Fényképalbum12

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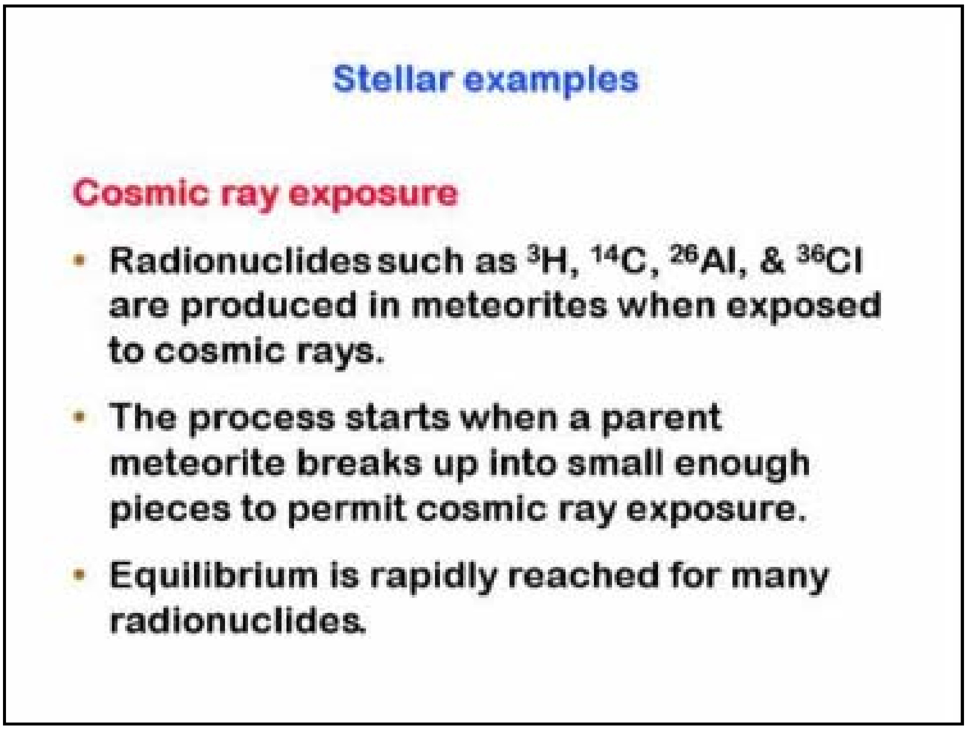


Stellar examples

Cosmic ray exposure

- Radionuclides such as ^{3}H, ^{14}C, ^{26}Al, & ^{36}Cl are produced in meteorites when exposed to cosmic rays.
- The process starts when a parent meteorite breaks up into small enough pieces to permit cosmic ray exposure.
- Equilibrium is rapidly reached for many radionuclides.

Nuclear dating

Nuclear decay has been used to measure the 'age' of a many samples.

Once living materials
Artifacts
Rocks
Meteorites
Natural waters
Solar system

Nuclear dating

All dating methods rely on:

$$N_1 = N_0\, e^{-\lambda(t_0 - t_1)}$$

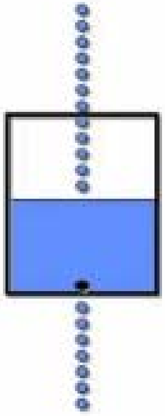
$$t_0 - t_1 = \frac{1}{\lambda} \ln \frac{N_0}{N_1}$$

N_0 - quantity of radionuclide present at t_0
N_1 - quantity of radionuclide present at t_1
λ - decay constant for the species.

Nuclear dating

- We can typically assume that decay constants are independent of chemical form, temperature, pressure and other phenomena.
- The problem with dating methods is knowing the original amount of the parent radionuclide.
- Two methods can be used - **equilibrium decay clock** and **accumulation clock**.

Equilibrium decay clock

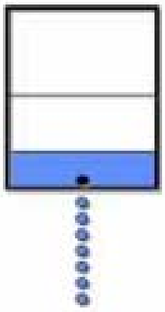


With this model, an equilibrium for the parent is reached where the rate of production and decay are the same.

This holds as long as the parent is being produced.

