610-280 Environmental Chemistry

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Energy: Nuclear Fuel background

- The nuclear debate
- What is radiation?
- α, β, and γ-radiation
- Decay mechanisms and half lives
- Decay series of ^{238}U

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References

- Baird, C. and Cann M. Environmental Chemistry, 3rd Ed., 2005
- Wright, J. Environmental Chemistry, 2003
- www.epa.gov/radiation/
- www.wikipedia.org

Nuclear Power

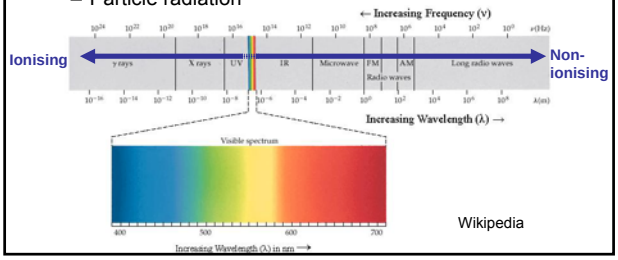
Wikipedia

The Nuclear Debate

- Advantages
- Disadvantages

Radiation

- The action or process of emitting energy in the form of waves or high speed particles
  - Electromagnetic radiation
  - Particle radiation



Wikipedia

Radiation

- Non-ionising radiation
  - low frequency, high wavelength
- Ionising radiation
  - Individual particle or photon capable of ionising (displacing electrons from) atoms or molecules thereby producing ions

Three main types of ionising radiation

α, β and γ - radiation

- α – particles (^4_2He or $^4_2\alpha$)
  - 2 neutrons and 2 protons, most strongly ionising
  - Penetrate ~0.01 cm into tissue, stopped by sheet of paper
  - Common for nuclides of mass no. > 209 atomic no. > 82
- β – particles ($^0_{-1}\beta$ or $^0_{+1}\beta$)
  - Negative or positive charge, generally electrons
  - Penetrate ~1 cm into tissue, stopped by sheet of Al
  - Occurs when nucleus contains excess of neutrons
- γ – rays
  - Photons, no mass, no charge, less ionising
  - Penetrate ~100 cm into tissue, stopped by cms of Pb
  - Accompany emission of α or β particles or de-excitation of electronically excited nucleus

Radioactivity

- Radioactivity – spontaneous disintegration of an energetically unstable atomic nucleus resulting in the emission of radiation.
- Unstable nuclei are radioactive they undergo change to become more stable
  - Convert neutrons to protons, emitting β-particle (electron) $^1_0n \rightarrow {}^1_1p + {}^0_{-1}\beta$
  - Convert protons to neutrons, emitting β-particle (positron) $^1_1p \rightarrow {}^1_0n + {}^0_{+1}\beta$
  - Eject an α-particle from nucleus $^4_2\alpha$

Radioactive decay

- The process by which an unstable nucleus gives off energy (emits radiation) to become a more stable isotope or element
- Rates of radioactive decay are first order and independent of temperature

Radioactive decay mechanisms

Examples of α-decay

$^{226}_{88}\mathrm{Ra} \rightarrow {}^{222}_{86}\mathrm{Rn} + {}^{4}_{2}\mathrm{He}$

$^{210}_{84}\mathrm{Po} \rightarrow {}^{206}_{82}\mathrm{Pb} + {}^{4}_{2}\mathrm{He}$

Examples of β-decay

$^{214}_{82}\mathrm{Pb} \rightarrow {}^{214}_{83}\mathrm{Bi} + {}^{0}_{-1}\beta$

$^{90}_{38}\mathrm{Sr} \rightarrow {}^{90}_{39}\mathrm{Y} + {}^{0}_{-1}\beta$

Examples of γ-decay

$^{137}_{55}\mathrm{Cs} \rightarrow {}^{137}_{56}\mathrm{Ba} + {}^{0}_{-1}\beta + \gamma$

$^{125}_{52}\mathrm{Te}^{*} \rightarrow {}^{125}_{52}\mathrm{Te} + \gamma$

Quick Quiz

$^{222}_{86}\mathrm{Rn} \rightarrow \ldots\ldots + {}^{4}_{2}\mathrm{He}$

$^{214}_{83}\mathrm{Bi} \rightarrow \ldots\ldots + {}^{0}_{-1}\beta$

$^{214}\mathrm{Pb} \rightarrow {}^{214}\mathrm{Po} + \ldots\ldots$

$\ldots\ldots \rightarrow {}^{234}_{90}\mathrm{Th} + \alpha$

Half life

- Half life – a measure of how quickly the radioactivity of a radionuclide will decrease.
- Half life – time required to decay half of the radionuclides present at t=0.
- Activity (number of disintegrations per unit of time) of radioactive element is inversely proportional to the half life.
- Example, $\tau_{\frac{1}{2}}$ = 21 y for Pb-210,
  If there were initially 600 radioactive atoms,
  after 21 y there would be 300,
  after another 21 y there would be 150,
  after another 21 y there would be 75,….

