Chapter 25: Nuclear Chemistry

25.1: Nuclear Radiation

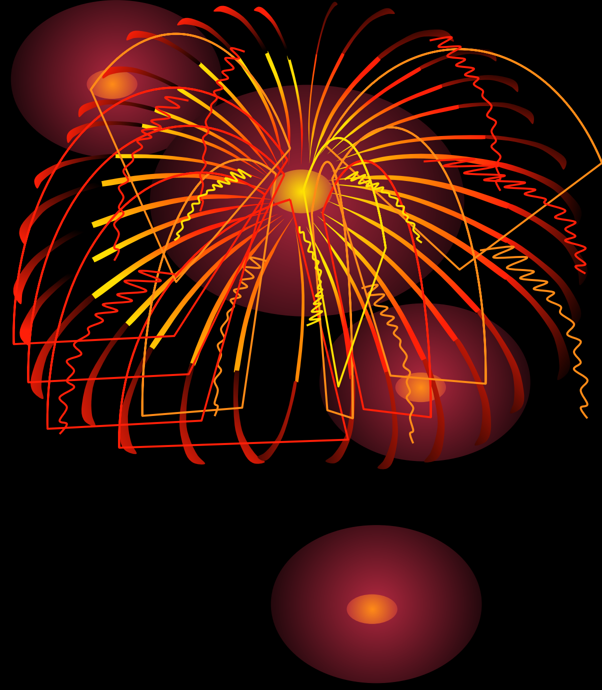
- Marie Curie (1867-1934) and Pierre Curie (1859-1906) were able to show that rays emitted by uranium atoms caused fogging in photographic plates.
  - Marie Curie named the process by which materials give off such rays <u>**radioactivity**</u>.
  - The penetrating rays and particles emitted by a radioactive source are called <u>**radiation.**</u>

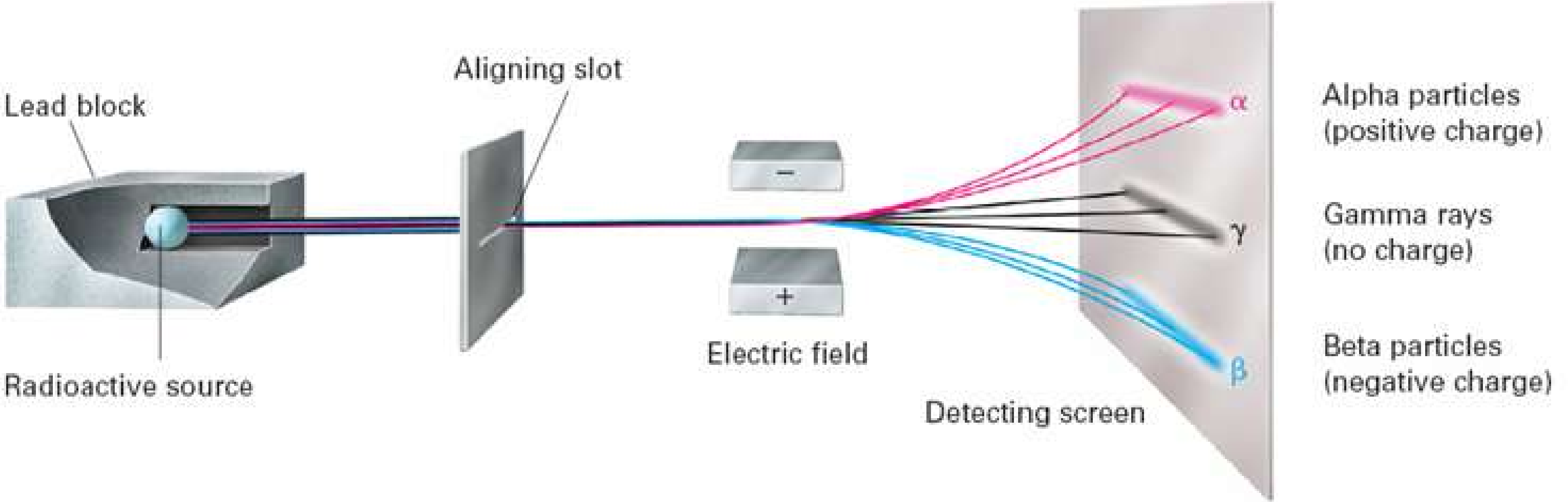
- Nuclear reactions differ from chemical reactions in a number of important ways.
  - In chemical reactions, atoms tend to attain stable electron configurations by losing or sharing electrons.
  - In nuclear reactions, the nuclei of unstable isotopes, called **radioisotopes**, gain stability by undergoing changes.

Radioactivity

- An unstable nucleus releases energy by emitting radiation during the process of radioactive decay.

- The three main types of nuclear radiation are alpha radiation, beta radiation, and gamma radiation.





