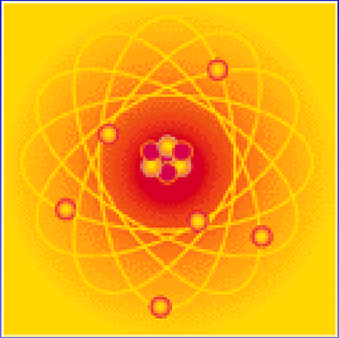

II. Basic Physics of Ionizing Radiation

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Objectives

- **Distinguish the electromagnetic and particulate forms of ionizing radiation.**
- **Identify alpha, beta and gamma radiation.**
- **Understand the units of radiation quantity, exposure and dose.**

What is “Radiation”?

- **Comes from the root word “radiate”.**
- **Radiate:**
  - **1 : to proceed in a direct line from or toward a center.**
    2 : to send out rays : shine brightly.
- **Radiation:**
  - **1a : something that is radiated; b : energy radiated in the form of waves or particles**

What is "Radiation"?

- **Radiation can be thought of as the transmission of energy through space.**
- **Two major forms of radiation:**
  - **<u>Electromagnetic</u> (EM) radiation**
  - **<u>Particulate</u> radiation**
- **Both forms can interact with matter, and transfer their energy to the matter.**

Electromagnetic Radiation

- **Electromagnetic radiation has no mass, and moves through space at the speed of light (3.0 x10^8 meters per second).**
- **Electromagnetic radiation can be described by two models:**
  - **Wave Model**
  - **Photon Model**

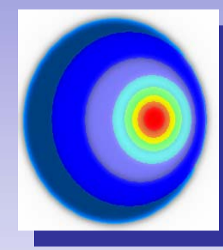
EM Radiation: Wave Model

- **EM radiation is a pair of perpendicular, time-varying electric and magnetic fields traveling through space with the <u>velocity</u> of light (c).**
- **The distance between maxima of the EM fields is the <u>wavelength</u> (λ).**
- **The <u>frequency</u> (ν) of the wave is given by:**

$$\nu = c / \lambda$$

EM Radiation: Photon Model

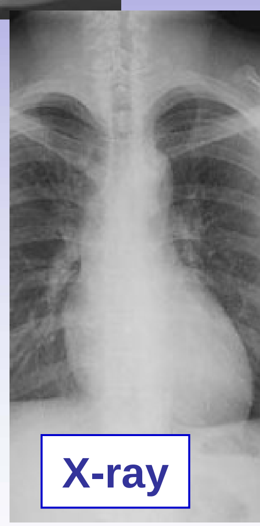
$$E = h\,c\,/\,\lambda$$



Electromagnetic radiation can also be described as discrete packets of energy called photons. The energy (E) is related to the wavelength (λ) in the wave model through Planck's Constant (h) and the speed of light (c).

