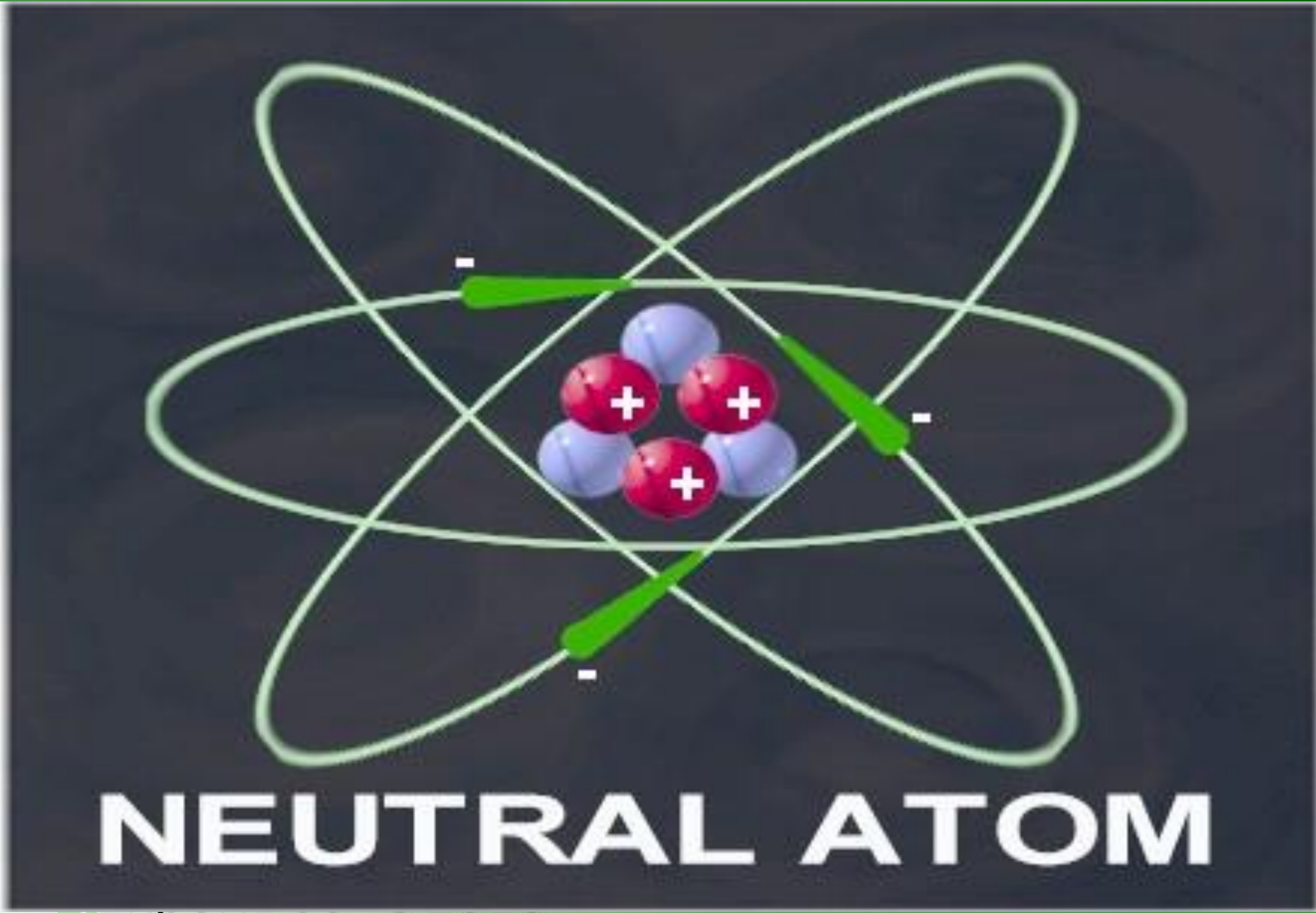
Introduction to Ionizing Radiation



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

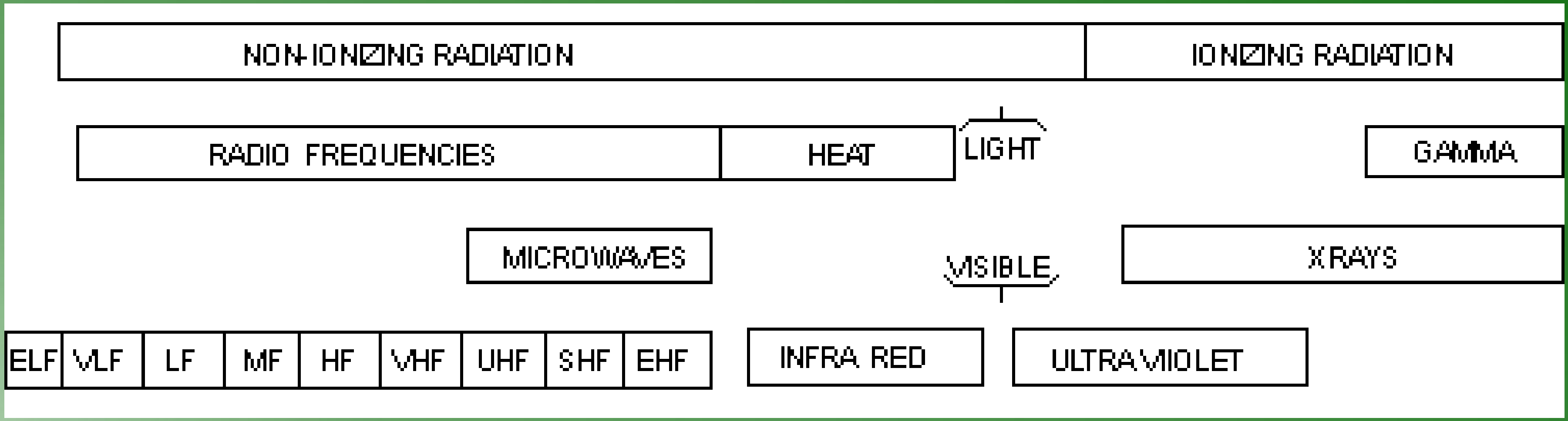
- Any electromagnetic or particulate radiation capable of producing ion pairs by interaction with matter.
- Scope limited to X and gamma rays, alpha particles, beta particles (electrons), neutrons, and charged nuclei.
- Important biologically since media can be altered (e.g., ionized atom in DNA molecule 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 eV = 1.6 x 10^{-19} Joules = 1.6 x 10^{-12} ergs