- Alpha Radiation
  - Alpha radiation consists of helium nuclei that have been emitted from a radioactive source. These emitted particles, called **alpha particles**, contain two protons and two neutrons and have a double positive charge.

$$ {}^{238}_{92}\mathrm{U} \xrightarrow[\text{decay}]{\text{Radioactive}} {}^{234}_{90}\mathrm{Th} + {}^{4}_{2}\mathrm{He}\ (\alpha \text{ emission}) $$

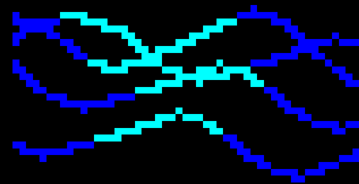
Uranium-238 Thorium-234 Alpha particle

- Beta Radiation
  - An electron resulting from the breaking apart of a neutron in an atom is called a **beta particle**.

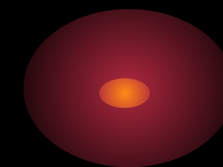
$$ {}^{1}_{0}\mathrm{n} \longrightarrow {}^{1}_{1}\mathrm{H} + {}^{0}_{-1}\mathrm{e} $$

Neutron | Proton | Electron (beta particle)

Types of Radiation



- Gamma Radiation
  - A high-energy photon emitted by a radioisotope is called a <u>**gamma ray**</u>**.** The high-energy photons are electromagnetic radiation.

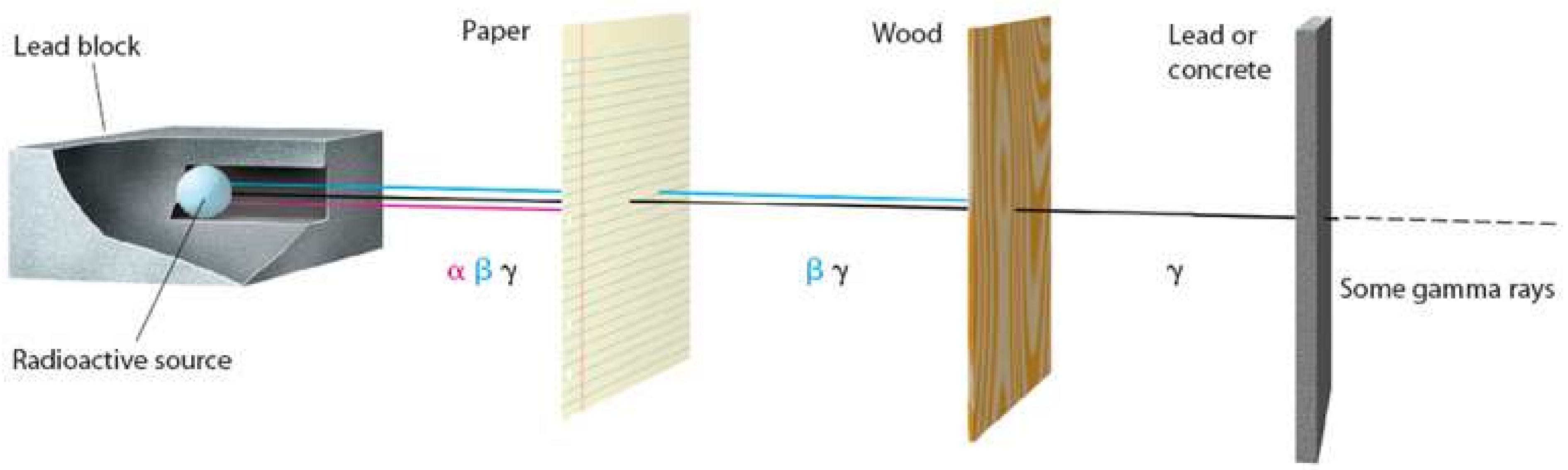


$$^{230}_{90}\mathrm{Th} \longrightarrow {}^{226}_{88}\mathrm{Ra} + {}^{4}_{2}\mathrm{He} + \gamma$$

Thorium-230	Radon-226	Alpha particle	Gamma ray

Types of Radiation

- Alpha particles are the least penetrating. Gamma rays are the most penetrating.



Types of Radiation

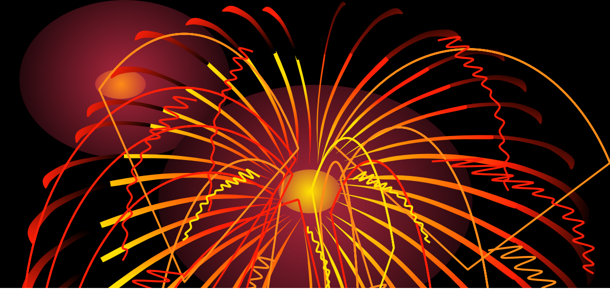


Table 25.1

Characteristics of Some Types of Radiation

Property	Alpha radiation	Beta radiation	Gamma radiation
Composition	Alpha particle (helium nucleus)	Beta particle (electron)	High-energy electro-magnetic radiation
Symbol	α, ${}^{4}_{2}He$	β, ${}^{0}_{-1}e$	γ
Charge	2+	1−	0
Mass (amu)	4	1/1837	0
Common source	Radium-226	Carbon-14	Cobalt-60
Penetrating power	Low (0.05 mm body tissue)	Moderate (4 mm body tissue)	Very high (penetrates body easily)
Shielding	Paper, clothing	Metal foil	Lead, concrete (incompletely shields)

25.1 Section Quiz.

- 1.Certain elements are radioactive because their atoms have

  a) more neutrons than electrons

  b) an unstable nucleus.

  c) a large nucleus.

  d) more neutrons than protons.