Shorter Wavelengths

Longer Wavelengths



Higher Frequencies and Energies

Lower Frequencies and Energies

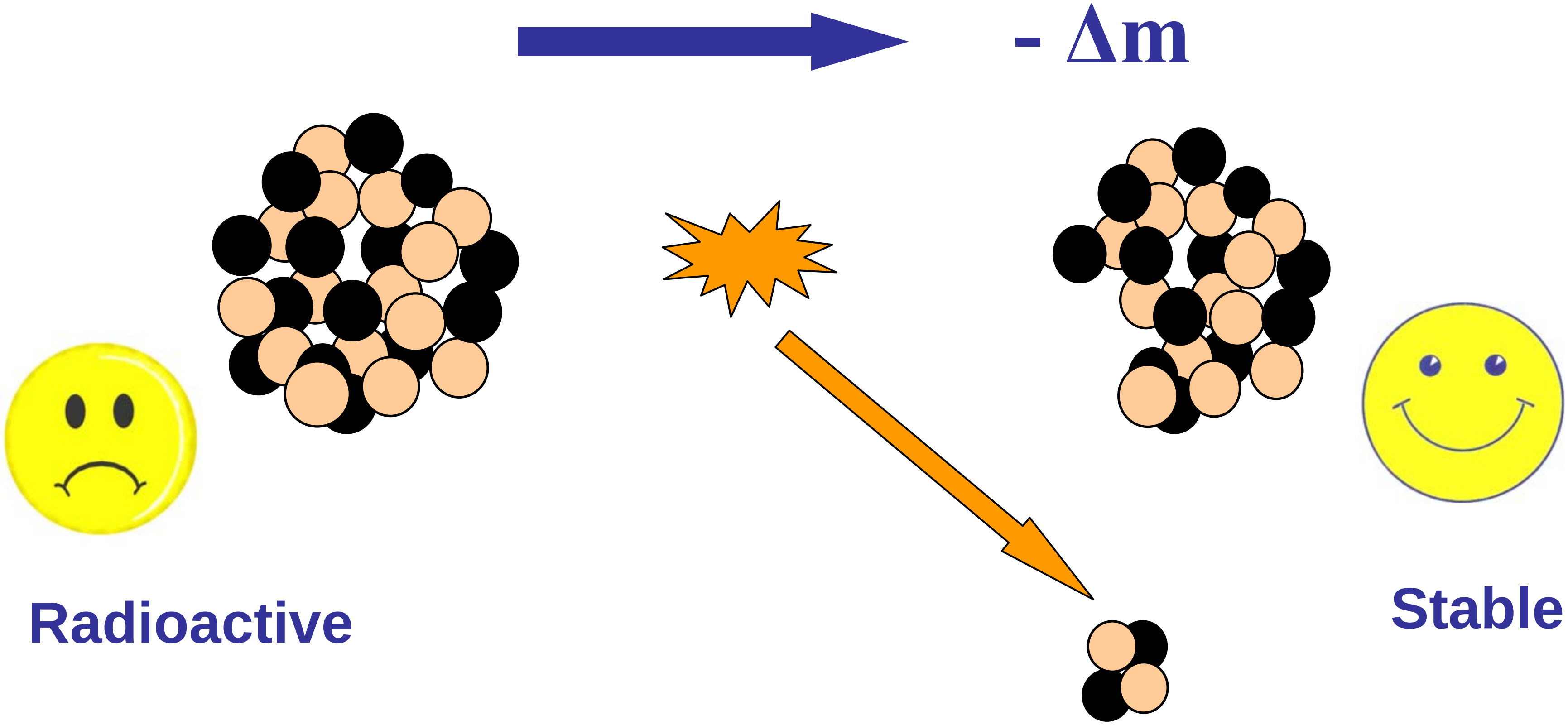
Ionizing EM Radiation

- **EM radiation with wavelengths shorter than 100 nanometers can remove electrons from the outer atomic shells.**
- **This process produces <u>ions</u>.**
- **Ions can interact with living tissue to produce biological damage.**
- **A major source of ionizing radiation is <u>nuclear transformation</u>.**

