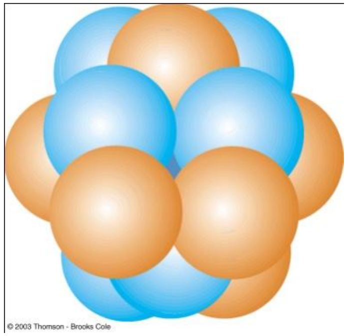
Nuclear Medicine

For Medical Students

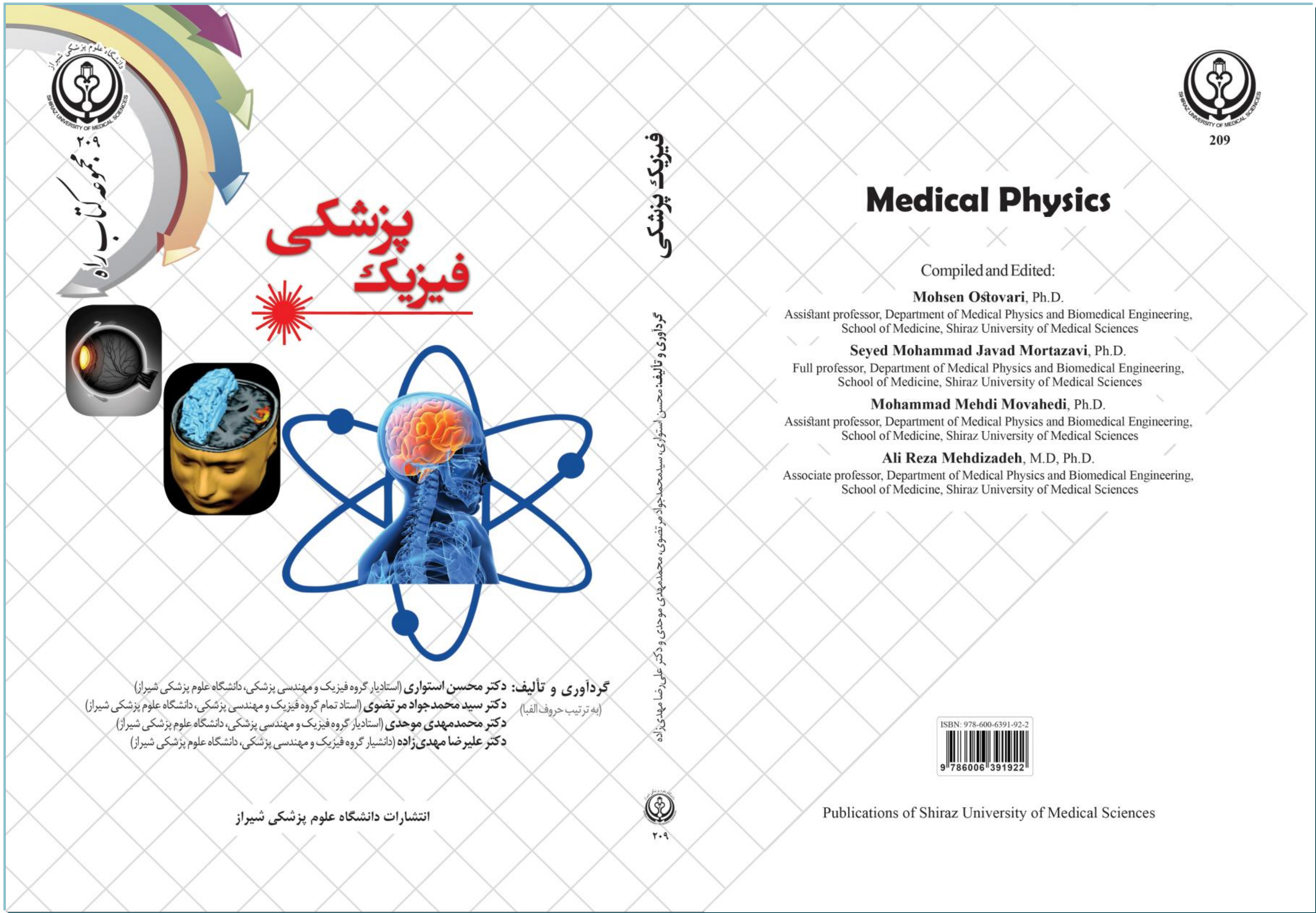
Sessions 1 and 2
Fall Semester, Acad. Year 1404-1405

