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Ionium Age Determination

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IONIUM AGE DETERMINATION

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Natural radioactive decay provides a means of determining the age of geological specimens. It is found that the number of atoms of a radioactive isotope disintegrating per unit time is linearly proportional to the existing number of atoms and independent of exterior parameters. This may be expressed by the differential equation:
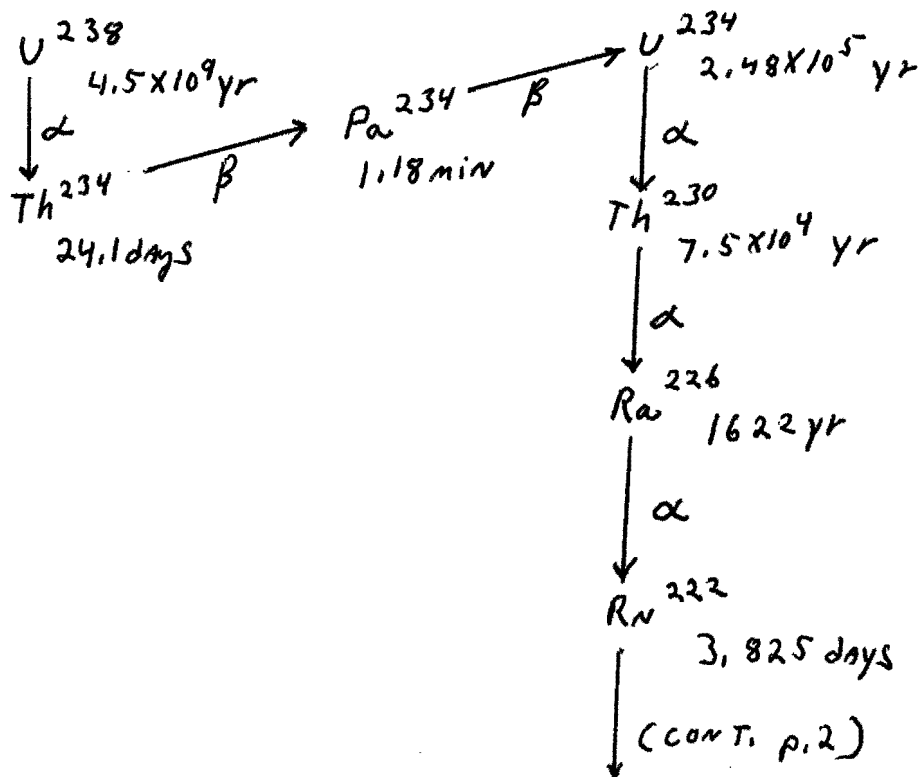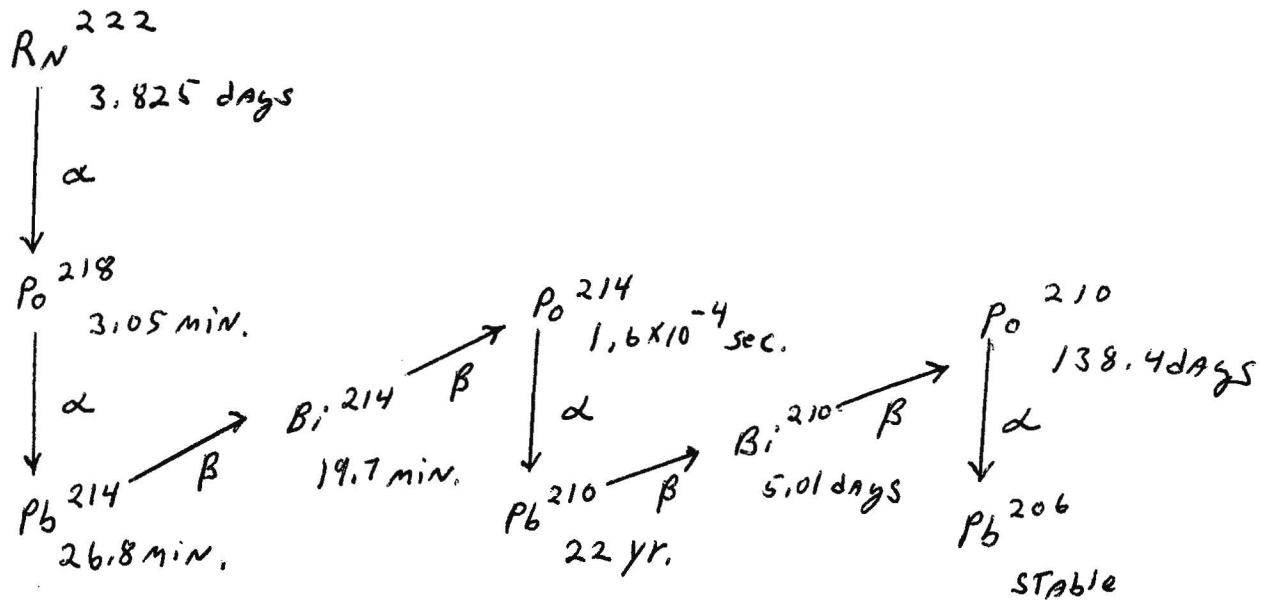
$$dN/dt = -\lambda N$$

