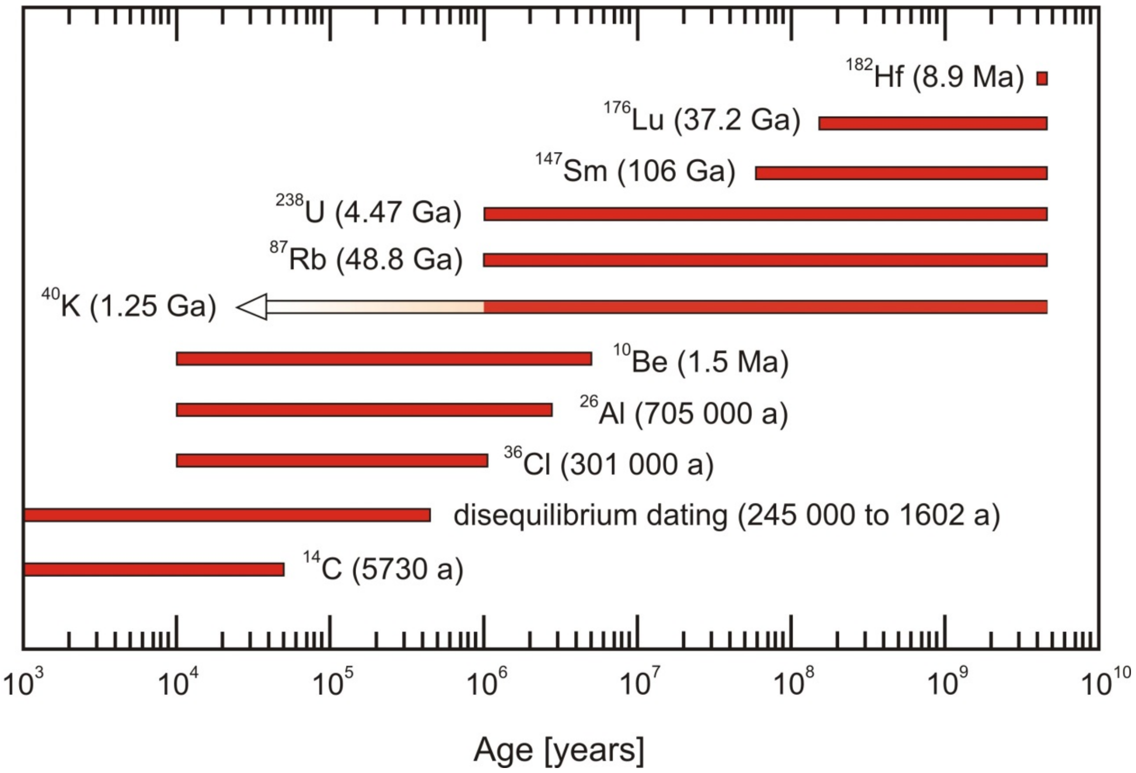
Tools and methods



Geochronology

Methods relying on the decay of naturally occurring radiogenic isotopes:

Parent isotope		Daughter isotope
1. Potassium-40	->	Argon-40
2. Rubidium-87	->	Strontium-87
3. Uranium-235	->	Lead-207
4. Uranium-238	->	Lead-206
5. Thorium-232	->	Lead-208

Radioactivity

Natural and artificial radioactivity

Natural radioactivity

Isotopes that have been here since the earth formed: 238U, 235U, 232Th, 40K

Isotopes produced by cosmic rays from the sun, i.e cosmogenic radionuclides: 14C, 10Be, 36Cl

Synthetic radioisotopes

Made in nuclear reactors when atoms are split (fission).

Produced usinc cyclotrons, linear accererators...

