King Saud University
College of Applied Studies
and Community Service
Department of Natural Sciences

Nuclear Reaction and Radiation Detectors

General Physics II
PHYS 111

Nouf Alkathran
nalkathran@ksu.edu.sa

Outline

- Nuclear Reactions

  1. Fission

Chain Reaction

Mass-Energy Equivalence

  2. Fusion

Dose of Radiation

Typical Doses

Types of Exposure & Health Effects

Outline

- HIGH Doses, Radiation Causes Harm
- Effects of ACUTE Exposures
- LOW Doses
- Radiation Detectors
- Alpha
- Neutrons and gamma-rays
- Types of Detector
- Questions

Nuclear Reactions

- There are two main types of nuclear reactions that can release energy:

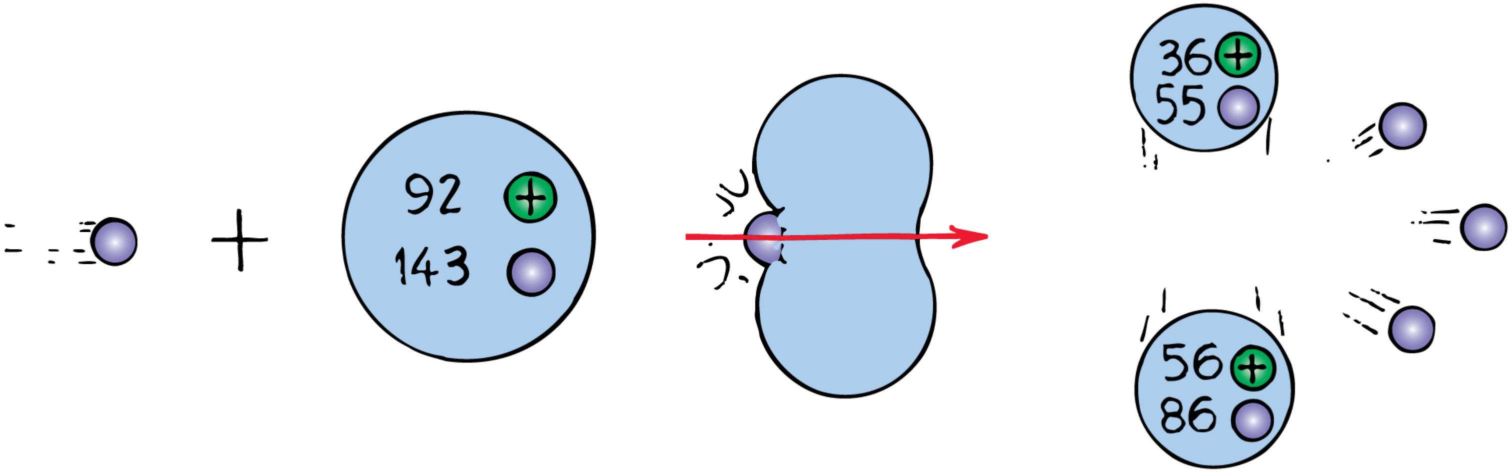
1. Fission
2. Fusion

1.Fission

- the process of causing a large nucleus ($A > 120$) to split into multiple smaller nuclei, releasing energy in the process.
- It can start when the large nuclei absorbs a neutron, causing it to become unstable to the point that it falls apart.
- This is the reaction that we use in nuclear power plants and early nuclear weapons.
- Fission is relatively easy to do, but also leaves us with lots of nuclear waste that must be stored for thousands of years .

Fission

- In a typical example of nuclear fission, one neutron starts the fission of the uranium atom and three more neutrons are produced when the uranium fissions.



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

Chain Reaction

- the most typical fuel used in a fission reactor is uranium-235.
  - In 1939 four German scientists discovered that uranium-235 would become very unstable if it gained an extra neutron, forming uranium-236.
  - Uranium-236 is so unstable that a fraction of a second later it will split to form two smaller atoms, and in the process release energy.
  - Here are two common fission reactions that uranium-236 can go through...

