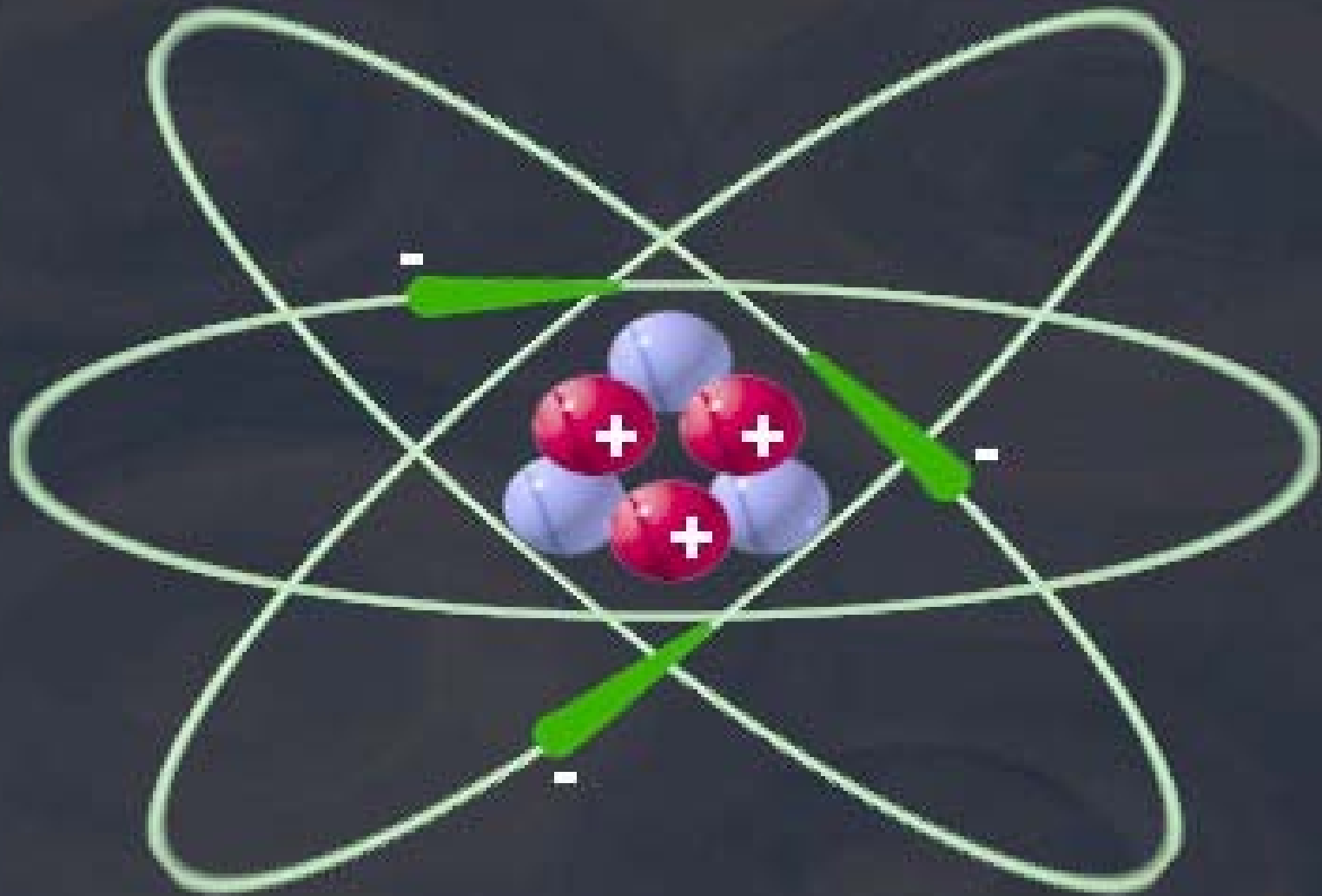


Introduction to Ionizing Radiation

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Supplement to Lecture Outline
V. 10.02



NEUTRAL ATOM

Basic Model of a Neutral Atom

- Electrons(-) orbiting nucleus of protons(+) and neutrons.
- Same number of electrons as protons; net charge = 0.
- Atomic number (number of protons) determines element.
- Mass number (protons + neutrons) gives mass in terms of 1/12th mass of Carbon atom.

Ionization vs. Excitation

- Excitation transfers enough energy to an orbital electron to displace it further away from the nucleus.
- In ionization the electron is removed, resulting in an ion pair.
 - the newly freed electron(-) and the rest of the atom(+).

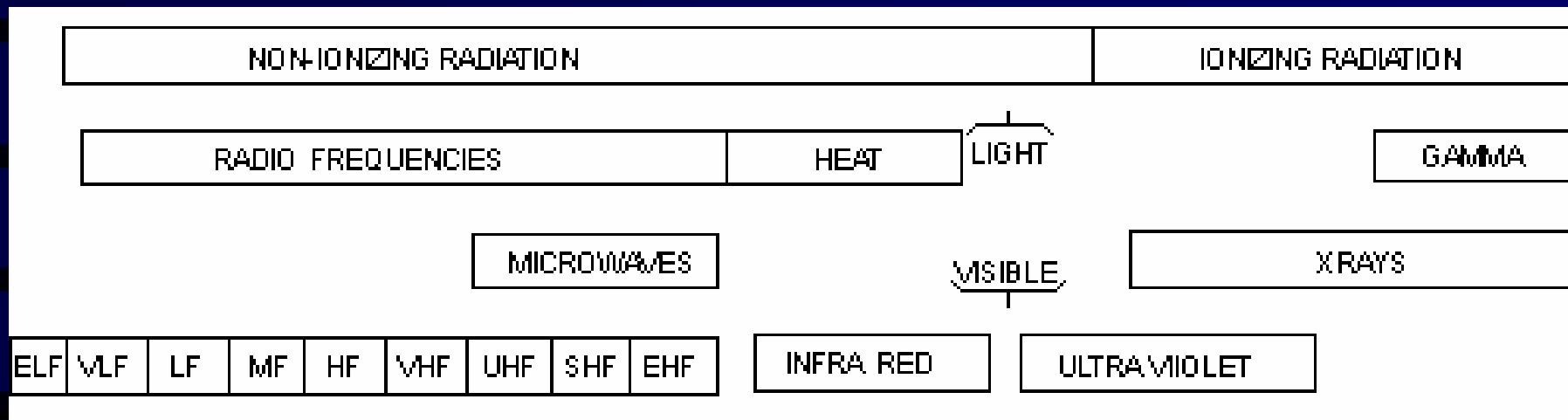
Ionizing Radiation

- Any electromagnetic or particulate radiation capable of producing ion pairs by interaction with matter.
- Scope limited to X and gamma rays, alpha particles, beta particles (electrons), neutrons, and charged nuclei.
- Important biologically since media can be altered (e.g., ionized atom in DNA molecule may be altered, thereby causing cell death, or mutation).

Particulate vs. Electromagnetic Radiations

- Particulate Radiations are sub-atomic particles with mass (e.g., alpha and Beta particles, electrons, neutrons).
- EM Radiations (X-rays and gamma rays) have no mass and no charge.

