- It is possible to determine the probability that one nucleus will decay in the next time period (such as a second).

- The Bequerel (Bq) is the unit used to measure the number of decays per second in a sample.
  - One Bequerel is equal to one decay per second.
  - The activity of a sample is a measure of the strength of the radioactive source.
    - The SI unit for activity is the Bequerel.

$$\boxed{A = \lambda N}$$

  - In the above equation:
    - A=Activity (Bq)
    - λ=Probability that a nucleus will decay in the next second.
    - N=Number of radioactive nuclei in the sample.
- The Curie (Ci) is a unit that equals to the number of decays per second in a gram sample of Radium-226.
  - 1 Ci=3.70×10^{10}Bq
- Activity is equal to the negative of the rate of change of the number of radioactive nuclides in the sample.
  - Activity refers to the number of decays per second and thus, the rate of change must be the negative of this value.

$$\frac{dN}{dt} = -A = -\lambda N$$
$$\frac{dN}{dt} = -\lambda N$$
$$\frac{dN}{N} = -\lambda dt$$
$$\ln[N] = -\lambda t + C$$
$$N(t) = e^{-\lambda t + C}$$
$$N(t) = e^{C}e^{-\lambda t}$$
$$\text{By substituting t} = 0$$
$$N(0) = e^{C}$$
$$N(t) = N(0)e^{-\lambda t}$$

  - Given by the equation:
    - N(t)=Number of radioactive nuclides after period, t (seconds)
    - N(0)=Number of radioactive nuclides initially (seconds)
    - λ =Probability that any given radioactive nuclide will decay in the next second.
    - t=time (seconds)
- Using this formula, we can also calculate the half-life using the probability of decay after one second.

$$N(t) = N(0)e^{-\lambda t}$$
$$Let\ N(t) = \frac{1}{2}N(0)$$
$$\frac{1}{2}N(0) = N(0)e^{-\lambda t_{1/2}}$$
$$\frac{1}{2} = e^{-\lambda t_{1/2}}$$
$$\ln\frac{1}{2} = -\lambda t_{1/2}$$
$$-\ln 2 = -\lambda t_{1/2}$$
$$t_{1/2} = \frac{\ln 2}{\lambda}$$
$$\text{By equating with the previous equation:}$$
$$N(t) = N(0)e^{-\left(\frac{t\ln 2}{t_{\frac{1}{2}}}\right)}$$

- It should be noted that half-life and activity are related.
  - ➔ High activity means shorter half-life while lower activity means longer half-life.
- To determine molar activity (activity/mole), we set $N(0)=6.022\times10^{23}$
- To determine specific activity (activity/gram), we set $N(0)=6.022\times10^{23}/M$
  - ➔ M=atomic mass of the specific nuclide.
- It is important to note that molar activity, specific activity and half-life are independent of the amount of radioactive material in the sample.
  - ➔ Molar activity and specific activity give a certain amount – one mole and one gram, respectively.
- Carbon dating is based on the fact that all living matter containing a fixed fraction of carbon-14 present amongst all of its carbon.
  - ➔ Most carbon-14 is atmospherically generated.
  - ➔ At death, carbon is no longer exchanged with the atmosphere and carbon in the organism begins to decay with a half-life of approximately 5730 years.
    - By comparing the concentration of carbon-14 between living and dead matter, it is possible to determine how long the sample has been dead.

$$^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}e$$

  - ➔ Radiocarbon dating can be done using either:
    - Concentration of carbon-14 in a sample.
    - Measuring the activity due to β decay (using scintillation counters).