SMJ Mortazavi, Ph.D
Professor of Medical Physics

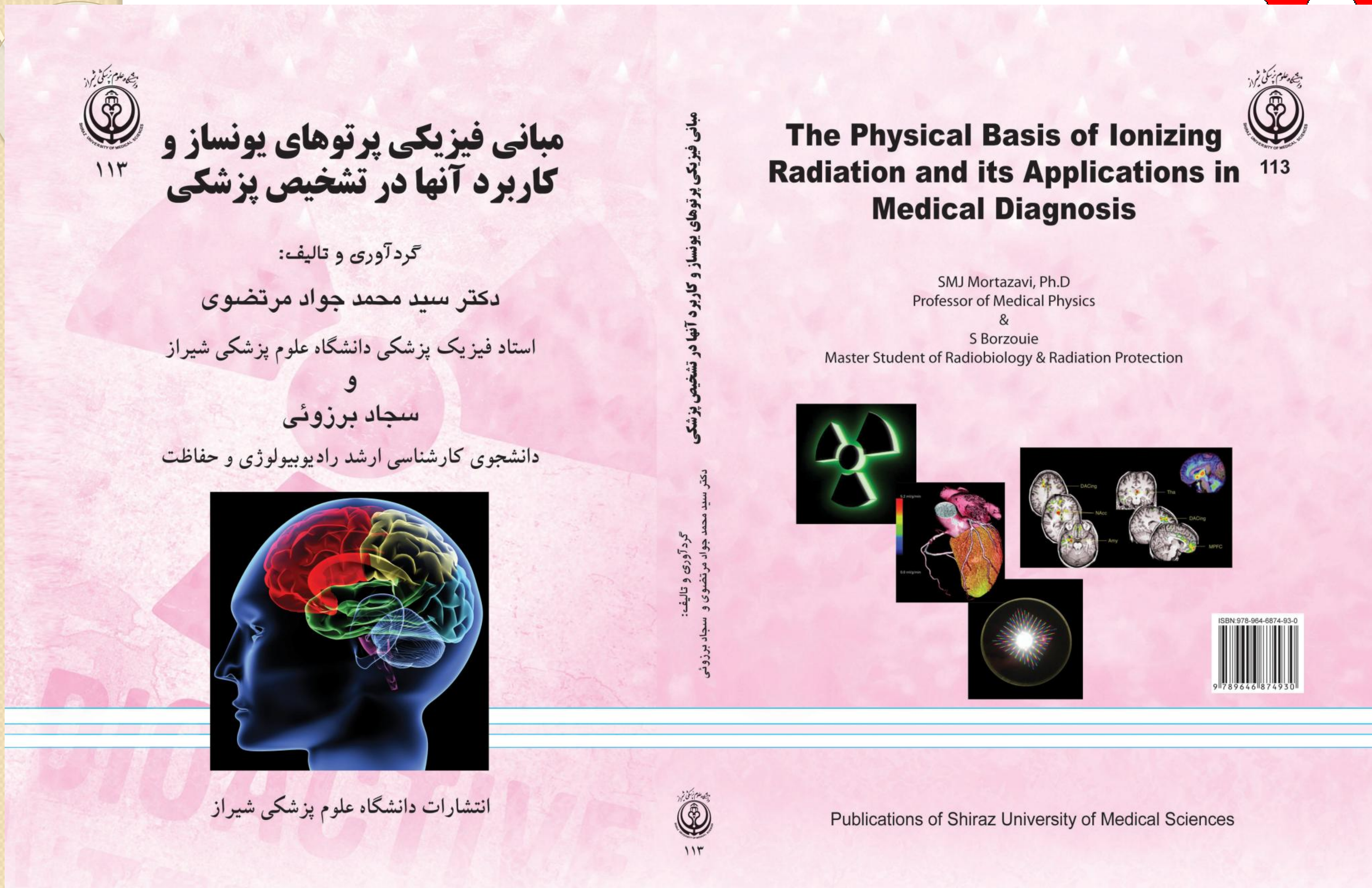



بسم الله الرحمن الرحیم

Main Reference



Other References



Other References

- **فیزیک پزشکی برای دانشجویان پزشکی و دندانپزشکی**

محمدجواد ابوالحسنی، محمدتقی بحرینی طوسی، سعید سرکار

ناشر: مهرو ماه نو

What is Nuclear Medicine?