Electromagnetic Spectrum

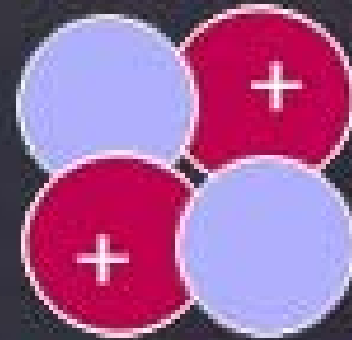
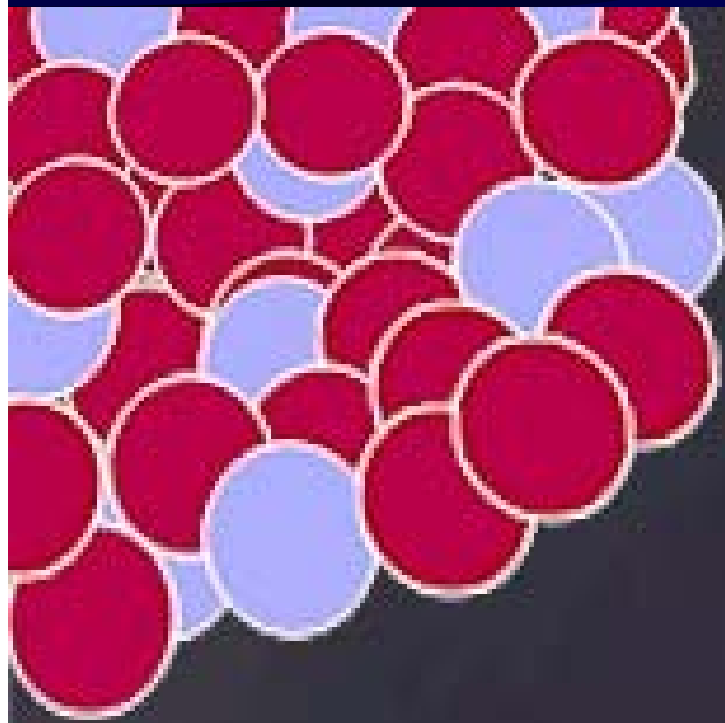


High vs. Low Energy Radiation

- Absorption of radiation is the process of transferring the energy of the radiation to the atoms of the media through which it is passing.
- Higher energy radiation of the same type will penetrate further.
- Usually expressed in KeV or MeV
- $1 \text{ eV} = 1.6 \times 10^{-19} \text{ Joules} = 1.6 \times 10^{-12} \text{ ergs}$

High vs. Low Linear Energy Transfer (LET)

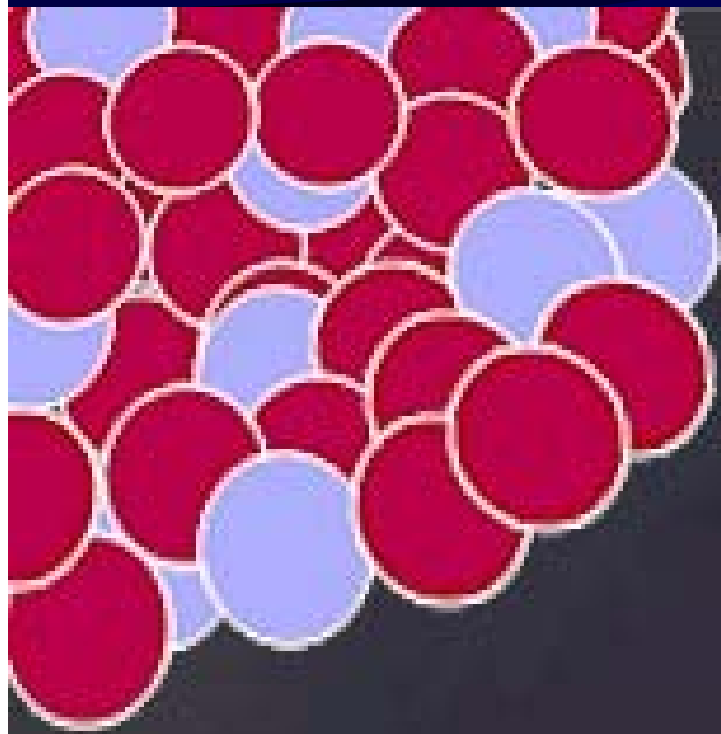
- LET is measured by the ionization density (e.g., ion pairs/cm of tissue) along the path of the radiation.
- Higher LET causes greater biological impact and is assigned a higher Quality Factor(QF).
 - Example QF values: X, gamma, and beta have QF = 1; alpha QF=20; thermal neutrons QF=3; "fast" neutrons (>10 KeV) QF = 10; fission fragments QF >20.



ALPHA PARTICLE

Alpha Particles (or Alpha Radiation)

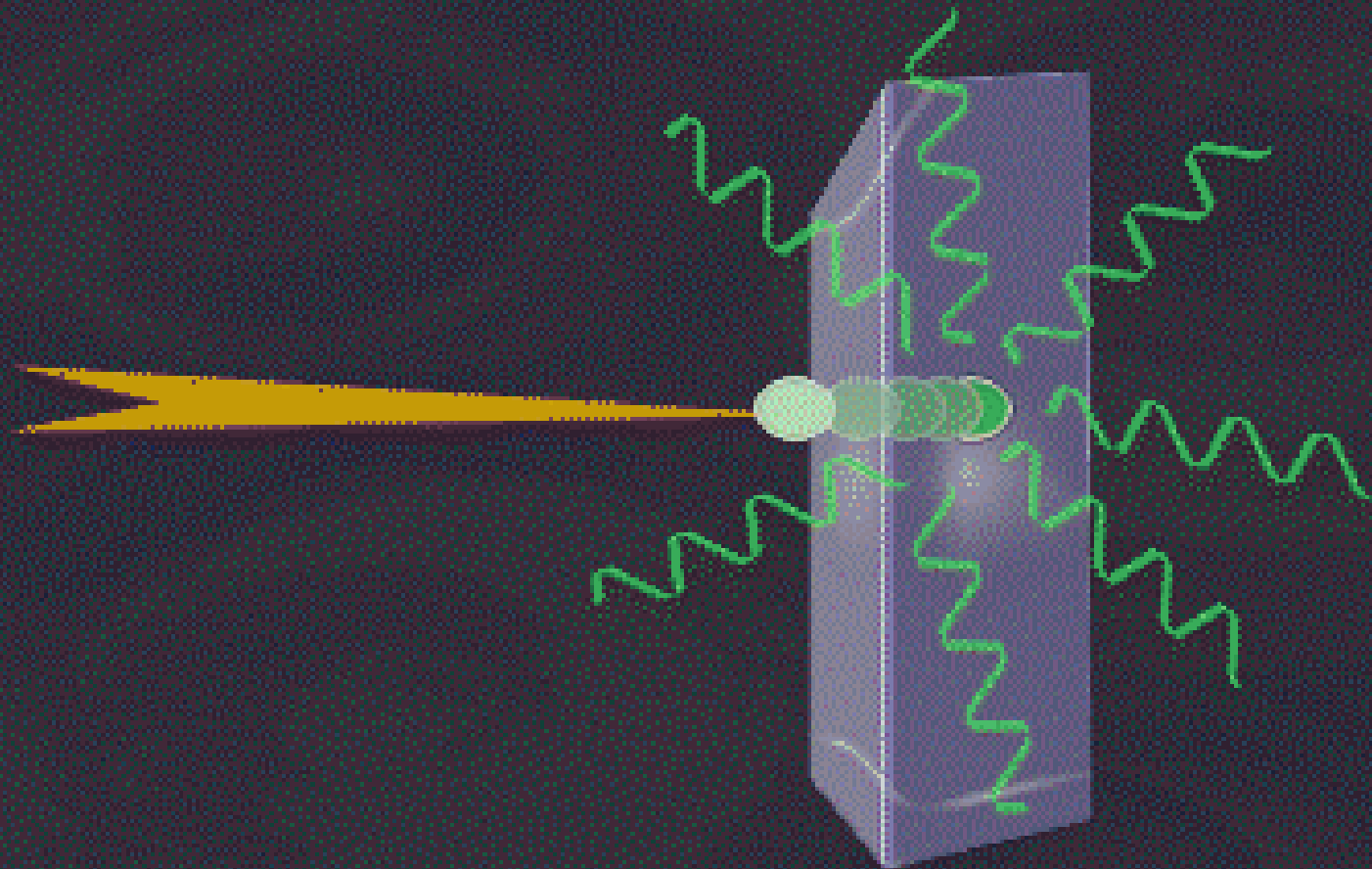
- Helium nucleus (2 neutrons and 2 protons); +2 charge; heavy (4 AMU).
Typical Energy = 4-8 MeV;
- Limited range (<10cm in air; 60 μ m in tissue);
- High LET (QF=20) causing heavy damage (4K-9K ion pairs/ μ m in tissue);
- Easily shielded (e.g., paper, skin) so an internal radiation hazard.