25.1 Section Quiz.

- 2.An unstable nucleus releases energy by
  - a) emitting radiation.
  - b) thermal vibrations.
  - c) a chemical reaction.
  - d) giving off heat.

25.1 Section Quiz.

- 3.Which property does NOT describe an alpha particle?
  - a) 2+ charge
  - b) a relatively large mass
  - c) a negative charge
  - d) low penetrating power

25.1 Section Quiz.

- 4.When a radioactive nucleus releases a high-speed electron, the process can be described as

  a) oxidation.

  b) alpha emission.

  c) beta emission.

  d) gamma radiation.

25.2 Nuclear Transformations

- The **nuclear force** is an attractive force that acts between *all* nuclear particles that are extremely close together, such as protons and neutrons in a nucleus
  - At these short distances, the nuclear force dominates over electromagnetic repulsions and hold the nucleus together.

Nuclear Stability and Decay

- Too few or too many neutrons cause decay.
- A **<u>positron</u>** is a particle with the mass of an electron but a positive charge. During positron emission, a proton changes to a neutron.

Table 25.2

Decay Processes

Beta Emission

$$^{66}_{29}\mathrm{Cu} \longrightarrow {}^{66}_{30}\mathrm{Zn} + {}^{\;0}_{-1}\mathrm{e}$$

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

Electron Capture

$$^{59}_{28}\mathrm{Ni} + {}^{\;0}_{-1}\mathrm{e} \longrightarrow {}^{59}_{27}\mathrm{Co}$$

$$^{37}_{18}\mathrm{Ar} + {}^{\;0}_{-1}\mathrm{e} \longrightarrow {}^{37}_{17}\mathrm{Cl}$$

Positron Emission

$$^{8}_{5}\mathrm{B} \longrightarrow {}^{8}_{4}\mathrm{Be} + {}^{\;0}_{+1}\mathrm{e}$$

$$^{15}_{8}\mathrm{O} \longrightarrow {}^{15}_{7}\mathrm{N} + {}^{\;0}_{+1}\mathrm{e}$$

Alpha Emission

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

$$^{232}_{90}\mathrm{Th} \longrightarrow {}^{228}_{88}\mathrm{Ra} + {}^{4}_{2}\mathrm{He}$$

Nuclear Decay Practice

- $^{12}_{5}B \rightarrow ^{12}_{6}C +$ _____
- $^{225}_{89}Ac \rightarrow ^{221}_{87}Fr +$ _____
- $^{63}_{28}Ni \rightarrow$ _____ $+ ^{0}_{-1}e$
- $^{212}_{83}Bi \rightarrow$ _____ $+ ^{4}_{2}He$

Complete the Equations

- $^{27}_{13}Al + {}^{4}_{2}He \rightarrow {}^{30}_{14}Si +$ _____
- $^{214}_{83}Bi \rightarrow {}^{4}_{2}He +$ _____
- $^{27}_{14}Si \rightarrow {}^{0}_{-1}e +$ _____
- $^{66}_{29}Cu \rightarrow {}^{66}_{30}Zn +$ _____

Practice

- 1) $^{214}_{83}\text{Bi}$ produces β
- 2) $^{237}_{93}\text{Np}$ produces α
- 3) $^{116}_{47}\text{Ag}$ produces β
- 4) $^{211}_{83}\text{Bi}$ produces α

Practice

- Write a balanced nuclear reaction for the reaction in which oxygen-15 undergoes positron emission.
- Write the balanced nuclear equation for the electron capture of rubidium-81.

Half-Life

A **half-life** ($t_{1/2}$) is the time required for one-half of the nuclei of a radioisotope sample to decay to products.

- After each half-life, half of the existing radioactive atoms have decayed into atoms of a new element.

for Sample Problem 25.1

7. Manganese-56 is a beta emitter with a half-life of 2.6 h. What is the mass of manganese-56 in a 1.0-mg sample of the isotope at the end of 10.4 h?

Practice Problems

1. A 0.456 mg sample of hydrogen-3 was collected. After 24.52 years, 0.114 mg of the sample remains. What is the half-life of hydrogen-3?
2. Strontium-90 has a half-life of 29 years. What is the mass of strontium-90 in a 5.0g sample at the end of 87 years?