Human Transformation

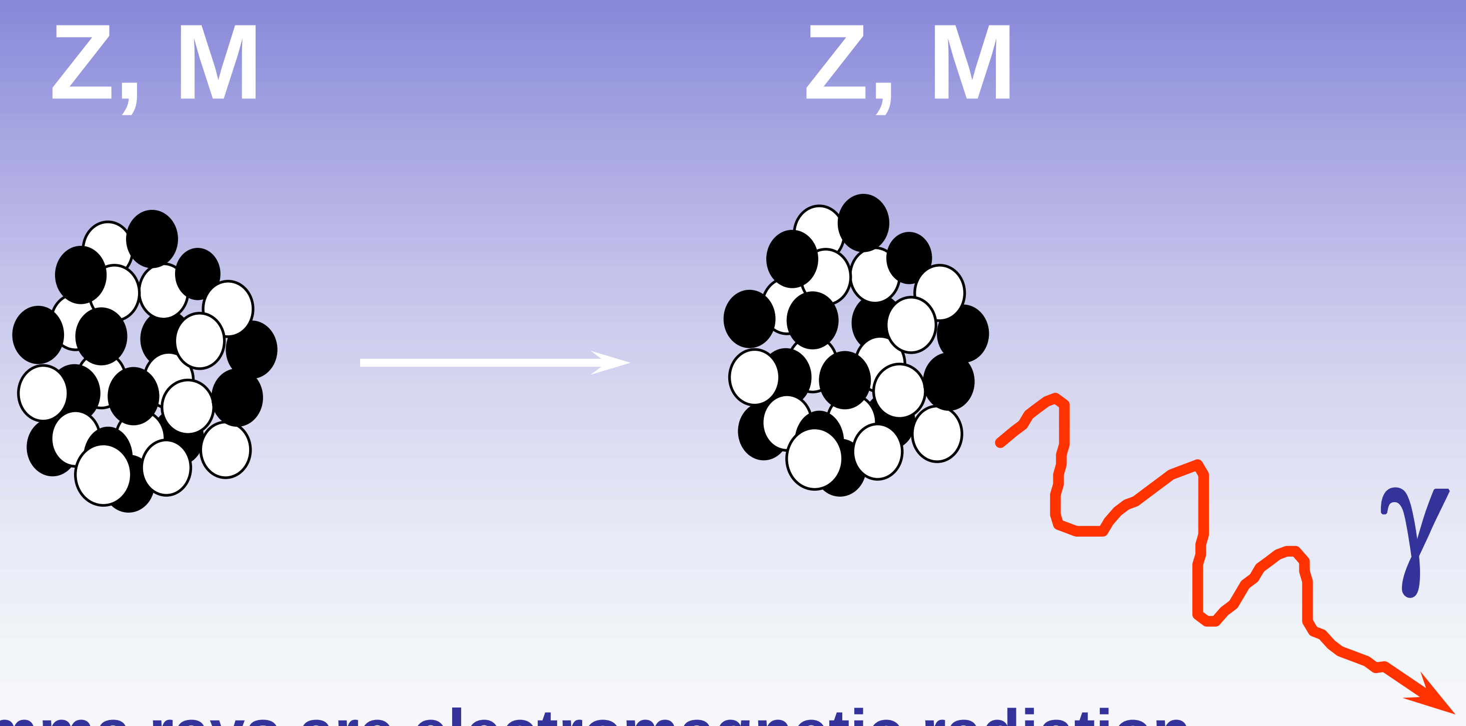
$\longrightarrow$ $-\Delta m$

Nuclear Transformation



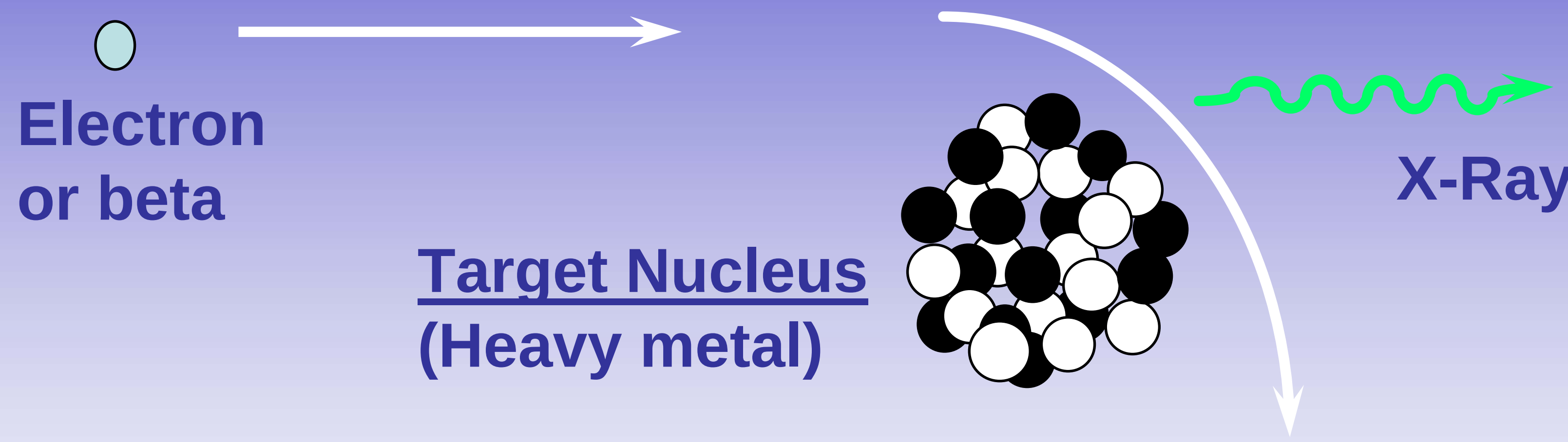
<u>Ionizing</u> <u>Radiation</u>: α, β, or γ

Gamma Rays



<u>Gamma</u> <u>rays</u> are electromagnetic radiation resulting from nuclear transformation.