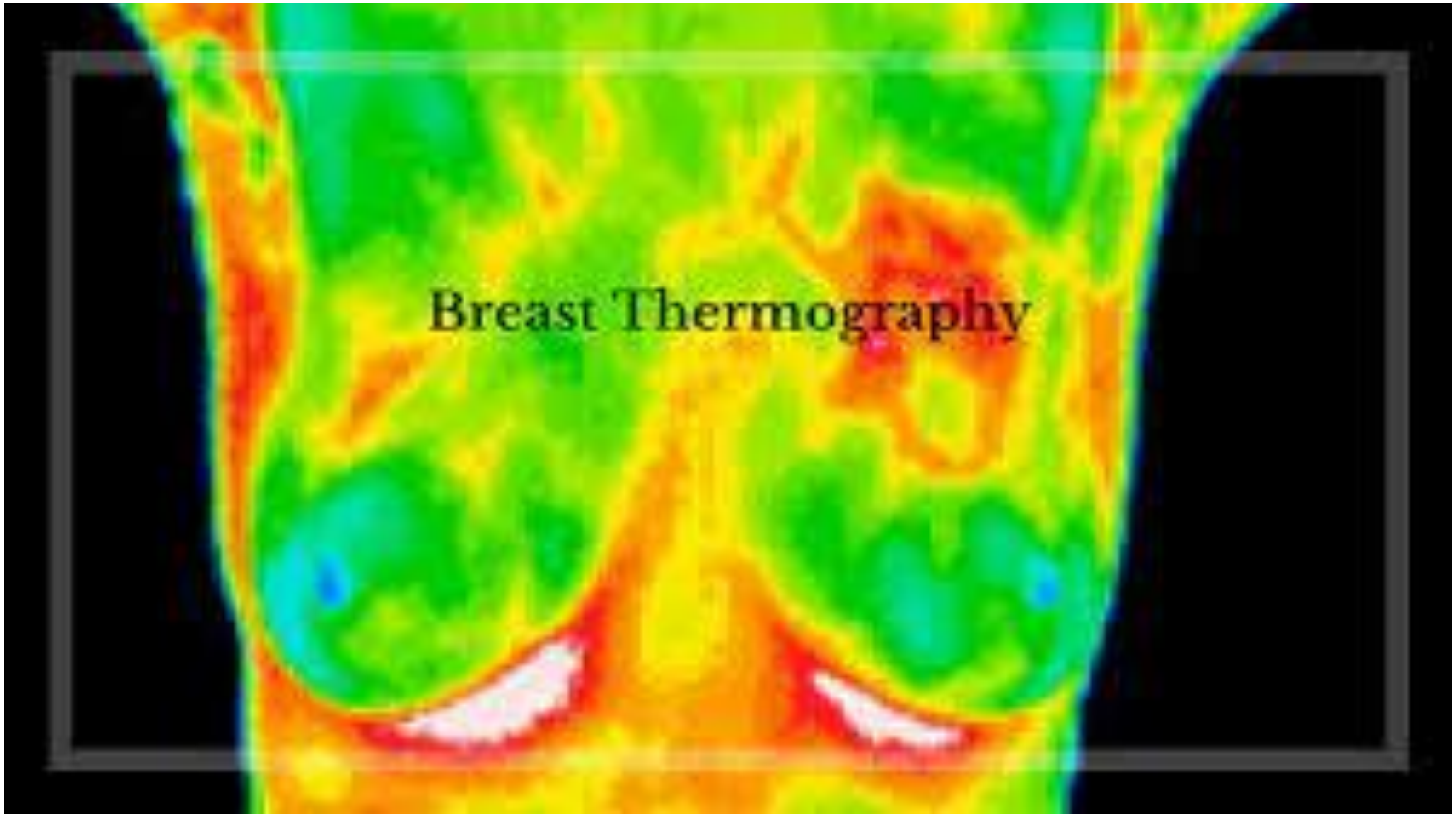
- Nuclear medicine involves the use of small amounts of radioactive materials (or tracers) to help diagnose and treat a variety of diseases.

http://med.stanford.edu/nuclearmedicine/patient_care.html

Medical Imaging

- Medical imaging uses various technologies, such as X-rays, CT scans, MRI, ultrasound, and nuclear medicine, to create images of the inside of the body to diagnose and monitor diseases and injuries.