Half-life Practice

3. The half-life of iodine-131 is 8.1 days. How long would it take for ¾ to decay?

4. Radon-222 has a half-life of 3.82 days. How long would it take for 15/16 to decay?

Half-Life Practice

- 5.A radioisotope has a half-life of 4 days. How much of a 20-gram sample of this radioisotope remains at the end of 4 days? 8 days?
- 6.The mass of cobalt-60 in a sample has decreased from 0.8 g to 0.2 g over a period of 10.5 years. Calculate the half-life of cobalt-60.

Half-life Formula

- $N = N_0(1/2)^n$
- N is the remaining amount
- N_0 is the initial amount
- *n* is the number of half lives that have passed

Half-life

- The half-life of tritium is 12.3 y. If 48.0 mg of tritium is released from a nuclear power plant during the course of a mishap, what mass of the nuclide will remain after 49.2 y? After 98.4 y?

Half-life

- An unknown radioisotope exhibits 8540 decays per second. After 350 min, the number of decays has decreased to 1250 per second. What is the half-life?

Half-life

- The table shows the amounts of radioisotopes in three different samples. To the nearest gram, how much will be in Sample B and Sample C when Sample A has 16.2 g remaining?

Sample	Radioisotope	Half-life	Amount (g)
A	Cobalt-60	5.27 y	64.8
B	Tritium	12.32 y	58.4
C	Strontium-90	28.79 y	37.6

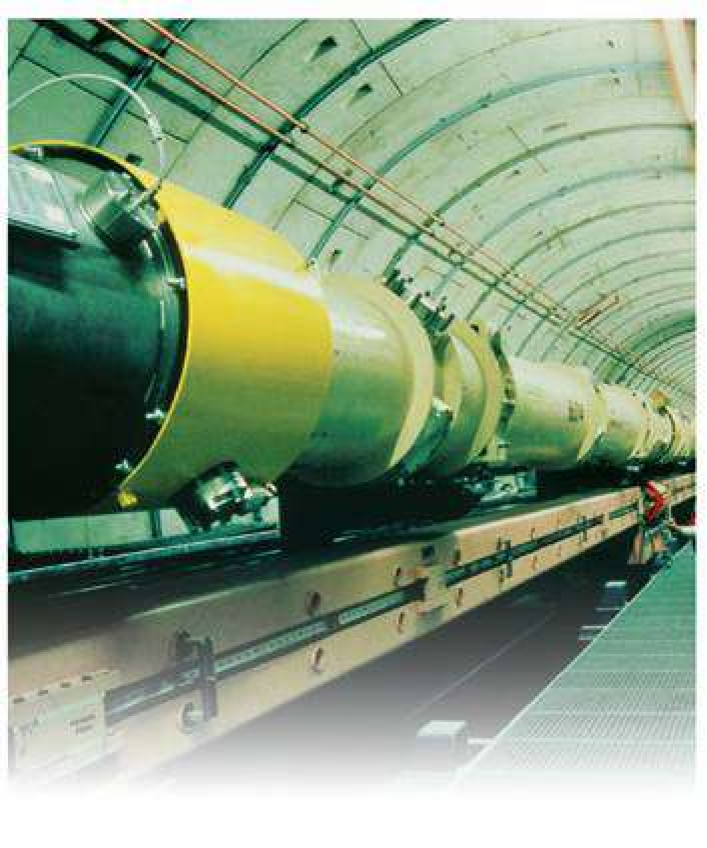
Transmutation Reactions

- The conversion of an atom of one element to an atom of another element is called **transmutation**.
  - Transmutation can occur by radioactive decay or when particles bombard the nucleus of an atom.

- The elements in the periodic table with atomic numbers above 92, the atomic number of uranium, are called the **<u>transuranium elements</u>**.
  - None of the transuranium elements occur in nature, and all of them are radioactive.

Transmutation Reactions

- Transuranium elements are synthesized in nuclear reactors and nuclear accelerators.



Transuranium

- Write a balanced nuclear equation for the induced transmutation of oxygen-16 into nitrogen-13 by proton bombardment. An alpha particle is emitted from the nitrogen atom in the reaction.

Einstein's equation

- $\Delta E = \Delta mc^2$
- ΔE is the change in energy in Joules, m is mass in kg, c is the speed of light in m/s
- A small change in mass results in a large change in energy

Mass defect and binding energy

- The mass of the nucleus is always less than the sum of the masses of the individual protons and neutrons that comprise it.
- Mass defect – difference in mass between a nucleus and its component nucleons

Mass defect and binding energy

- <u>Nuclear binding energy</u> – energy needed to break one mole of nuclei into individual nucleons
  - the larger the binding energy, the more strongly the nucleons are held together

Calculating Mass Defect

- Mass defect = $m_{\text{nucleus}} - [N_p m_p + N_n m_n]$
- m_{nucleus} is the mass of the nucleus
- m_p is the mass of a proton
- m_n is the mass of a neutron
- N_p is the number of protons
- N_n is the number of neutrons
- The mass defect is then used in Einstein's equation to determine energy

Calculating mass defect

- Calculate the mass defect and binding energy of lithium-7. The mass of lithium-7 is 7.016003 amu.
  - Use 1.007825 amu for m_p and 1.008665 amu for m_n

25.2 Section Quiz.

- 1.When potassium-40 (atomic number 19) decays into calcium-40 (atomic number 20), the process can be described as

  a) positron emission.

  b) alpha emission.

  c) beta emission.

  d) electron capture.