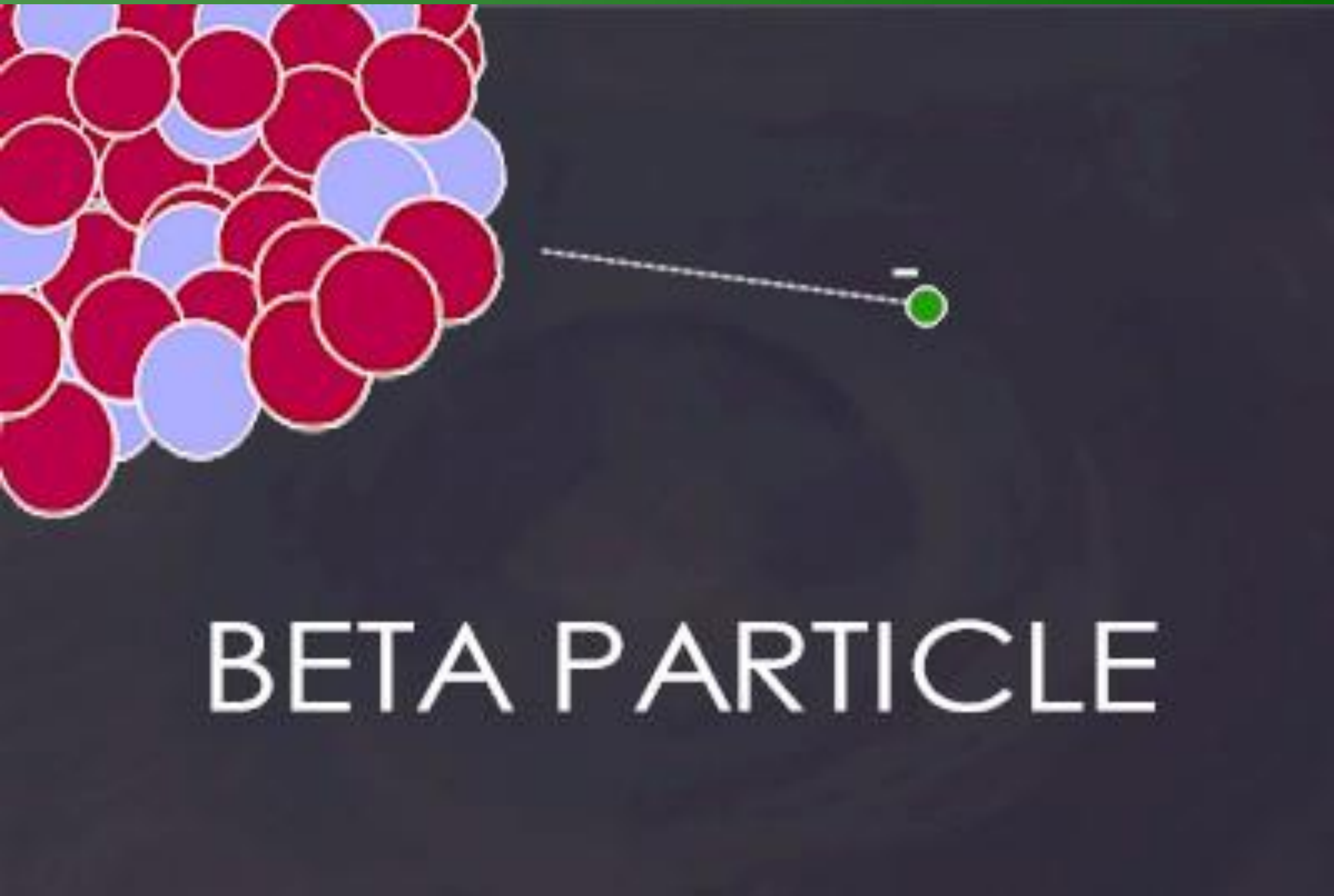
High vs. Low Linear Energy Transfer (LET)

- 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

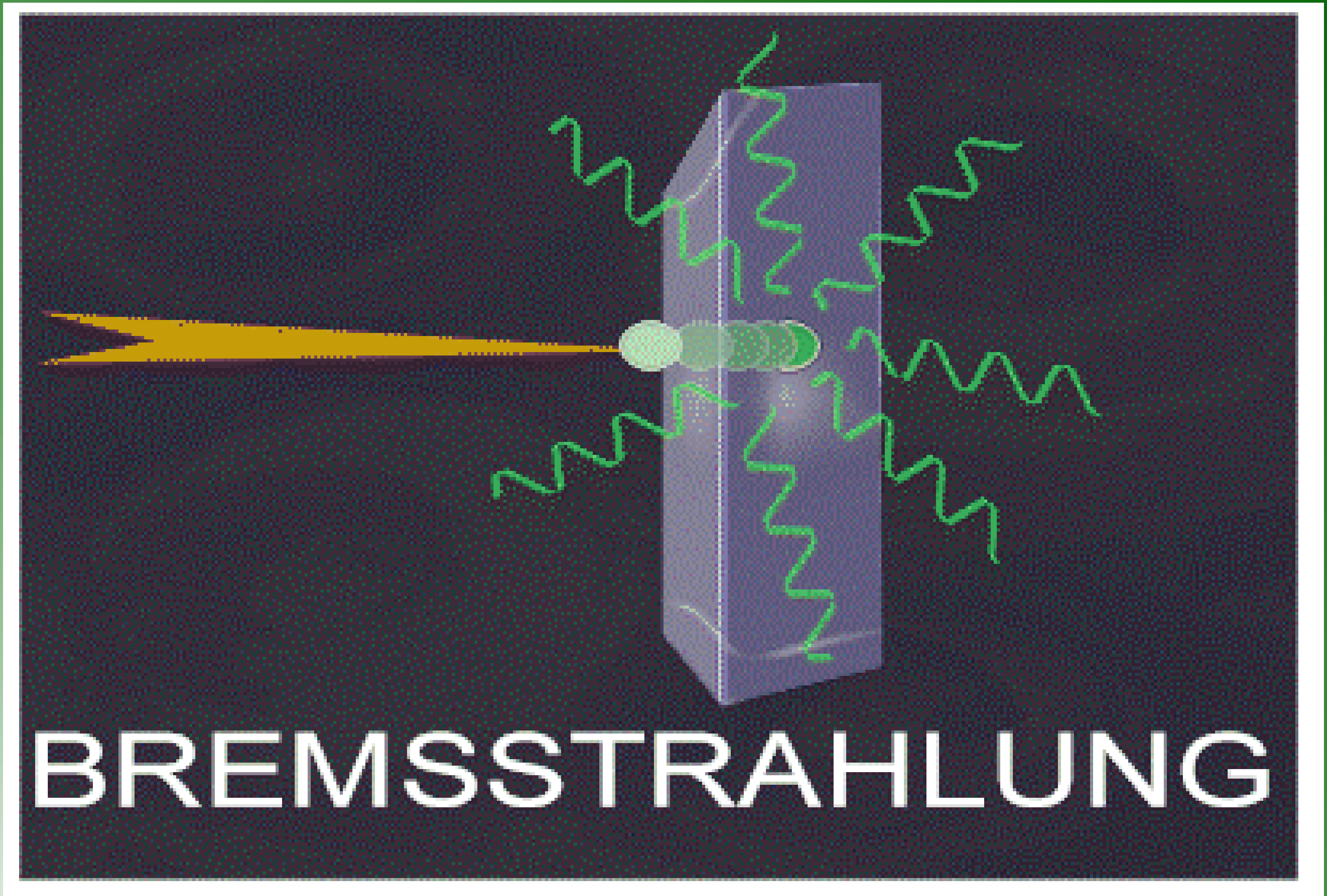
Alpha Particles
(or Alpha Radiation)