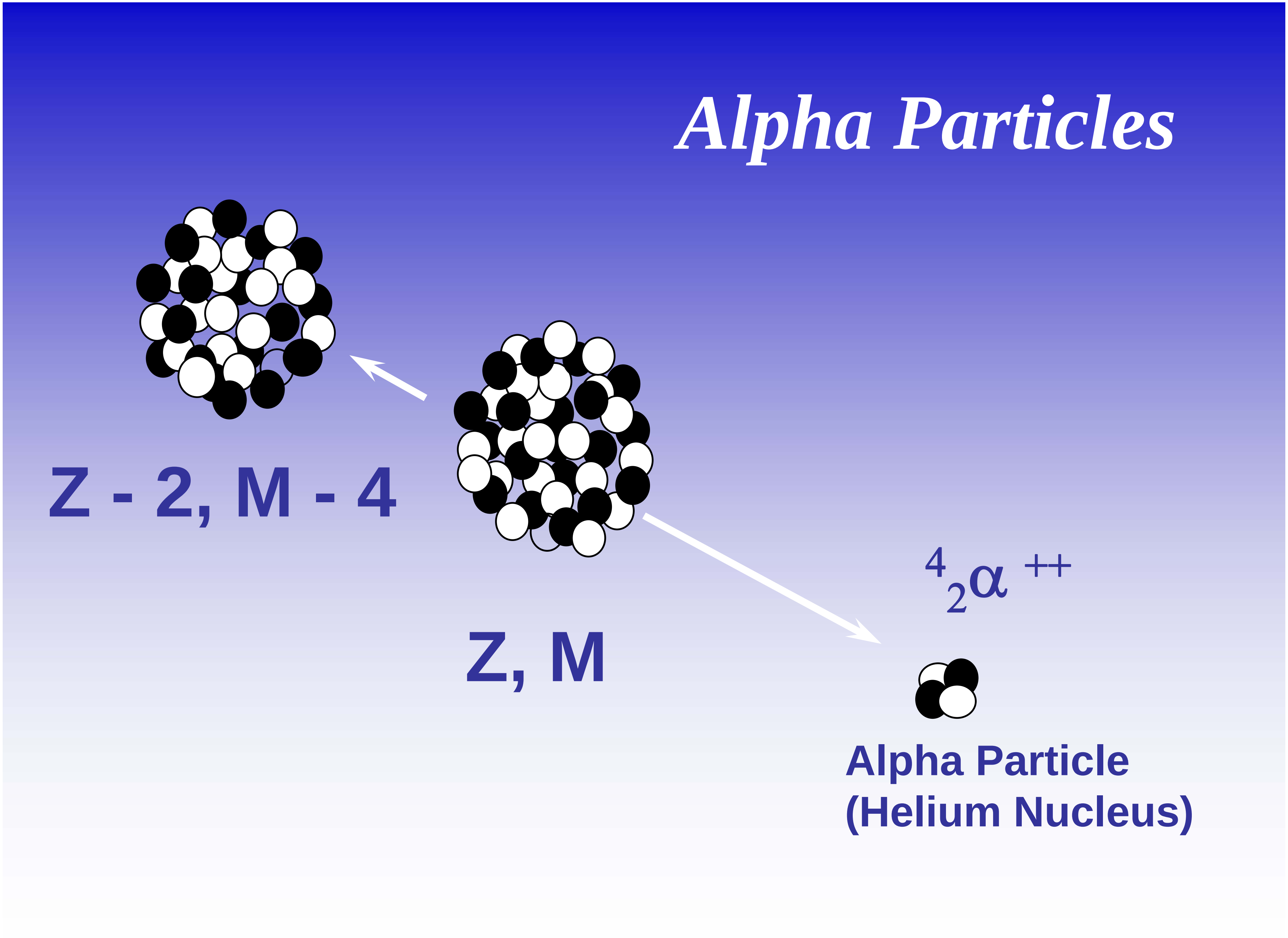
Production of X-Rays



<u>X-rays</u> are produced when a charged particles (electrons or betas) are decelerated by a strong electrostatic field, such as that found near the nuclei of heavy metals (tungsten, lead).