The equilibrium level represents N_0 at t_0

Equilibrium decay clock



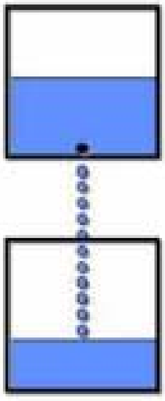
If parent is no longer produced, the level will decrease as a function of time.

$$A_t = A_0 e^{-\lambda t}$$

^{14}C and tritium dating both rely on this approach.

Both radionuclides are constantly produced by cosmic rays and are in equilibrium with the environment.

Accumulation clock



This type of dating relies on the decay of the parent into a stable nuclide, which simply accumulates.

The system must be chemically closed - no parent or daughter can enter or leave the system.

This approach is used for many geological dating methods such as the U-Pb, Rb-Sr and K-Ar methods.

Nuclear dating

Three general types.

Geochronology	Looks at long half-life isotopes to date minerals.
Tritium dating	Good for determining the age of natural waters.
Carbon dating	Use a radioactive form of carbon to look at things that were once alive.

Carbon dating

^{14}C is constantly being produced by the Sun an an almost constant rate.

$$^{14}N + {}^{1}n \longrightarrow {}^{14}C + {}^{1}H$$

Since it is produced as a 'hot atom', it rapidly combines with oxygen to produce CO_2.

$$^{14}C + O_2 \longrightarrow {}^{14}CO_2$$

Carbon dating

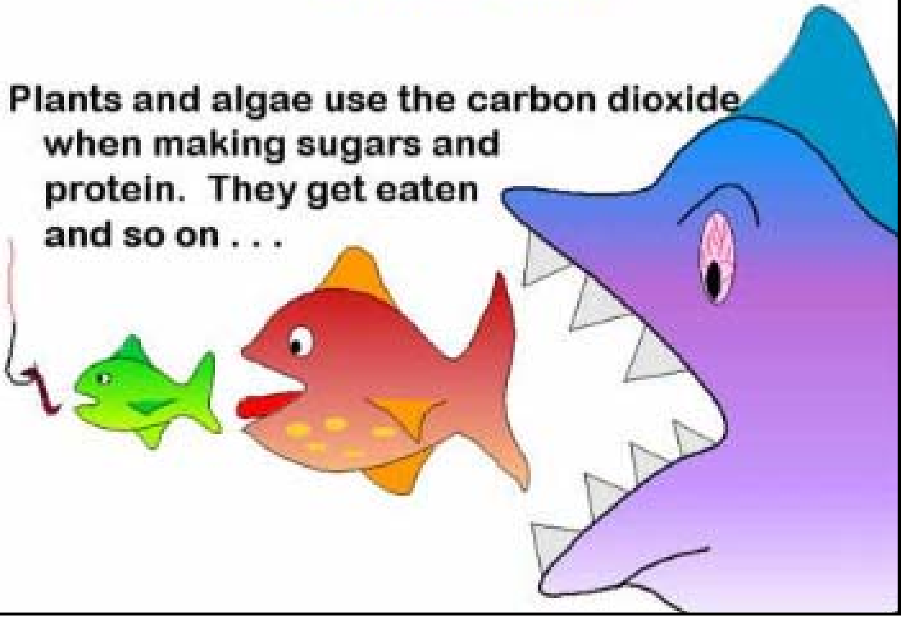
Assumptions

- ^{14}N levels and production of ^{1}n have been relative constant for the last 50,000 years.
- The 'natural' abundances of ^{12}C and ^{13}C have not altered in our environment.
- As a result, the average level of ^{14}C has been 16 dpm / g carbon.
- ^{14}C is in equilibrium will all 'living carbon.'

We know that these are not 'perfect' and corrections can and have been made.

Carbon dating

Plants and algae use the carbon dioxide when making sugars and protein. They get eaten and so on . . .