- Helium nucleus (2 neutrons and 2 protons); +2 charge; heavy (4 AMU). Typical Energy = 4-8 MeV;
- Limited range (<10cm in air; 60µm in tissue);
- High LET (QF=20) causing heavy damage (4K-9K ion pairs/µm 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

Bremsstralung (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

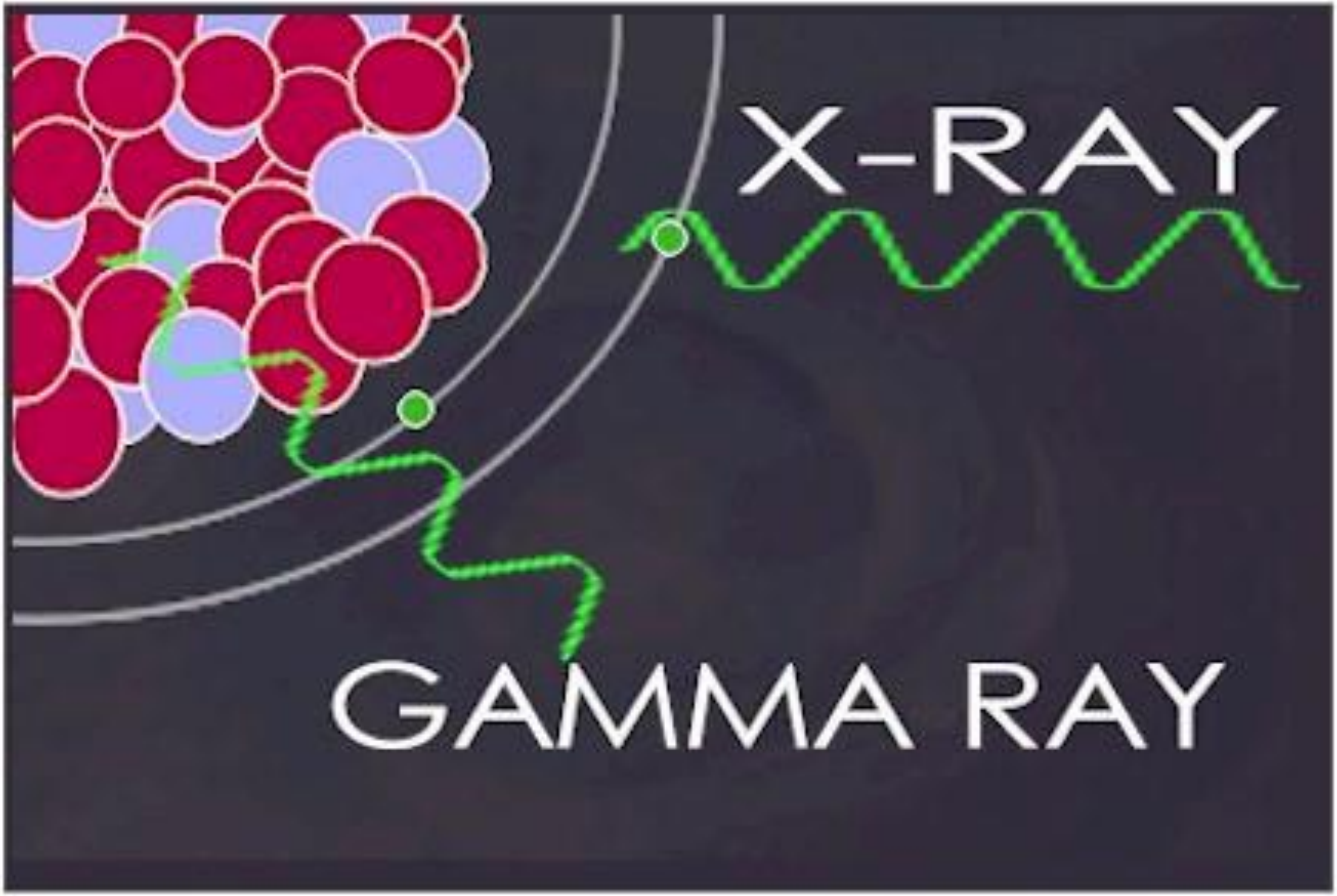
- Beta particles with an opposite (+) charge.
- Quickly annihilated by combination with an electron, resulting in gamma radiation.

Neutrons

- Neutrons ejected from a nucleus; 1 AMU; 0 Charge;
- Free neutrons are unstable and decay by Beta emission (electron and proton separate) with T½ 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-RAY
GAMMA RAY

