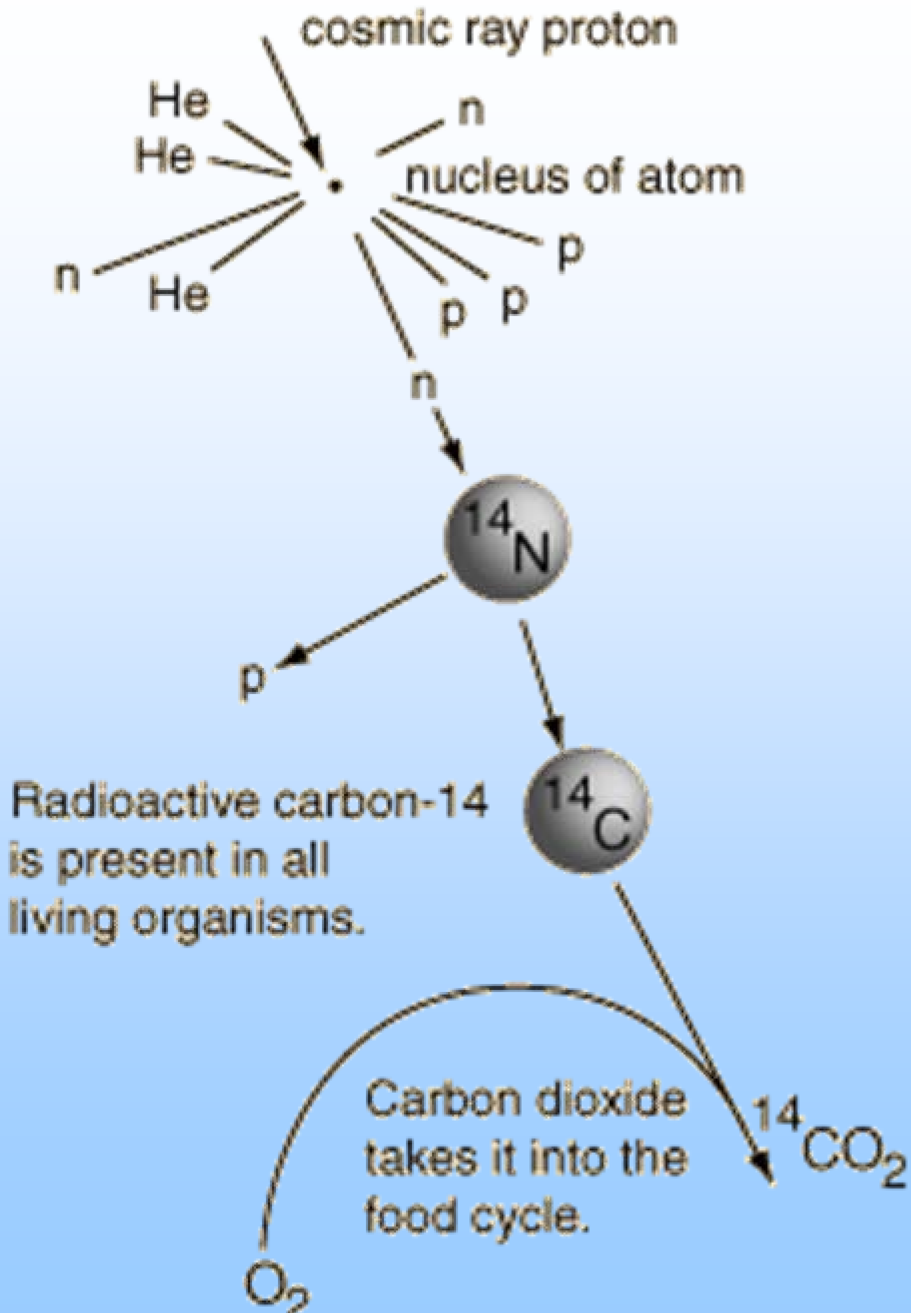
Carbon-14 Dating



Carbon dating is a variety of radioactive dating which is applicable only to matter which was once living and presumed to be in equilibrium with the atmosphere, taking in carbon dioxide from the air for photosynthesis.

http://hyperphysics.phy-astr.gsu.edu/hbase/nuclear/cardat

How does ^{14}C form? Mostly from cosmic rays.