$$^{39}_{19}K\ (n, p)\ ^{39}_{18}Ar$$

The dawn of radiometric dating

“U-Pb” method

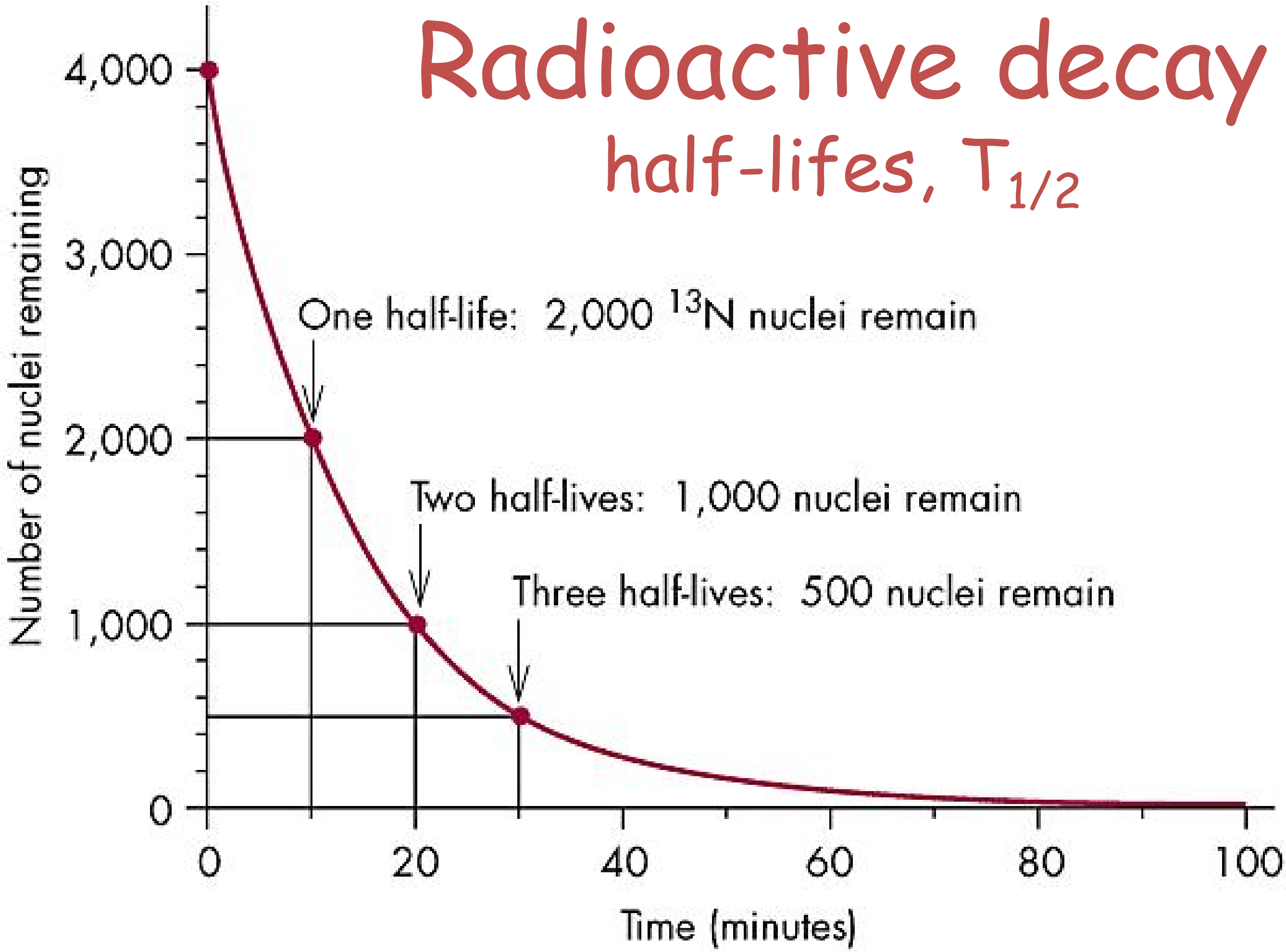
- Boltwood studied radioactive elements and found that Pb was always present in uranium and thorium ores. Pb must be the final product of the radioactive decay.
- In 1907, he reasoned that since he knew the rate at which uranium breaks down (its half-life), he could use the proportion of lead in the uranium ores (chemical dating, isotopes not discovered yet) as a meter or clock.
- His observations and calculations put Earth's age at 2.2 billion years.