Half life

- Rate of radioactive decay $\frac{dN}{dt} = -kN$
- Integrate knowing that at t = 0, N = N_0 $N_t = N_0 e^{-kt}$
- Consider when $N_t = 0.5N_0$, therefore $\ln\left(\frac{N_0}{N_t}\right) = kt$
  ln(1/0.5) = ln(2) = 0.693,
  $t = \tau_{\frac{1}{2}}$ $\tau_{\frac{1}{2}} = \frac{0.693}{k}$

Half life

Radionuclide	Half life	Decay mode
$^{238}_{92}U$	4.51 x 10^9 y	α
$^{239}_{94}Pu$	2.44 x 10^4 y	β
$^{222}_{86}Rn$	3.823 d	α
$^{238}_{94}Pu$	90 y	α
$^{131}_{53}I$	8.070 d	β

Large variation in decay rates

Quick Quiz

- Lead-210, half life of 21 y, how long does it take to reach 1 % of its original activity?

Decay Series

- Radioactive decay often occurs through a series of transformations rather than one step. Throughout transformation the radionuclides are transmitting radiation as they become another radionuclide, ending in a stable nuclide.
- Radionuclide decay series are important for the management of radioactive materials and disposal of waste and site clean up.

Decay of ^{238}U

$$^{238}_{92}U \xrightarrow{\alpha,\ 4.51\times10^{9}\ y} {}^{234}_{90}Th \xrightarrow{\beta^-,\ 24.1\ d} {}^{234}_{91}Pa \xrightarrow{\beta^-,\ 1.18\ min}$$

$$^{234}_{92}U \xrightarrow{\alpha,\ 2.48\times10^{5}\ y} {}^{230}_{90}Th \xrightarrow{\alpha,\ 8.0\times10^{4}\ y} {}^{226}_{88}Ra \xrightarrow{\alpha,\ 1.62\times10^{3}\ y}$$

$$^{222}_{86}Rn \xrightarrow{\alpha,\ 3.82\ d} {}^{218}_{84}Po \begin{cases} \xrightarrow{\alpha,\ 30.5\ min} {}^{214}_{82}Pb \xrightarrow{\beta^-,\ 26.8\ min} \\ \xrightarrow{\beta^-,\ 30.5\ min} {}^{218}_{85}At \xrightarrow{\alpha,\ 1.3\ s} \end{cases}$$

$$^{214}_{83}Bi \begin{cases} \xrightarrow{\beta^-,\ 19.7\ min} {}^{214}_{84}Po \xrightarrow{\alpha,\ 1.6\times10^{-4}\ s} \\ \xrightarrow{\alpha,\ 19.7\ min} {}^{210}_{81}Tl \xrightarrow{\beta^-,\ 1.31\ min} \end{cases} {}^{210}_{82}Pb \xrightarrow{\beta^-,\ 21\ y}$$

$$^{210}_{83}Bi \begin{cases} \xrightarrow{\beta^-,\ 5\ d} {}^{210}_{84}Po \xrightarrow{\alpha,\ 138.4\ d} \\ \xrightarrow{\alpha,\ 5\ d} {}^{206}_{81}Tl \xrightarrow{\beta^-,\ 4.20\ min} \end{cases} {}^{206}_{82}Pb\ (\text{stable})$$

Fission of ^{235}U

Some examples

$$^{1}_{0}n + {}^{235}_{92}U \longrightarrow {}^{142}_{56}Ba + {}^{91}_{36}Kr + 3{}^{1}_{0}n$$

$$^{1}_{0}n + {}^{235}_{92}U \longrightarrow {}^{139}_{52}Te + {}^{94}_{40}Zr + 3{}^{1}_{0}n$$

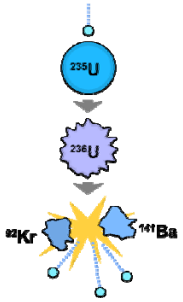
$$^{1}_{0}n + {}^{235}_{92}U \longrightarrow {}^{95}_{39}Y + {}^{138}_{53}I + 3{}^{1}_{0}n$$

$$^{1}_{0}n + {}^{235}_{92}U \longrightarrow {}^{90}_{35}Br + {}^{143}_{57}La + 3{}^{1}_{0}n$$

$$^{1}_{0}n + {}^{235}_{92}U \longrightarrow {}^{97}_{39}Y + {}^{137}_{53}I + 2{}^{1}_{0}n$$

$$^{1}_{0}n + {}^{235}_{92}U \longrightarrow {}^{90}_{36}Kr + {}^{144}_{56}Ba + 2{}^{1}_{0}n$$

etc.



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Controlled Fission

Uncontrolled Fission

Fission of ^{238}U?

$$^{1}_{0}n + {}^{238}_{92}U \longrightarrow {}^{239}_{92}U + \gamma$$

$$^{239}_{92}U \longrightarrow {}^{239}_{93}Np + {}^{0}_{-1}\beta$$

$$^{239}_{93}Np \longrightarrow {}^{239}_{94}Pu + {}^{0}_{-1}\beta$$

In summary

<u>Energy: Nuclear Fuel background</u>

- Discussed advantages/disadvantages of Nuclear Power
- Defined radiation (ionising, non-ionising), radioactivity, half life
- Differentiated 3 main types of radiation
- Balanced decay mechanisms, conducted calculations related to half lives
- Looked at decay series of ^{238}U