k8 The special case of Carbon-14 dating < short half-life, Libby >

But nothing in his [Rutherford's] tool kit [unlike, later, in Enrico Fermi's] suggested perishable material particles. When the neutron [discovered by James Chadwick in 1932] decays [half-life ~10.3 minutes], it disappears as an identifiable object just as surely as if it had vanished into thin air. There is no way to interpret its decay as a mere rearrangement of preexisting components. Its vanishing act defies classical mechanics as well as common intuition.
—Hans Christian von Baeyer, *Maxwell's Demon*, 1998.[1]

Willard Frank Libby in 1947 developed a Carbon-14 (^{14}C) dating technique[2] to determine the absolute age of organic materials 500 to 50,000 years old. This time bridges from historical time deep into the Wisconsin glacial epoch. However, accuracy falls off rapidly beyond 26,000 calendar years. Radiocarbon dating is routinely used in archaeology and anthropology and the general public who express an awareness of radiometric dating will usually quote the use of carbon-14 as an example. But Carbon-14 dating is atypical, except in some soothsaying environmental studies, of radiometric dating methods in geology. Radiometric dating of greatly old material measures radiometric isotopes that are still in existence from the beginning of geologic time. ^{14}C, with a half-life of 5730 years, could not be such and so some ongoing process must be continually making it.

Cosmic-ray collision with air molecules produce neutrons by spallation. Libby discovered that a slow neutron so produced can knock a proton out of a $_7^{14}N$ nucleus to make it $_6^{14}C$. This radiogenic isotope of carbon is radioactive. Ordinary carbon is the non-radioactive carbon-12 ($_6^{12}C$) isotope.[3]

Cosmic rays are supernova-related phenomena. Each supernova produces a shockwave that travels outward compressing an envelope of interstellar material. This is struck from behind by following ionized hydrogen, helium, oxygen, and blast-generated heavier elements moving at thousands of miles per second. Interactions for a period of about a thousand years create cosmic rays of electrons and protons and other particles that travel throughout the galaxy at velocities near the speed of light. Spiraling (along magnetic field lines) in from presumably innumerable supernovae sources (1 per 50 years in our galaxy alone)[4] at various great distances (a count in a studied thin cone of the visible universe indicates 50 billion or more galaxies exist!), galactic cosmic-ray flux that reaches us is isotropic and constant (after averaging out the 11-year solar cycles of the heliosphere shield strength). Most (78%) of Earth's atmosphere is nitrogen (N_2) and there is no reason to suppose that this rather inert gas has varied significantly in the last 50,000 years. For these two reasons, a volumetric constant rate of ^{14}C production in the upper atmosphere is safely assumed for the last 50,000 years.

A model for a dynamic equilibrium system is a tap (source) with water flowing from it at a constant rate into a bucket with a hole (sink) in its bottom. Initially, water will accumulate in the bucket until the pressure driving water out through the hole results in an outflow that exactly equals the inflow. At equilibrium, the bucket will hold a constant amount of water. If the bucket is taken away from the tap, the amount of water held will lessen exponentially (as pressure driving its flow lessens) as it drains away. The analogy is: The input of ^{14}C into the atmosphere is at a constant rate. ^{14}C accumulates in the atmosphere until the amount of ^{14}C removed by decay to ^{14}N exactly equals the amount entering. While it exists, the ^{14}C in the atmosphere reacts with oxygen to form $^{14}CO_2$. This mixes into the gases of the atmosphere with the result that the ratio of $^{14}CO_2$ to ordinary $^{12}CO_2$ measured in any volume of air is constant. Remove a volume of air from the mixing in of replacement $^{14}CO_2$ (the leaky bucket taken away from the tap) and ratio of $^{14}CO_2$ to ordinary $^{12}CO_2$ in that isolated volume gets smaller as $^{14}CO_2$ changes to $^{14}NO_2$. Libby realized that when a plant takes in CO_2 it does not discriminate between $^{14}CO_2$ and $^{12}CO_2$ and so initially the carbon it sequesters in its tissue will be in the ratio of ^{14}C to ^{12}C that is in the atmosphere. When the plant dies, amount of ^{14}C in its tissue dwindles according to the physics of its half-life. How much smaller the ratio $^{14}C/^{12}C$ in the plant tissue is compared to that in air is a measure of its age.

In order to test the validity of this way of dating organic materials Libby and others compared ^{14}C ages found for such things as historical-datable wood from Egyptian tombs or wood with its absolute-age known from tree-ring counting (dendrochronology), as say from the cedar "bonsai" of the cliffs of the Niagra escarpment, Ontario,[5] and New Zealand's kauri trees.[6] A close agreement is found but as data accumulated systematic-departures of known calendar dates and radiometric dates are revealed. The variable is the amount of ^{12}C in the atmosphere at any time and place.

Calculations assume $^{14}C/^{12}C$ in the atmosphere to be constant but the historical record is that it is not. The amount of ^{12}C is increased by the burning of fossil fuels (in which ^{14}C has long vanished). This activity has greatly increased in some regions since the beginning of the industrial revolution and for say European 500 year old organic materials, ^{14}C dates determined are decades younger than they should be (as going back there was less ^{12}C per unit volume of air). Empirically corrected Carbon-14 curves (***Figure k8.1***) are now used to date materials in geographic regions.

Calendar years before present are indicated by numerals followed by BP. To avoid confusion, radiocarbon years before 1950 CE should be indicated by numerals followed by YBP or RYBP. For example, 11,000 YBP is equal to 12,500 BP (as determined directly by say varve counting or by dendrochronology) when the "present" was the year 1950 CE (0 YBP) and is equal to 12,557 BP when the "present" was the year 2007 CE.[7]

Absolute Dating, or the determination of an actual age of an object, techniques now include:[8]

Archaeomagnetism	Oxidizable Carbon Ratio (OCR)
Astronomical Dating	Potassium-Argon Dating
Dendrochronology	Racemization
Electron Spin Resonance	Radio-Carbon Dating (Carbon-14)
Fission Track	Thermoluminescence Dating
Optically Stimulated Luminescence	Uranium-Thorium Dating

Figure k8.1 [9]

An illustration of how a plot of true ages determined by dendrochronology and historical information can be used to correct for the discrepancy between it and Carbon-14 ages of materials.

IntCal04, the 2004 "official" Carbon-14 international calibration curve from tree-ring records, foraminifera from varved sediments, and corals, stops at 26,000 calendar years before 1950 CE (the year zero of radiocarbon years, or 0 YBP). No consensus is for extensions of the calibration curve from 26,000 to 50,000 calendar years BP that have been based variously on: annually laminated sediments (varves) from Lake Suigetsu in Japan, corals from the uplifted terraces of New Guinea, sediments of the former Lake Lisan in Israel, carbonate deposits from a submerged cave of the Bahamas, and deepsea-sediments stratigraphy tied to Greenland Summit Icecore stratigraphy.[10]