* Primary → cosmic rays are dominantly protons (H nuclei-- GeV-- much energy associated with them).
- Secondary → when protons enter into the upper atmosphere they produce neutrons, which have high enough energies to split off portions of small nuclei.

* In the upper atmosphere where there is a lot of ^{14}N, ^{14}N is hit by a neutron which knocks off a proton to form ^{14}C [$^{14}N(n,p)^{14}C$].

→ The amount of ^{14}C is a function of the number of neutrons which is dependent upon the amount of primary protons which enter the upper atmosphere.

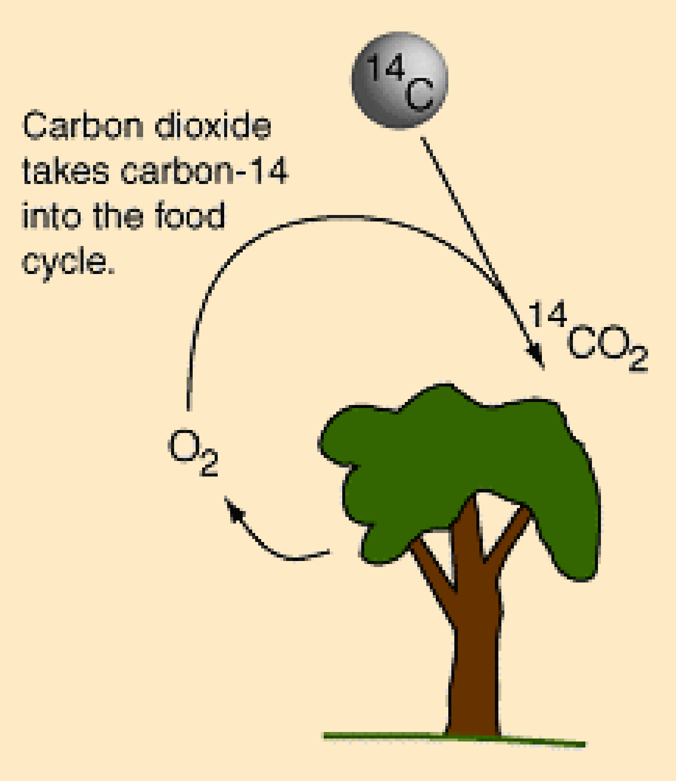
- →← This ratio was assumed not to have changed, but in the past 10 years, it was discovered that it has changed over Earth's history.
  - H+ is a charged particle and is therefore affected by magnetic fields, including the earth's and the sun’s. The charge must have a certain energy in order to pass through the magnetic field. A stronger magnetic field or a particle with lower energy will cause the particle to have more trouble passing through the earth's magnetic field.
  - If the earth's (and/or sun’s) field varies as a function of time, then the number of H+ particles that pass into the upper atmosphere varies as a function of time, and therefore so does ^{14}C concentration.

→ The amount has been relatively constant over the last 7000 - 8000 years.

- This is known because other isotopes are made by cosmic rays and because of historic age information, tree rings etc..
- It is possible to measure trace quantities of ^{3}He in various surface rocks if know age of eruption → can show how the earth's magnetic field has varied.