BETA PARTICLE

Beta Particles

- High speed electron ejected from nucleus; -1 charge; light 0.00055 AMU; Typical Energy = several KeV to 5 MeV;
- Range approx. 12'/MeV in air, a few mm in tissue;
- Low LET (QF=1) causing light damage (6-8 ion pairs/ μm in tissue);
- Primarily an internal hazard, but high beta can be an external hazard to skin.



BREMSSTRAHLUNG

Bremsstrahlung (or Braking) Radiation

- High speed electrons may lose energy in the form of X-rays when they quickly decelerate upon striking a heavy material.
- Aluminum and other light (<14) materials and organo-plastics are used for shielding.

Positrons

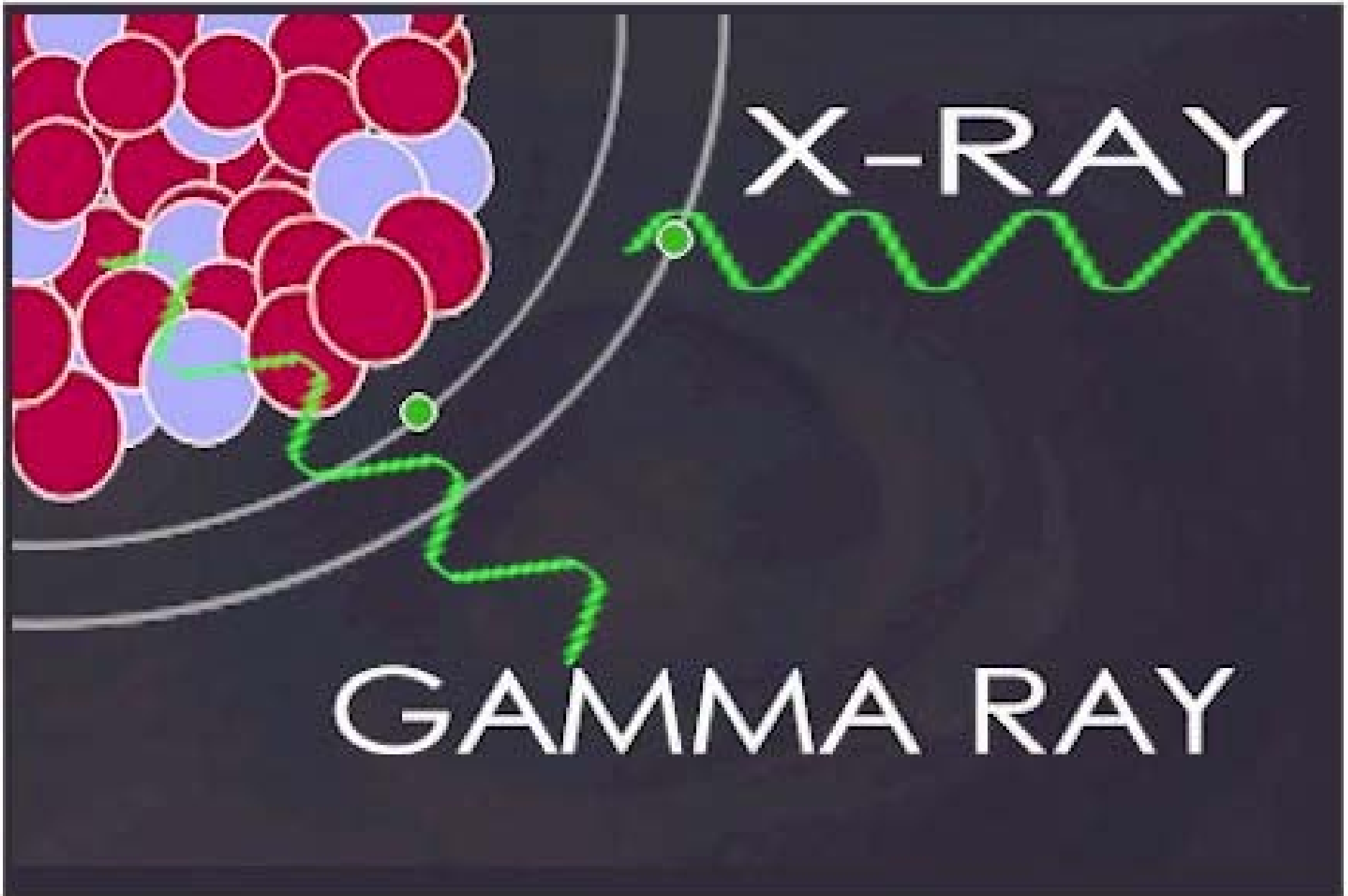
- Beta particles with an opposite (+) charge.
- Quickly annihilated by combination with an electron, resulting in gamma radiation.

Neutrons

- Neutrons ejected from a nucleus;
1 AMU; 0 Charge;
- Free neutrons are unstable and decay by Beta emission (electron and proton separate) with $T_{1/2}$ of approx. 13 min;
- Range and LET are dependant on "speed": Slow (<10 KeV), "Thermal" neutrons, $QF=3$; and Fast (>10 KeV), $QF=10$.

Shielding Neutrons

- Shielded in stages: High speed neutrons are "thermalized" by elastic collisions in hydrogenous materials (e.g., water, paraffin, concrete).
- The "hit" nuclei give off the excess energy as secondary radiation (alpha, beta, or gamma).
- Slow neutrons are captured by secondary shielding materials (e.g., boron or cadmium).