where N is the number of atoms present and λ is the decay constant ($0.693/t_{\frac{1}{2}}$). Integration of this expression yields:

$$N = N_0 e^{-\lambda(t-t_0)}$$

where N_0 is the number of atoms at t_0, and N is the number of atoms at time t.

One natural radioactive series of interest in deep sea dating is the U^{238} series.

Rn^{222} — 3.825 days — α →
Po^{218} — 3.05 min. — α →
Pb^{214} — 26.8 min. — β →
Bi^{214} — 19.7 min. — β →
Po^{214} — 1.6×10^{-4} sec. — α →
Pb^{210} — 22 yr. — β →
Bi^{210} — 5.01 days — β →
Po^{210} — 138.4 days — α →
Pb^{206} — stable

Applying knowledge of radioactive decay to this series will allow determination of geological ages.

The time span $(t - t_o)$ is the time elapsed since the parent isotope was trapped in ocean sediments or corals. This will allow the time the sediment or coral material was formed to be determined.

Two parameters must be known to be able to determine an age. One parameter is connected with the time of formation of the investigated material and the other with the present time. In simple cases these parameters are N_o, the number of atoms present t years ago, and N_1, the number of atoms present now. The first parameter must be determined indirect means. The second, however, is measured directly. Part of the inaccuracy in age determination is due to the indirect measurements. Another problem is due to the fact that in determining the number of atoms of an isotope present we must relate this number to a volume or a mass. Since in sediment the concentration of radioactive species is determined by rate of sedimentation as well as decay, another source of error is present.

There are three basic methods of age determination. The first deals with two radioactive nuclides in equilibrium. We have already determined that the first species's behavior can be described by the equation:

$$dN_1/dt = -\lambda_1 N_1$$

$$\text{or} \quad N_1 = N_1^0 e^{-\lambda_1 t}$$

The first species decays at a rate $\lambda_1 N_1$. The daughter species is formed at the rate the parent decays, $\lambda_1 N_1$, and itself decays at a rate $\lambda_2 N_2$. We can say:

$$d N_2/dt = \lambda_1 N_1 - \lambda_2 N_2$$

$$\text{or} \quad d N_2/dt + \lambda_2 N_2 - \lambda_1 N_1^0 e^{-\lambda t} = 0$$

Solution of this differential equation yields:

$$N_2 = \frac{\lambda_1}{\lambda_2 - \lambda_1} N_1^0 (e^{-\lambda_1 t} - e^{-\lambda_2 t}) + N_2^0 e^{-\lambda_2 t}$$