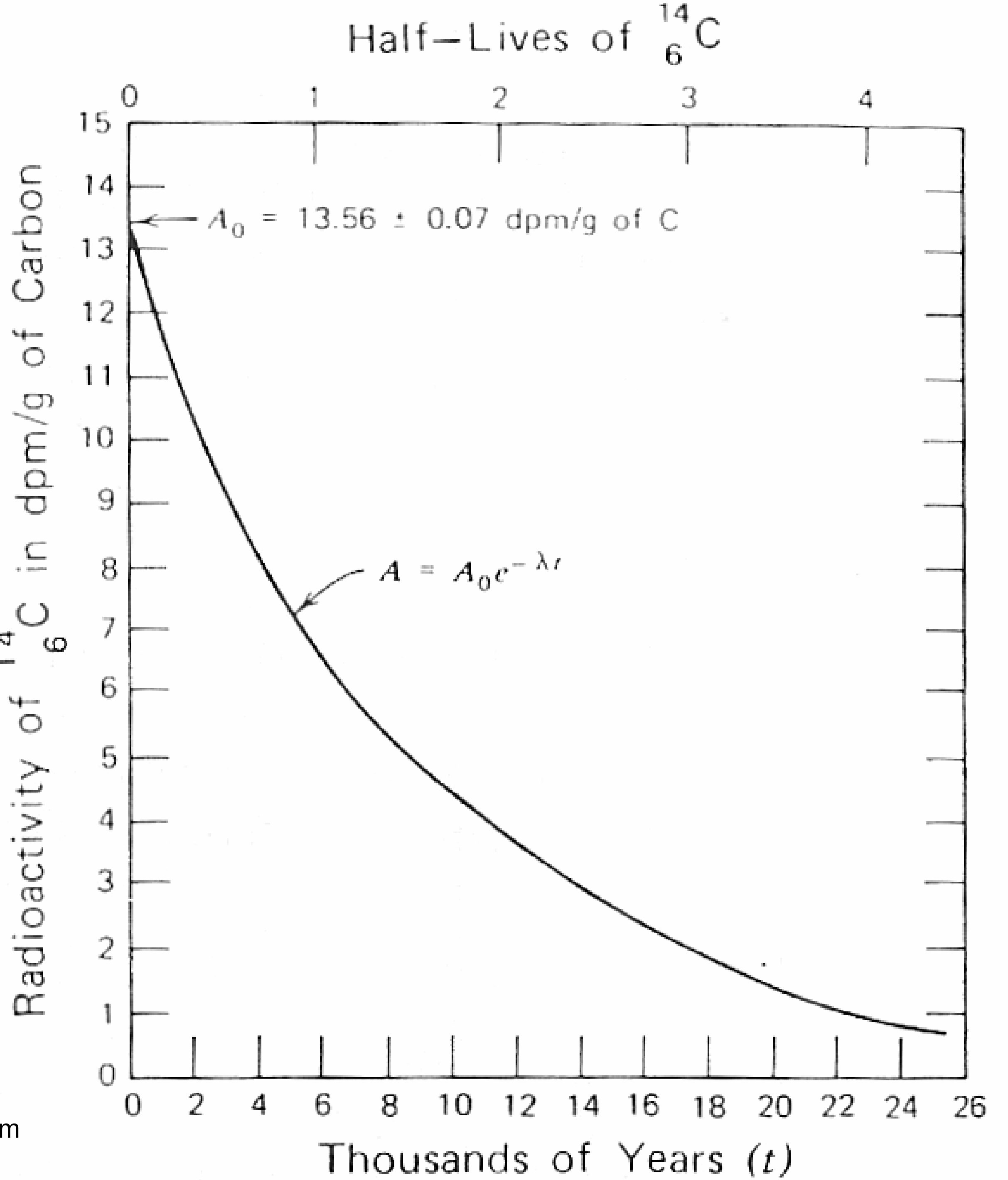
* ^{14}C becomes part of $^{14}CO_2$

- Rate of CO_2 ratio in the atmosphere show how well CO_2 is cycled through the biosphere and the oceans.
  - This will also affect the $(^{14}C/C)_{atm}$.
- Since 1950, ^{14}C dating has been messed up because:
  1. Nuclear explosions release large amount of CO2 into the atmosphere (increases ^{14}C).
  2. The burning of fossil fuels puts carbon into the atmosphere which contains no ^{14}C (↓ $^{14}C/C$ ratio)



Presuming the rate of production of carbon-14 to be constant, the activity of a sample can be directly compared to the equilibrium activity of living matter and the age calculated. Various tests of reliability have confirmed the value of carbon data, and many example provide an interesting range of application. Carbon-14 decays with a halflife of about 5730 years by the emission of an electron of energy 0.016 MeV. This changes the atomic number of the nucleus to 7, producing a nucleus of nitrogen-14. At equilibrium with the atmosphere, a gram of carbon shows an activity of about 15 decays per minute.