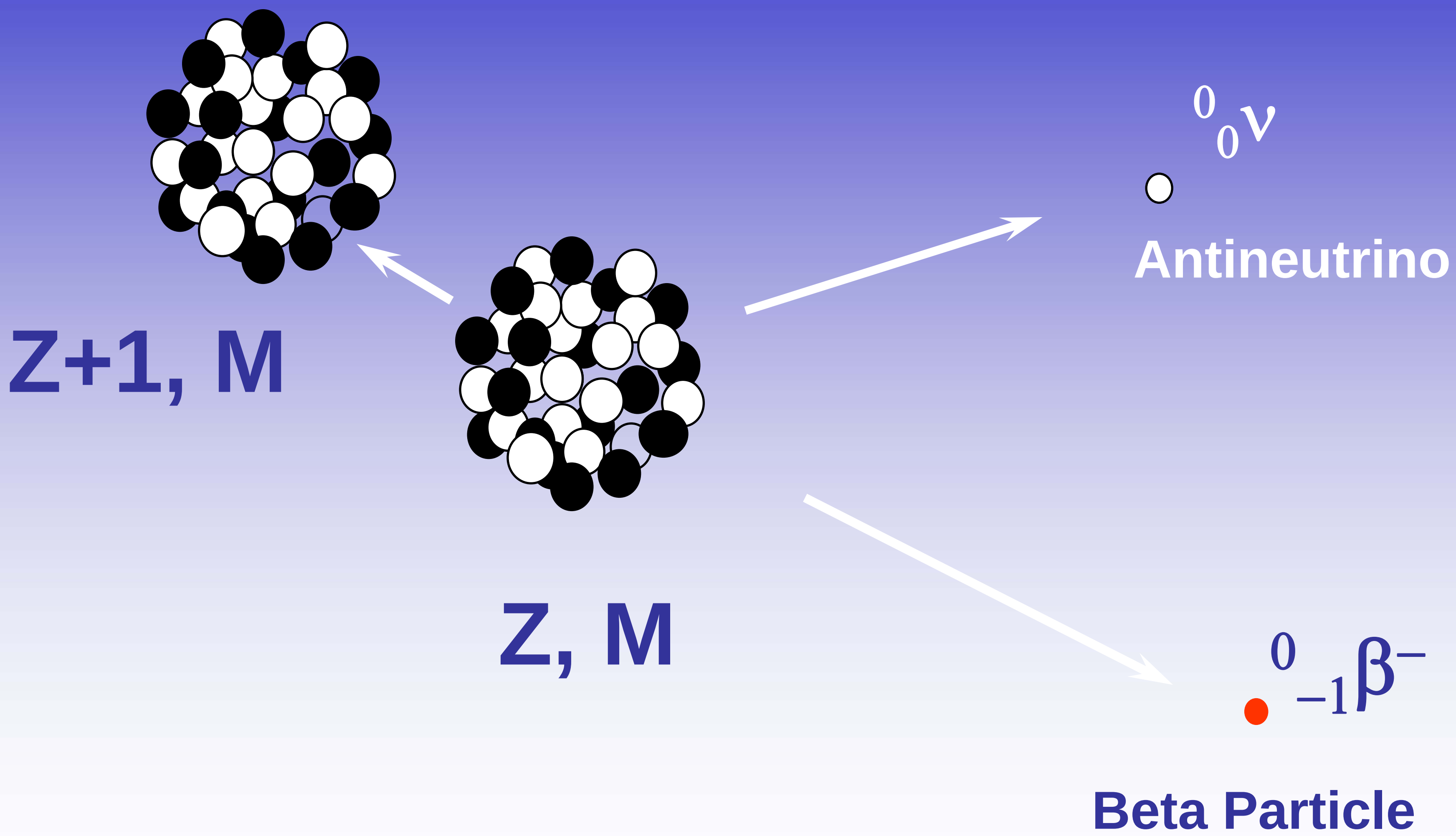
Particulate Radiation

- **Charged particles are emitted from the atomic nucleus at high energy in some nuclear transformations. These include alpha and beta particles.**
- **Uncharged particles (neutrons) are produced by fission or other nuclear reactions.**
- **Both types of particles produce ionization.**



Alpha Particles
Z - 2, M - 4
Z, M
$^{4}_{2}\alpha^{++}$
Alpha Particle
(Helium Nucleus)

Beta Particles



Concept of Physical Half-life

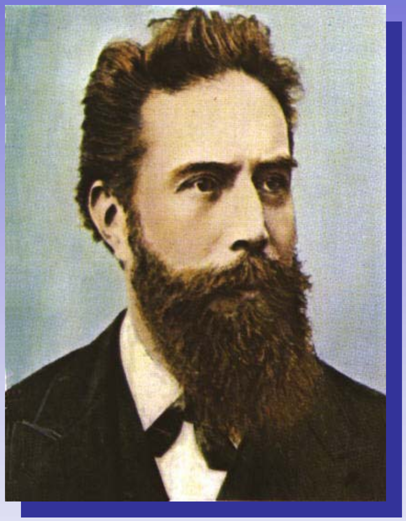
- **Radioactive nuclei undergo disintegration at a rate that is proportional to the number of untransformed nuclei present.**
- **The <u>physical</u> <u>half-life</u> is the time required for one-half of the remaining nuclei to transform.**
