smaller than the Wapstra and Bos tabulation[1]. We have therefore carried out a precise determination of the ^{147}Gd mass by using single-neutron pickup reactions with light ions on a radioactive ^{148}Gd target ($t_{1/2}$ = 75 y).

The target material was produced from spallation of Ta bombarded in the Isotope Production Facility (IPF) at the Los Alamos Meson Physics Facility (LAMPF).[4,5] The target consisted of a water-cooled stack of three Ta plates, each 80 x 80 x 3.2 mm^3. This target received a total proton irradiation of approximately 1.5 to 3 x $10^5 \mu A \cdot h$ during a four-month period ending in November, 1980. The LAMPF beam energy was ≈750 MeV, but the energy at the Ta target was degraded by an undetermined amount because of other targets upstream from the IPF.

The initial chemical processing of the Ta target was carried out in the hot cells of the LANL Medical Radioisotope Research Group.[5] Assay by γ-ray and α spectroscopy showed that the Gd fraction contained 280 μg of ^{148}Gd and similar amounts of ^{151}Gd and ^{153}Gd. This fraction was further purified at the Livermore laboratory, and sources for the isotope separator were prepared by molecular deposition from a non-acqueous solution onto a W ribbon. The isotope separator runs produced two good targets deposited on thin carbon foils. Each target contained 0.9 μg of ^{148}Gd deposited on an area of 2 to 5 mm^2, so the target thickness was between about 20 and 40 μg/cm^2. The carbon backing foil was 40 μg/cm^2 thick.

We determined Q-values of the (p,d), (d,t), and (^{3}He,α) reactions on ^{148}Gd by comparison with several calibration targets that have accurately known Q-values. The (p,d) experiments were carried out at the QQDDQ Big Karl magnet spectrograph at the IKP Jülich, and the other experiments at the QDDD spectrograph at the TU München tandem accelerator. In order to obtain accurate and reliable results we performed each experiment in a series of steps, in which the calibration target was run immediately before and immediately after the ^{148}Gd target while holding the spectrometer settings constant. Each set of experiments produced lines from several known levels that provided an accurate calibration of the spectrometer energy scale.

Figure 1 illustrates the data for the (d,t) reactions at 20 degrees on the ^{148}Gd and ^{148}Sm targets. In this figure the two spectra, consisting of several peaks from the ^{148}Sm target and the single ground-state peak from the ^{148}Gd target, have been added together for display purposes. The ^{147}Gd ground-state peak appears shifted by 148 keV toward a less negative Q-value from the position, at approximately channel 202, where it would be expected according to the 1977 mass evaluation. Since the mass numbers of the ^{148}Gd and the calibration targets are equal in this case, there is no significant kinematical shift between the two spectra. In general, the data analysis procedure took into account all kinematical effects, non-linearities of the spectrometer energy calibration, and small (~1 keV, typically) energy losses in the target and backing materials.

Table 1 shows the results of the seven independent relative Q-value determinations together with some experimental details. The results are expressed in terms of the correction that must be added to the ^{147}Gd mass adopted in the 1977 evaluation.[1] The compounded error specified for each individual result takes into account the uncertainties associated with the beam energy, energy losses in the target and backing materials, reaction angle, counting statistics, spectrometer calibration function, and the calibration Q-values (δS_n). By combining the weighted average (-149 ± 2 keV) of these results with the ^{148}Gd mass excess from the 1977 mass table we get

$$\Delta M(^{147}\mathrm{Gd}) = -75356 \pm 6 \text{ keV}.$$

The error of 6 keV is almost entirely due to the uncertainty in the ^{148}Gd mass. This result agrees very well with recent Q_β measurements[2,6], but it disagrees with the HI-transfer result[3] and with the 1977 and 1984 adopted mass values[1,7].

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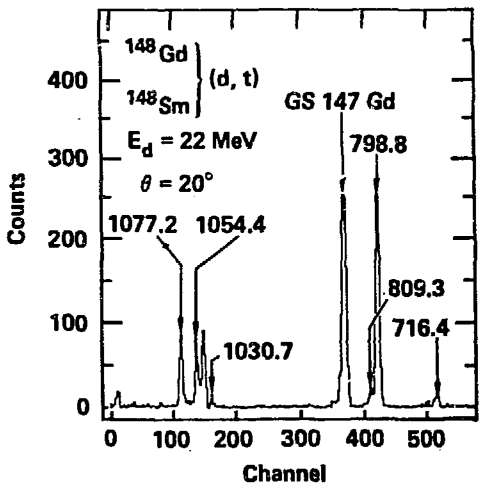
Table I - Measured mass excess deviations for ^{147}Gd, $\Delta M_{exp} - \Delta M_{Wap77}$, in keV

Calibration target and δS_n(keV)	(p,d) E_p = 25 MeV Θ = 20°	(d,t) E_d = 22 MeV Θ = 20°	(^{3}He, α) E_τ = 30 MeV Θ = 25°
^{104}Ru(6)		-141(8)	
^{144}Sm(10)	-144(10)		
^{146}Sm(6)			-166(11)
^{148}Sm(0.6)	-149(2)	-148(2)	-149(3)
^{208}Pb(0.7)	-153(4)		

Figure Caption

Fig. 1 A composite spectrum, showing the triton energy spectrum from the $^{148}Sm(d,t)$ reaction superimposed on the spectrum from the $^{148}Gd(d,t)$ reaction. Level energies are given in keV for calibration peaks in the Sm spectrum.



148Gd
148Sm
(d, t)
Ed = 22 MeV
θ = 20°
GS 147 Gd
798.8
1077.2
1054.4
809.3
716.4
1030.7
Counts
400
300
200
100
0
0
100
200
300
400
500
Channel