Figure 22.1. Decay of ^{14}C in plant or animal tissue that was initially in equilibrium with $^{14}CO_2$ molecules of the atmosphere or hydrosphere. When the plant or animal dies, the exchange stops and the activity due to ^{14}C decreases as a function of time with half-life of 5730 years. After measuring the remaining ^{14}C activity (A), the carbon-14 age (t) of the specimen can be read from this graph or can be calculated from Equation 22.5



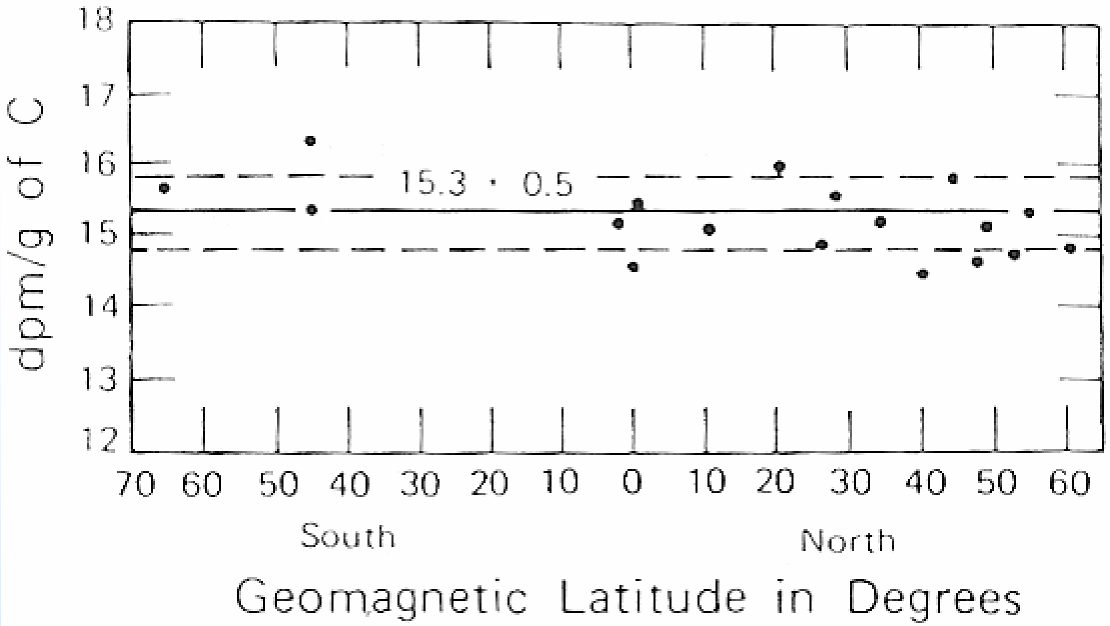


Figure 22.2 Measurements of the specific activity of ^{14}C in contemporary samples of plant tissue from different geomagnetic latitudes on the Earth. These data were used by Anderson and Libby (1951) to demonstrate that the ^{14}C activity of biospheric samples is essentially constant and independent of latitude. Their average specific activity was 15.3 ± 0.5 dpm/g of carbon. This value has been superseded by more recent determinations using more efficient detection equipment which indicate a value of 13.56 ± 0.07 dpm/g of carbon (Libby, 1955).

