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THERMAL NEUTRON ACTIVATION CROSS SECTION FOR ^{48}CA

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ABSTRACT

The measurement of Calcium by Neutron Activation is performed using the $^{48}Ca(n,\gamma)^{49}Ca$ activation reaction; the compiled value for this reaction's cross section, though, has an uncertainty of more than 12%, and the best result found in the literature has an uncertainty of about 5%; this is a problem when analyzing Calcium by the Absolute Neutron Activation method, as the uncertainty in the cross section's uncertainty is propagated to the calculated concentration.

In this work, the thermal neutron capture cross section for ^{48}Ca was obtained through the irradiation of certified standard samples (*NIST 1400 Bone Ash*) in a nuclear reactor neutron beam; our resulting value (0.973±0.025b) is in agreement with the compiled value (1.09±0.14b) and also confirms the best value found on reference (0.982±0.046b), but with a lower uncertainty.

1. INTRODUCTION

Recent studies have been pointing out the many advantages of the ANAA (Absolute Neutron Activation Analysis) technique in the analysis of biological samples [1,2]; the main advantage of this technique towards the more usual INAA (Instrumental Neutron Activation Analysis) method is due to the fact that the latter requires certified standard samples to be irradiated together with the interest material at all times, thus making the analysis more expensive and time-consuming.

The ANAA technique, though, requires good knowledge of all the parameters involved in the activation calculation, as cross-sections, isotopic abundances, detector efficiency, absolute γ–ray intensities and so on. While for most isotopes and elements these parameters are very well determined, resulting in overall activation uncertainties that cope well with the ones obtained from INAA, in some extraordinary cases this may not be the case, so the ANAA results may present uncertainties that greatly surpass the ones from INAA.

One such case, and possibly the most important when dealing with biological samples, is Calcium. In this specific case, the most naturally abundant isotopes can't be used for neutron activation, as their irradiation result in stable nuclei, which are clearly not suitable for this purpose, so the most suitable reaction for the NAA measurement of Calcium is $^{48}Ca(n,\gamma)^{49}Ca$. In this case, though, the rarely-abundant (~0.1%) ^{48}Ca isotope presents relatively high uncertainties in both the neutron capture cross section and isotopic abundance.

The determination of the isotopic abundance of ^{48}Ca is a complicated issue, because of the natural instability in the abundance of the most abundant Calcium isotope, ^{40}Ca, which is constantly being produced by the decay of the naturally-occurring radioactive isotope ^{40}K; recently though, *NIST* [3] has proposed a new reference value for the abundance of the Calcium isotopes, with much lower uncertainties.

On the other hand, the compiled value for the cross section for the ^{48}Ca(n,γ)^{49}Ca reaction is (1.09±0.14)*b* [4], with an uncertainty over 12%, probably as a side effect of the large uncertainty in the recommended abundance value by the time the compilation was done (1981). One measurement was found in the literature [5] that used 77.87%-enriched $^{48}CaCO_3$ samples, resulting in a value of (0.982±0.046)*b*. Thus, in order to both confirm this value and possibly reduce even further the uncertainty, a new measurement was made using natural Calcium.

2. EXPERIMENTAL PROCEDURE

For the determination of the cross-section for ^{48}Ca, ~20mg samples of NIST 1400 *Bone Ash* standard material were irradiated in the IEA-R1 reactor, under a thermal neutron flux of approximately 10^{12}n.cm^{-2}.s^{-1}, for 180 seconds. In order to precisely determine the neutron flux, two Gold foils (~800μg each), one bare and one Cadmium-covered, were irradiated together with each sample.

After irradiation, both the samples and the Gold foils were separately gamma-counted in a system composed of a 198cm^3 HPGe detector connected to a standard spectroscopy amplifier and a MCA ADCAM module. The resulting spectra were then carefully analysed and the areas corresponding to the peaks of interest were determined using a model consisting of a Gaussian summed up with a step function and an exponential tail [6]; the background radiation was taken into account by subtracting a sourceless spectrum, taken subsequentially to the source measurement, from the spectrum to be analysed. The detection efficiency of the system was determined using a set of ^{152}Eu and ^{56}Co standard sources.

The determination of the thermal neutron flux was made for each measurement by subtracting the epithermal flux, obtained from the activation of the Cadmium-covered Gold foil, from the total (thermal + epithermal) flux obtained from the activation of the bare Gold foil.

The thermal cross section was then obtained from Equation 1, where σ is the thermal neutron cross-section, A_l is net area under the interest peak, M_A is the atomic mass, l is the decay constant, N_A is Avogadro's number, f is the thermal neutron flux, F_m is the mass fraction of the interest element in the sample, m is the sample mass, I_g is the intensity of the chosen gamma ray, e is the system's detection efficiency for the energy of that gamma ray, F_I is the isotopic abundance of the interest isotope, T_i is the irradiation time, T_e is the time elapsed between the end of the irradiation and the start of the counting and T_c is the counting time.

$$s = \frac{l . \cdot A_l \cdot M_A}{j \cdot e \cdot m \cdot N_A \cdot F_m \cdot I_g \cdot F_I \cdot (1 - e^{-l \cdot T_i}) \cdot (1 - e^{-l \cdot T_c}) \cdot e^{-l \cdot T_e}} \qquad (1)$$

3. RESULTS AND DISCUSSION

The results from the two independent measurements are presented in Table 1, together with their respective uncertainties; the last line shows the weighted (σ^{-2}) average of these measurements. Table 2 compares the value obtained in this work and the values from references [4,5], showing that the present measurement, while compatible with the previous data, presents a lower uncertainty.

Table 1. Experimental results for the thermal neutron absorption cross-section for ^{48}Ca.

measurement	*cross-section (barn)*
1	0.974 ± 0.035
2	0.973 ± 0.035
weighted average	0.974 ± 0.025

Table 2. Comparison of the previously available values for the thermal neutron activation cross-section of ^{48}Ca to the present result.

Reference	*cross-section (barn)*	*uncertainty (%)*
[4]	1.09 ± 0.14	12.8
[5]	0.982 ± 0.046	4.68
Present Work	0.974 ± 0.025	2.57

3. CONCLUSIONS

In this work the thermal neutron absorption cross section for ^{48}Ca was determined as (0.974±0.025)b; this result, while in perfect agreement with the values found on reference [4,5], was determined with a much better accuracy, resulting in an uncertainty about 2.5% (which is 18% of the uncertainty of the compiled value and 55% of the best value so far), and thus should allow much more precise results for the determination of Calcium using the ANAA technique.

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