25.2 Section Quiz.

- 2. If there were 128 grams of radioactive material initially, what mass remains after four half-lives?

  a) 4 grams

  b) 32 grams

  c) 16 grams

  d) 8 grams

25.2 Section Quiz.

- 3.When transmutation occurs, the __________ always changes.

  a) number of electrons

  b) mass number

  c) atomic number

  d) number of neutrons

25.2 Section Quiz

- 4. Transmutation occurs by radioactive decay and also by

  a) extreme heating.

  b) chemical reaction.

  c) high intensity electrical discharge.

  d) particle bombardment of the nucleus.

25.3 Fission and Fusion of Atomic Nuclei

Nuclear Fission

- When the nuclei of certain isotopes are bombarded with neutrons, they undergo **fission**, the splitting of a nucleus into smaller fragments.

Nuclear Fission

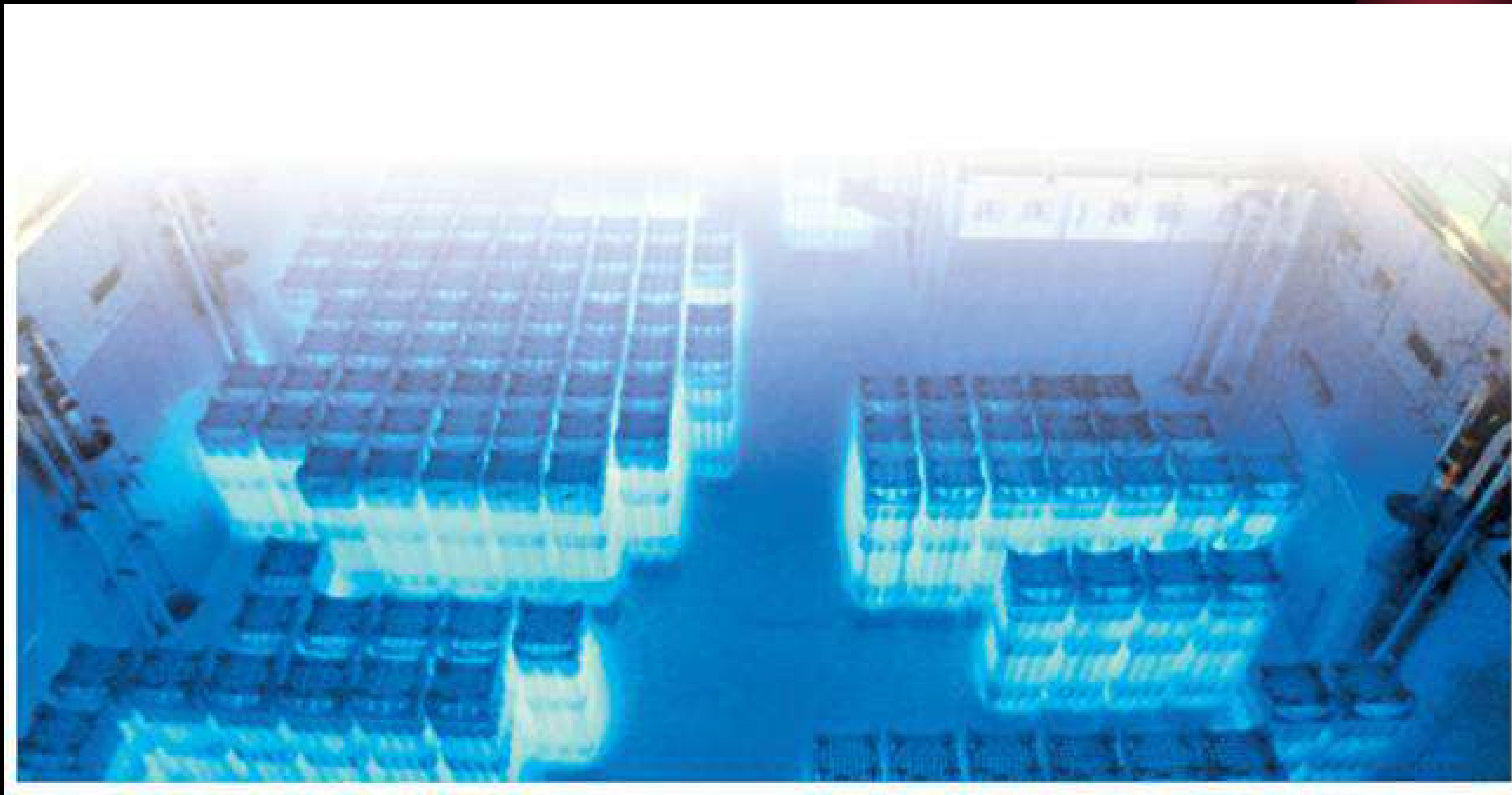
- In a **<u>chain reaction</u>**, some of the neutrons produced react with other fissionable atoms, producing more neutrons which react with still more fissionable atoms.