Table 17.1 Material Suitable for Dating by the Carbon-14 Method

MATERIAL	AMOUNT REQUIRED IN GRAMS	COMMENTS
Charcoal and wood	25	Usually reliable, except for finely divided charcoal which may adsorb humic acids, removable by treatment with NaOH. Subject to "post-sample-growth error," i.e., difference in time between growths of tree and use of the wood by humans.
Grains, seeds, nutshells, grasses, twigs, cloth, paper, hide, burned bones	25	Usually reliable. These materials are "short lived" and have negligible post-sample-growth errors.
Organic material mixed with soil	50–300	Should contain at least 1% organic carbon in the form of visible pieces. Efforts should be made to remove as much soil as possible in the field.
Peat	50–200	Often reliable, but intrusive roots of modern plants must be removed. The coincidence of peat formation with the occupation of archaeological sites requires careful consideration.
Ivory	50	Often well preserved and reliable. Interior of tusks is younger than the exterior. Some ivory tools may have been carved from old rather than contemporary material.
Bones (charred)	300	Heavily charred bones are reliable. Lightly charred bones are not, because exchange with modern radiocarbon is possible.

Table 17.1 Material Suitable for Dating by the Carbon-14 Method

MATERIAL	AMOUNT REQUIRED IN GRAMS	COMMENTS
Shells (inorganic carbon)	100	The carbon in calcite or aragonite of shells may exchange with radiocarbon in carbonate-bearing groundwater. Shell carbon may be initially enriched in ^{14}C relative to wood due to isotope fractionation. It may also be depleted in ^{14}C due to incorporation of "dead" carbon derived by weathering of old carbonate rocks. The reliability of "shell dates" is therefore questionable.
Shells (organic carbon)	Several kilograms	Organic carbon is present in the form of conchiolin which makes up 1 to 2% of modern shells. Dates may be subject to systematic errors due to uncertainty of initial ^{14}C activity of this material.
Lake marl and deep-sea or lake sediment	Variable	Such materials are datable on the basis of the radiocarbon content of calcium carbonate. Special care must be taken to evaluate errors due to special local circumstances.
Pottery and iron	2 to 5 kg	Pottery sherds and metallic iron may contain radiocarbon that was incorporated at the time of manufacture. Reliable dates of such samples have been reported.

[a] The approximate amounts of material required for dating are based on the assumption that 6 grams of carbon should be available which is sufficient to fill an 8-liter counter with CO_2 at a pressure of 1 atmosphere.

<u>Testing back through time</u>:

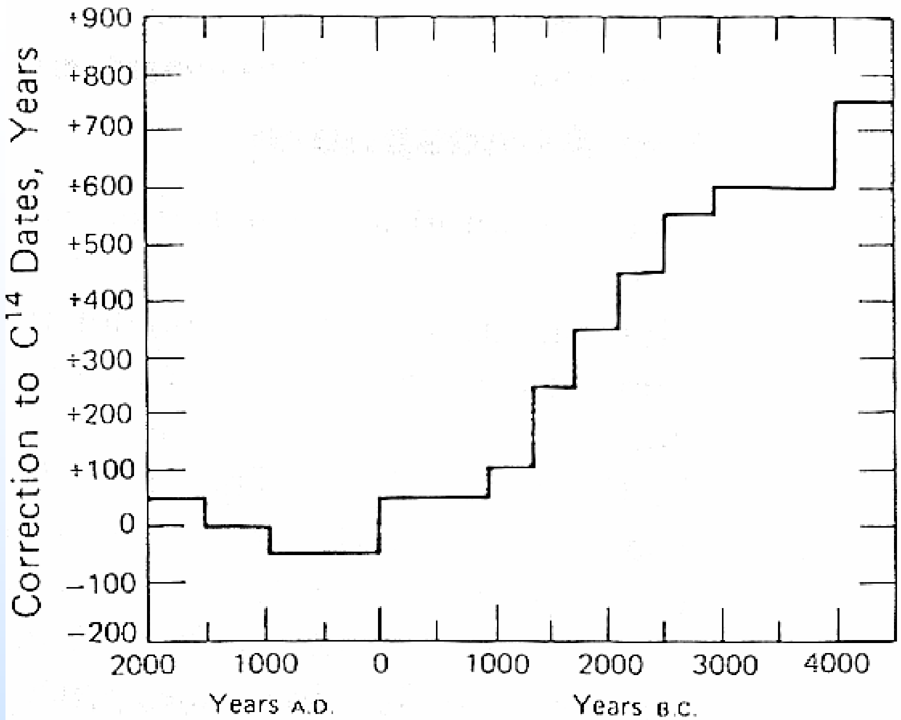
* 4000 B.C. → know age of death of "mummies" and can measure the ^{14}C and check the variation over 6000 years.