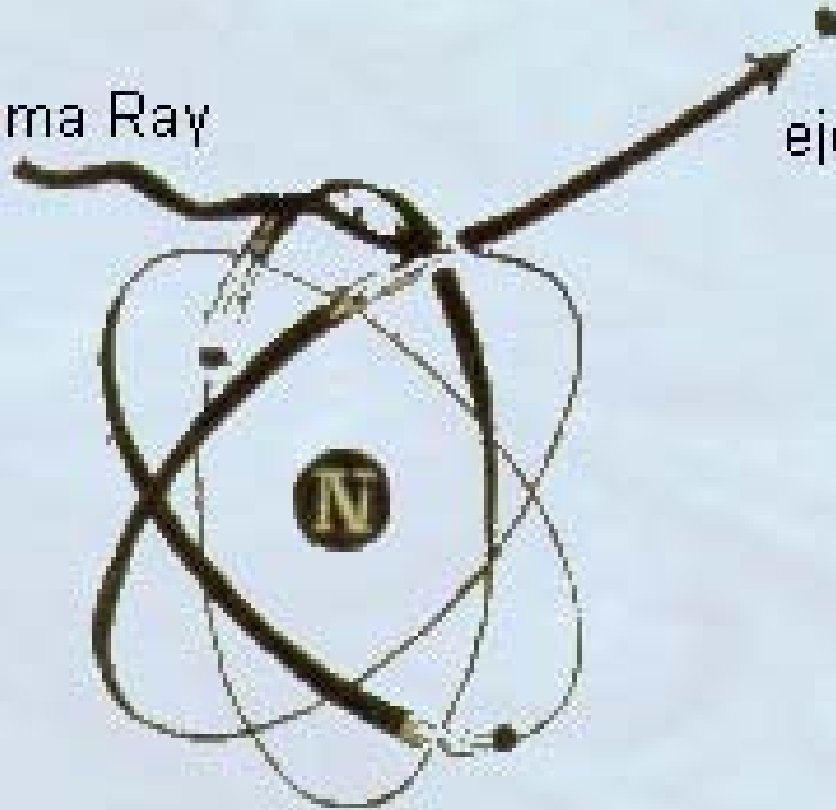
X-Rays and Gamma Rays

- X-rays are photons (electromagnetic radiations) emitted from electron orbits, such as when an excited orbital electron "falls" back to a lower energy orbit.
- Gamma rays are photons emitted from the nucleus, often as part of radioactive decay.

X-rays and Gamma Radiation

- Gamma rays typically have higher energy (Mev's) than X-rays (KeV's), but both are unlimited.
- No mass; Charge=0; Speed = C;
Long range (km in air, m in body);
Light damage (QF=1);
- An external hazard (>70 KeV penetrates tissue); Usually shielded with lead or concrete.

X-Ray or Gamma Ray

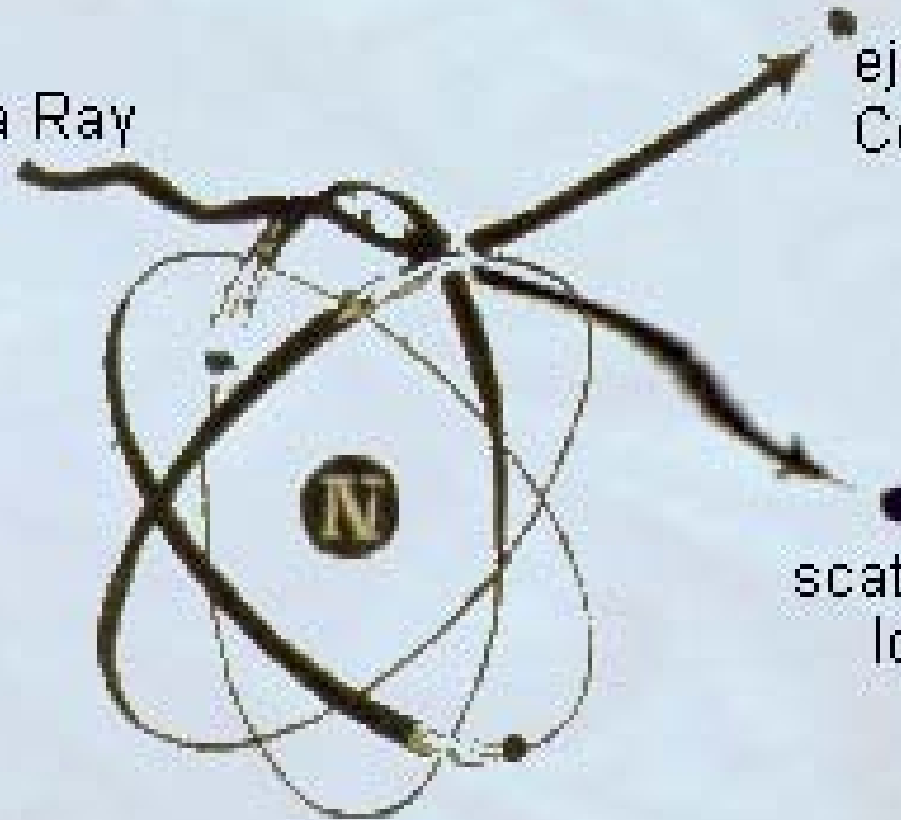


ejected photoelectron

$E \lesssim 0.5 \text{ MeV}$

Photoelectric Effect
(primarily low-energy photon)