He accumulation method

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

Radioactive decay

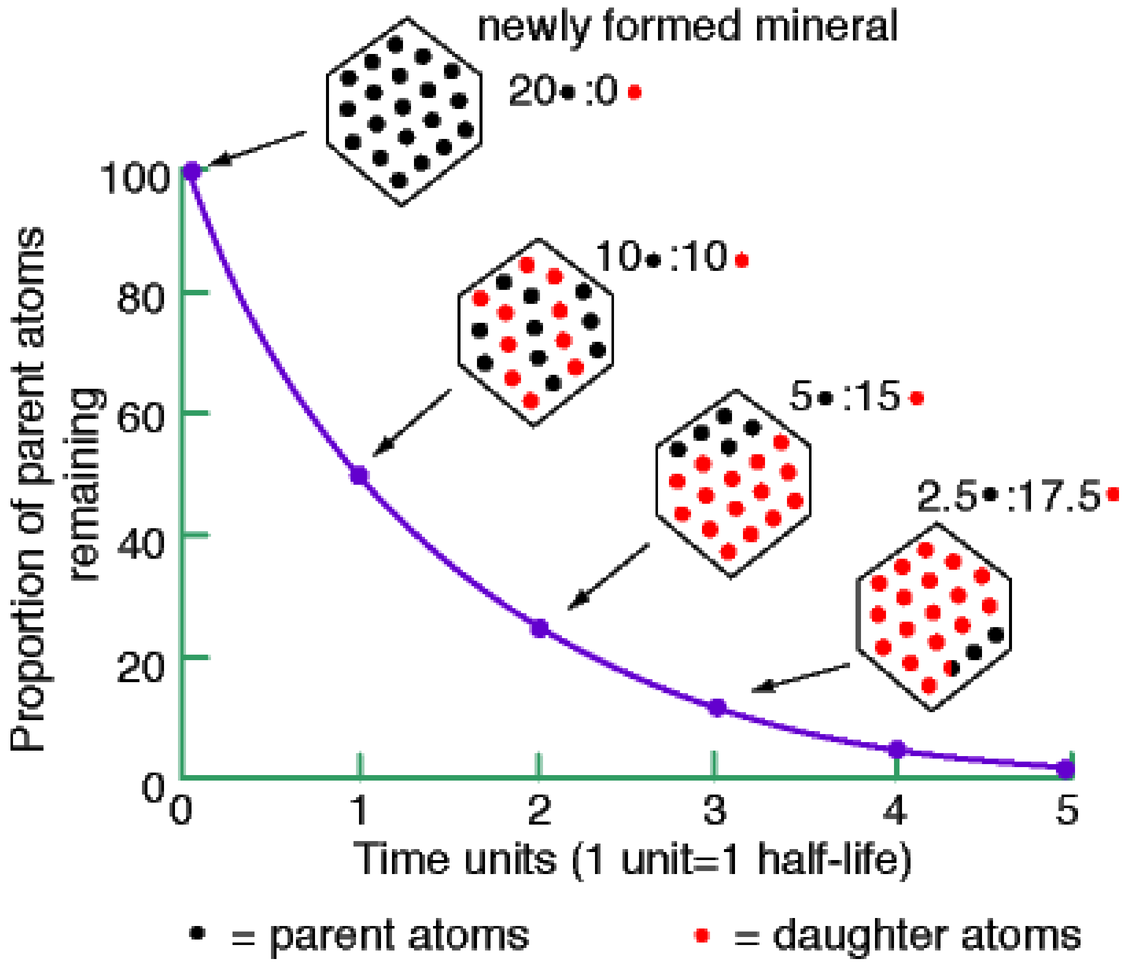
half-lifes, $T_{1/2}$



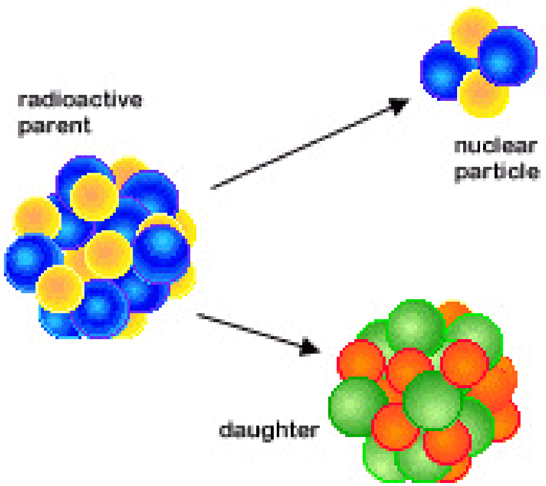
- if it is possible to determine the ratio of the PARENT and DAUGHTER atoms, it is then possible to determine how long ago the decay process started → age determination