  [→ Not really beyond this point –that is bootstrapping]

* 10,000 years back → tree rings.

  [Beyond this point, big time changes in $^{14}C/C$ ratios; obscured by
  no reliable time estimates.]

* $N = N_o e^{-\lambda t}$ works if we known N_o



C^{14} Dates of Wood Using $T_{1/2}$ = 5730 Years

Figure 22.3 Corrections that must be added to radiocarbon dates to bring them into agreement with tree-ring dates, based on 143 analyses of wood of sequoia and bristlecone that were dated by dendrochronology. These systematic deviations in the radiocarbon dates are due to variations in the radiocarbon content of the atmosphere in the past 6000 years. (Michael and Ralph, 1970). A more detailed and more accurate comparison between carbon-14 and dendrochronology dates for the time interval A.D. 1840 to B.C. 4760 has been published by Ralph et al. (1973).

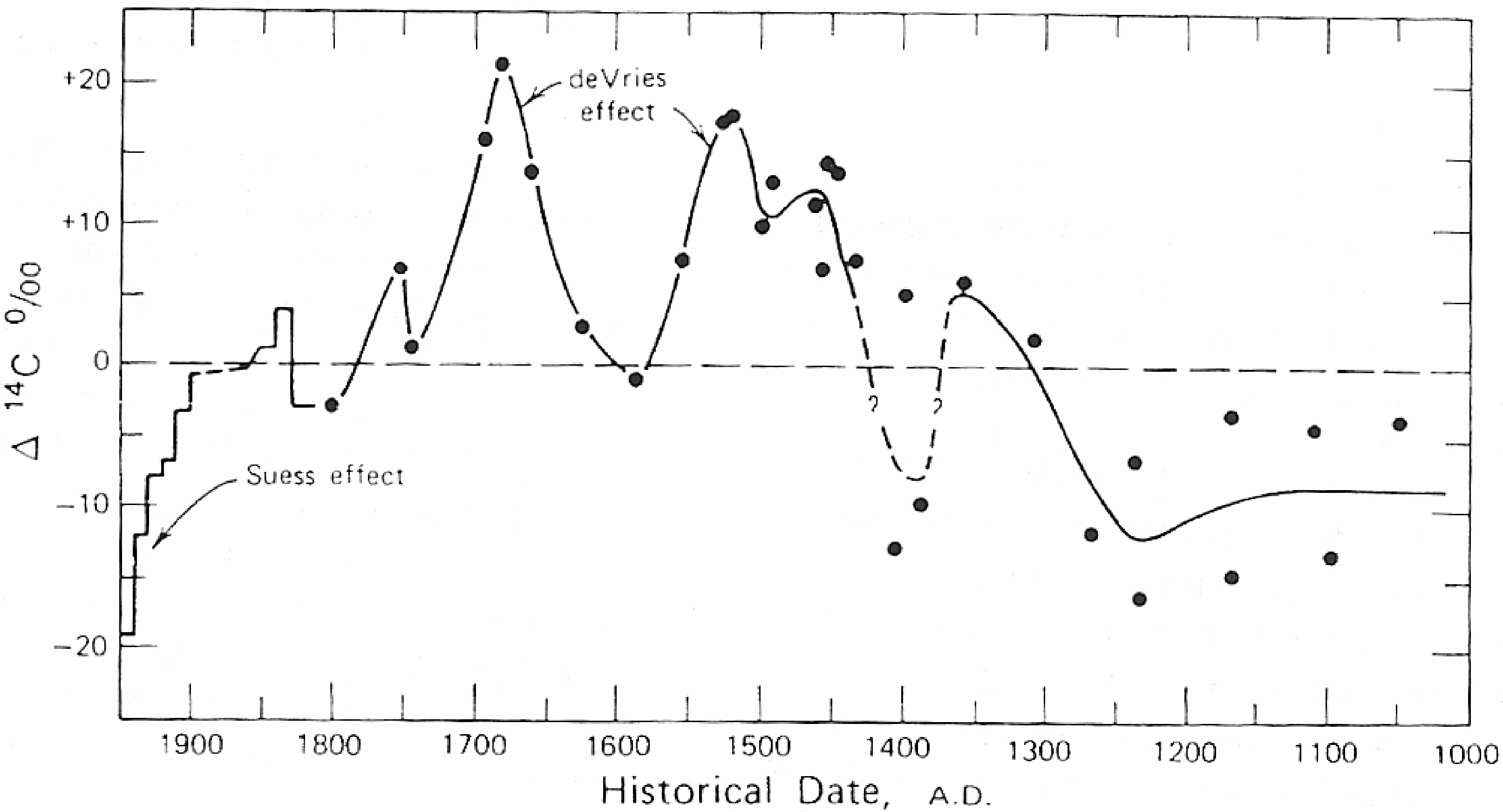


Figure 22.4 Deviation of the initial radiocarbon activity in per mil of wood samples of known age relative to 95 percent of the activity of the oxalic acid standard of the National Bureau of Standards. The observed activities were corrected for carbon isotope fractionation and recalculated using a value of 5730 years for the half-life of ^{14}C. The decline in the radiocarbon content starting at about 1900 results from the introduction of fossil CO_2 into the atmosphere by the combustion of fossil fuels (Suess effect). The anomalously high radiocarbon activity around 1710 and 1500 A.D. is known as the "de Vries effect." Its causes are not understood. (Data from Table 6a and b of Lerman et al., 1970.)

How is the measured amount of ^{14}C calibrated?

- Corals incorporate ^{238}U and ^{230}Th (dominant isotope: ^{232}Th) into their skeletons
- Since there is not ^{230}Th in sea water, it forms by decay:

$^{238}U \rightarrow\rightarrow\ ^{230}Th$ Half lives: ^{238}U -- 4.5by ; ^{230}Th – 70,000y