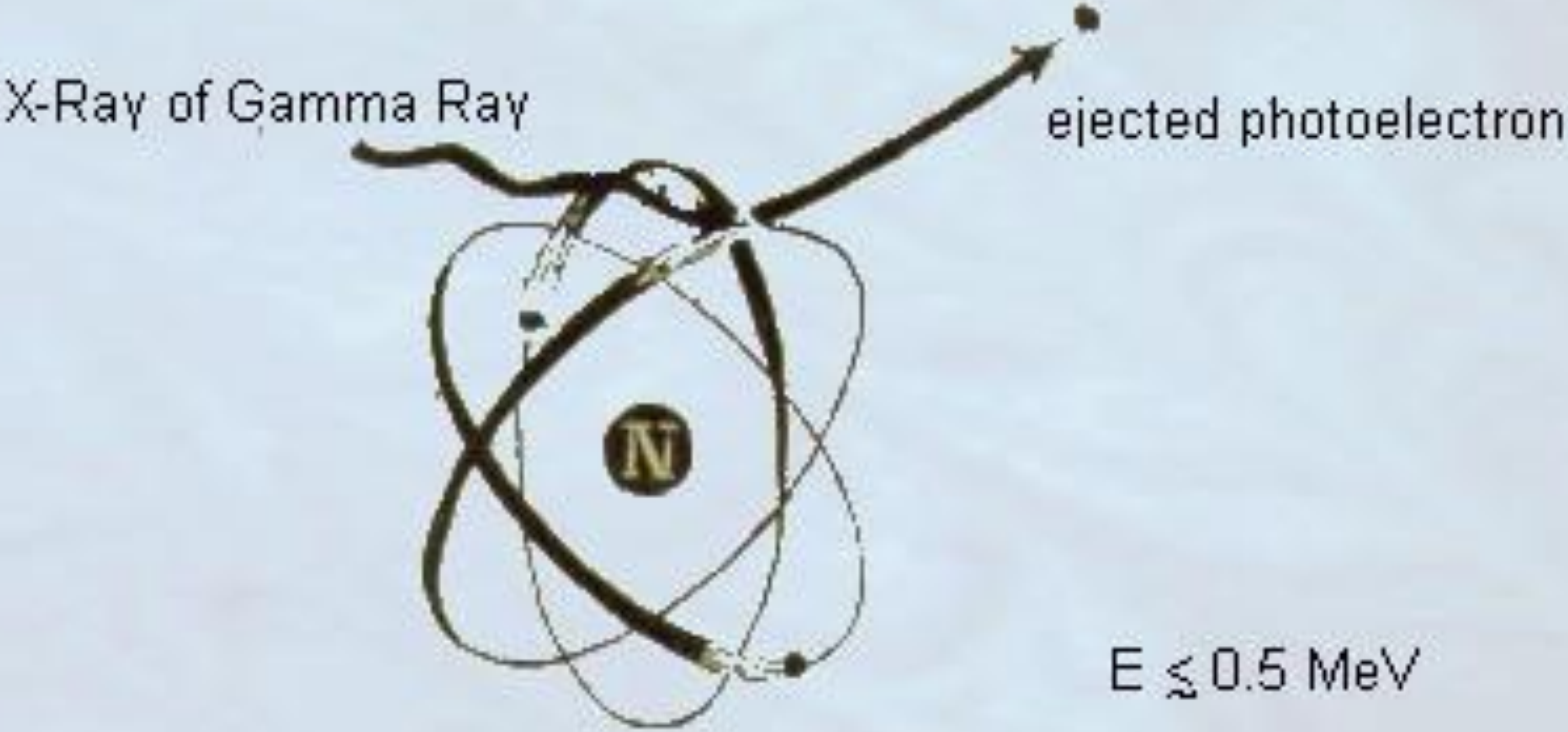
X-Rays and Gamma Rays

- X-rays are photons (electromagnetic radiations) emitted from electron orbits, such as when an excited orbital electron "falls" back to a lower energy orbit.

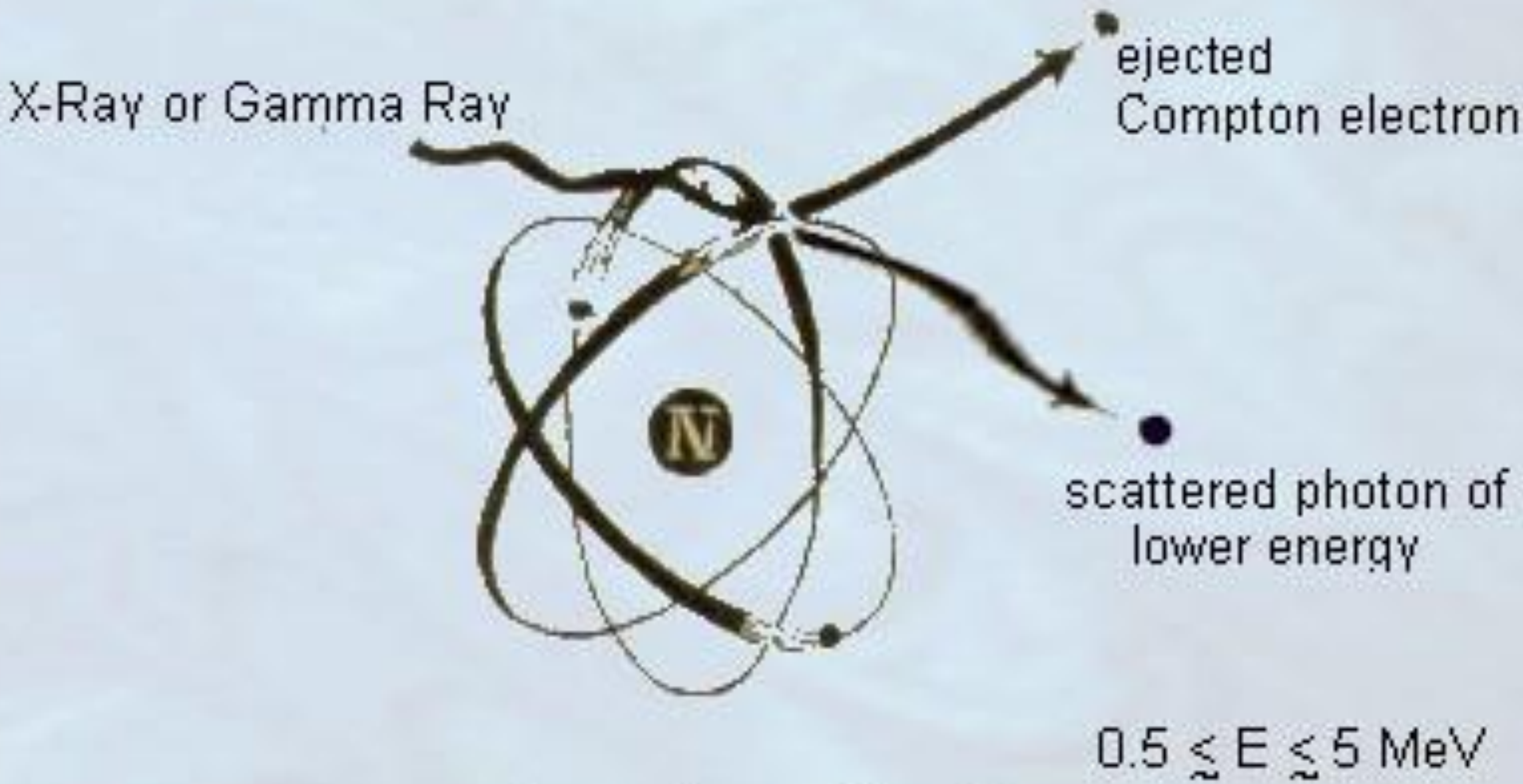
- Gamma rays are photons emitted from the nucleus, often as part of radioactive decay.

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.