Nuclear Fission

- 2 ways to slow down reactions:
  - **<u>Neutron moderation</u>** is a process that slows down neutrons
  - **<u>Neutron absorption</u>** decreases the number of neutrons using control rods

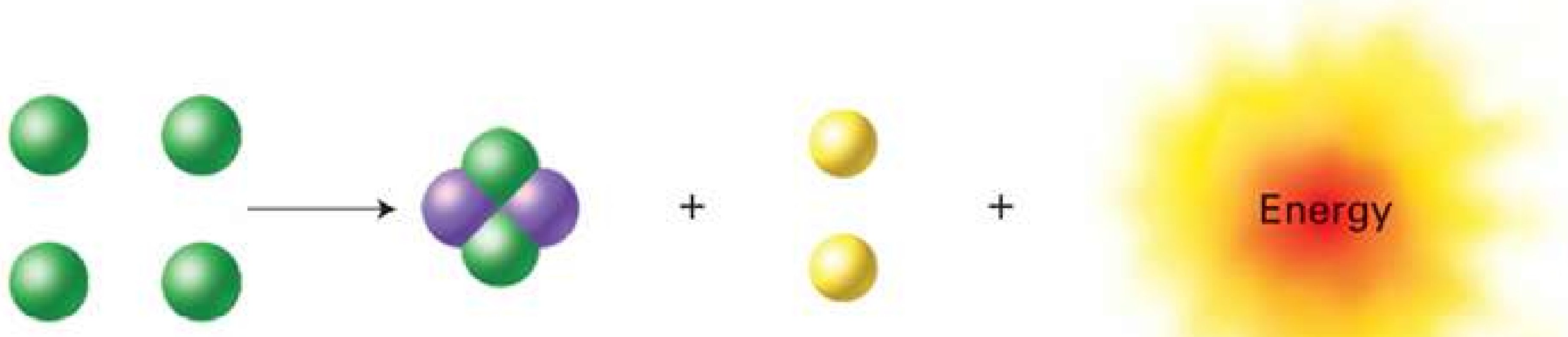
Nuclear Waste

- Water cools the spent rods, and also acts as a radiation shield to reduce the radiation levels.



Nuclear Fusion

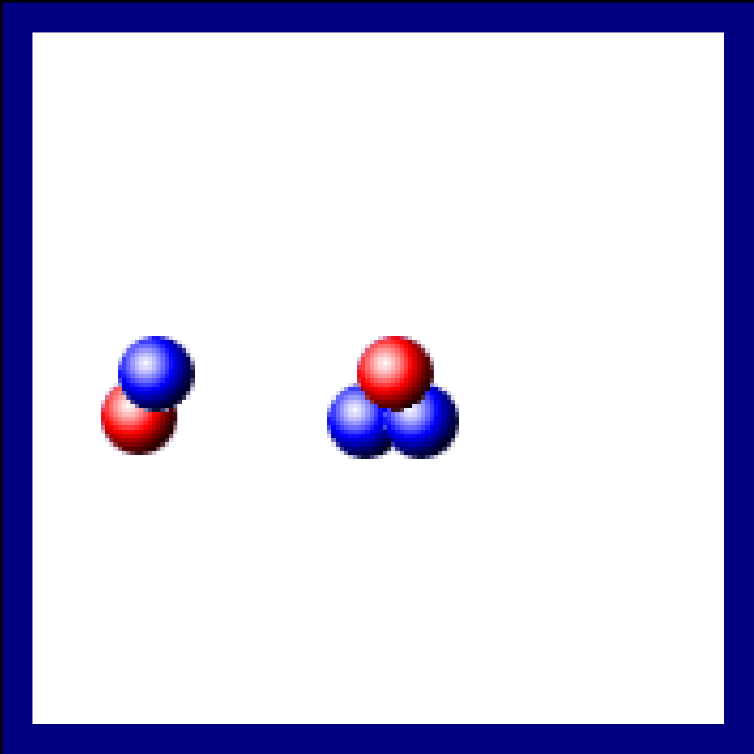
- **Fusion** occurs when nuclei combine to produce a nucleus of greater mass. In solar fusion, hydrogen nuclei (protons) fuse to make helium nuclei and two positrons.



$4\,^{1}_{1}H$ hydrogen nuclei → $^{4}_{2}He$ helium nucleus + $2\,^{0}_{+1}e$ positrons + Energy

Nuclear Fusion

- Fusion reactions, in which small nuclei combine, release much more energy than fission reactions, in which large nuclei split.



Nuclear Fusion

- The use of controlled fusion as an energy source on Earth is appealing.
  - The potential fuels are inexpensive and readily available.
  - The problems with fusion lie in achieving the high temperatures necessary to start the reaction and in containing the reaction once it has started.