Since we assume no daughter present initially we may neglect the last term leaving
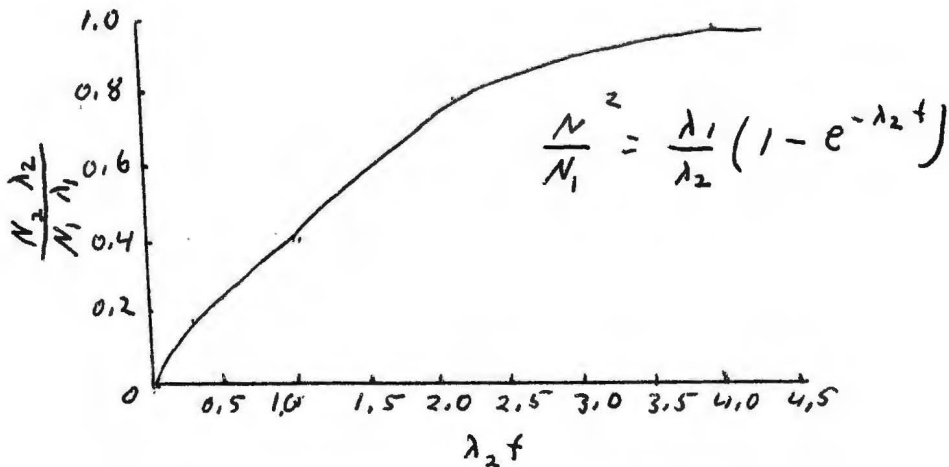
$$N_2 = \frac{\lambda_1}{\lambda_2 - \lambda_1} N_1^0 (e^{-\lambda_1 T} - e^{-\lambda_2 t})$$

If λ_1 is much smaller than λ_2, $N_0' \to N'$ and the equation may be approximated:

$$N_2 = N_1 \frac{\lambda_1}{\lambda_2} (1 - e^{-\lambda_2 t})$$

which gives the formula for age as:

$$t = \frac{1}{\lambda_2} \ln \left(1 - \frac{N_2^x \lambda_2}{N_1 \lambda_1}\right)$$

$$\frac{N_2}{N_1} = \frac{\lambda_1}{\lambda_2}\left(1 - e^{-\lambda_2 t}\right)$$
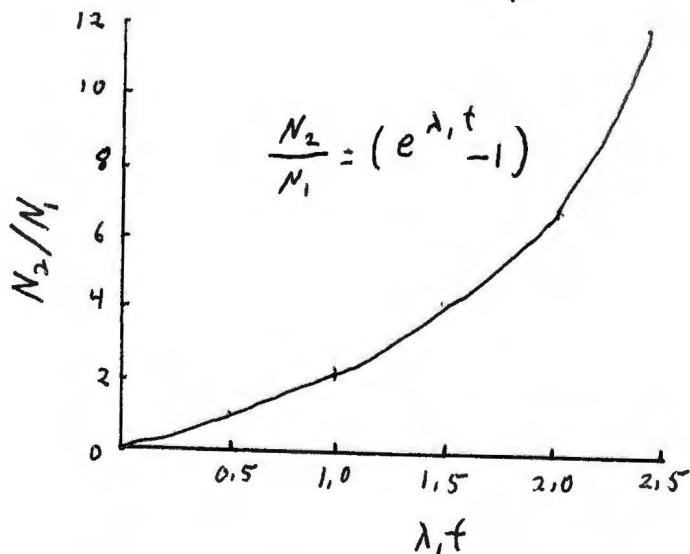
Age determination with the aid of the ratio of two radioactive
elements from the same series where the decay constant of the
daughter product is large compared with the decay constant of
the parent element. The ordinate gives the ratio of activities
of the two radio-elements. The abscissa gives the time scale in
non-dimensional units as multiples of mean lifetime.

if, however, λ_1 is much larger than λ_2, the equation is approximated
by:

$$N_2 = N_1^0 \left(1 - e^{-\lambda_1 t}\right)$$

Since $N_1^0 = N_1 e^{\lambda_1 t}$, the formula for age is:

$$t = \frac{1}{\lambda_1} \ln\left(1 + \frac{N_2}{N_1}\right)$$

$$\frac{N_2}{N_1} = \left(e^{\lambda_1 t} - 1\right)$$

Age determination using the ratio of two elements from radioactive

series for the case whenthe decay constant of the parent element is much larger than the decay constant of the daughter element. The ordinate gives the ratio of the two radioisotopes. The abscissa gives the time scale in non-dimensional units as multiples of mean lifetime.