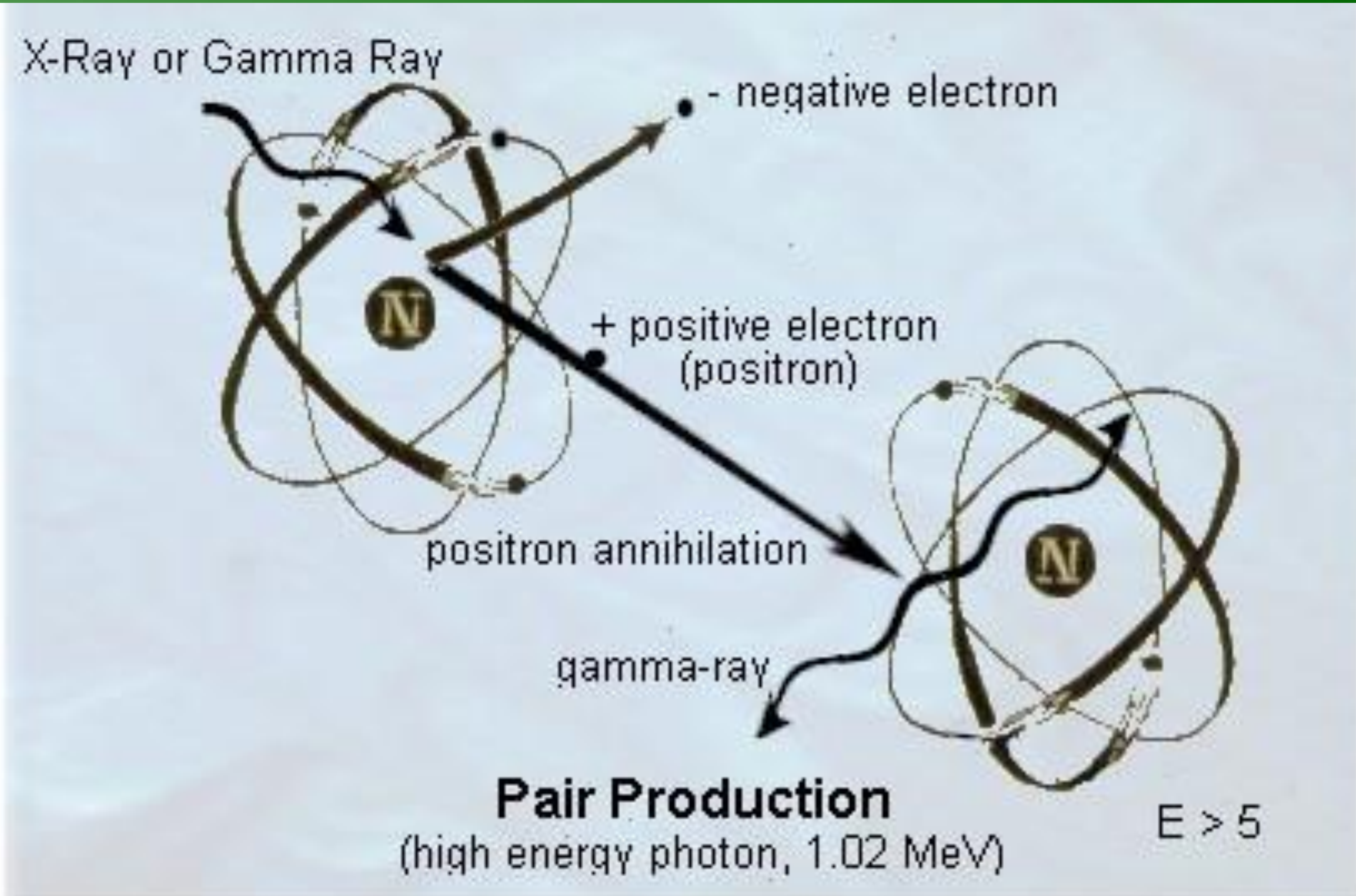


Photoelectric Effect
(primarily low-energy photon)



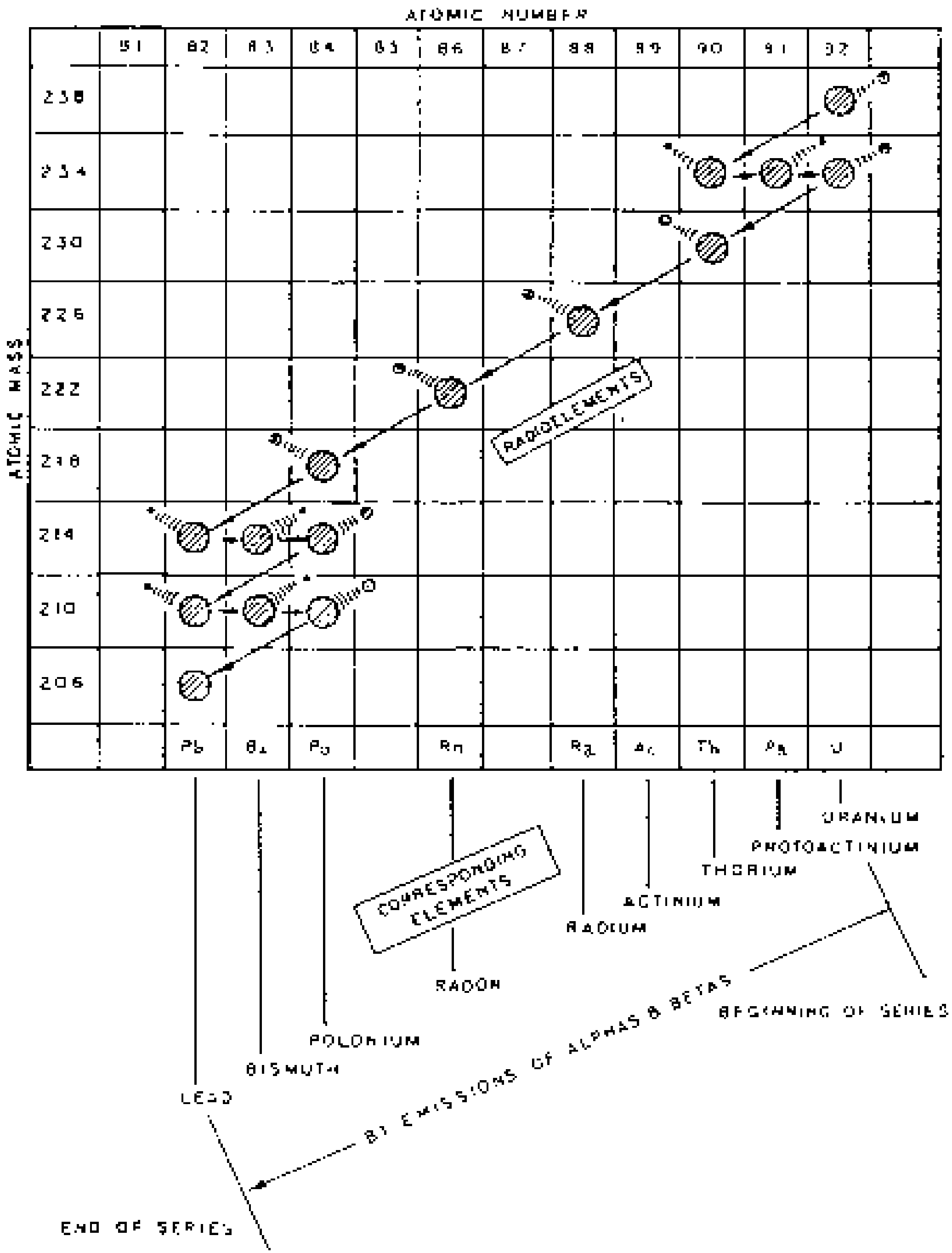
Compton Effect

(primarily medium energy photon)


X-Ray or Gamma Ray
- negative electron
N
+ positive electron
(positron)
positron annihilation
N
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.