X-Ray or Gamma Ray



ejected
Compton electron

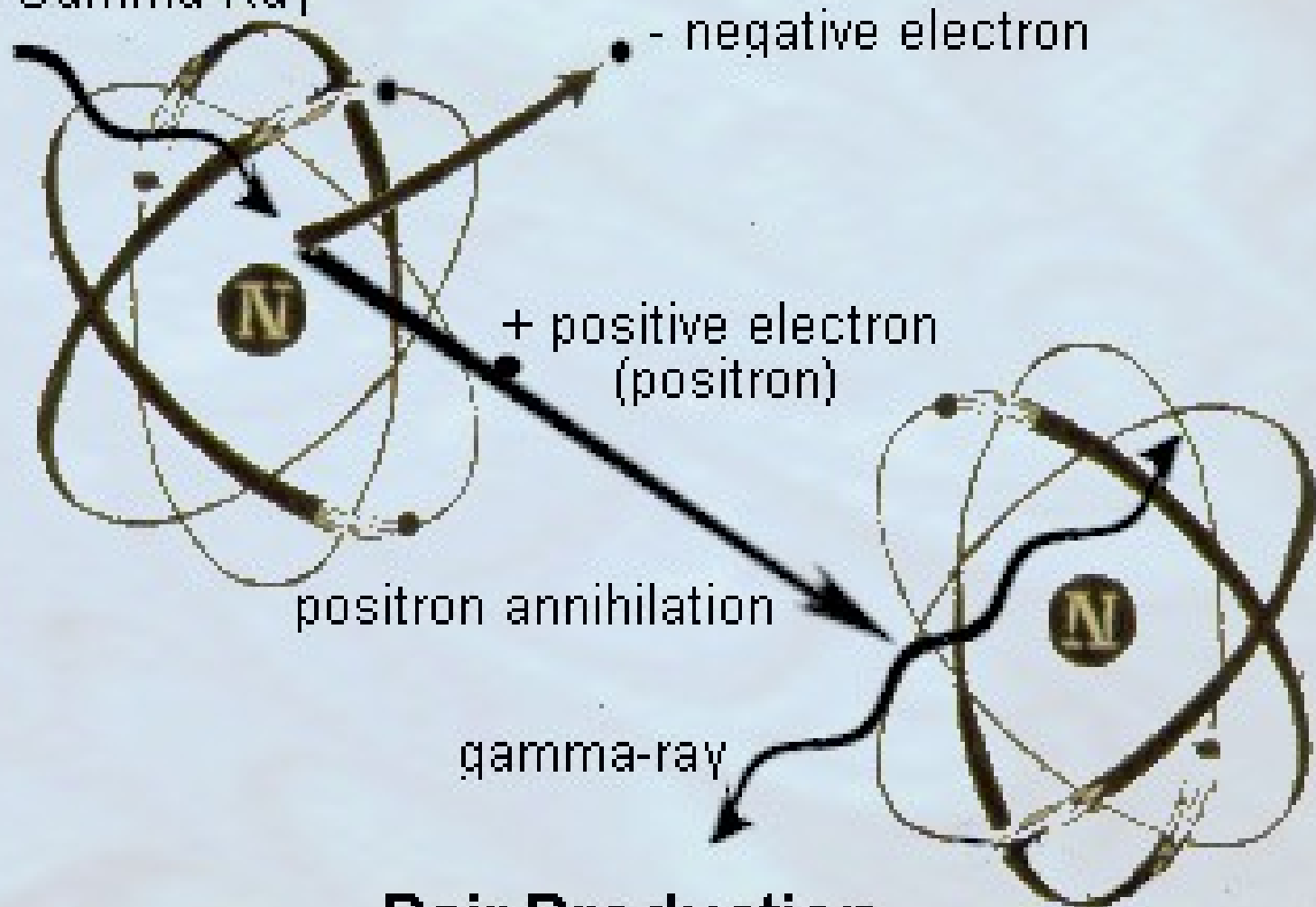
scattered photon of
lower energy

$$0.5 \lesssim E \lesssim 5 \text{ MeV}$$

Compton Effect

(primarily medium energy photon)

X-Ray or Gamma Ray

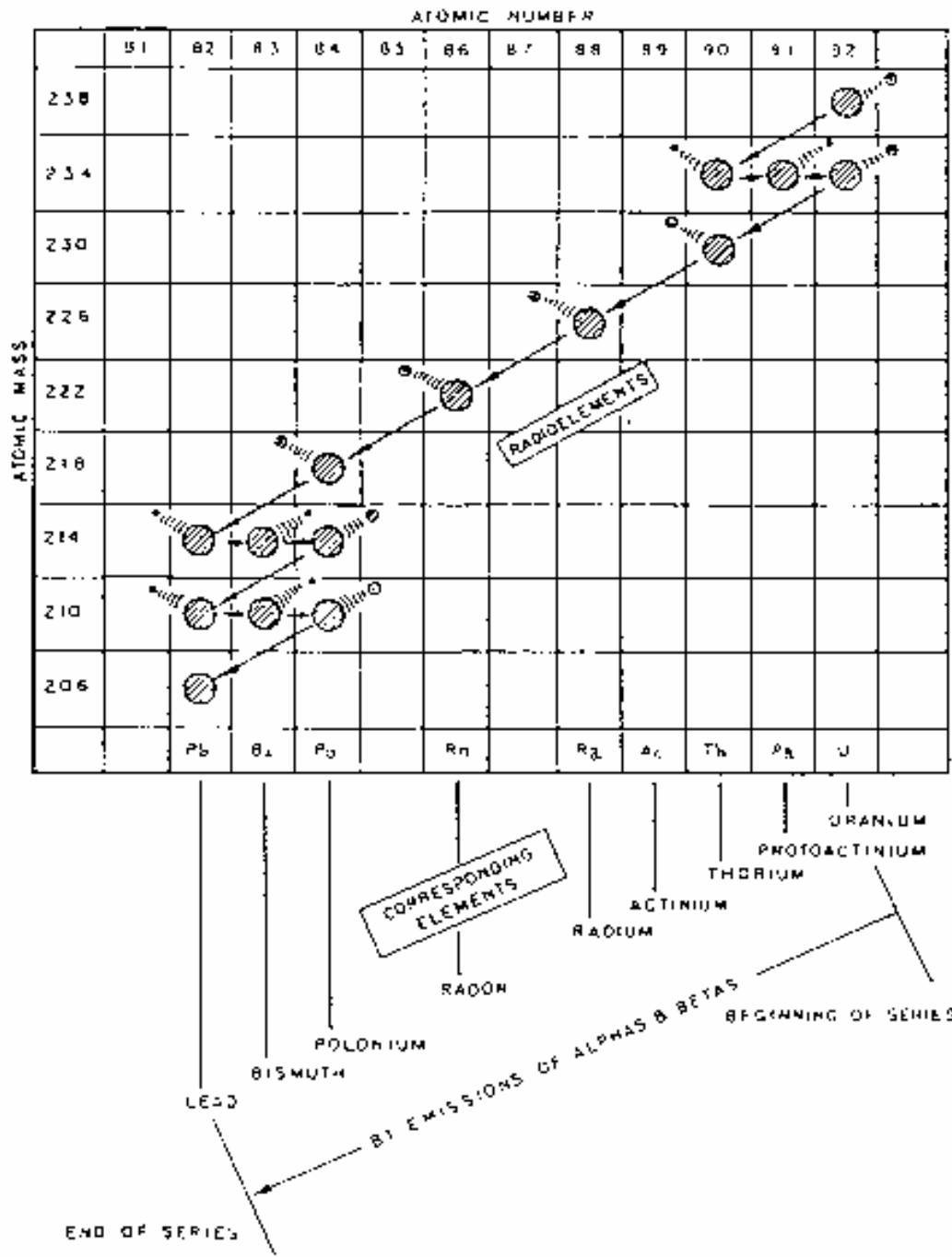


Pair Production
(high energy photon, 1.02 MeV)

$$E > 5$$

Radioactive Decay

- Matter transforms from unstable to stable energy states.
- Radioactive materials are substances which spontaneously emit various combinations of ionizing particles (alpha and beta) and gamma rays of ionizing radiation to become more stable.
- Radioisotopes are isotopes (same number of protons but different numbers of neutrons) which are radioactive.