The second method is one where two isotopes of the same element decay to form two distinctive daughters. The ratio of the isotopes can then be used for age determination. The ratio of the parent isotopes must be constant in nature. The decay of each is expressed by:

$$N_2{}^t = \frac{\lambda_1}{\lambda_2} N_1 \left(1 - e^{-\lambda_2 t}\right)$$

And

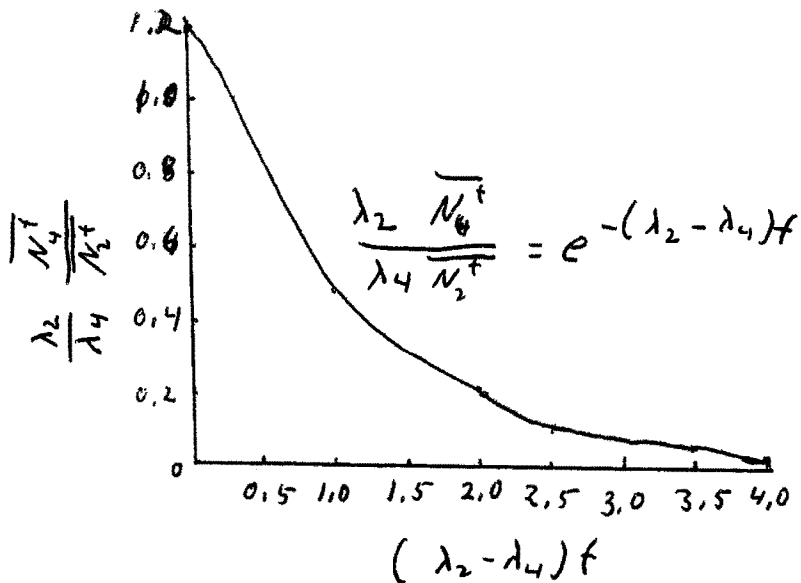$$N_4{}^t = \frac{\lambda_3}{\lambda_4} N_3 \left(1 - e^{-\lambda_4 t}\right)$$

The ratio of the two yields:

$$\frac{N_2{}^t}{N_4{}^t} = \frac{\lambda_1 \lambda_4}{\lambda_2 \lambda_3} \frac{N_1}{N_3} \frac{\left(1 - e^{-\lambda_2 t}\right)}{\left(1 - e^{-\lambda_1 t}\right)}$$

if the ratio of the parent isotopes is constant, the concentrations given in units of per cent-equivalent, and the precipitation is faster than 100 years, the equation for the age is:

$$t = \frac{1}{\lambda_2 - \lambda_4} \ln \left[\frac{\lambda_2}{\lambda_4} \cdot \frac{\overline{N_4{}^t}}{\overline{N_2{}^t}} \right]$$

By eliminating N_o, we are able to make absolute age determinations without any theoretical assumptions.

$$\frac{\lambda_2 \, \overline{N_4^t}}{\lambda_4 \, \overline{N_2^t}} = e^{-(\lambda_2 - \lambda_4)t}$$

(ordinate label) $\overline{N_4^t} / \overline{N_2^t}$, $\frac{\lambda_2}{\lambda_4}$

(abscissa label) $(\lambda_2 - \lambda_4)t$

Age determination by the ratio of two radio-nuclides that are produced by two radio-iostopes of the same element. The ordinate gives the ratio of activities of the two radio-nuclides and the abscissa gives the time scale in non-dimensional units as multiples of mean lifetime.