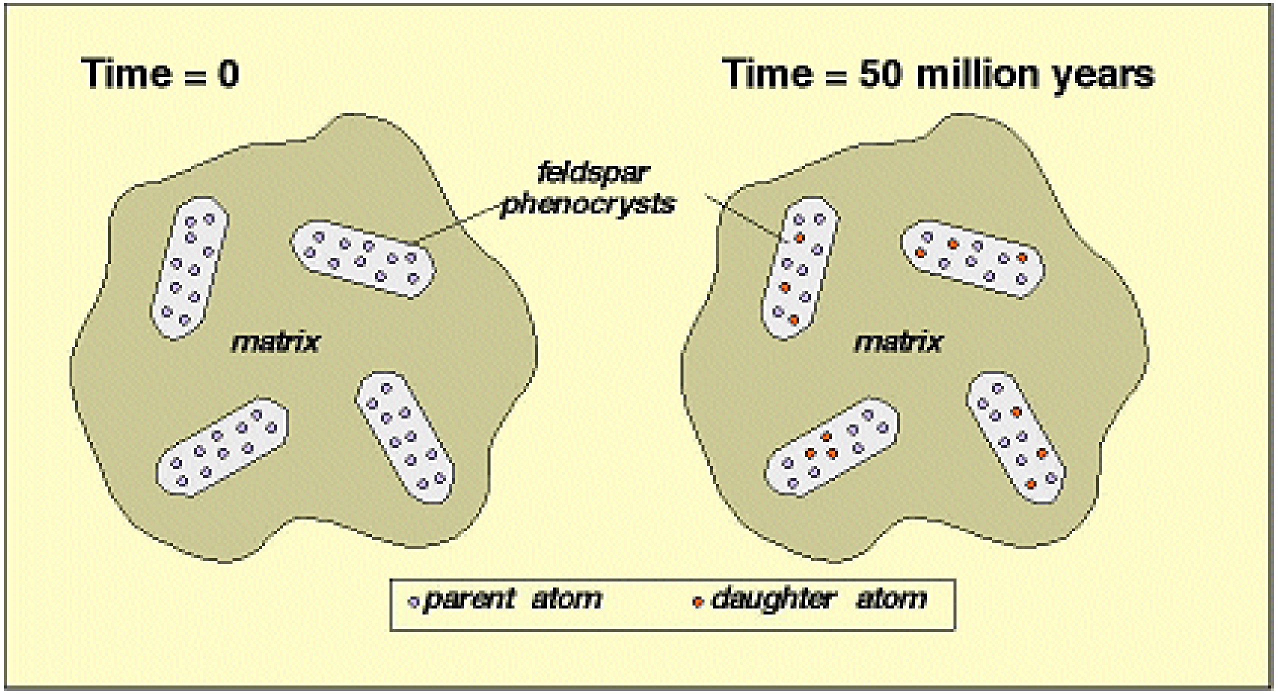
Radioactive decay

half-lifes, $T_{1/2}$



Radiometric dating

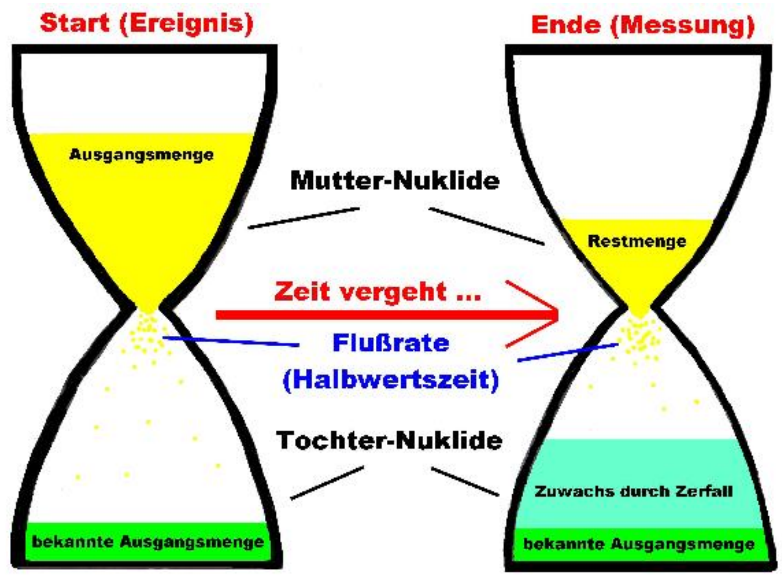




Radiometric dating

Method is restricted to minerals 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 (or D_0 must be known)



Radioactive decay

- Rate of decay is proportional to the number of decaying nuclei
- Integrate to find the change in N with time

$$\frac{dN}{dt} = -\lambda N$$

$$\frac{dN}{N} = -\lambda \cdot dt$$

λ = decay constant

Radioactive decay

- Integrate:

$$\int_{N_o}^{N(t)} \frac{1}{N}\, dN = -\int_0^t \lambda\, dt$$

- Find N(t):

$$N = N_0\, e^{-\lambda t}$$

Parent-Daughter system:

$$D = D_0 + N(e^{\lambda t} - 1)$$

Radioactive decay and age equation

Parent—daughter system:
$D = N_0 - N$
D – Number of daughter atoms, today
N – Number of parent atoms, today
N_0 – Number of parent atoms, initially present

$$N = N_o \cdot e^{-\lambda \cdot t}$$

or

$$N_O = N \frac{1}{e^{-\lambda t}} = Ne^{\lambda t}$$

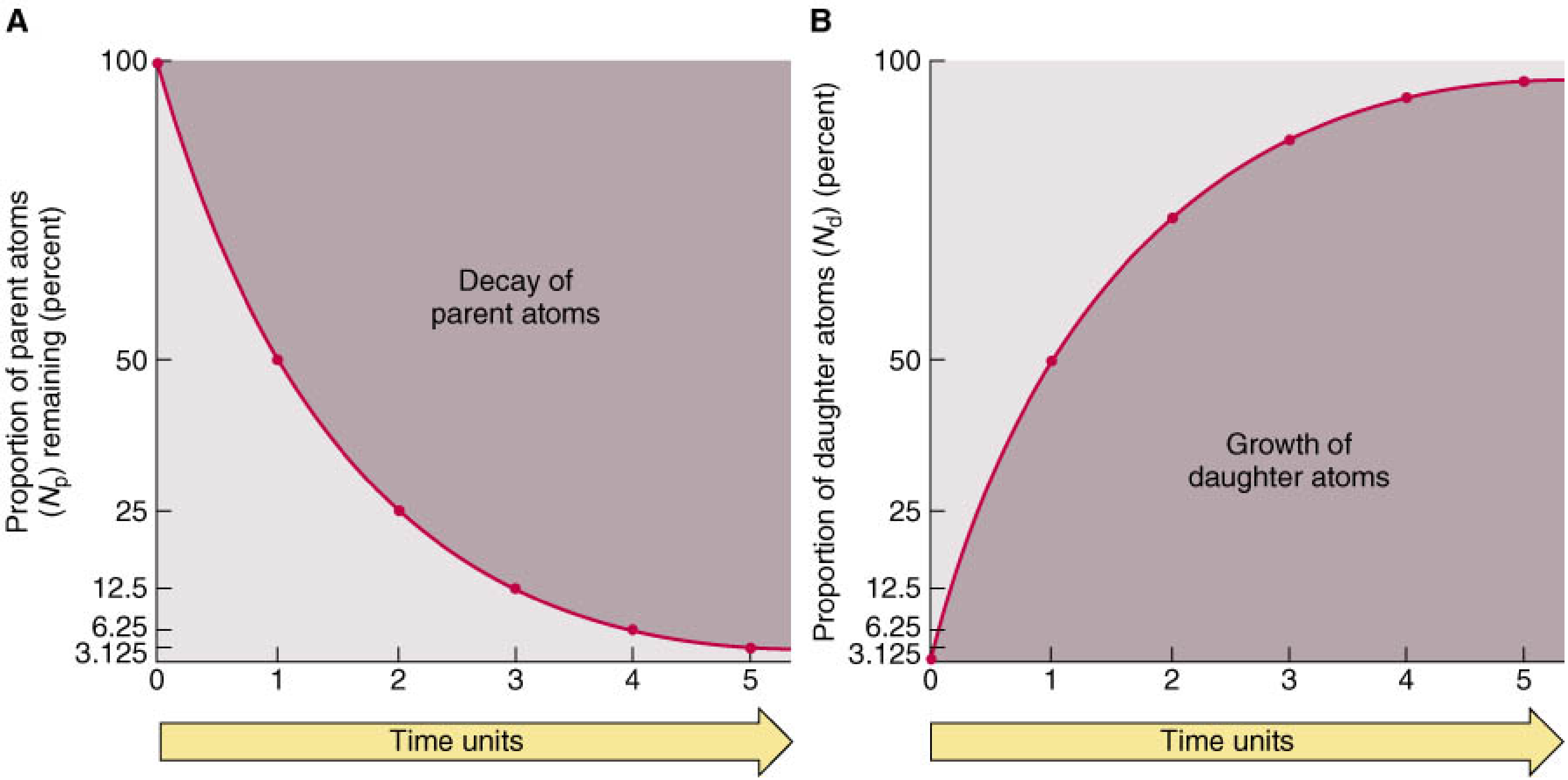
$N_0 = D + N$, hence: $D + N = Ne^{\lambda t}$, or $D = N e^{\lambda t} - N$, or $D = N(e^{\lambda t} - 1)$