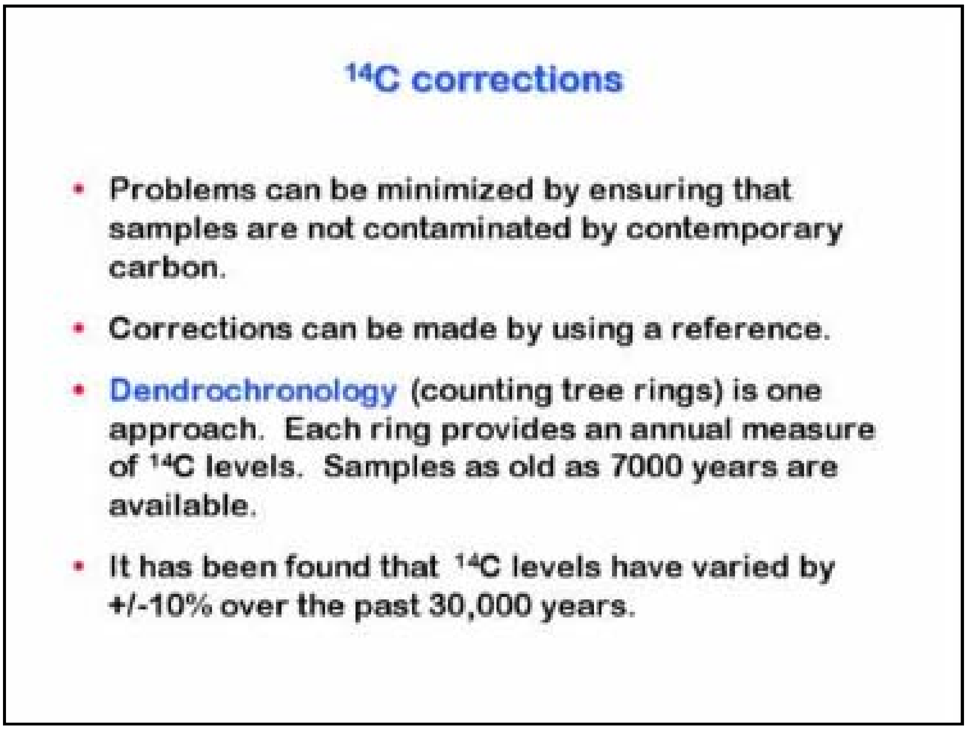
Carbon dating

- After death, the carbon-14 decays with a half-life of 5760 years.
- We tell how old things are based on the amount of carbon-14 that remains.
- The method is pretty good in 1,000-20,000 year range.
- Ideal tool for dating the artifacts of man
  - or at least it was!

^{14}C corrections

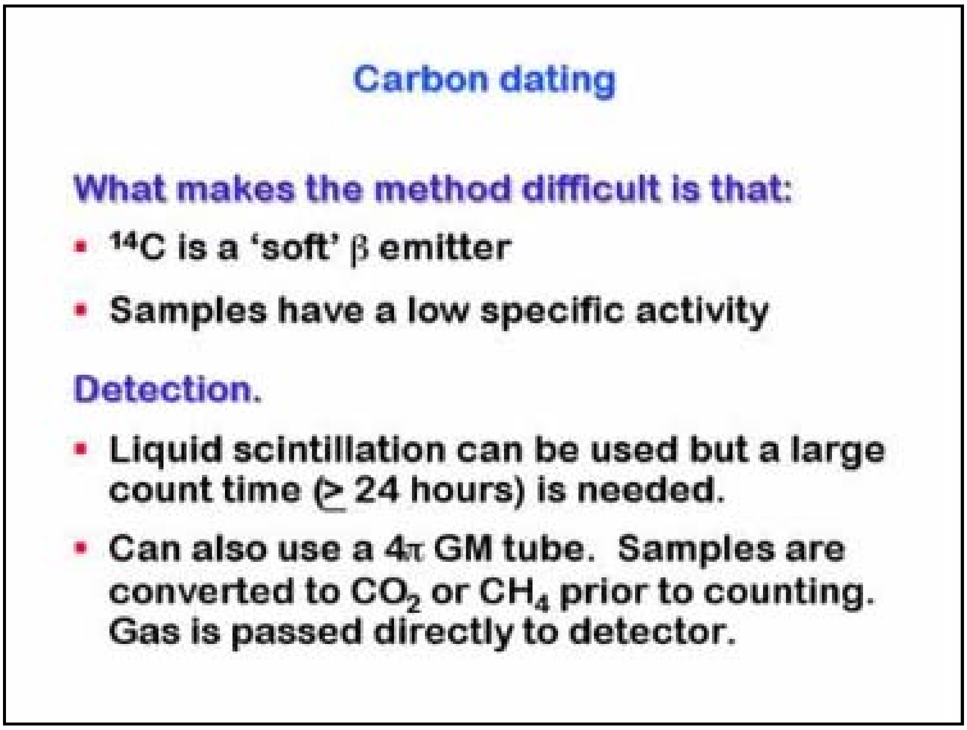
The assumption that ^{14}C levels are constant is not true. Corrections are required.