The third method is one where assumptions must be made to estimate the original N_0. The assumption that there is a constant ratio between the radioactive isotope and a stable isotope of the same element is most common. This includes the assumption that there is a constant rate of production of the radio-isotope. Therefore:
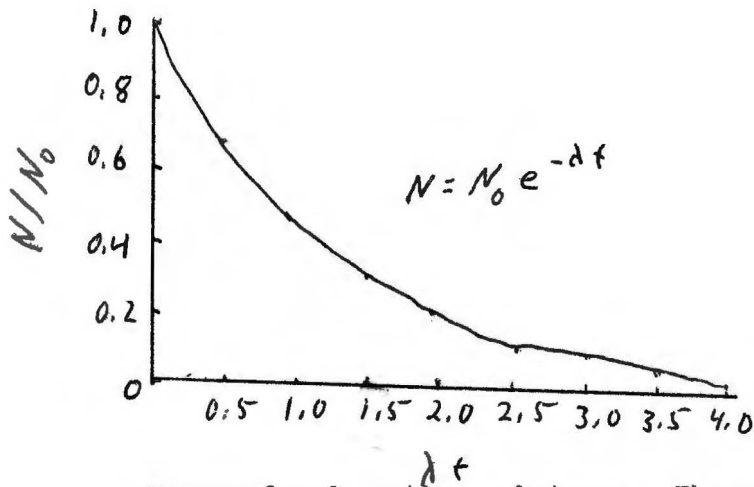
$$\frac{N}{I} = \frac{N_0}{I} e^{-\lambda t}$$

When the element is isolated it decays producing a change in this ratio. Age may be expresses as:

$$t = \frac{1}{\lambda} \left[\ln \frac{N_0}{I} - \ln \frac{N}{I} \right]$$

$$= \frac{1}{\lambda} \ln \frac{N_0}{N}$$
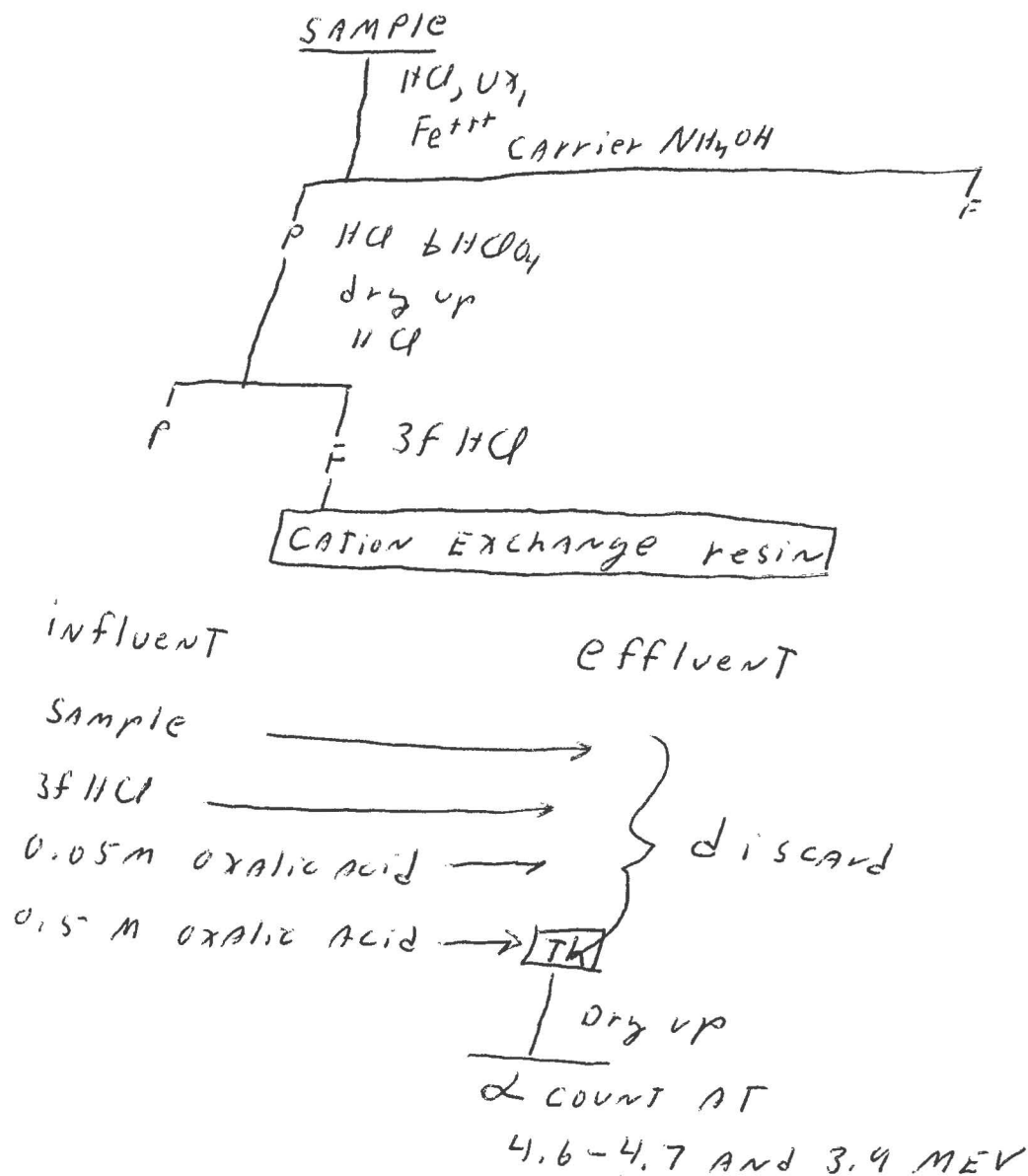
$$N = N_0 e^{-\lambda t}$$