- **The half-life is characteristic if the radionuclide.**

Radiation Exposure, Dose and Quantity

- **Exposure is an index of the ability of a radiation field to ionize air.**
- **Dose is a measure of the energy imparted to matter, per unit mass, when an ionizing radiation field interacts with matter.**
- **Quantity of radioactive material is expressed as "activity", the number of nuclear disintegrations that occur in a sample per second.**

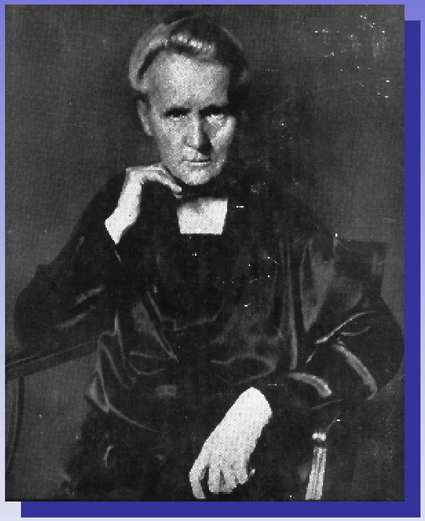
Units of Exposure and Quantity

Roentgen (R)



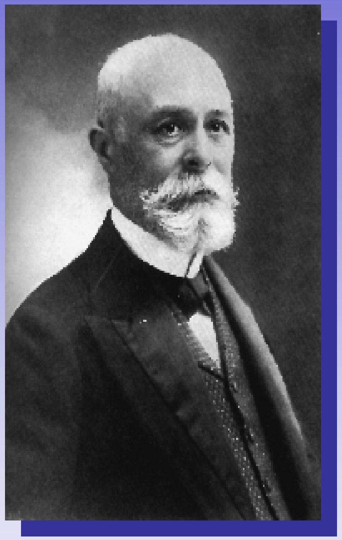
2.58×10^{-4} coulombs / kg dry air at STP

Curie (Ci)



Disintegrations per second in 1 gm radium (3.7×10^{10} dps)