$$t = \frac{1}{\lambda} \ln\left(1 + \frac{D}{N}\right)$$

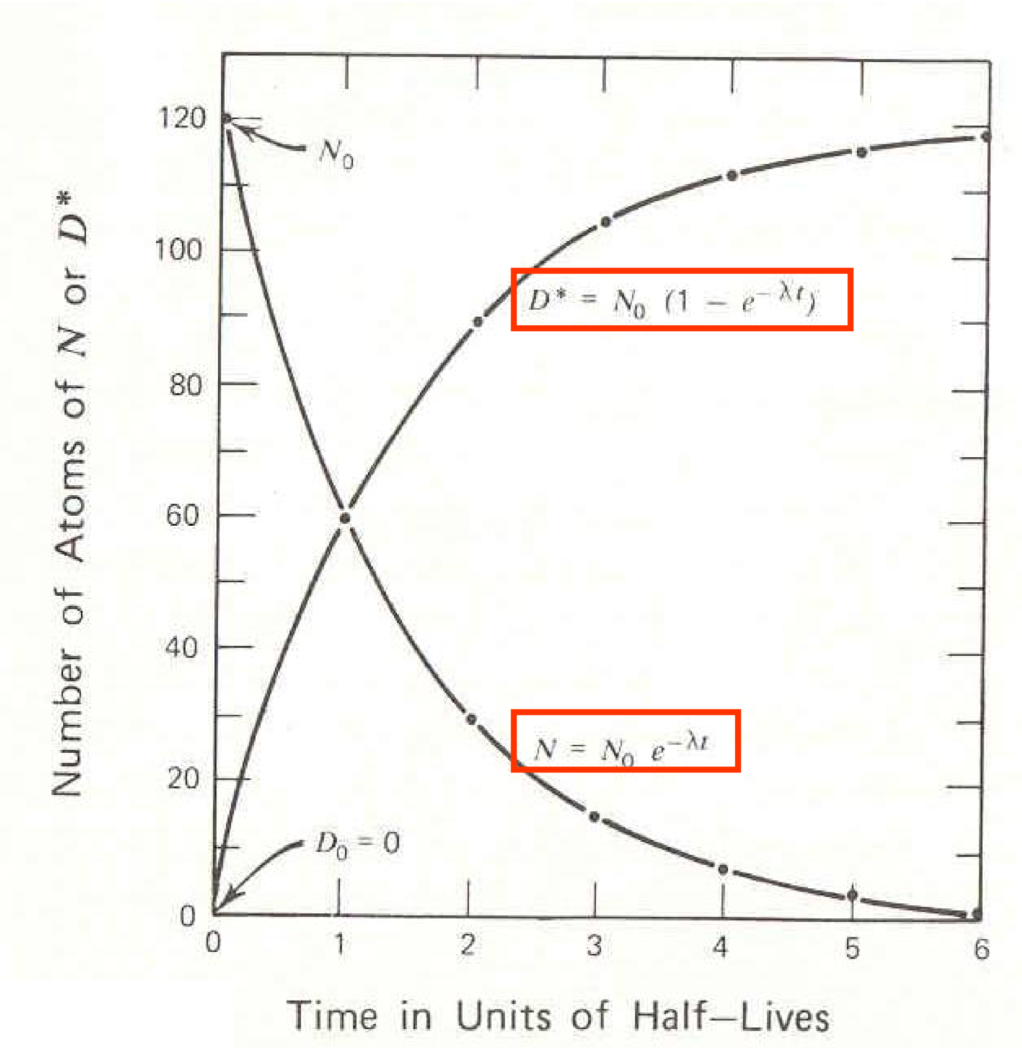
This is the mathematical expression that relates radioactive decay to geologic time!!