Breast thermography



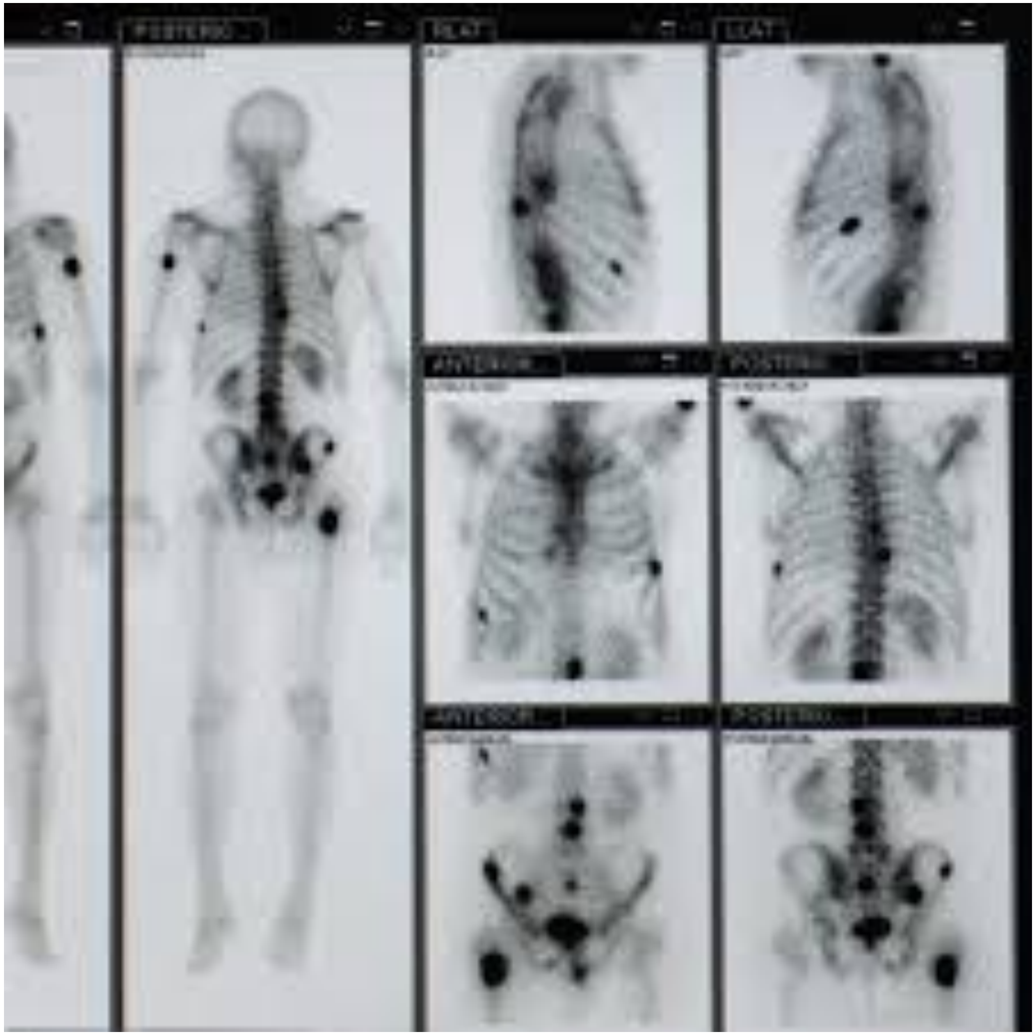
X-ray

CT scan of the abdomen

Brain MRI

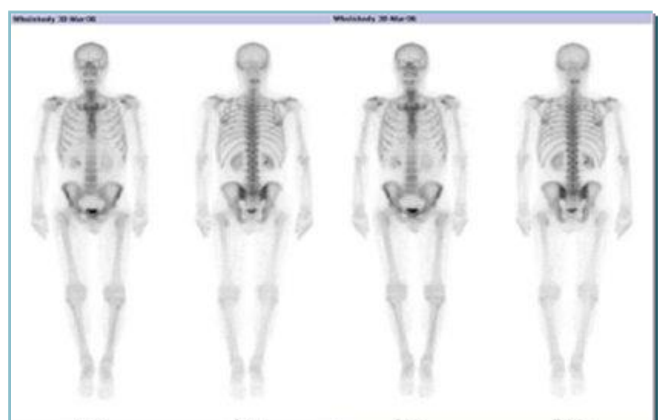
Ultrasound