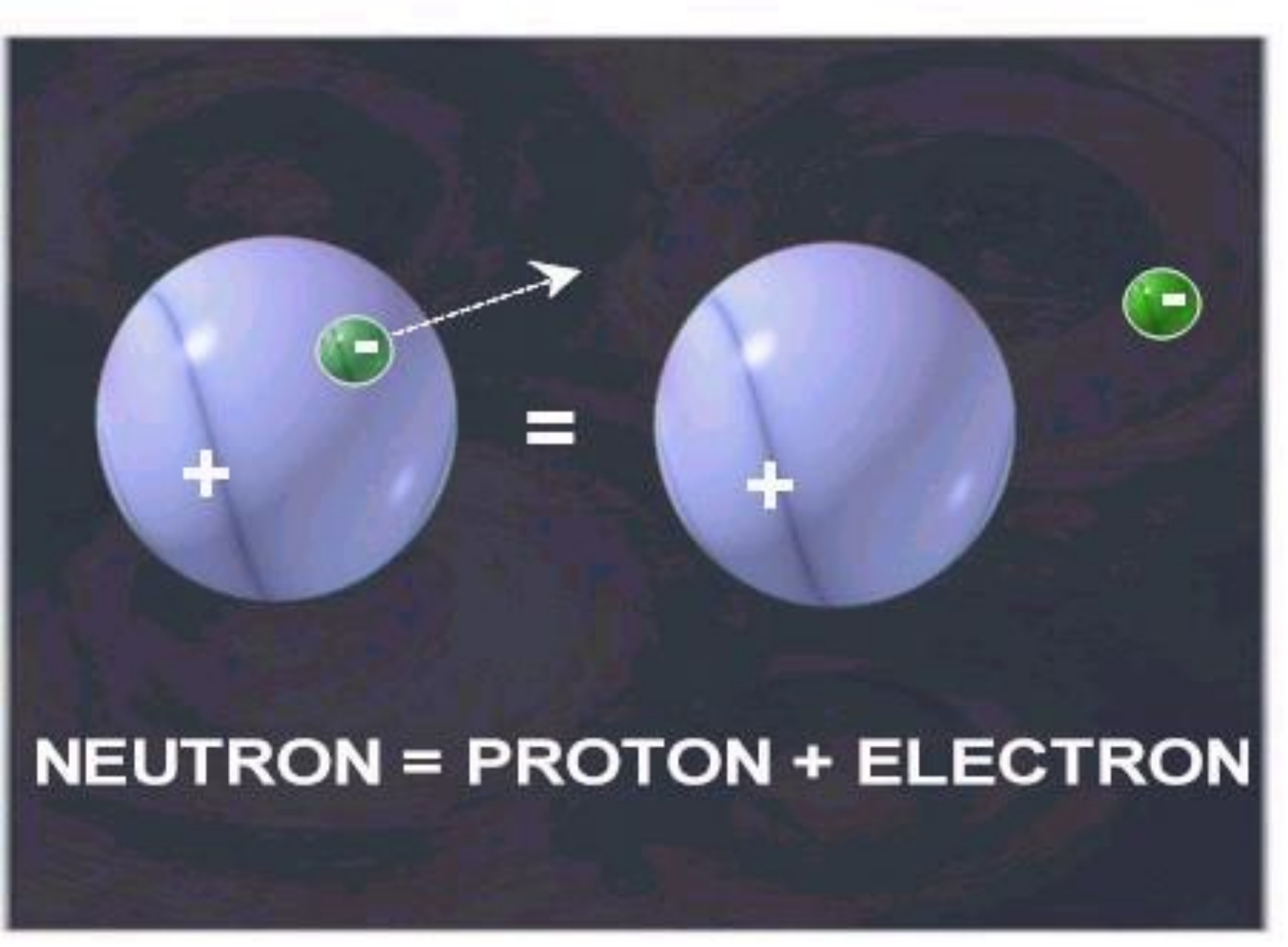
Decay Series

$$\text{Radium} \rightarrow \text{alpha particle} + \text{Radon}$$

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

$$^{90}_{38}\mathrm{Sr} \rightarrow \text{Beta electron} + {}^{90}_{39}\mathrm{Y}$$