25.3 Section Quiz.

- 1.One of the control mechanisms for a sustainable nuclear chain reactor involves slowing down the released neutrons so they may be captured by other nuclei. This is done using
  - a) moderators.
  - b) shielding.
  - c) absorbers.
  - d) control rods.

25.3 Section Quiz.

- 2.Choose the correct words for the spaces. In solar fusion, _________ nuclei fuse to form _________ nuclei.

  a) helium, hydrogen

  b) hydrogen-1, hydrogen-2

  c) hydrogen, helium

  d) hydrogen-1, hydrogen-3

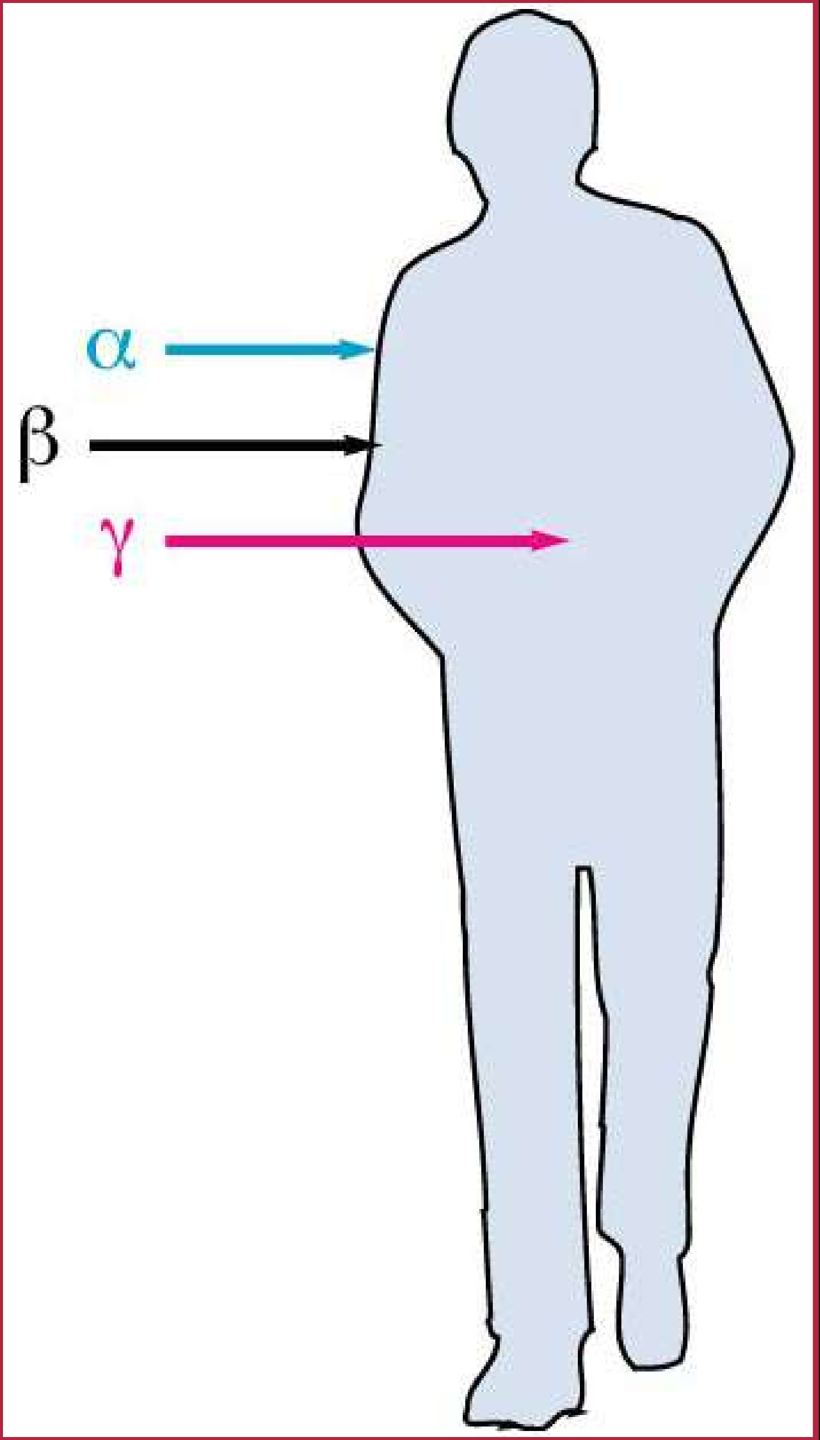
25.4 Radiation in Your Life

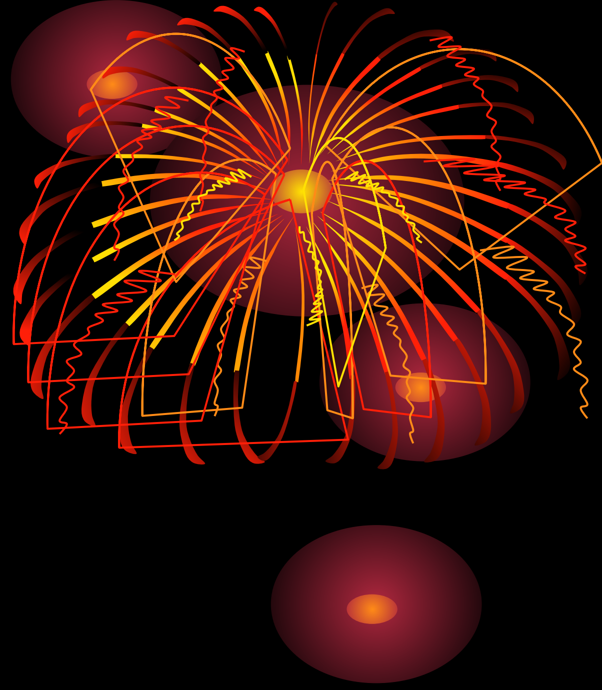
Detecting Radiation

- **<u>Ionizing radiation</u>** is radiation with enough energy to knock electrons off some atoms of the bombarded substance to produce ions.
  - Devices such as Geiger counters, scintillation counters, and film badges are commonly used to detect radiation.

Detecting Radiation

- Radiation can produce ions, which can then be detected, or it can expose a photographic plate and produce images.





- Radioactive particles and rays vary greatly in penetrating power

Detecting Radiation

- Geiger Counter
  - A **<u>Geiger counter</u>** uses a gas-filled metal tube to detect radiation.

Detecting Radiation

- Scintillation Counter
  - A **scintillation counter** uses a phosphor-coated surface to detect radiation.