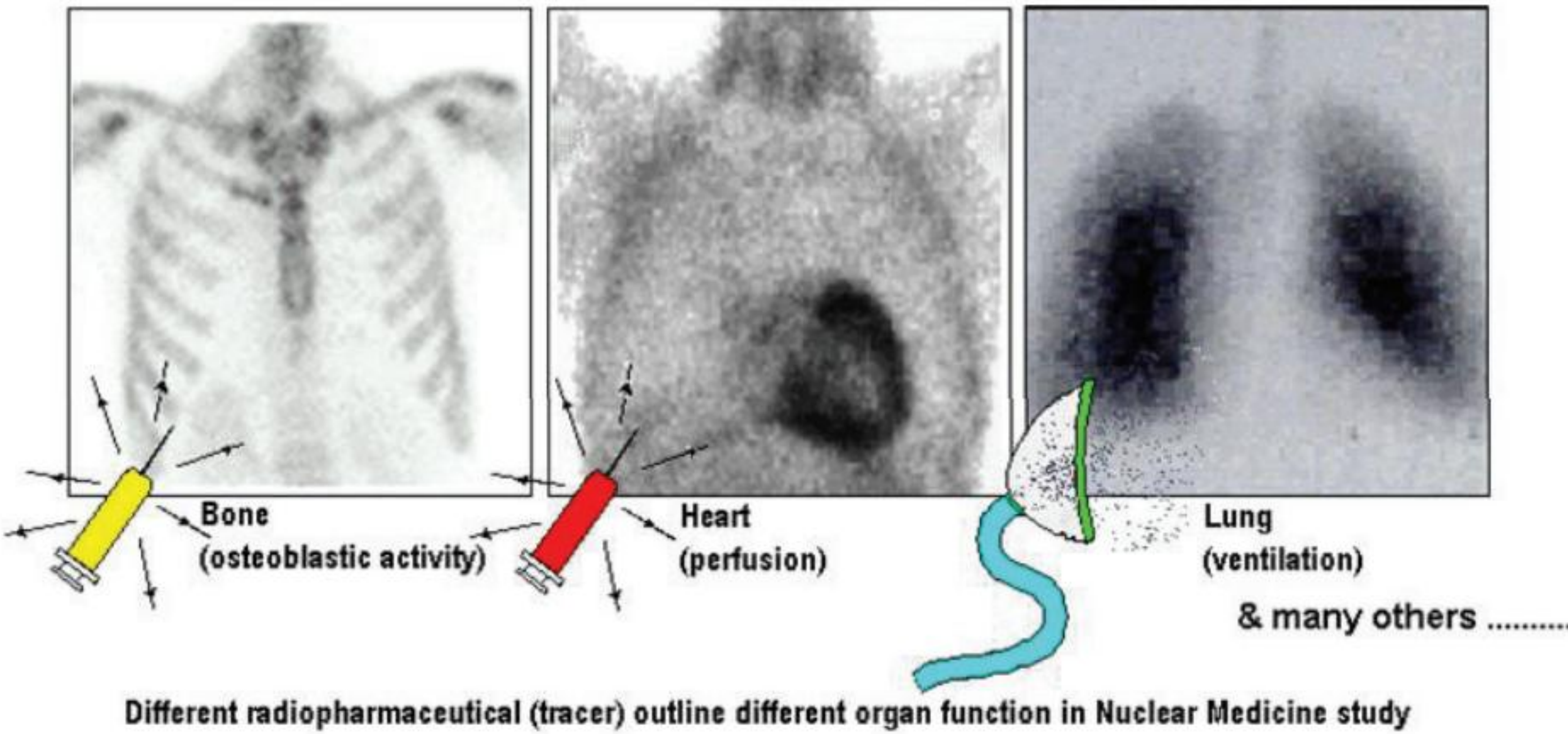
Nuclear Medicine

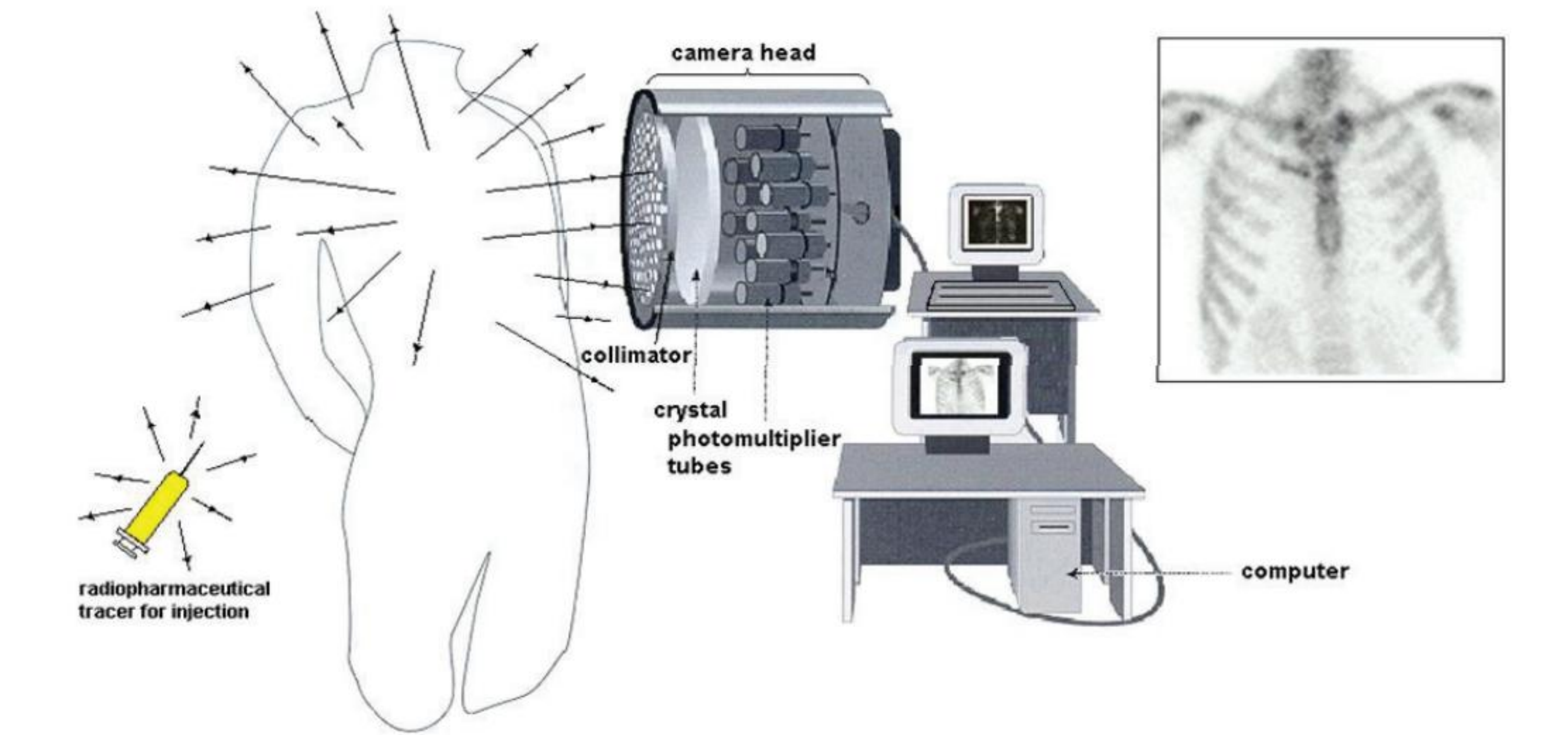


Diagnostic imaging

- Nuclear Medicine is an imaging modality that involves injection or inhalation of radioactive tracers to visualize various organs.
- https://www.who.int/diagnostic_imaging/imaging_modalities/dim_plain-radiography/en/index7.html