Proton "Gain" during Beta Decay

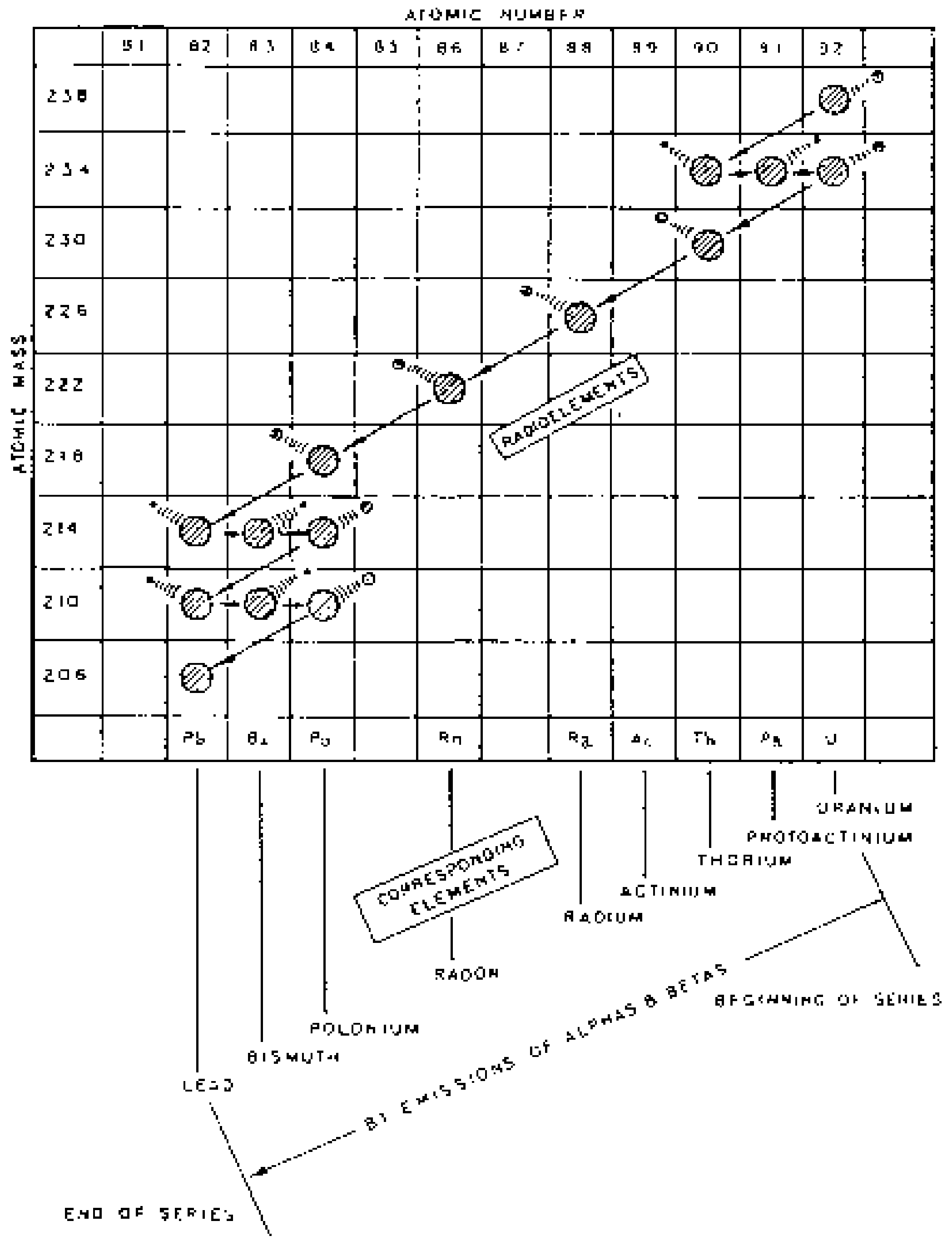


Beta Decay

- 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

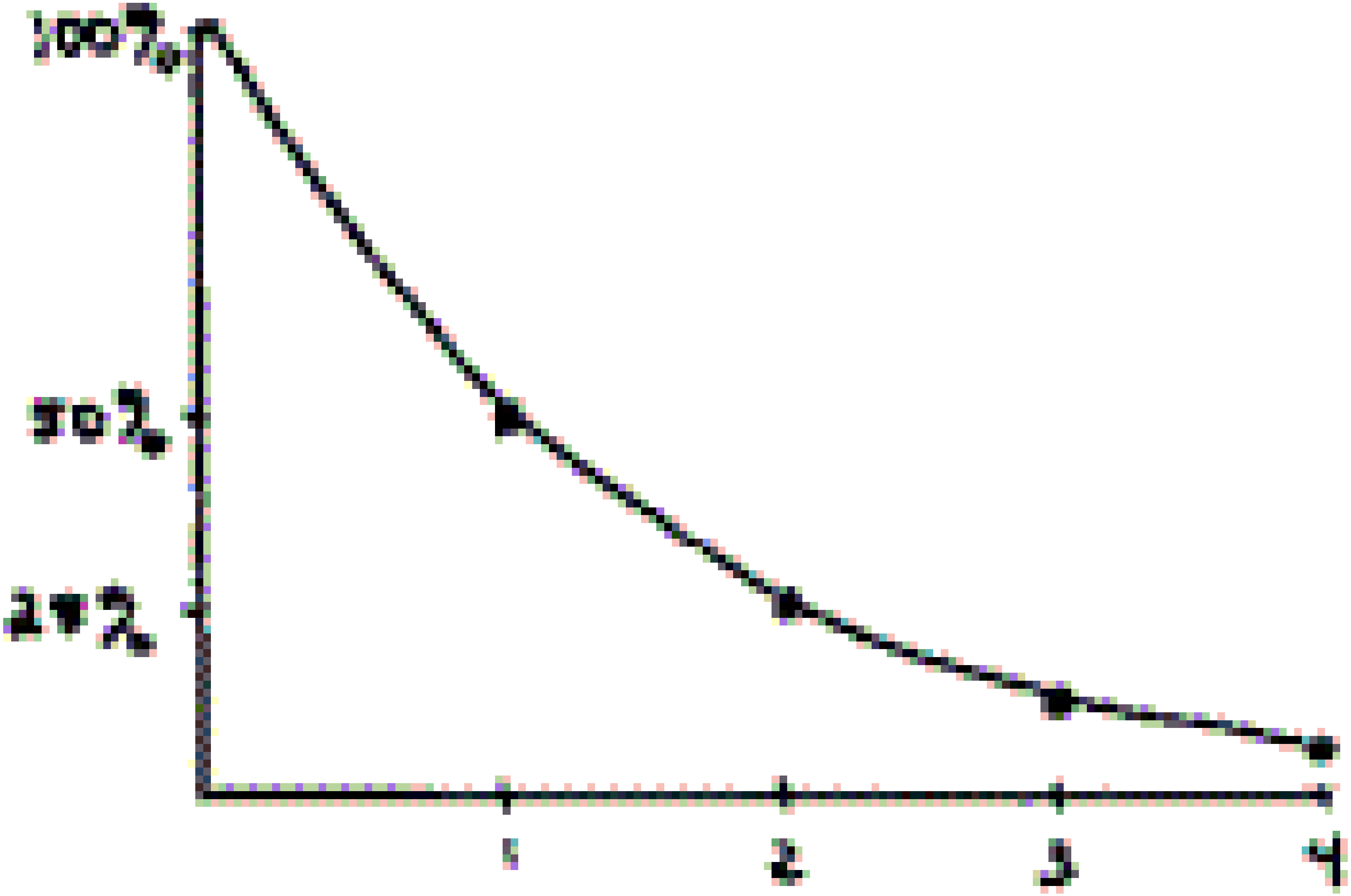
- Radioactive parent decays to a **"daughter"** which may also be radioactive, therefore, is also simultaneously decaying.
- Resulting exposure is to the combination of both decays (and possibly additional daughters).
- Radon daughters are an important example of series decay exposure in uranium mines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



Series Decay

$$\text{With alpha} = {}^{9}_{4}\text{Be} + {}^{4}_{2}\text{He}^{+2} \rightarrow {}^{1}_{0}\text{neutron} + {}^{12}_{6}\text{C}$$


x100
x10
x1
bat.
off
493
VICTOREEN
phone



100%
50%
25%
1
2
3
4

Note common formula structure.

$$A_t = A_o e^{(-\lambda t)}$$

$$N_t = N_o e^{(-\lambda t)}$$

$$I_x = I_o e^{(-\mu x)}$$

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

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

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

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

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

$$= (300)(0.00416) = 1.25\,\mu Ci$$

$$A = Ai(0.5)^{\frac{t}{T_{1/2}}}$$

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

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

$$I = I_0 e^{\frac{-0.693 \bullet x}{HVL}} = (100) e^{\frac{-0.693(2'')(25.4\ mm/inch)}{5\ mm}}$$

$$= (100) e^{-7.04} = 100(0.000876) = 0.088\ R/hr$$

Calibration Source

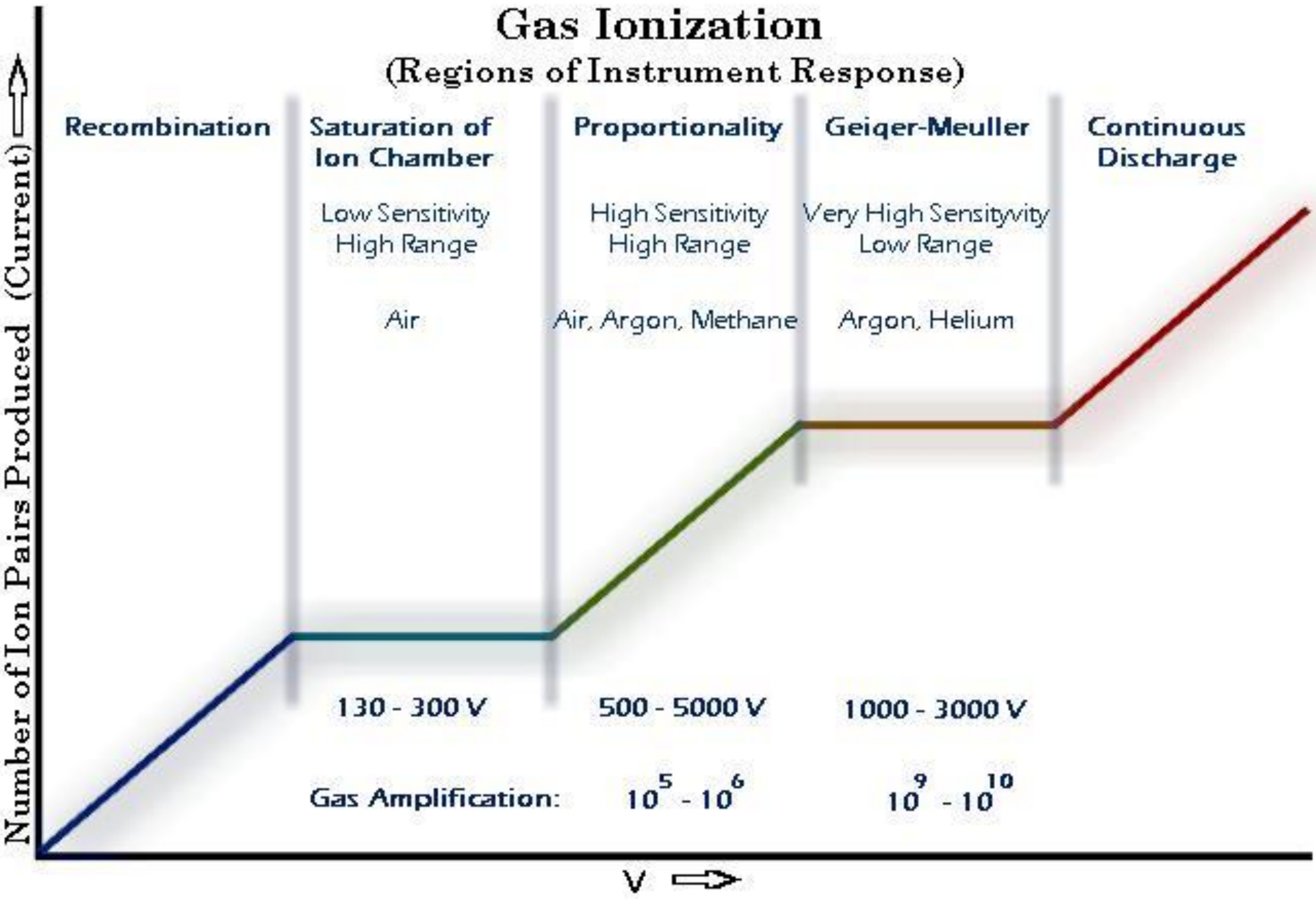
$$\frac{I_1}{I_2} = \left(\frac{d_1}{d_2}\right)^2 \quad I_1 = 500 \quad d_1 = 6 \quad d_2 = 50$$