Detecting Radiation

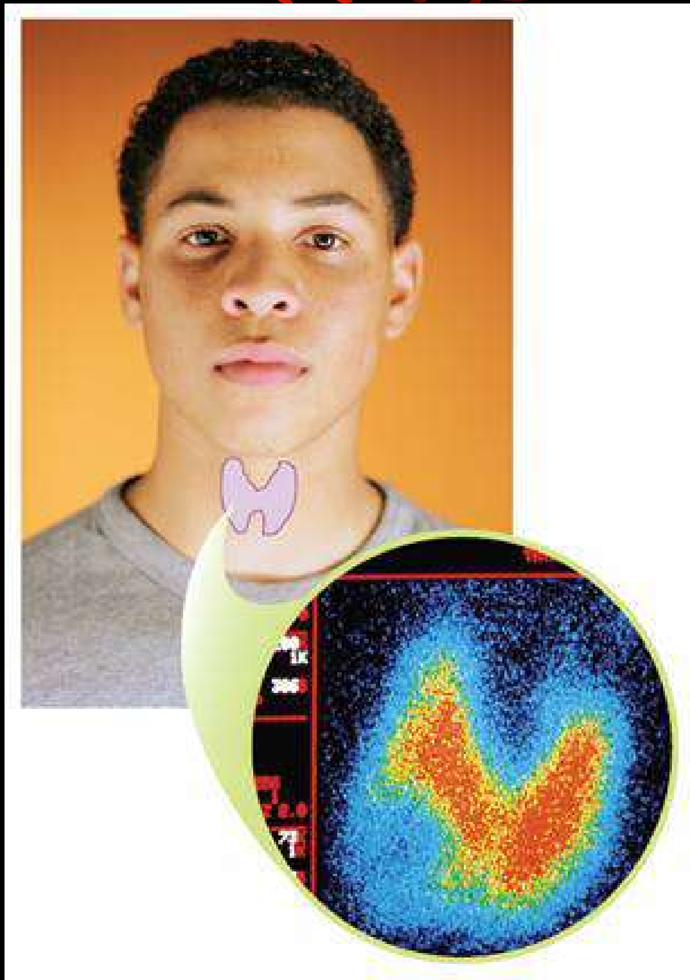
- Film Badge
  - A **film badge** consists of several layers of photographic film covered with black lightproof paper, all encased in a plastic or metal holder.

Using Radiation

- Radioisotopes can be used to diagnose medical problems and, in some cases, to treat diseases.

Using Radiation

- This scanned image of a thyroid gland shows where radioactive iodine-131 has been absorbed.



25.4 Section Quiz.

- 1. Ionizing radiation can remove _________ from atoms.

  a) protons

  b) neutrons

  c) positrons

  d) electrons.

25.4 Section Quiz.

- 2.Which of the following is NOT a device used to detect radiation?

  a) Geiger counter

  b) scintillation counter

  c) film badge

  d) radioisotope

25.4 Section Quiz.

- 3.Choose the correct words for the space. When a tumor is treated by radiation, more cancer cells than normal cells are killed because cancer cells _______________ than normal cells.

  a) are more susceptible to damage because they grow faster

  b) absorb more radiation because they are larger

  c) grow slower

  d) are smaller

25.4 Section Quiz.

- 4.How do scientists detect thyroid problems?

  a) with teletherapy

  b) by neutron activation analysis

  c) using an iodine-131 tracer

  d) using a radioisotope sealed in a gold tube