Accuracy of Carbon 14 Dating I

The half-life of Carbon 14, that is, the time required for half of the Carbon 14 in a sample to decay, is variable: not every Carbon 14 specimen has exactly the same half-life. The half-life for Carbon 14 has a distribution that is approximately normal with a standard deviation of 40 years. This explains the why Wikipedia article on Carbon 14 lists the half-life of Carbon 14 as 5730 ± 40 years. Other resources report this half-life as the absolute amounts of 5730 years, or sometimes simply 5700 years.

a. Explain the meaning of these three quantities (5730 ± 40, 5730, and 5700) focusing on how they differ.
b. Can all three of the reported half-lives for Carbon 14 be correct? Explain.
c. What are some of the benefits and drawbacks for each of the three ways of describing the half-life of Carbon 14?

Commentary

This task examines, from a mathematical and statistical point of view, how scientists measure the age of organic materials by measuring the ratio of Carbon 14 to Carbon 12. The focus here is on the statistical nature of such dating. The decay of Carbon 14 into stable Nitrogen 14 does not take place in a regular, determined fashion: rather it is governed by the laws of probability and statistics formalized in the language of quantum mechanics. As such, the reported half-life of 5730 ± 40 years means that 40 years is the standard deviation for the process and so we expect that roughly 68 percent of the time half of the Carbon 14 in a given sample will decay within the time span of 5730 ± 40 years. If greater likelihood is sought, we could look at the interval 5730 ± 80 years, encompassing two standard deviations, and the likelihood that the half-life of a given sample of Carbon 14 will fall in this range is a little over 95 percent.

This task addresses a very important issue about precision in reporting and understanding statements in a realistic scientific context. This has implications for the other tasks on Carbon 14 dating which will be addressed in "Accuracy of Carbon 14 Dating II."

The statistical nature of radioactive decay means that reporting the half-life as 5730 ± 40 is more informative than providing a number such as 5730or 5700. Not only does the ± 40 years provide extra information but it also allows us to assess the reliability of conclusions or predictions based on our calculations.

This task is intended for instructional purposes. Some more information about Carbon 14 dating along with references is available at the following link: Radiocarbon Dating

Solution

a. Of the three reported half-lives for Carbon 14, the clearest and most informative is 5730 ± 40. Since radioactive decay is an atomic process, it is governed by the probabilistic laws of quantum physics. We are given that 40 years is the standard deviation for this process so that about 68 percent of the time, we expect that the half-life of Carbon 14 will occur within 40 years of 5730 years. This range of 40 years in either direction of 5730 represents about seven tenths of one percent of 5730 years.

   The quantity 5730 is probably the one most commonly used in chemistry text books but it could be interpreted in several ways and it does not communicate the statistical nature of radioactive decay. For one, the level of accuracy being claimed is ambiguous -- it could be being claimed to be exact to the nearest year or, more likely, to the nearest ten years. In fact, neither of these is the case. The reason why 5730 is convenient is that it is the best known estimate and, for calculation purposes, it avoids working with the ± 40 term.

   The quantity 5700 suffers from the same drawbacks as 5730. It again fails to communicate the statistical nature of radioactive decay. The most likely interpretation of 5700 is that it is the best known estimate to within one hundred years though it could also be exact to the nearest ten or one. One advantage to 5700, as opposed to 5730, is that it communicates better our actual knowledge about the decay of Carbon 14: with a standard deviation of 40 years, trying to predict when the half-life of a given sample will occur with greater accuracy than 100 years will be very difficult. Neither quantity, 5730 or 5700, carries any information about the statistical nature of radioactive decay and in particular they do not give any indication what the standard deviation for the process is.

b. As was described in part (a) the three reported half-lives, 5730 ± 40, 5730, and 5700 are all consistent but do not carry the same information. The most informative is 5730 ± 40 while the most convenient is 5730. The number 5700 has the advantage of communicating the general level of accuracy for when the half-life is likely to occur but it is not as good an estimate as 5730 and is less informative than 5730 ± 40.

c. The advantage to 5730 ± 40 is that it communicates both the best known estimate of 5730 and the fact that radioactive decay is not a deterministic process so some interval around the estimate of 5730 must be given for when the half-life occurs: here that interval is 40years in either direction. Moreover, the quantity 5730 ± 40 years also conveys how likely it is that a given sample of Carbon 14 will have its half-life fall within the specified time range since 40 years is represents one standard deviation. The disadvantage to this is that for calculation purposes handling the ± 40 is challenging so a specific number would be more convenient.

   The number 5730 is both the best known estimate and it is a number and so is suitable for calculating how much Carbon 14 from a given sample is likely to remain as time passes. The disadvantage to 5730 is that it can mislead if the reader believes that it is always the case

that exactly one half of the Carbon 14 decays after exactly 5730 years. In other words, the quantity fails to communicate the statistical nature of radioactive decay.

The number 5700 is both a good estimate and communicates the rough level of accuracy. Its downside is that 5730 is a better estimate and, like 5730, it could be interpreted as meaning that one half of the Carbon 14 always decays after exactly 5700 years.