Half-life

Contributed by: Farrington Daniels, Joseph H. Hamilton

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The time required for one-half of a given material to undergo chemical reactions; also, the average time interval required for one-half of any quantity of identical radioactive atoms to undergo radioactive decay.

Chemical reactions

The concept of the time required for all of a given material to react is meaningless, because the reaction goes very slowly when only a small amount of the reacting material is left and theoretically an infinite time would be required. The time for half-completion of the reaction is a definite and useful way of describing the rate of a reaction.

The specific rate constant k provides another way of describing the rate of a chemical reaction. This is shown in a first-order reaction (1),

$$k = \frac{2.303}{t}\log\frac{c_0}{c} \tag{1}$$

where c_0 is the initial concentration and c is the concentration at time t. The relation between specific rate constant and period of half-life, t, in a first-order reaction is given by Eq. (2).

$$t_{1/2} = \frac{2.303}{k}\log\frac{1}{1/2} = \frac{0.693}{k} \tag{2}$$

In a first-order reaction, the period of half-life is independent of the initial concentration, but in a second-order reaction it does depend on the initial concentration according to Eq. (3).

$$t_{1/2} = \frac{1}{kc_0} \tag{3}$$

See also: CHEMICAL KINETICS.

Farrington Daniels

Radioactive decay

The time it takes for one-half of the original atoms of a radioactive isotope to decay is called the half-life, $T_{1/2}$, or half-period. If one starts with A_0 atoms at time $t = 0$, then the number of atoms present at a later time is given by Eq. (4),

$$A = A_0 e^{-\lambda t} \tag{4}$$

where λ is called the decay constant. Each radioactive isotope has a unique characteristic λ. The number of atoms and the activity of the sample, given by $A\lambda$, decrease exponentially with time. After one half-life, when $A/A_0 = {}^1/_2$, the time is given by Eq. (5), which relates the half-life to the decay constant.

$$t = T_{1/2} = (\text{In } 2)/\lambda = 0.693/\lambda \tag{5}$$

After two half-lives, $A/A_0 = {}^1/_4$; after three half-lives, $A/A_0 = {}^1/_8$; and so on.

Radioactive decay follows a statistical probability. The probability is exactly ${}^1/_2$ that the actual life span of one individual radioactive atom will exceed $T_{1/2}$. When the number of atoms is very large, then one-half that number will have decayed in $T_{1/2}$. For a small number of initial atoms, however, the number remaining after the $T_{1/2}$ can vary considerably around ${}^1/_2$. One can typically follow the radioactive decay of an isotope for about ten half-lives. The isotope ^{14}C is produced in the Earth's atmosphere and has a half-life of 5700 years. Living plants take in ^{14}C along with stable ^{12}C. When the plant dies, the ratio decreases and can be used to tell the time when the plant died up to 10 $T_{1/2} \approx 57{,}000$ years, but not older. *See also:* PROBABILITY (PHYSICS); RADIOACTIVITY; RADIOCARBON DATING.

Joseph H. Hamilton

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