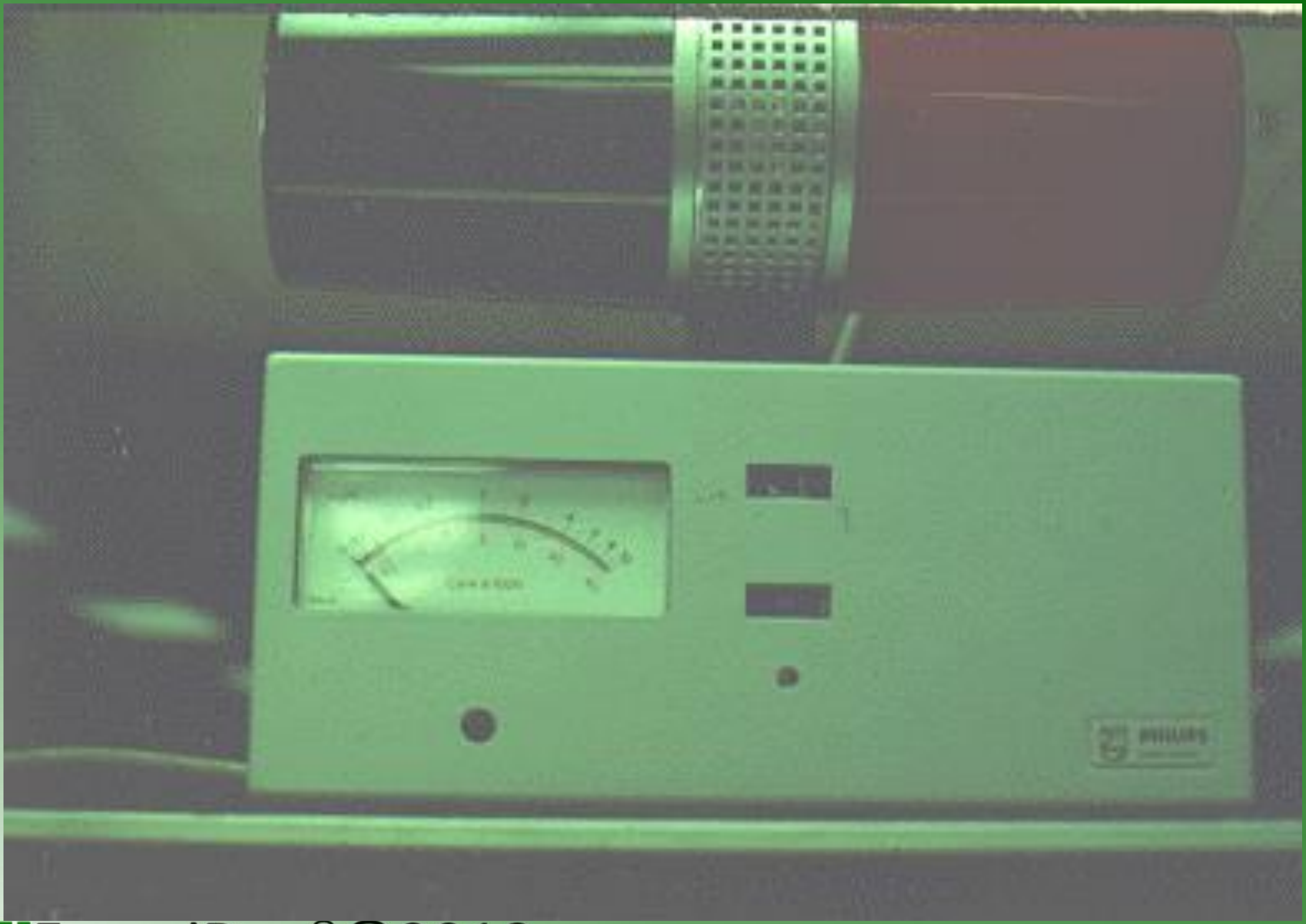
$$I_2 = \frac{I_1}{\left(\frac{d_2}{d_1}\right)^2} = \frac{500}{\left({}^{50}\!/\!_{6}\right)^2} = \frac{500}{(833)^2} = \frac{500}{69.4} = 72\ {}^{mR}\!/\!_{hr}$$

$$D = 0.869\ f\ X\ (R)\ rads$$

$$D = (0.869)(0.965)(0.5 \times 10^{-3}\ {}^{R}/_{hr})$$

$$= 0.419\ {}^{m\,rad}/_{hr}$$


Gas Ionization
(Regions of Instrument Response)
Recombination
Saturation of Ion Chamber
Proportionality
Geiqer-Meuller
Continuous Discharge
Low Sensitivity
High Range
High Sensitivity
High Range
Very High Sensityvity
Low Range
Air
Air, Argon, Methane
Argon, Helium
130 - 300 V
500 - 5000 V
1000 - 3000 V
Gas Amplification:
$10^5 - 10^6$
$10^9 - 10^{10}$
Number of Ion Pairs Produced (Current)
V




DANGER


RADIOACTIVE SYMBOLS
4
2
3
RADIOACTIVE
I
7
NFPA 704M LABEL
D.O.T. LABEL