If some daughter nuclides, D_0, are there initially: ***$D = D_0 + N(e^{\lambda t} - 1)$***

Parent-Daughter system



Decay of radionuclide (N) to stable radiogenic daughter (D*)



$N = N_0 e^{-\lambda t}$

$D^* = N_0 - N$

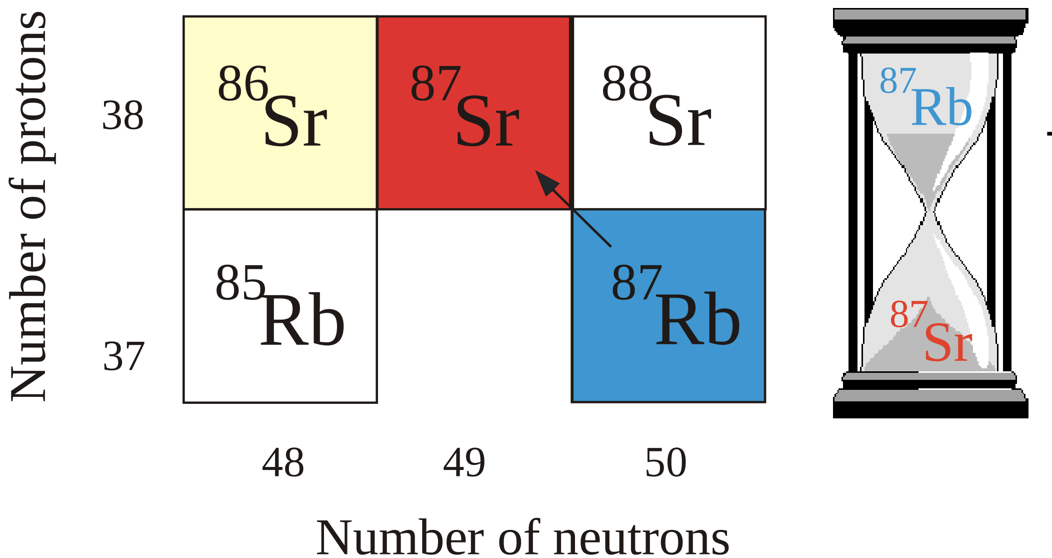
$D^* = N_0 - N_0 e^{-\lambda t}$

$D^* = N_0 (1 - e^{-\lambda t})$

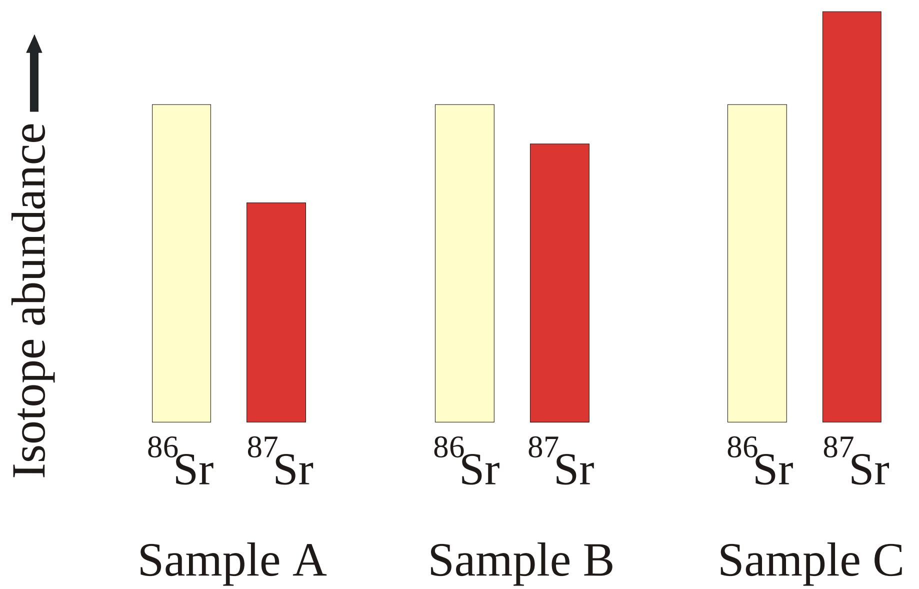
Auflösen nach t:

$$t = \ln(1 + D^*/N_0)/\lambda$$

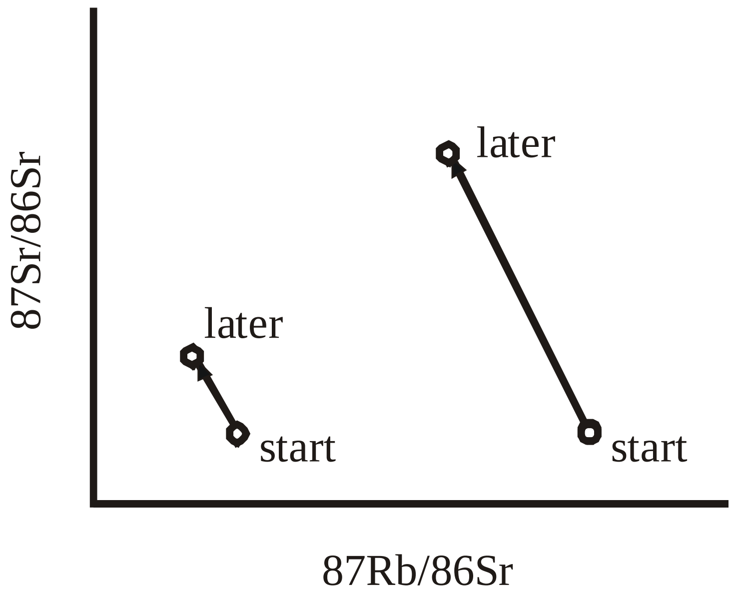
Rb–Sr system

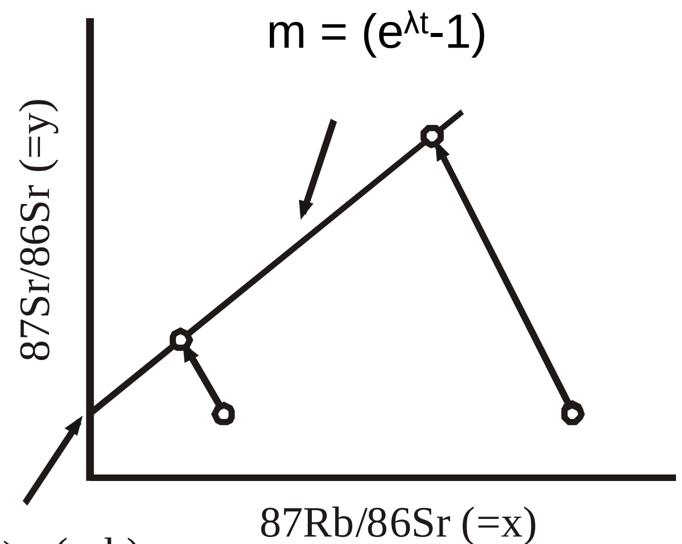


$T_{1/2} = 4.8 \times 10^{10}$ years



Rb–Sr system





$$^{87}Sr/^{86}Sr = (^{87}Sr/^{86}Sr)_0 + {}^{87}Rb/^{86}Sr\,(e^{\lambda t}-1)$$

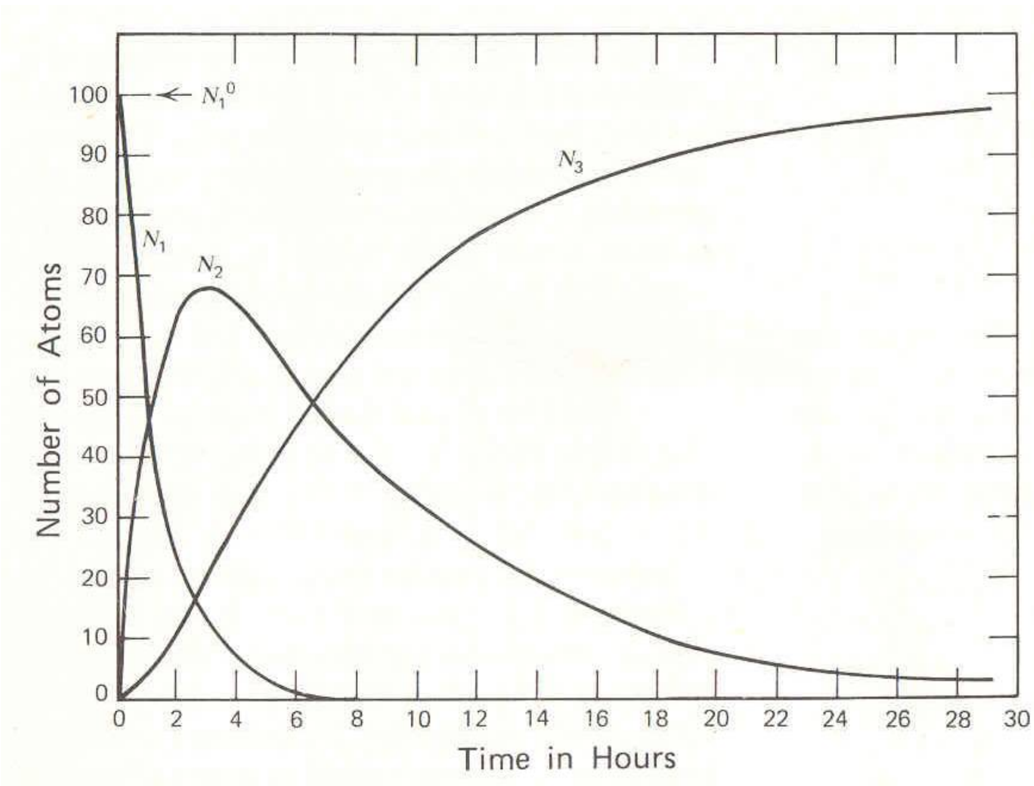
$$y \quad = \quad b \quad + \quad x \quad m$$