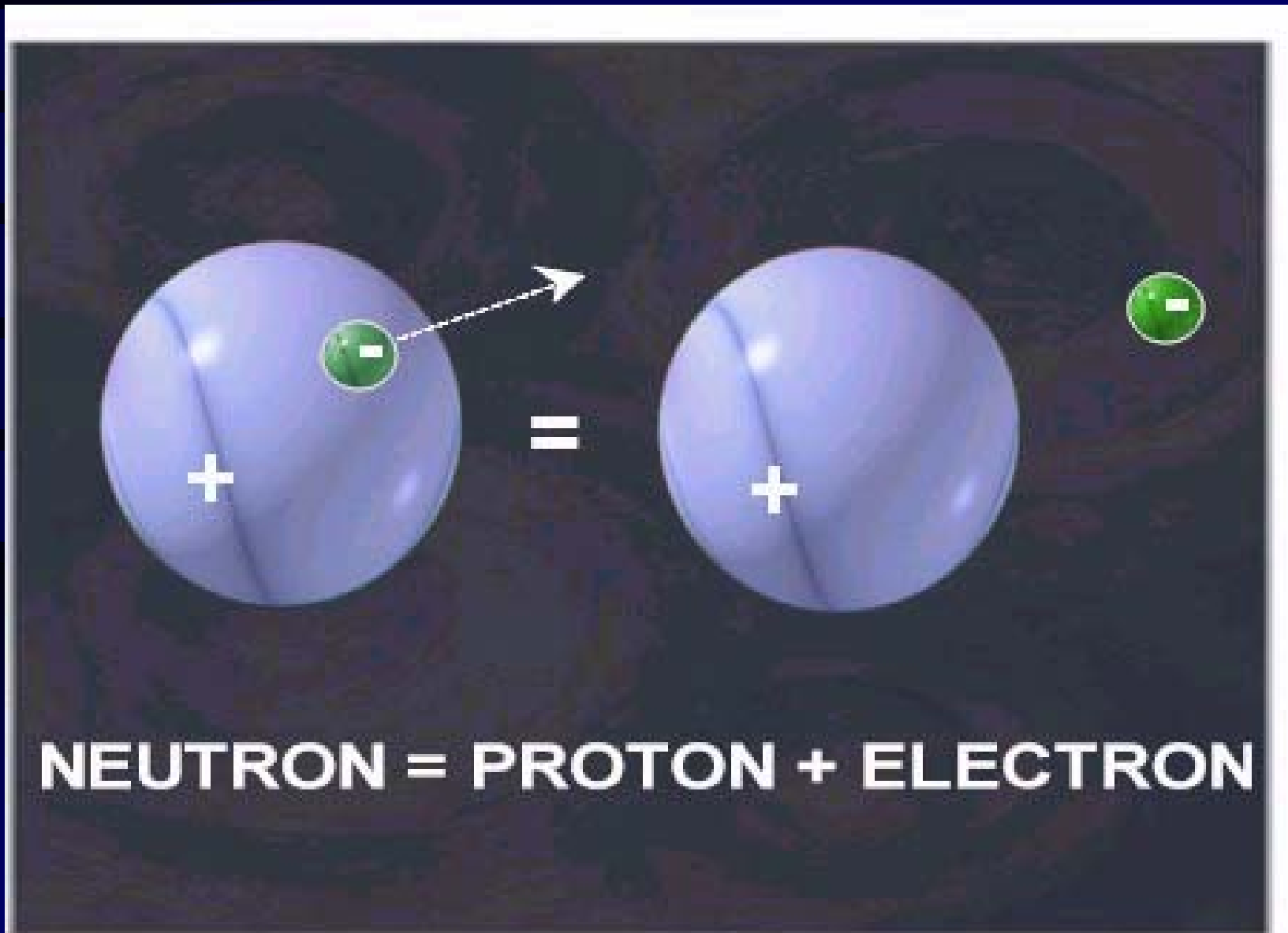
Decay Series

Radium \rightarrow alpha particle + Radon





Proton "Gain" during Beta Decay

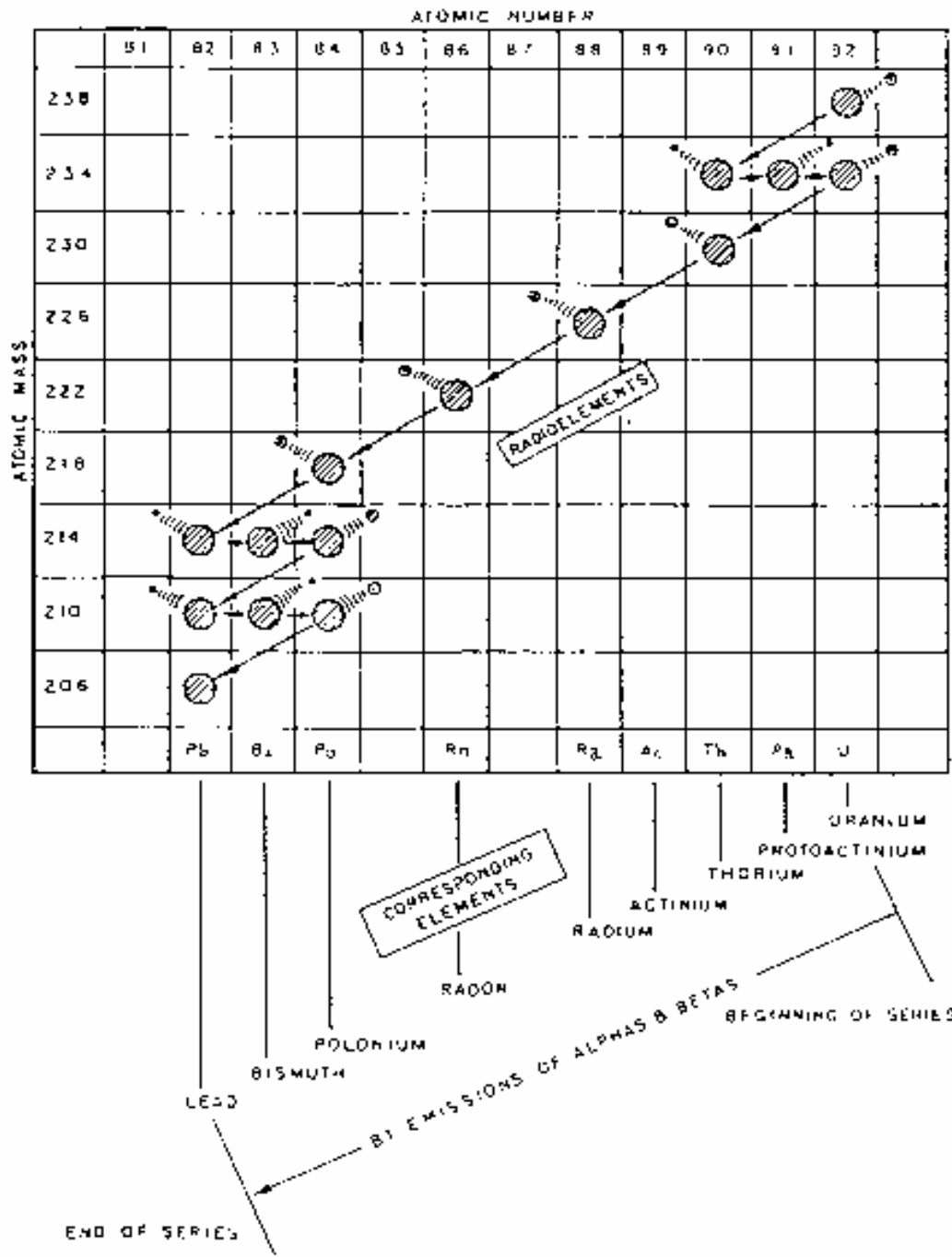


Beta Decay

- No change in atomic mass; protons increase by 1.
- Consider a neutron as a proton embedded with an electron; net charge = 0. When the electron is ejected, a proton is "created", thus increasing the atomic number.

