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Nuclear Data Review

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Introduction

Non-neutron nuclear data are periodically reviewed and evaluated. The recommended values are published in the Table of the Isotopes of the Chemical Rubber Company's Handbook of Chemistry and Physics. A 2004 review has begun to re-examine some data of interest to the International Union of Geological Sciences (IUGS) sub-commission on Geochronology dealing with radioactive decay constants and isotopic abundance ratios. Among the decay constants that are being evaluated are those of the following nuclides: ^{40}K, ^{87}Rb, ^{138}La, ^{147}Sm, ^{176}Lu, ^{174}Hf, ^{187}Re, ^{190}Pt, ^{232}Th, ^{235}U, ^{238}U.

General Procedure

Each experiment is reviewed and the published values are revised for the latest estimates of the various parameters originally reported by each author, e.g., branching ratios, half-lives of other nuclides, isotopic abundance in natural samples, nuclidic masses and the physical constants. When detailed information on the uncertainties is available for each experiment, the statistical standard deviation is combined with one third of the estimated systematic error to produce an uncertainty at the one-sigma level (1σ). The result of this procedure is that the limit of error of the half-life would be obtained from the sum of the estimated systematic error plus three standard deviations, the three-sigma level (3σ).

When there is no adequate discussion of the possible systematic error and the total error is extremely small, 0.1% or less, a systematic error of 0.1% is estimated. One third of this amount approximately 350 parts per million (ppm) is added to the published uncertainty to obtain the value. Variance weighting is used to obtain the recommended value and the uncertainty.

Many of the radioactive half-lives (decay constants) were reviewed in detail about fifteen years ago in a series of articles[1,2,3]. Since that time, as new data became available for particular nuclides, those nuclides were reevaluated on an annual or biennial basis for review articles in the Chemical Rubber Company (CRC) Handbook of Chemistry and Physics[4].

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Discussion on Decay Constants of Individual Nuclides

^{40}K – There have been new measurements[5,6] since the last detailed review. The modes of decay are β^+, β^-, and electron-capture, EC, with the relative branching ratios of 0.001%, 89.64% and 10.36%, respectively. The half-lives for the 11 measurements of the β^- branch and for the 6 measurements of the EC branches are, respectively, 1.40×10^9 years and 12.1×10^9 years. A preliminary estimate of the total half-life value for ^{40}K has been obtained by an un-weighted average of the two most recent measurements and the average of the β^- and the EC branch half-lives. The resulting preliminary recommended total half-life is 1.25 (1) $\times 10^9$ years. The preliminary uncertainty is 0.8%. The half-life corresponds to a total decay constant of 5.55 (4) $\times 10^{-10}$ years^{-1}.

^{87}Rb – There has been three recent measurements[7,8,9], since the last detailed review. If one groups the measurements by technique, there are direct counting experiments, there are in-growth experiments and there are geological experiments. The weighted average of the half-life values by these three techniques are 5.03×10^{10} years, 4.76×10^{10} years and 4.94×10^{10} years, respectively. An un-weighted average of these techniques would be a total half-life of 4.91 (8) $\times 10^{10}$ years, or 4.9 (1) $\times 10^{10}$ years. This corresponds to a total decay constant of 1.41 (3) $\times 10^{-11}$ years^{-1}.

^{138}La – There have been two new measurements[10,11], since the last detailed review. A weighted average of the four most recent total half-life measurements gives a preliminary recommended value of 1.02 (2) $\times 10^{11}$ years, while the β^- branch has a partial half-life value of 2.97 (6) $\times 10^{11}$ years. The two best geological results give a weighted average of 2.91 (10) $\times 10^{11}$ years for the half-life of the partial β^- branch.

^{147}Sm – There has been one new measurement by Martins[12], since the last detailed review. Martins determined the number of decays using a thin film of samarium oxide. They apparently did not correct for oxygen, when they subsequently reported a half-life value of 1.23 (4) $\times 10^{11}$ years (see Begemann[13]). Using the latest atomic weight values for samarium and oxygen, the correction factor is 0.86236. This gives 1.06 (4) $\times 10^{11}$ years for the revised half-life value. Averaging this latest measurement with two earlier measurements, including one using a 97% enriched ^{147}Sm sample gives a preliminary recommended half-life value of 1.06 (2) $\times 10^{11}$ years. This corresponds to a total decay constant of 6.54 (12) $\times 10^{-12}$ years^{-1}.

^{176}Lu – There have been seven new measurements[14,15,16,17,18,19,20], since the last detailed review. The calculation of the half-life and the evaluation of the uncertainties lead to a weighted average of all measurements in the last thirty years of 3.74 (1) $\times 10^{10}$ years. This would imply that the two best measurements as reported by experimenters lie two to three standard deviations away from the average value. If the data for counting measurements and for geological measurements are each weighted separately and these two techniques are simply averaged, the result is 3.72 (3) $\times 10^{10}$ years. Finally, an un-weighted average of the counting and the geological measurements gives a preliminary total half-life value of 3.78 (6) $\times 10^{10}$ years. Until a thorough evaluation of the uncertainties for each of the experiments is completed, the preliminary recommendation

is to use the un-weighted average rounded to a total half-life value of 3.8 (1) x 10^{10} years. This corresponds to a total decay constant of 1.83 (4) x 10^{-11} $years^{-1}$.