- Over time, small changes in solar activity have resulted in variations in ^{14}C activity.
- Man has also caused changes:
  - Burning of fossil fuels reduce the specific activity for ^{14}C in the atmosphere.
  - Suess effect - doubling of ^{14}C levels due to nuclear testing.



^{14}C corrections

- Problems can be minimized by ensuring that samples are not contaminated by contemporary carbon.
- Corrections can be made by using a reference.
- Dendrochronology (counting tree rings) is one approach. Each ring provides an annual measure of ^{14}C levels. Samples as old as 7000 years are available.
- It has been found that ^{14}C levels have varied by +/-10% over the past 30,000 years.



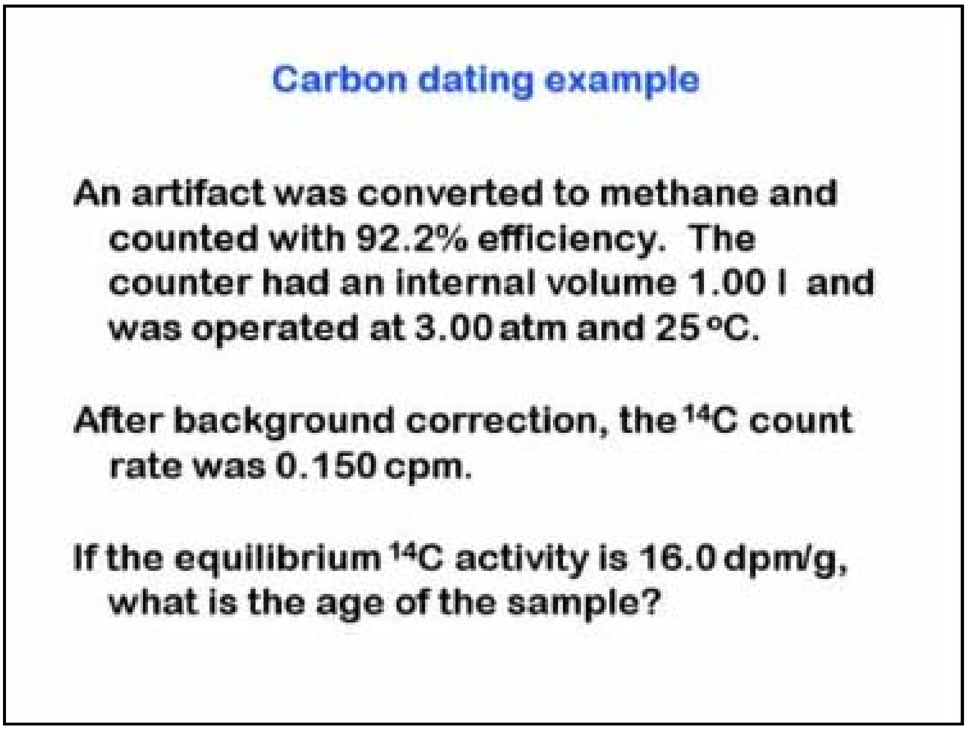
Carbon dating

What makes the method difficult is that:

- ^{14}C is a 'soft' β emitter
- Samples have a low specific activity

Detection.

- Liquid scintillation can be used but a large count time ($\geq$ 24 hours) is needed.
- Can also use a 4π GM tube. Samples are converted to CO_2 or CH_4 prior to counting. Gas is passed directly to detector.

