10.2 Applications of Nuclear Physics

Radioactive Decay

Applications of radioactivity

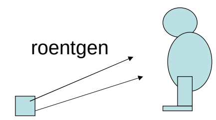
14C Dating

Smoke detectors

Medical Applications

Measures of radiation

- Amount of radiation. Curie (Ci, decays per second)
- Exposure Roentgen (energy dissipated/kg air)
- Absorbed dose Rad (radiation deposits 10^{-2}J /1kg)
- Effective dose Rem (Rad corrected for biological damage effectiveness)



Radiation exposure

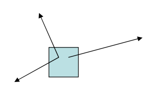
Maximum exposure 2,000 mrem per year recommended by the International Commission on Radiological Protection (ICRP).

A person would receive a dose equivalent of 1 mrem from any one of the following activities:

- 3 days of living in Atlanta
- 2 days of living in Denver
- 1 year of watching television (on average)
- 1 year of wearing a watch with a luminous dial
- 1 coast-to-coast airline flight
- 1 year living next door to a normally operating nuclear power plant

Decay rate

Radioactive decay is a random process.



The rate of decay, R, for N nuclei is proportional to N

$$R = \frac{\Delta N}{\Delta t} = \lambda N$$

λ = decay constant (units $time^{-1}$)

Activity – (rate of radioactive decay)

Units Curie,

1Ci = 3.7×10^{10} Decays/s

Radioactive decay

The amount of material remaining varies exponentially with time.

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

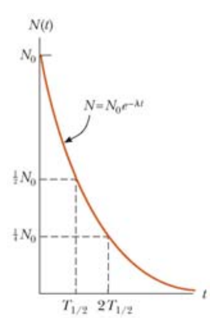
λ is the decay constant (units 1/time)

This can also be expressed as

$$N = N_o \left(\frac{1}{2}\right)^{t/T_{\frac{1}{2}}}$$

where

Half Life = $T_{\frac{1}{2}} = \frac{\ln 2}{\lambda} = \frac{0.693}{\lambda}$



Example 29.3

The half life of radium Ra is 1.6×10^3 yr. If the sample contains 3.00×10^{16} nuclei. Find the activity in curies. (1Ci=3.7×10^{10} decays/s)

R=λN

$$T_{\frac{1}{2}} = \frac{\ln 2}{\lambda} = \frac{0.693}{\lambda}$$

$$\lambda = \frac{0.693}{T_{1/2}} = \frac{0.693}{1.6\times10^3 yr(365 day/yr)(24 hr/day)(3600 s/hr)}$$

$$= 1.37\times10^{-11} s^{-1}$$

R=$1.37\times10^{-11}s^{-1}$ (3.00×10^{16}nuclei) =4.12×10^5 decays/s

R=1.1×10^{-5} Ci or 11μcuries 3.7×10^{10}decays/sCi

Example 29.3

The half life of radium Ra is 1.6×10^3 yr. If the sample contains 3.00×10^{16} nuclei. Find the number of nuclei after 4.8×10^3 yr.

$$N = N_o \left(\frac{1}{2}\right)^{t/T_{1/2}}$$

$$N = 3.00 \times 10^{16} \left(\frac{1}{2}\right)^{4.8 \times 10^3 / 1.6 \times 10^3}$$

$N = 3.00 \times 10^{16}\ (1/8) = 3.75 \times 10^{15}$ nuclei

Example 29.3

The half life of radium Ra is 1.6×10^3 yr. If the sample contains 3.00×10^{16} nuclei. Find the activity after 4.8×10^3 yr.

$R = \lambda N$

After this time since the no. of nuclei is reduced by a factor of 8
the decay rate will also be reduced by a factor of 8.

$R = 11\ \mu Ci/8 = 1.4\ \mu Ci$

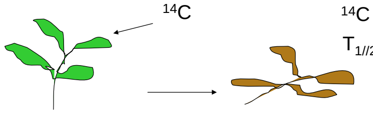
Radioactive dating

^{14}C is continually formed by cosmic rays in the upper atmosphere.

$n + {}^{14}N \rightarrow {}^{14}C + p$

so that the concentration of ^{14}C is relatively constant over long times (longer than the half life).

^{14}C



^{14}C decays

$T_{1/2}$= 5730 years

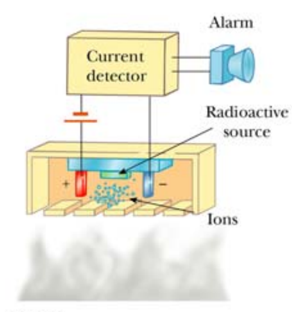
The fraction of ^{14}C decays exponentially with time.

Dating the pharoah's boat

^{14}C dating was used to determine that the Pharoah's boat was 4,500 years old.