Decay of radioactive substance. The ordinate gives the ratio of
the original amount of the radio-nuclide to the amount left after
a certain time. The abscissa gives the non-dimensional units indicating
the time as multiples of mean lifetime.

The ratio of ionium (Th^{230}) to U^{234} provides an excellent measure

of age. In theory this method should be adequate for a time span of

about 4 half-lives of ionium, or 360,000 years.

For this dating method to be valid several prerequisites must be

met. The Io/Th ratio in the water adjacent to the sediment must remain

constant over the time interval to be measured. Also the ionium and

thorium should be in the same chemical form. Since thorium exists

only in the $+4$ state under normal conditions in aqueous solution,

and any ionium has several thousands of years to become the more stable

species, there is little question about this assumption. Also any

uranium-supported ionium should be small or subtracted from the total

ionium.

To determine the Io/Th^{232} ratio one may merely find the ratio of

their activities, since both are radioactive and their activity is pro-

portional to the number of atoms present. In order to determine the

activities we must first determine the Io and Th^{232} present. One method of determination is as follows: The Th^{232} and Io are coprecipitated with ferric hydroxide. The thorium is redissolved in HNO_3 and separated in a cation-exchange column. The thorium is eluted with oxalic acid and the column rinced with HCl and oxalic acid. The effluent is placed on a Pt disk, dried, and the oxalic acid burned out. The activities of Th^{230} and Th^{232} are determined by α counting with an α spectrometer at 4.6-4.7 and 3.9 MEV.

SAMPle

HCl, UO$_2$,
Fe^{+++} CARRIER NH$_4$OH

P HCl bHClO$_4$
dry up
HCl

P

F 3f HCl

CATION EXCHANGE resin

INfluent   effluent

SAmple ⟶
3f HCl ⟶
0.05m oxalic acid ⟶   } discard
0.5 M oxalic Acid ⟶ Th

Dry up
α COUNT AT
4.6-4.7 AND 3.9 MEV

Work by Thurber, Broecker, Blanchard, and Potratz shows that the Io/Th ratio must be greater than 20 to give reliable results. They also found that $Io-U^{234}$ ages are very sensitive to small changes in relative concetrations of U^{234} and Io. When the Io is near equilibrium, precise calculation of ages is not possible. Their work is being applied to studies of coral formations.

Cherdyntsev, Malyshev, Sokolova, Kazachevskii, and Borisov are using similar proceedures in studying ages of peat in Russia. Goldberg and Koide are using this process to study the history of the Pacific Ocean. The Io/Th. dating process should prove to be a very valuable tool in learning about the origin of our earth.

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