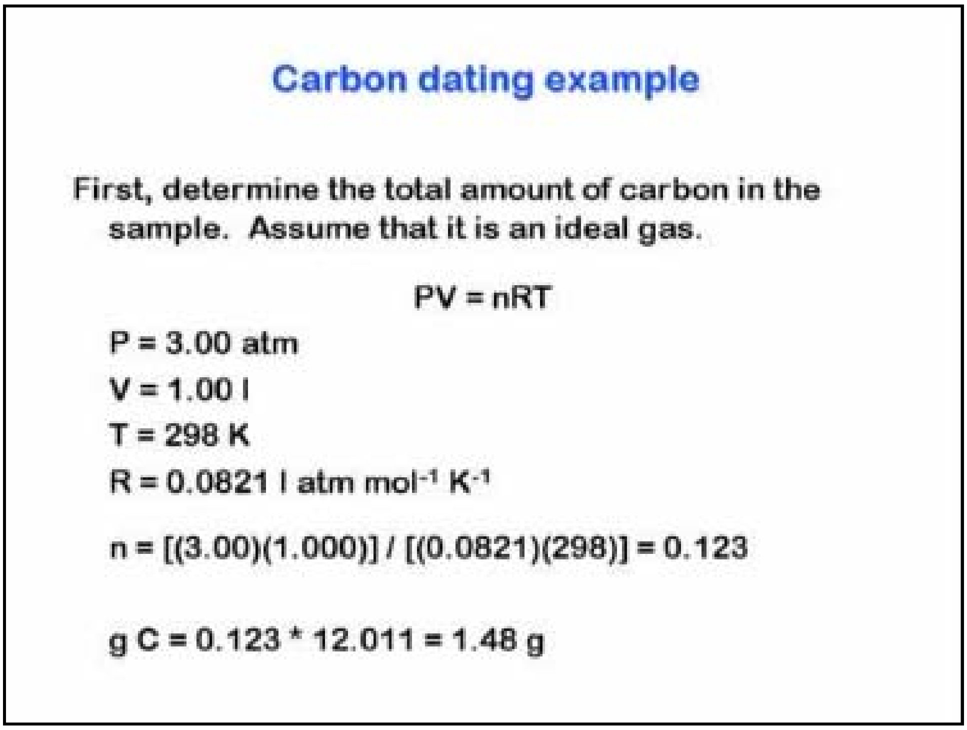


Carbon dating example

An artifact was converted to methane and counted with 92.2% efficiency. The counter had an internal volume 1.00 l and was operated at 3.00 atm and 25 °C.

After background correction, the ^{14}C count rate was 0.150 cpm.

If the equilibrium ^{14}C activity is 16.0 dpm/g, what is the age of the sample?



Carbon dating example

First, determine the total amount of carbon in the sample. Assume that it is an ideal gas.

$$PV = nRT$$

$P = 3.00$ atm

$V = 1.00$ l

$T = 298$ K

$R = 0.0821$ l atm mol^{-1} K^{-1}

$n = [(3.00)(1.000)] / [(0.0821)(298)] = 0.123$

g C = $0.123 * 12.011 = 1.48$ g

Carbon dating example

The count rate was 0.150 cpm with 92.2% efficiency so the actual activity was:

activity = (0.150 cpm)/0.922
= 0.163 dpm

Since we had 1.48 g carbon, the specific activity was:

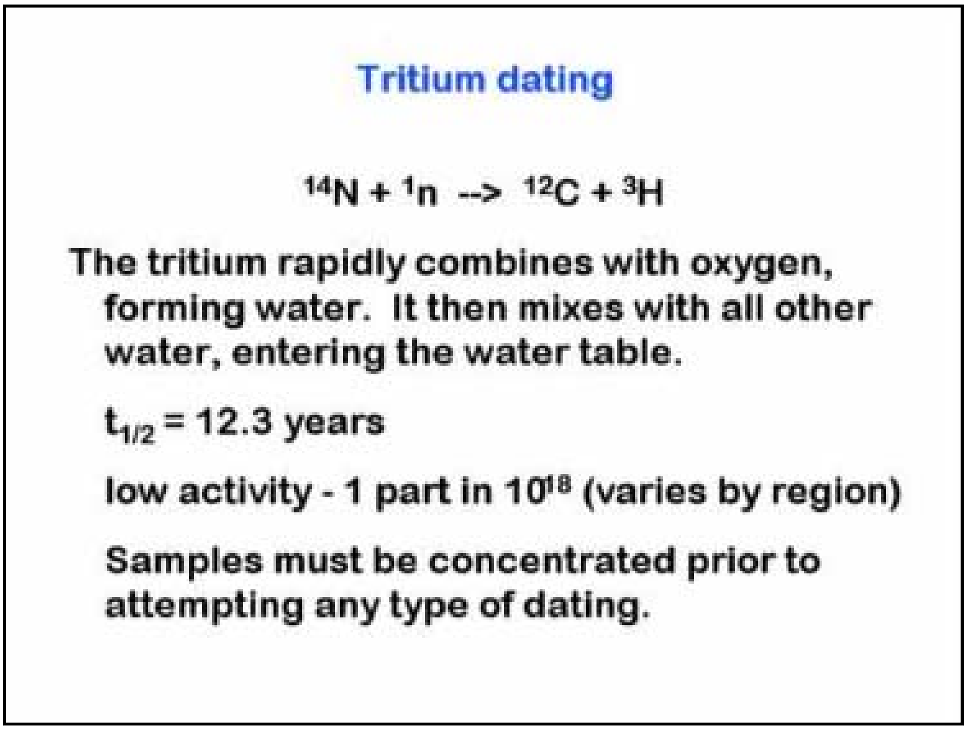
SA = 0.163 dpm / 1.48 g
= 0.110 dmp/g C

Carbon dating example

$$SA_1 = SA_0\, e^{-\lambda t}$$

$t_{1/2}$ = 5730 y
λ = 0.693 / 5730 y = 1.21×10^{-4}
SA_1 = 0.110 dmp/g
SA_0 = 16.0 dpm/g

$\ln(SA_0/SA_1) / \lambda = t$ = 41,200 years



Tritium dating

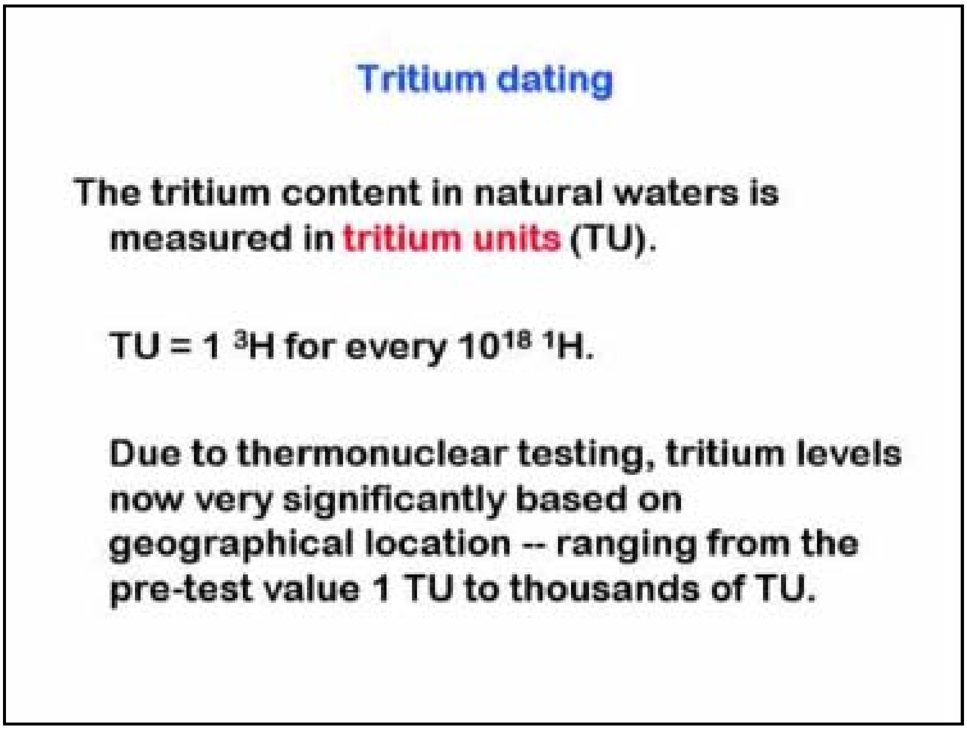
$^{14}N + ^{1}n \rightarrow ^{12}C + ^{3}H$

The tritium rapidly combines with oxygen, forming water. It then mixes with all other water, entering the water table.