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{236}_{92}U \rightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3\,^{1}_{0}n$$

and

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{236}_{92}U \rightarrow ^{140}_{54}Xe + ^{94}_{38}Sr + 2\,^{1}_{0}n$$

Chain Reaction

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{236}_{92}U \rightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3\,^{1}_{0}n$$

and

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{236}_{92}U \rightarrow ^{140}_{54}Xe + ^{94}_{38}Sr + 2\,^{1}_{0}n$$

- Some things to notice...
  - Both reactions start the same when we add a single neutron to uranium-235, which forms uranium-236 for a split second.
  - Barium-141, krypton-92, xenon-140, and strontium-94 are smaller nuclei that uranium-236 could split into.
  - At any point in the reaction the conservation of nucleons stays the same.
  - In the first reaction three neutrons were ejected, while in the second reaction only two were ejected. Although it is possible for as many as 5 neutrons to be ejected in some fission reactions, on average it is about 2.5 neutrons.
  - These reactions are exothermic (they release energy).

Chain Reaction

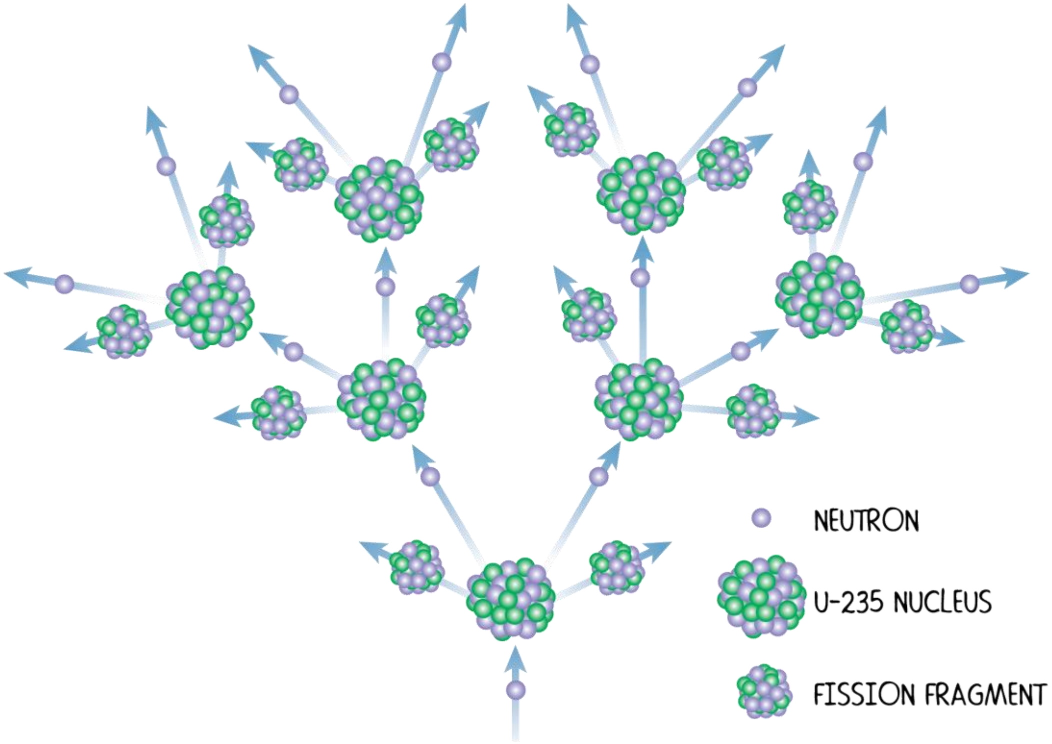
- Note that one neutron starts the fission of the uranium atom, and, in the example shown, three more neutrons are produced.
  - Most nuclear fission reactions produce two or three neutrons.
  - These neutrons can, in turn, cause the fissioning of two or three other nuclei, releasing from four to nine more neutrons.
  - If each of these succeeds in splitting an atom, the next step will produce between 8 and 27 neutrons, and so on.
- The basic reaction is written out as...

$$^{235}_{92}\mathrm{U} + {}^{1}_{0}\mathrm{n} \longrightarrow {}^{236}_{92}\mathrm{U} \longrightarrow X + Y + 2.5\ {}^{1}_{0}\mathrm{n}$$

- X and Y represent any of the smaller nuclei that uranium-236 will split into.