^{174}Hf – There have been no new measurements since the last detailed review. The stated total half-life recommendation of 2.0 (4) x 10^{15} years remains in effect.

^{187}Re – There have been five new measurements[21,22,23,24,25] since the last detailed review. The twelve most recent measurements, which include counting, in-growth and geological results have a range from 3.5 x 10^{10} years to 6.6 x 10^{10} years. If one averages the in-growth, the geological and the counting measurements, but excludes the outlier values, an un-weighted average for each technique is 4.3 x 10^{10} years. This leads to a preliminary recommended half-life value of 4.3 (1) x 10^{10} years.

^{190}Pt – There has been one new measurement[26], since the last detailed review. It was a geological measurement quoted to 1% accuracy but the isotopic abundance was too low by a factor of 10%. The weighted average of five measurements gives a preliminary recommended value of 6.2 (4) x 10^{11} years.

^{232}Th – There has been no new measurements performed since the last detailed review. The preliminary recommended half-life is 1.40 (1) x 10^{10} years.

^{235}U – There has only been one new measurement[27] since the last detailed review. The preliminary recommended half-life value is 7.04 (1) x 10^{8} years.

^{238}U – There has been no new measurements performed since the last detailed review. The preliminary recommended half-life is 4.47 (1) x 10^{9} years.

Discussion of the Isotopic Abundance of Individual Nuclides

^{40}K – The best estimate of the isotopic composition for the minor isotope of potassium comes from the measurement by Garner[28]. It is 0.0001167 (2). This value has been rounded to 0.000117 (1) when the abundance is quoted for average properties, so that the total isotopic composition will add up to unity for all stable isotopes.

Pt – The best estimate of the isotopic composition for the minor isotope of platinum comes from the measurement by Taylor[29]. It is 0.000136 (4). This value has been rounded to 0.00014 (1) when the abundance is quoted for average properties, so that the total isotopic composition will up to unity for all stable isotopes.

Some Comments on the Problem of Error Estimation

Absolute certainty is a privilege of uneducated minds and fanatics. It is for scientific folk, an unattainable ideal[30]. Eisenhart[31] noted that a reported value whose accuracy is entirely

unknown is worthless. A reported value whose accuracy is significantly overestimated is extremely misleading, particularly if a truly honest effort has not been made to identify and quantify the various sources of systematic error. Most present day measurements rely on measured values of various other parameters as auxiliary constants and if all of these had unknown sources of systematic error, which biased their results, we would have an enormous problem.

Usually, recommended values and uncertainties are based on the averages obtained by weighting each measurement by the reciprocal square of the quoted standard deviation, so-called variance-weighted averages. Occasionally, recommendations may be based on selecting the one good recent measurement. There are times when a discrepancy in values and uncertainties quoted by a given technique require that the techniques be averaged to produce a more reasonable recommendation.

There are measurements, where authors quote uncertainties that are orders of magnitude smaller than all other measurements, such that they disagree with and they exclude many other good recent measurements from consideration, if variance weighting were applied indiscriminately. Undoubtedly, systematic errors have not been carefully considered in these publications.

When experiments are performed at the level of five to ten percent accuracy, recording the number of counts is an important consideration. In Poisson statistics, increasing the number of counts can improve the overall accuracy, since the accuracy varies inversely with the total number of counts. However, when the overall accuracy reaches the level of one-half percent or better, the estimate of all systematic errors begins to control the total accuracy. Continuing to improve the statistical precision, by collecting more raw data points, does not significantly improve the total error, except superficially, in the absence of any effort to estimate the systematic error. Using variance weighting indiscriminately in such cases, penalizes authors who attempt the difficult task of estimating systematic error, while benefiting the authors who make no such attempt to determine all of their sources of error.

If one had a choice in designing the ideal experiment to measure the half-life, one would choose to make measurements on many samples, using a number of duplicate instruments and utilizing a variety of different methods or techniques. This should procedure should help to provide the necessary information to correctly estimate the systematic error.

Psychological Factors in Estimating Error

Finally, consider the psychological factor involved with systematic errors as noted by Birge[32] and Bridgman[33]. Individual authors search for all of the sources of error in their work, which will bring their result into agreement with all of the earlier measurements of the quantity. When the authors' renormalized value agrees with others, the author ceases to investigate further. Also, if their value is too large, the author does not look at factors,

which would cause the result to increase, but for factors that result in the reduction of their measured value.

For a number of years, the value for the charge on the electron had been based on a set of consistent measured values. When Rutherford's measured value was reported to be 60% larger than all previous results, all measurements subsequent to Rutherford were suddenly found to be consistent with his new higher value. In a similar manner, all of the early measurements of Planck's constant clustered about the same value, until Birge in 1941 raised that value by one and one-quarter percent in his analysis of the fundamental constants. After this breakthrough, all subsequent measurements have clustered around this "new" estimate.

We can conclude from this discussion that systematic errors are very difficult to estimate but they are extremely important to identify and to either eliminate them or to at least account for them.

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