Measuring the Age of things (Astro 202 2/12/08)

Nomenclature

Element: Number of Protons
Isotope: Number of Neutrons (Same No. of Protons)

Note diagrams not to scale!

Three Types of Nuclear Decay

α → Helium Nucleus
β → electron
γ → neutrino

Carbon 14 Decay

Carbon 14 → Nitrogen 14
→ electron
→ neutrino
Imagine we found a piece of wood which contains 100 nuclei of Carbon-14, which has a half-life of 6000 years.

Assuming the wood did not gain or lose atoms to its environment, how many Carbon-14 nuclei would the object have:

6000 years ago?

200

12000 years ago?
Imagine we found a piece of wood which contains 100 nuclei of Carbon-14, which has a half-life of 6000 years.

Assuming the wood did not gain or lose atoms to its environment, how many Carbon-14 nuclei would the object have:

- 6000 years ago? 200
- 12000 years ago? 400
- 18000 years ago? 800

So, How old is this tree?

To figure out how old an object is using an unstable nucleus, we need to know how many nuclei it contains now and how many nuclei it contained originally.

How can we do this reliably?
Ancient Trees and Modern trees obtain Carbon-14 from the same place

Carbon-14 is produced by cosmic rays striking the atmosphere

Cosmic rays are nuclei that move through space at speeds approaching the speed of light.

All living organisms acquire carbon-14 from the atmosphere

If the Carbon-14 content of the atmosphere has remained constant, then ancient trees have comparable amounts of Carbon-14 as modern trees
A 5,730 year old tree would have half the Carbon-14 of a modern tree.

By comparing Carbon-14 dates with independent age measurements, we can confirm the Carbon-14 content of the atmosphere has remained rather constant.

Data from Libby’s 1960 Nobel Prize Lecture.

A 11,460 year old tree would have one-quarter the Carbon-14 of a modern tree.
Variations in Carbon-14 content of the atmosphere can be detected and accounted for...

These variations can tell us something about the history of Earth’s climate and solar system magnetic fields

Data from radiocarbon.org INTCAL04

These trees have roughly 1/4 of their original Carbon-14 remaining, so these trees are between 10,000 and 12,000 years old.

These trees date to the end of the last Ice Age, and give unique insights into the shifting climate.....

Leavitt et al. 2007 in Radiocarbon 49(2) 855-864
See also www.ltrr.arizona.edu/~sleavitt/YoungerDryasLinknew.htm
How do we date earlier events, like the Chicxulub Impact crater?

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- Carbon-12
- Aluminum-26
- Potassium-39
- Potassium-40
- Rubidium-87
- Uranium-235
- Uranium-238

Potassium-40 has two ways it can decay:

- 90% decay to Calcium 40
- 10% decay to Argon 40

Half-lives of different nuclei….

- Carbon-14: 5,730 years
- Aluminum-26: 717,000 years
- Potassium-40: 1,280,000,000 years
- Rubidium-87: 47,500,000,000 years
- Uranium-235: 704,000,000 years
- Uranium-238: 4,468,000,000 years

Numbers from http://ie.lbl.gov
Potassium-40 can be used to measure the age of melted rocks.

Potassium-40 decay in hot or molten rock:
- Potassium-40
- Argon-40
- Calcium-40

Potassium-40 decay in a cold, solid rock:
- Potassium-40
- Argon-40
- Calcium-40

The Rock Today:
- Potassium-40
- Argon-40
- Calcium-40
Potassium-40 measurements of small particles of glass and melt from the impact date this event to 64.98 +/- 0.05 million years ago.

Comparing the date of the impact with those of fossil deposits confirms the impact occurred close to the end of the age of the dinosaurs.

Swisher et al. 1992 in Science, 257 (954)
Summary points:

Unstable nuclei are potentially powerful tools for determining the age of things, because whether a given nucleus decays or not depends only on the interactions between the protons and neutrons in individual nuclei and because groups of unstable nuclei decay in a predictable, regular way characterized by a parameter known as the half-life.

Carbon-14 nuclei, which have a half-life of 5,730 years, are useful for dating objects that used to be part of living things that lived during the last ~50,000 years. This is because the original Carbon-14 content of these organisms are comparable to that of similar organisms living today.

Potassium-40 nuclei, which have a half-life of 1.28 billion years, are useful for measuring the age of ancient volcanic rocks that are millions or billions of years old. This is because molten rocks contain little Argon-40, so the amount of Argon-40 in a rock is a measure of how much Potassium-40 decayed in the rock since it last solidified.