$t_{1/2}$ = 12.3 years

low activity - 1 part in 10^{18} (varies by region)

Samples must be concentrated prior to attempting any type of dating.



Tritium dating

The tritium content in natural waters is measured in **tritium units** (TU).

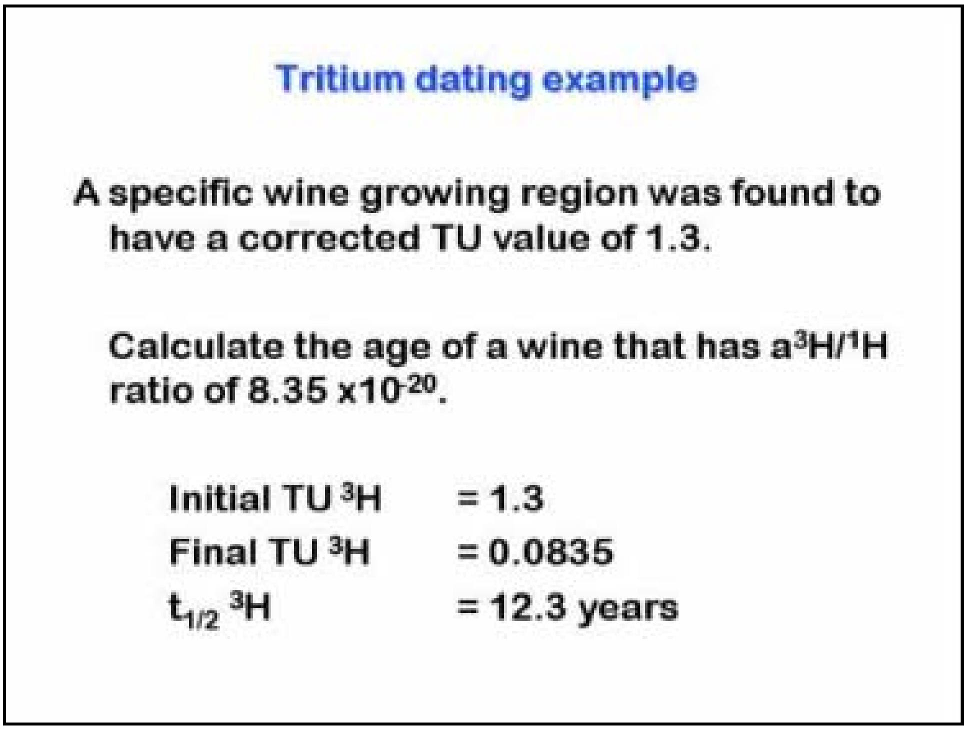
TU = 1 ^{3}H for every 10^{18} ^{1}H.

Due to thermonuclear testing, tritium levels now very significantly based on geographical location -- ranging from the pre-test value 1 TU to thousands of TU.

Tritium dating

Applications

- Used to trace water sources.
- Sources directly fed by rainwater will contain the same levels as rain water.
- Trapped aquifers will have no tritium.
- Slow traveling aquifers will have a reduced amount.
- Age of 'recent' materials.



Tritium dating example

A specific wine growing region was found to have a corrected TU value of 1.3.

Calculate the age of a wine that has a $^3H/^1H$ ratio of 8.35×10^{-20}.

Initial TU ^3H = 1.3
Final TU ^3H = 0.0835
$t_{1/2}$ ^3H = 12.3 years

Tritium dating example

$$SA_1 = SA_0\, e^{-\lambda t}$$

$t_{1/2}$ = 12.3 y

λ = 0.693 / 12.3 y = 0.0563

SA_1 = 0.0835 TU

SA_0 = 1.3 TU

$\ln(SA_0/SA_1) / \lambda$ = t = 48.8 years

Geochronology

Method is based on some assumptions.

- Prior to sample formation, all materials were free to move - molten.
- A radioactive nuclide parent (P) will ultimately decay to a daughter species (D)
- Measurement of the D/P ratio and knowledge of the $t_{1/2}$ of the parent will give an estimate of the age of the sample.

$$\text{age} = \ln(1 + D/P) / \lambda$$

Geochronology

Method is restricted to structures which:

- Still contain some of the parent nuclei.
- Allowed for no gain or loss of D or P as time passed.
- Initially contained no D.