Decay Series

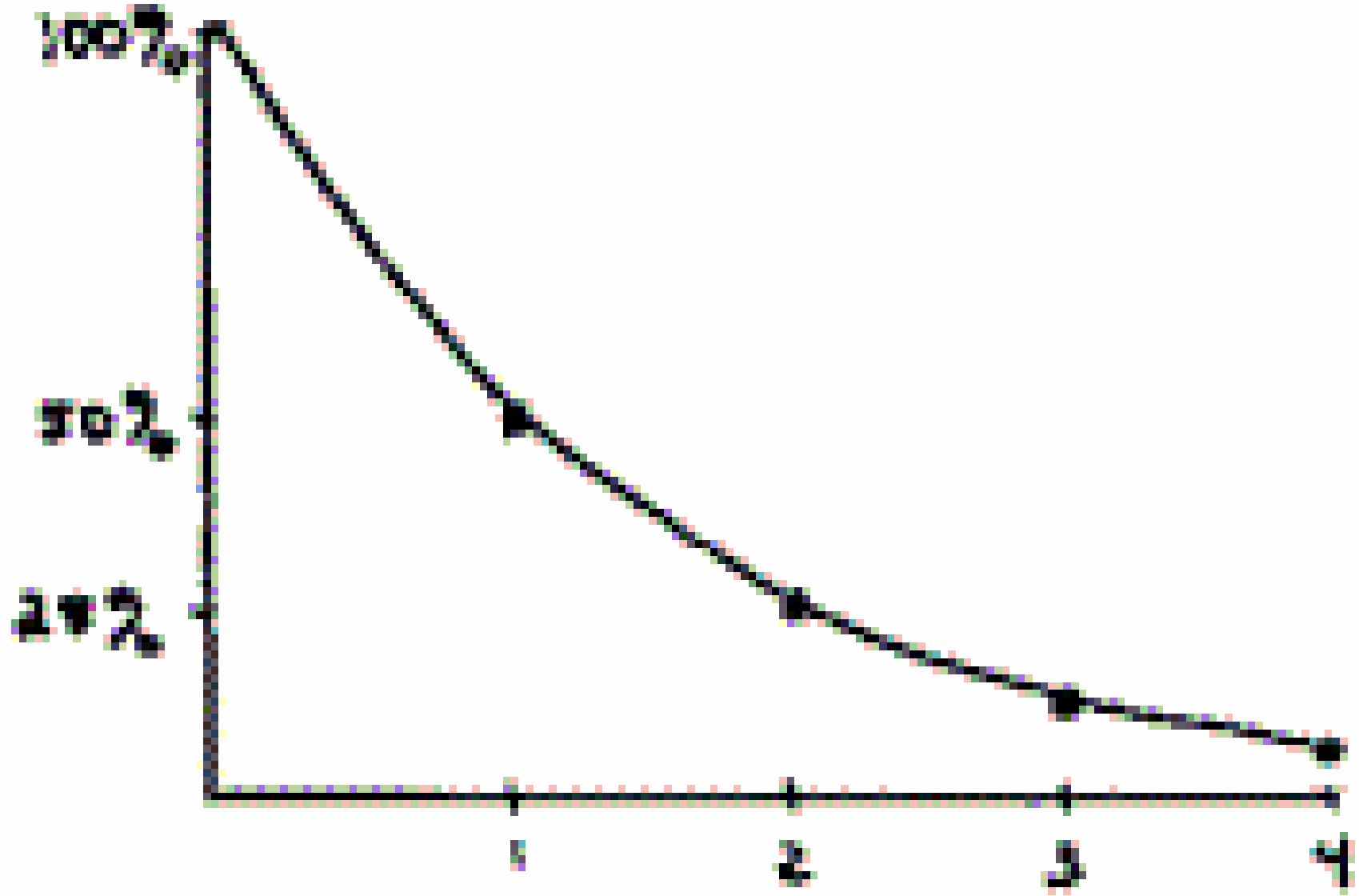
- Radioactive parent decays to a "**daughter**" which may also be radioactive, therefore, is also simultaneously decaying.
- Resulting exposure is to the combination of both decays (and possibly additional daughters).
- Radon daughters are an important example of series decay exposure in uranium mines and basements.



Series Decay







Note common formula structure.

$$A_t = A_0 e^{-\lambda t}$$

$$N_t = N_0 e^{-\lambda t}$$

$$I_x = I_0 e^{-\mu x}$$

$$\lambda = \frac{.693}{\text{Half - Life}} = \text{Decay Constant}$$

$$\lambda = \frac{.693}{\text{Half - VL}} = \text{Linear Coeff. of ABS}$$

$$3 \text{ yr} = 3(365) = 1095 \text{ days}$$

$$A_t = A_0 e^{-\lambda t} = A_0 e^{-\frac{0.693}{T_{1/2}} t}$$

$$A_t = (300) e^{-\frac{0.693 \cdot 1095}{138.4}} = (300) e^{-5.48}$$

$$= (300) (0.00416) = 1.25 \mu\text{Ci}$$

$$A = A_i(0.5)^{\frac{t}{N}}$$

$$n = \frac{1095 \text{ days}}{138.4 \text{ days / half - life}} = 7.91 \text{ half lives}$$

$$A_n = 300 \left(\frac{1}{2} \right)^{7.91} = 300 (0.00416) = 1.25 \mu\text{Ci}$$

$$\begin{aligned}
 I &= I_0 e^{\frac{-0.693 \cdot x}{HVL}} = (100) e^{\frac{-0.693(2^7)(25.4 \text{ mm})}{5 \text{ mm}}} \\
 &= (100) e^{-7.04} = 100 (0.000876) = 0.088 \text{ R/hr}
 \end{aligned}$$

Calibration Source



$$\frac{I_1}{I_2} = \left(\frac{d_1}{d_2} \right)^2 \quad I_1 = 500 \quad d_1 = 6 \quad d_2 = 50$$