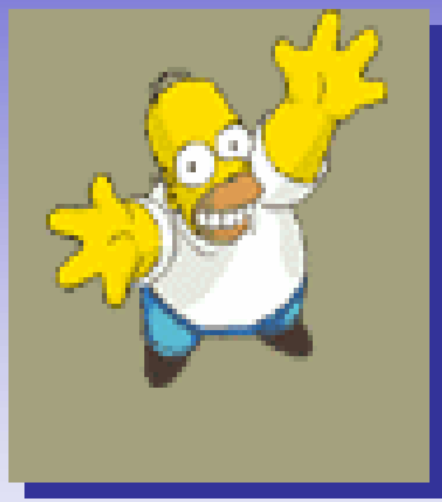
Becquerel (Bq)



Systeme Internationale **unit: one dps**

Units of Absorbed Dose

rad



radiation absorbed dose (100 erg/gm)

Gray (Gy)

S.I. unit: 1.0 J/kg (100 rads)

Concept of Equivalent Dose

- **For the <u>same</u> <u>absorbed</u> <u>dose</u> (deposited energy), different forms of ionizing radiation can have <u>different</u> biological effects.**
- **"Equivalent Dose" attempts to normalize these differences.**

Equivalent Dose

- **Equivalent Dose is the product of the dose and a modifying factor called the quality factor (QF), which reflects the relative biological effectiveness of the radiation:**

$$H_T = D \times QF$$

Quality Factors (QF)

- **QF are <u>indices</u> of the "relative biological effectiveness" (RBE) of a radiation. RBE is a complicated function of type of radiation, energy and the biological system under consideration.**
- **QF are not measured. They are determined by a committee.**

Quality Factors (QF)

Radiation	Quality Factor
Photons, electrons, betas	1
Thermal Neutrons	5
Alphas, Fast neutrons, misc.	20

Effective Dose Equivalent

- **<u>Effective Dose Equivalent (EDE)</u> is intended to reflect the total biological effect of a given exposure on a human. It is a <u>weighted</u> <u>average</u> of the individual doses to a number of important tissues:**

$$H_E = \Sigma (H_T \times W_T)$$

(sum is over all tissues)

Effective Dose Equivalent

- EDE is a <u>concept</u>, not a measurable quantity.
- Applies to situation where irradiation of organs and tissues is <u>non-uniform</u>.
- EDE yields the same "radiation detriment" as a numerically-equivalent whole-body dose.
- W_T values are assigned by a committee.

Effective Dose Equivalent (EDE)

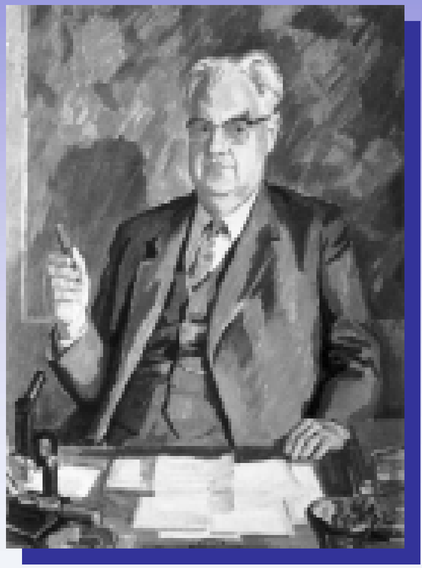
- **Tissue Weighting Factors for EDE are based on ICRP Report 26.**
- **EDE is the index of dose to be used for purposes of regulatory compliance in the United States (10 CFR 20).**
- **"Effective Dose" is conceptually the same as EDE. It uses slightly different weighting factors (based on ICRP Report 60).**

Units of Equivalent Dose and EDE

Rem (rem)

roentgen equivalent man (rad x quality factor)

Sievert (Sv)