They typically involve measuring members of a decay path.

He accumulation method

Helium clock

- Based on the fact that ^{235}U, ^{238}U and ^{232}Th emit 7,8 and 6 α particles respectively in their decay to Pb.
- The amount of U and Th can be determined chemically and the current rate of He production also easily calculated.
- The sample is heated to release the He and the helium-retention age is calculated.

U - Pb systems

^{238}U -> intermediates -> ^{206}Pb

$t_{1/2}$ = 4.51 x 10^9 years

λ = 1.54 x 10^{-10} / year

^{235}U -> intermediates -> ^{207}Pb

$t_{1/2}$ = 7.1 x 10^8 years

λ = 9.7 x 10^{-10} / year

Both are chemicaly closed systems.

Geochronology

Rb -> Sr system

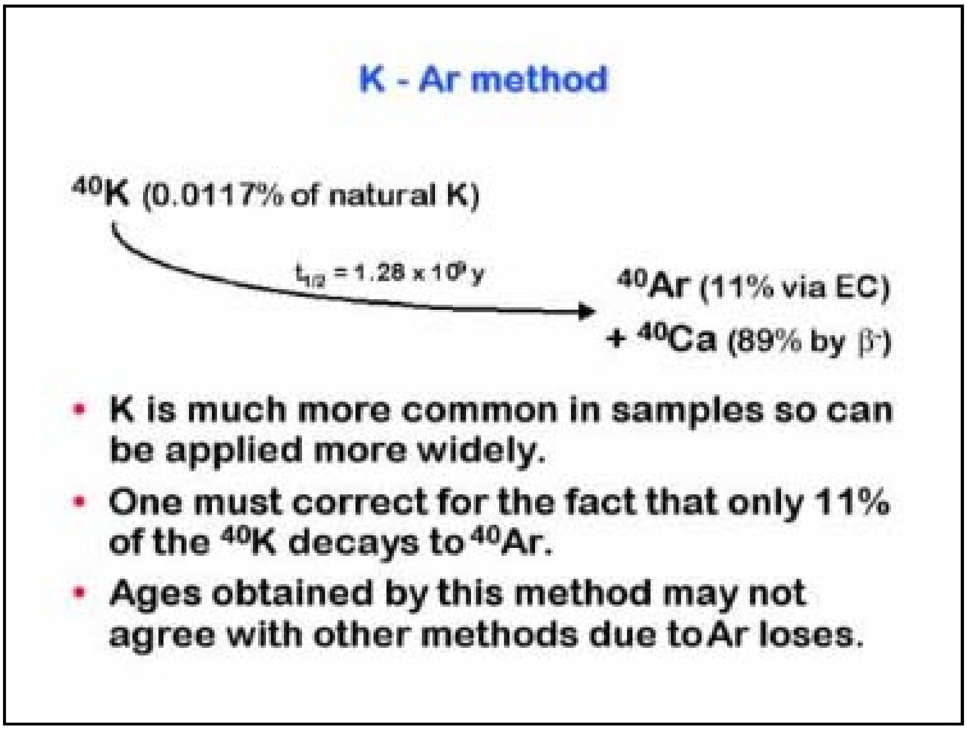
^{87}Rb --> ^{87}Sr

$t_{1/2}$ = 4.85 x 10^{10} years

λ = 1.43 x 10^{-11} / year

^{87}Sr is nonradioactive and quite common in nature.

The initial amount of Sr can be accounted for by determining the amount of ^{88}Sr present in the same sample.



K - Ar method

^{40}K (0.0117% of natural K)

$$^{40}K \xrightarrow{t_{1/2} = 1.28 \times 10^9\ y} {}^{40}Ar\ (11\%\ \text{via EC}) + {}^{40}Ca\ (89\%\ \text{by}\ \beta^-)$$

- K is much more common in samples so can be applied more widely.
- One must correct for the fact that only 11% of the ^{40}K decays to ^{40}Ar.
- Ages obtained by this method may not agree with other methods due to Ar loses.