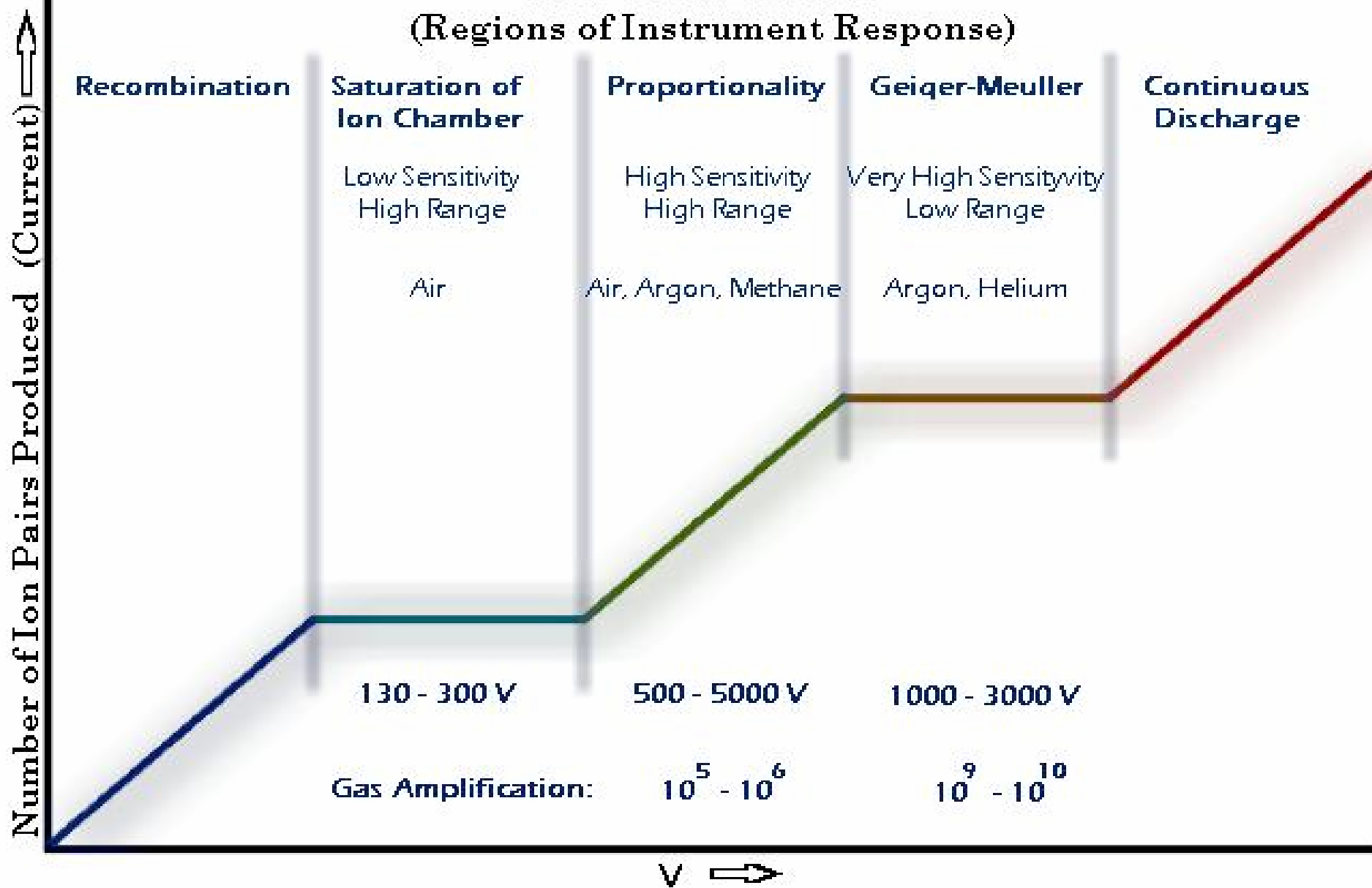
$$I_2 = \frac{I_1}{\left(\frac{d_2}{d_1} \right)^2} = \frac{500}{\left(\frac{50}{6} \right)^2} = \frac{500}{(8.33)^2} = \frac{500}{69.4} = 7.2 \text{ mR/hr}$$

$$D = 0.869 \int X (R) \text{ rads}$$

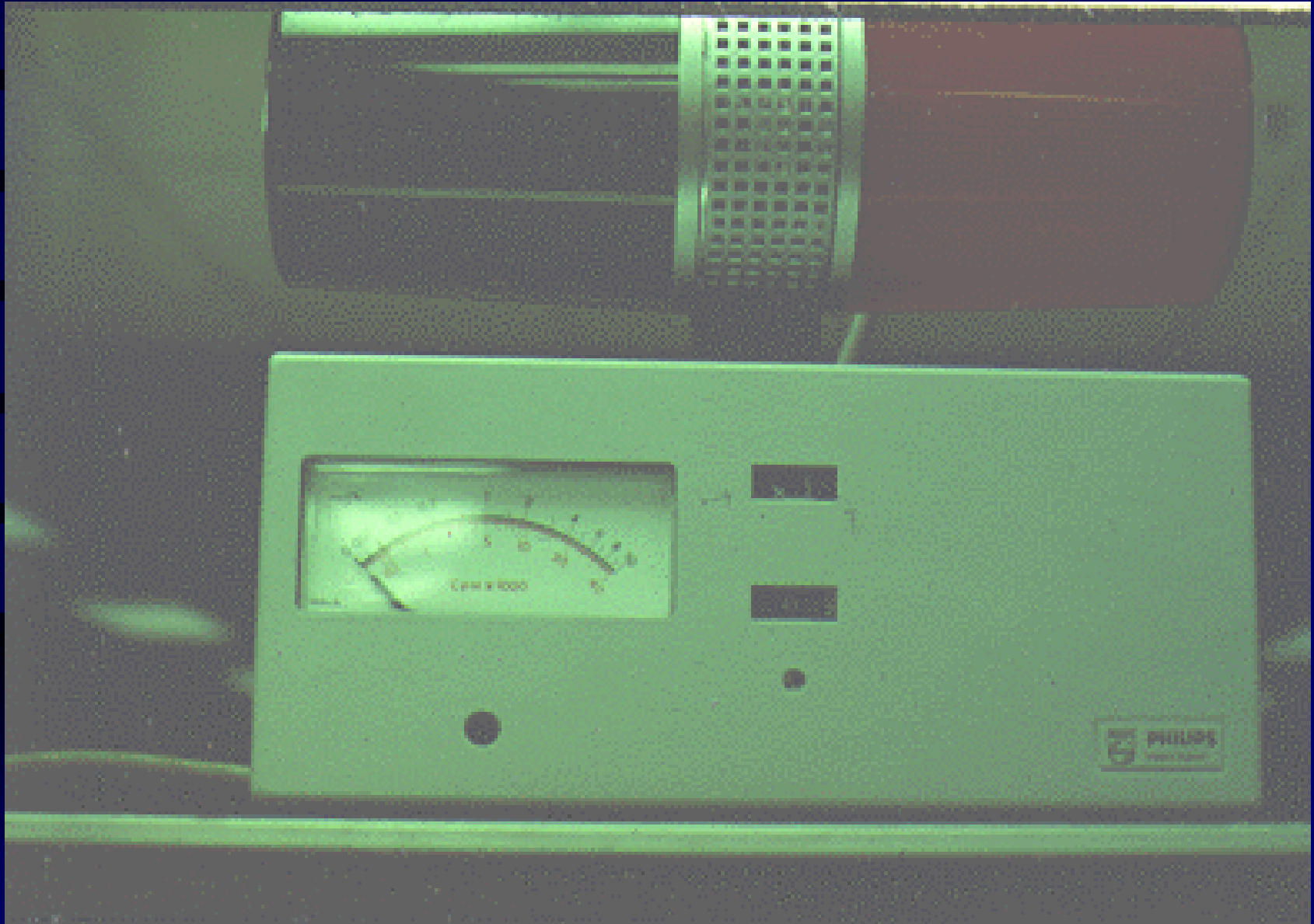
$$D = (0.869)(0.965)(0.5 \times 10^{-3} \text{ R/hr})$$
$$= 0.419 \text{ m rad/hr}$$

Gas Ionization

(Regions of Instrument Response)















RADIOACTIVE SYMBOLS



NFPA 704M LABEL



D.O.T. LABEL