Lecture 4: Biological Damage and Medical Imaging

- Radiation can be both used for good and bad.
  - ➔ Good: can be used in cancer therapy and medical imaging.
  - ➔ Bad: high levels can cause radiation sickness, cancers and radiation can be used as a weapon (for war).
- Radiation due to radioactivity has very high energy and can cause the ionisation of matter (ionising radiation).
  - ➔ Radiation is stopped by matter which it has interacted (ionised) with.
  - ➔ If it is highly penetrating, it is more likely to pass through matter without ionising it.
- As the body is made mostly of water, many reactions involve water. As gamma irradiation of water ionises it.

$$\gamma + H_2O_{(l)} \rightarrow H_2O^+_{(aq)} + e^-$$

  - ➔ The ionised water (H_2O^+) can now react with another water molecule to produce the hydronium ion (H_3O^+) and a hydroxyl radical (HO·).

$$H_2O^+_{(aq)} + H_2O_{(l)} \rightarrow H_3O^+_{(aq)} + \cdot HO$$

  - ➔ The electron from the first ionisation of water can also react with a water molecule to produce a hydrogen radical (H·) and a hydroxide ion (OH^-).
    - Free radicals are highly reactive and can cause damage to many molecules in the body such as DNA, membranes (cells) and proteins.
- There are three factors that determine the effect of radiation on the body.
  - ➔ Type of radiation.
    - Alpha is the most damaging but has very short penetration through air (least likely to reach the body).
    - Beta is less damaging but more penetrating through air (more likely to reach the body).
    - Gamma is least damaging but most penetrating through air (most likely to reach the body).
    - It is essentially a balance between more damaging if it reaches the body against the penetration through air – and thus, likelihood of reaching biological tissue.

- ➔ Length of exposure.
  - Short exposure, depending on the dose, can cause radiation sickness which might be possible to recover from.
  - Long exposure tends to do more damage and increases chances of producing cancers that are radiation-induced.
- ➔ Source of exposure.
  - Internal exposure (from inhalation or ingestion) is most dangerous, especially α and β because they are most likely to be absorbed into the tissue as they have low penetration while γ is most likely to escape the body.
  - External exposure is mostly caused by γ as α and β are very poor at penetrating the air and most likely blocked before it reaches biological tissue while gamma is more likely to reach the tissue and thus, have a much higher chance of being absorbed.

- Measuring radiation dose requires a lot of information.
  - ➔ <u>Activity of the source</u>: the number of decays by the source per second.
  - ➔ <u>Energy of radiation</u>: how much energy is released by each decay.
  - ➔ <u>Energy absorbed per unit mass</u>.
  - ➔ <u>The relative biological effectiveness (Q)</u>: takes into account the type of radiation and the fact that the less penetrating it is, the more damage it is capable of.

$$\boxed{Effective\ Dose = Q \times Absorbed\ Dose}$$

	Source activity	Energy of radiation	Energy absorbed per unit mass	Relative biological effectiveness (Q)	Effective dosage equivalent
SI Unit	Becquerel (Bq)	Joule (J)	Gray (Gy)	N/A	Sievert (Sv)
Base Unit	s^{-1}	$kgms^2s^{-2}$	J/kg	N/A	J/kg
Definition	Number of decays per second	Amount of energy per decay	How much energy the body absorbed over mass	Relative effect of radiation for the same amount of absorbed energy	Effective of the energy a body has absorbed

- Only seemingly small amounts of Sieverts can cause significant and noticeable damage.
  - ➔ 0.2 Sv causes bone marrow damage, tiredness and drop in red blood cells.
  - ➔ 0.5 Sv causes immune system damage and sickness.
  - ➔ 1.0 Sv causes nausea, fatigue and some deaths.
  - ➔ 3.0 Sv causes internal bleeding and many deaths (50% after a month).
  - ➔ 6.0 Sv is lethal, killing after 2 weeks.
- We are exposed to about 3 mSv per year from natural sources of radiation.
  - ➔ Radon is a radioactive gas in the air (very small amounts) can cause damage to the lungs to αparticles.
  - ➔ Potassium-40 is present in bananas, potatoes and some seeds.
  - ➔ Cosmic background radiation.
- Radiotherapy utilises radiation to kill cancerous cells by targeting the cancer cells – the radiation beam is focused precisely to the tumour to avoid damage to healthy cells. Internal use often uses α or β emitters to kill cancers.
- Radio imaging requires penetrating radiation so it can be detected and so its harm to the patient is limited (less is absorbed), usually by γ radiation.
  - ➔ Positron emission tomography
  - ➔ Gamma imaging