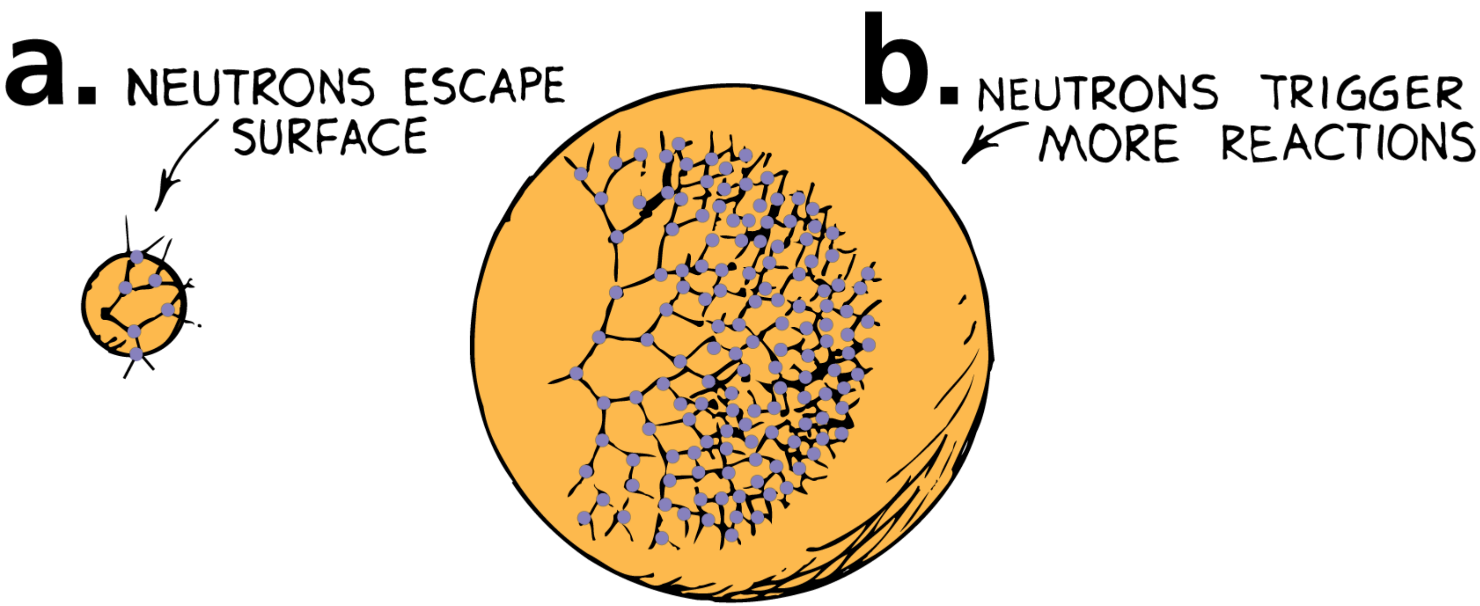
Chain Reaction

- A **chain reaction** is a self-sustaining reaction. A reaction event stimulates additional reaction events to keep the process going.