Smoke Detector

Ionization of air by a radioactive source produces a current. Smoke traps the electrons and reduces the current. setting off the alarm.



Medical Applications.

Radiation Damage.

- Nuclear particles have much higher energies than chemical bonds.
- Radiation breaks chemical bonds – forming reactive chemical species – radicals.
- Reactive chemicals cause radiation damage to biological systems – often reaction with DNA

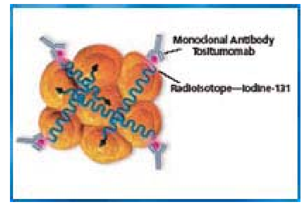
Radiation Therapy

Radiation is often used in treating cancer.

external radiation

Radioimmunotherapy

New methods for can deliver radiation more specifically to target cells



Treatment of non-Hodgkins lymphoma with radioimmunotherapy

Properties of ^{131}I

Iodine 131

Half-life – 8.07 days

Beta particle
  maximum energy- 807 keV
  average energy - 182 keV

Range in tissue -2.4 mm

Common clinical applications
  Radioimmunotherapy, thyroid ablation for benign and malignant disease

Medical Imaging

- X-ray Computer axial tomography (CAT)
- Positron emission tomography (PET)
- Magnetic resonance imaging (MRI)

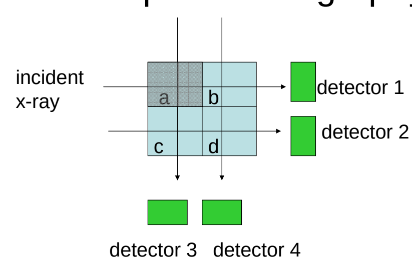
- Contrast
- Resolution.

CAT scan

Contrast – x-ray absorption may use heavy elements to increase contrast i.e I, Ba

A three- dimensional image is reconstructed from many two dimensional pictures.

Computer tomography



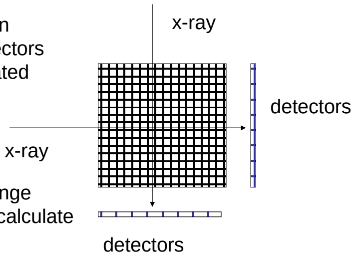
at each detector absorbance is due to the sum of the absorptions from each segment.

$A\ (\text{detector}) = A_i + A_j$

For 4 detectors -> 4 linear equations and 4 segment - > 4 unknowns ⇨ Solve for each absorbance

Higher resolution

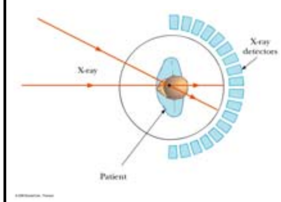
For higher resolution there are more detectors and the body is rotated and many pictures are taken



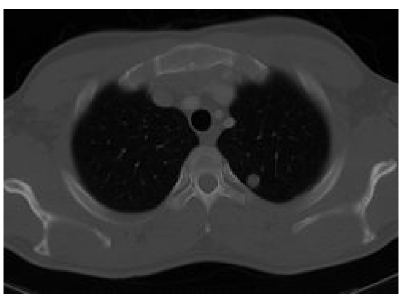
The absorbance change for each segment is calculate with a computer.
Solving ~10,000 linear equations.

Computer Axial Tomography

Axial Geometry



CAT scan of a chest



Positron Emission Tomography

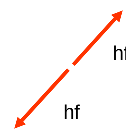
- Emission of 2 gamma ray photons traveling in opposite direction by Positron-Electron annihilation. (conservation of momentum)
- Positrons are produced by decay of short lived radioactive nuclei such as

^{18}F ($T_{1/2}$=110 min)

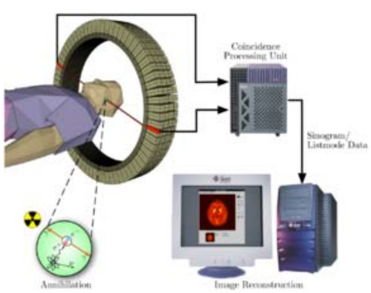
$$^{18}_{9}F \rightarrow ^{18}_{8}O + e^{+} + \nu$$

$$e^{+} + e^{-} \rightarrow \gamma + \gamma$$

Annihilation produces 2 0.51 MeV photons

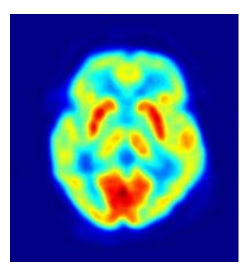


PET imaging system



Two coincident detectors are used to detect the gamma rays. The source is in a line directly between the two detectors.

PET scan of the human brain



^{15}O ($T_{1/2}$ =2 min) marks the consumption of O_2 due to brain activity.