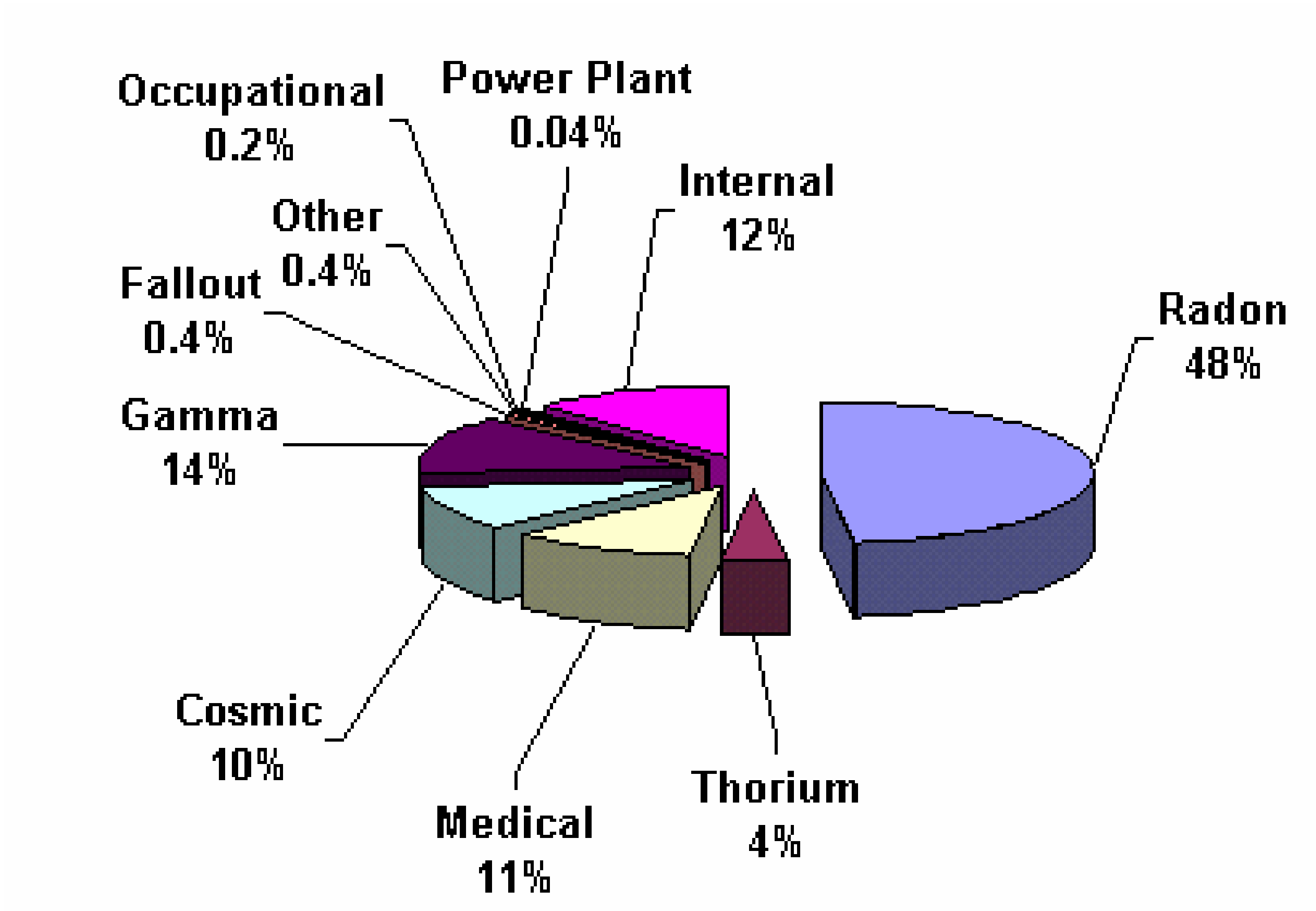
S.I. unit: Gy x quality factor

Genetically Significant Dose

- **Is an <u>index</u> of potential genetic damage to a population due to the irradiation of some members of the population.**
- **Is based on dose to the <u>gonads</u> and chances of reproduction.**
- **Is about 30 – 40 millirem per year in the U.S.**
- **No epidemiological evidence for genetic effects in humans.**

Sources of Ionizing Radiation

- **Cosmic rays and naturally-occurring radioactive elements**
- **Medical X-rays and nuclear medicine studies**
- **Manmade radioactive materials and radiation sources**



The <u>average</u> annual radiation dose to all individuals in the U.S. is about 300 millirem. Almost 90% of that dose is from natural sources. The single largest contributor to the average annual dose is inhaled radon.

End of Module II

- **This is the end of Module II.**
- **Please proceed to Module III, "Biological Effects of Ionizing Radiation"**