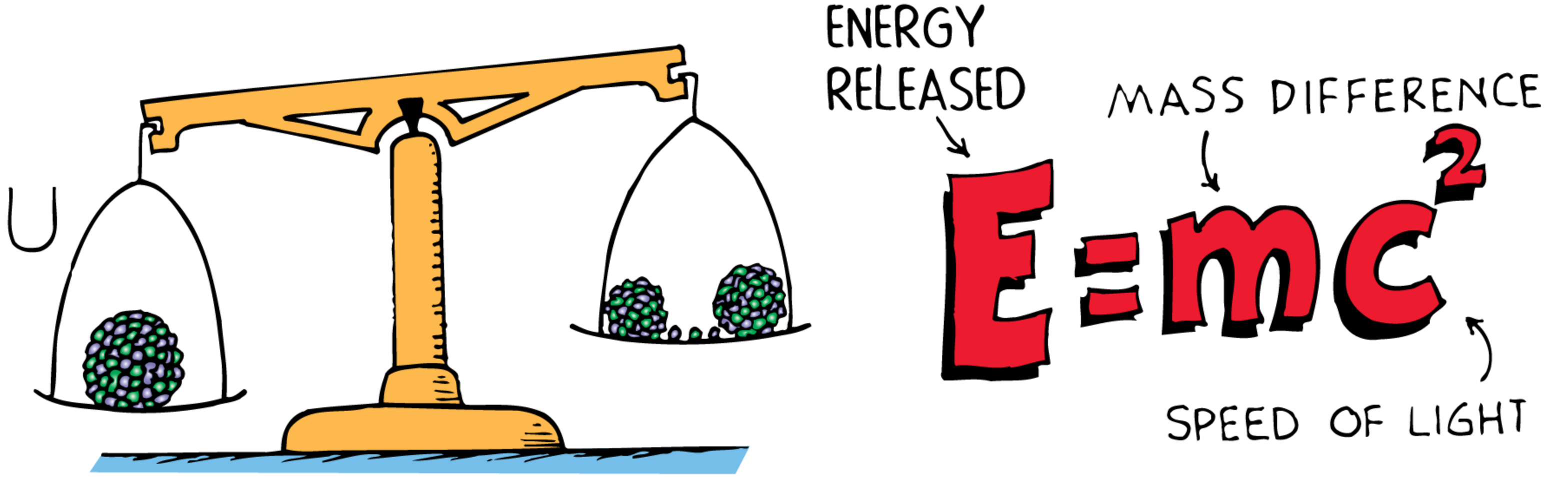
Chain Reaction

- An exaggerated view of a chain reaction is shown here.
  a. In a small piece of pure U-235, the chain reaction dies out.
  b. In a larger piece, a chain reaction builds up.



Mass-Energy Equivalence

- When this decrease in mass is multiplied by the speed of light squared, it is equal to the energy yielded by each uranium nucleus that undergoes fission.
- The missing mass is equivalent to the energy released.



2.Fusion

- Energy is released as light nuclei *fuse*, or combine, rather than split apart. This process is **nuclear fusion**

Fusion

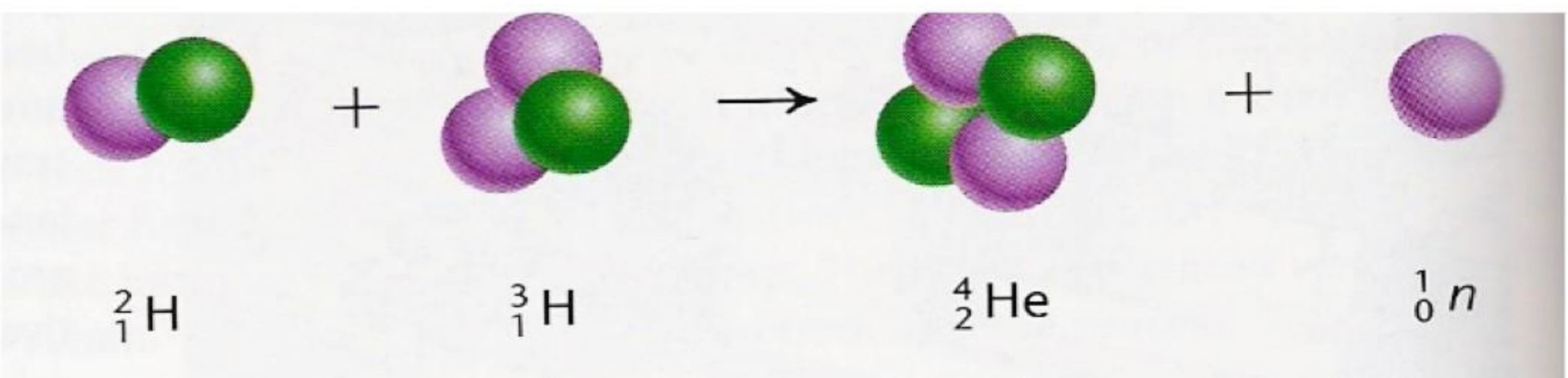
- The process of causing small nuclei to stick together into a larger nucleus, in the process releasing energy.
  - This is the process that drives our sun, and all other suns.
  - We can do it under the right conditions in a lab, but we end up putting in more energy than we get out.
  - The left over products of fusion are relatively safe, which is why a lot of research is going into developing fusion react