$$m = (e^{\lambda t}-1)$$

$$T = \ln(m + 1)/\lambda$$

Decay Series

Radioactive decay and growth in a three-component series

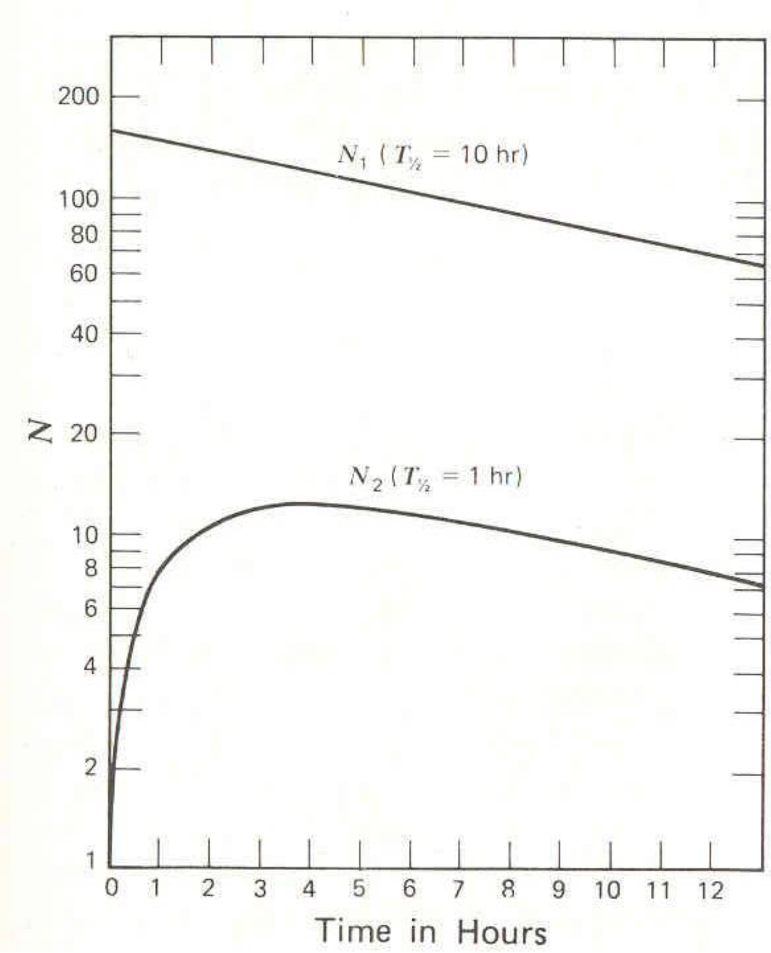


N_1: half-life = 1 hour
N_2: half-life = 5 hours
N_3: stable

Decay Series

Decay of a long-lived parent N_1 to a short lived daughter N_2

(similar to U-Pb decay-chain)

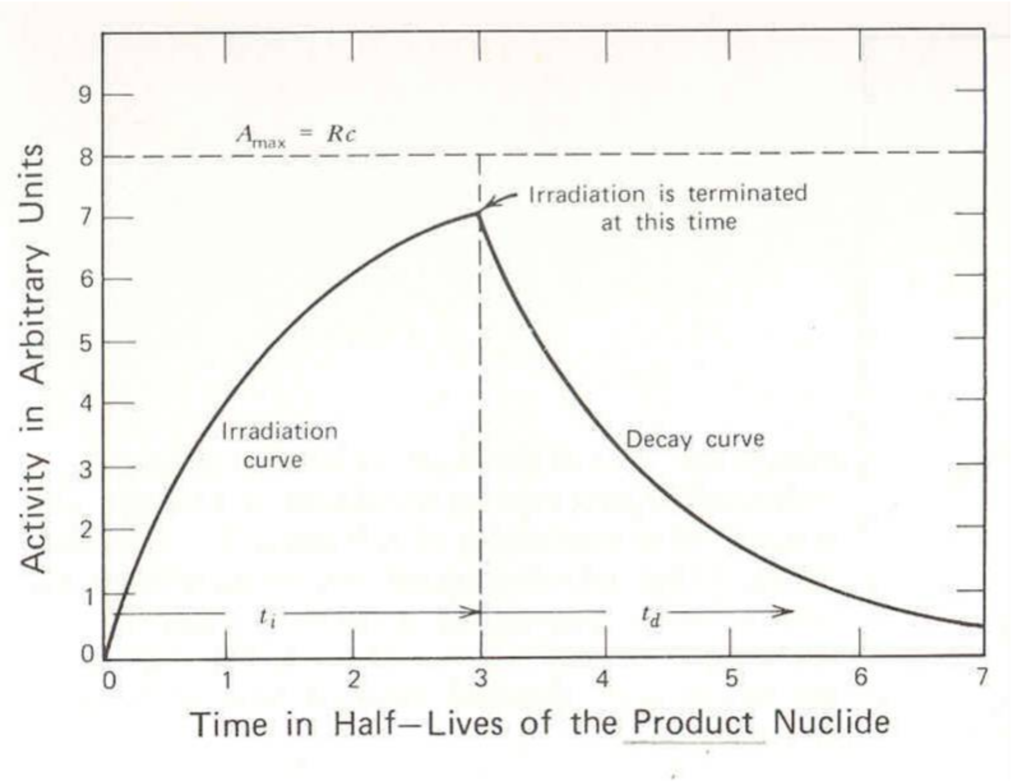


Radiochemical equilibrium is established after several half-lifes of N_2

Neutron Activation

Increase of activity of a product nuclide produced by a nuclear irradiation reaction

similar to ^{39}Ar produced from ^{39}K: $^{39}K\,(n, p)\,^{39}Ar$



Irradiation was terminated after three half-lives and the activity then decreased at a rate determined by the half-life of the produced radionuclide

Assumptions inherent in radiometric dating

Prior to sample formation, material was free to move – molten

A radioactive nuclide parent (N) 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

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

Assumptions inherent in radiometric dating

Method is restricted to minerals which:

- Still contain some of the parent nuclei
- Allowed for no gain or loss of D or N as time passed
- Initially contained no D (or D_0 must be known)

Assumptions inherent in radiometric dating

The values of N and D have changed only as a result of radioactive decay, i.e., the system is closed chemically

The isotopic composition of the parent was not altered by fractionation at the time of formation of the rock

The decay constant is known accurately

The “isochron” is not a mixing line

The analytical data are accurate