* By measuring the amount of ^{230}Th present, the age of the coral is simply a function of the half-life!
* Good for establishing dates up to 150,000 years.

- After this point, the Th begins to itself decay into ^{226}Ra (Radium) and at about 350,000 years, the amount of Th being produced equals the amount being decayed.

→ This calibration can be used to find an age with a conversion (if don't use calibration than a difference of 10,000 to 20,000 years will give an error of 10 - 20%).

* Know that cosmic ray intensity has changed.

13.6 dpm of ^{14}C/g of C → = 2.3 x 10-10

11,400 years (of at 5700 year half-life)

→ 13.6/4 = 3.4 dpm/gC assuming that 13.6 was the starting point.

* If 15 dpm/gC was the starting point than = 3.7 (and object will appear to be much younger than it actually is)
* If more ^{14}C produced in the atmosphere gives rise to a higher residual ratio, than the object will appear younger → good evidence that this is the case.

How much ^{14}C cycles through the ocean?

- Surface ocean contains 60 times the HCO_3^- than the CO_2 in the atmosphere.
- In glacial times, the concentration of CO_2 in the atmosphere was about 200 ppm (60 to 80 ppm lower than pre-1800).

→ Therefore the distribution between the atmosphere and the oceans was different in glacial vs. interglacial times. Glaciation would also cause a higher ratio in the atmosphere.

Not clear which process is more dominant:

1. Distribution in ocean vs. atmosphere

   or

2. Ocean as a buffer.

- ^{14}C used in almost all of glacial calculations to find glacial retreat age estimates. The process has been getting easier because now you need less C to test (only a few milligrams). Large accelerators are used;

  ie. Nuclear structure lab- get high accuracy.
- Method used by archeologists and oceanographers - need only a single shell or tooth, more homogeneity.