Fusion

- Fusion occurs when 2 nuclei join together to form a larger nucleus. Fusion is brought about by bringing together two or more small nuclei under conditions of high pressure and heat.
- The following equations represent fusion reactions, where p = proton.

$$^{2}_{1}H + ^{2}_{1}H \rightarrow ^{3}_{1}H + ^{1}_{1}p \qquad ^{3}_{2}He + ^{3}_{2}He \rightarrow ^{4}_{2}He + 2\,^{1}_{1}H$$

$$^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}n$$



<u>Dose of Radiation</u>

- When radiation's energy is deposited into our body's tissues, that is <u>a dose</u> of radiation.
- The more energy deposited into the body, the higher the dose.
- **Rem** is a unit of measure for radiation dose.
- Small doses expressed in **mrem = 1/1000 rem**.
- **Rad** & **R** (Roentgens) are similar units that are often equated to the Rem.

Typical Doses

Average Dose to US Public from All sources	360 mrem/year
Average Dose to US Public From Natural Sources	300 mrem/year
Average Dose to US Public From Medical Uses	53 mrem/year
Coal Burning Power Plant	0.2 mrem/year
Average dose to US Public from Weapons Fallout	< 1 mrem/year
Average Dose to US Public From Nuclear Power	< 0.1 mrem/year
Occupational Dose Limit for Radiation Workers	5,000 mrem/yr

Coast to coast Airplane roundtrip	5 mrem
Chest X ray	8 mrem
Dental X ray	10 mrem
Head/neck X ray	20 mrem
Shoe Fitting Fluoroscope (not in use now)	170 mrem
CT (head and body)	1,100 mrem
Therapeutic thyroid treatment (dose to the whole body)	7,000 mrem

Types of Exposure & Health Effects

- **Acute Dose**
  - Large radiation dose in a short period of time
  - Large doses may result in observable health effects
    - Early: Nausea & vomiting
    - Hair loss, fatigue, & medical complications
    - Burns and wounds heal slowly
  - Examples: medical exposures and accidental exposure to sealed sources
- **Chronic Dose**
  - Radiation dose received over a long period of time
  - Body more easily repairs damage from chronic doses
  - Does not usually result in observable effects
  - Examples: Background Radiation and Internal Deposition

Health Effects

- Rapidly dividing cells are more susceptible to radiation damage.
- Examples of radiosensitive cells are
  - Blood forming cells
  - The intestinal lining
  - Hair follicles
  - A fetus
- When cells are dividing (or undergoing mitosis) they are more susceptible to radiation damage because the cells don’t have their full suite of repair mechanisms. Because of this, cells that are often dividing like the cells that create our blood or line our intestine, also Hair follicles, and, of course, fetal cells are more susceptible to radiation damage.
- This is why the fetus has a exposure limit (over gestation period) of 500 mrem (or 1/10th of the annual adult limit)

HIGH Doses, Radiation Causes Harm

- High Dose effects seen in:
  - Radium dial painters
  - Early radiologists
  - Atomic bomb survivors
  - Populations near Chernobyl
  - Medical treatments
  - Criticality Accidents
- In addition to radiation sickness, increased cancer rates were also evident from high level exposures.

<u>Effects of ACUTE Exposures</u>

Dose (Rads*)	Effects
25-50	First sign of physical effects (drop in white blood cell count)
100	Threshold for vomiting (within a few hours of exposure)
320 - 360	~ 50% die within 60 days (with minimal supportive care)
480 - 540	~50 % die within 60 days (with supportive medical care)
1,000	~ 100% die within 30 days

*** For common external exposures 1 Rad ~ 1Rem = 1,000 mrem**

LOW Doses

- No physical effects have been observed
- Although somewhat controversial, this increased risk of cancer is presumed to be proportional to the dose (no matter how small).

Very Small DOSE = Very Small RISK

Radiation Detectors

- Range of Radiation
  - *Alpha*: Small. Shield with a piece of paper
  - *Beta*: Smallish Shield with a ½ inch or so of Pb
  - *Gamma*: Long Shield with a few inches of Pb
  - *Neutron*: Very long Shield with many inches of parafin

Radiation Detectors

- When an energetic charged particle passes through matter it will rapidly slow down and lose its energy by interacting with the atoms of the material (detector or body)
- Mostly with the atomic electrons
- It will 'kick' these electrons off of the atoms leaving a trail of ionized atoms behind it.
- Radiation detectors use a high voltage and some electronics to measure these vapor trails. They measure a (small) electric current).

Types of Detector

- Alpha, Beta and Gamma radiation
- Film Badges
- Gas Counters (Geiger counters)
- Scintillators
- Solid State Detectors

Alpha

- e.g. Alpha …. A few inches of air or a piece of paper stops it … if your detector is a few feet away, it will not detect the alpha …

- e.g. Alpha … if the sides of the detector are too thick the alpha will not get in and will not be detected

Neutrons and gamma-rays

- Neutrons and gamma-rays are neutral
- No charge… much longer range

- When they penetrate matter eventually they also will interact somehow (gamma-rays interact via Compton scattering, photoelectic effect or pair production, neutrons will collide with protons in the nuclei) and these interactions produce energetic charged particles.

- The detectors are sensitive to these secondary particles.

Film Badges

- Will detect: beta, gamma and neutron
- Need to send away and develop the film and then later will tell you what does you received
- Used by radiation workers

Gas Counters

- e.g. Geiger Counters
- Will Detect: Alpha, Beta, some gamma
- No identification … just tells you something is there
- With a thin entrance window GM-tube is sensitive to alphas

Scintillators

- Make a flash of light when something interacts
  - Sodium Iodide
  - Cesium Iodide
- Will Detect: Alpha (with thin window), beta (with thin window) and gamma.
- Gives moderate to bad energy information … some information on the type of radiation

Semiconductor Detectors

- Germanium
- Silicon
- Will Detect: Gamma rays (also beta and alphas in a laboratory)
- Excellent energy resolution: Can measure exactly was source you are looking at

Questions

- **Nuclear fusion releases energy when**

A. uranium splits into two fragments
B. heavy ions fuse together
C. uranium emits a neutron
D. very light nuclei fuse together

Questions

- **A unit that measures the effective dose of radiation in a human is the**
  a. curie.
  b. RBE.
  c. rad.
  d. rem

Questions

- **The chief hazard of radiation is**

  a. damage to living cells due to ionization.

  b. damage to cells due to heating.

  c. damage to living cells due to the creation of chemical impurities.

  d. the creation of new isotopes within the body

Questions

When the process of fission releases energy, the total mass of the material after the event is

a. less.
b. the same.
c. doubled.
d. tripled