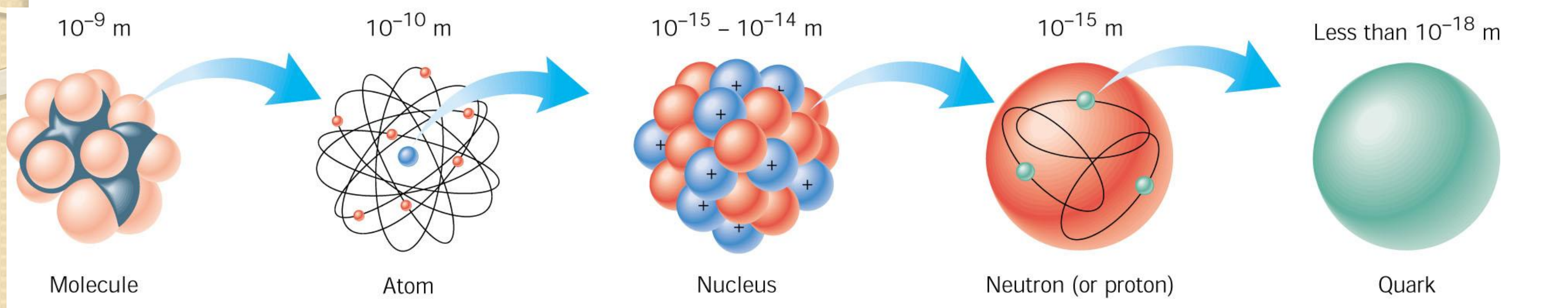


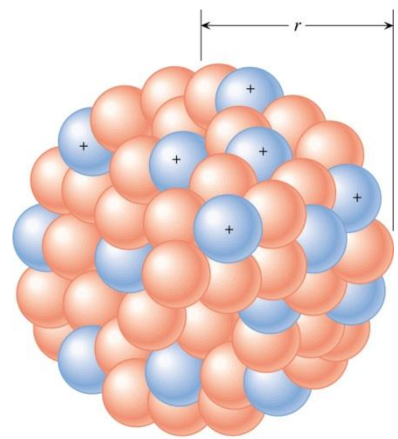

Bone
(osteoblastic activity)
Heart
(perfusion)
Lung
(ventilation)
& many others ....
Different radiopharmaceutical (tracer) outline different organ function in Nuclear Medicine study



Adapted from: Essential Nuclear Medicine Physics 2nd Edition by Rachel A. Powsner & Edward R. Powsner

Structure of Matter





Atomic Structure

- Nucleus - center of atom contains
  - protons: positive charge, mass of 1 amu
  - neutrons: neutral charge, mass of 1 amu
  - atomic mass = total # of protons + neutrons
- Electron shells
  - electrons: negative charge
  - # of electrons = # of protons, atoms have neutral charge
  - electrons further from nucleus have higher energy
  - valence electrons are in the outermost shell
    - interact with other atoms
    - determine chemical behavior
    - octet rule - atoms react to obtain a stable number of 8 valence electrons

Atomic and Mass Numbers

- ***Atomic number*** (Z) = number of protons in nucleus
- ***Mass number*** (A) = number of protons + number of neutrons
- = atomic number (Z) + number of neutrons

Mass Number → A
Atomic Number → Z

${}^{A}_{Z}X$

← Element Symbol
← Or charge for fundamental particles

$$ {}^{1}_{1}H_{0} \qquad {}^{238}_{92}U_{146} \qquad {}^{56}_{26}Fe_{30} $$

- Chemical symbol and Z are redundant
- N is not necessary since it is A-Z
- Nucleons
- Same number of protons different number of neutrons: *Isotopes (radioisotopes)*.
- Same N different Z : *Isotones.*

Nucleus

- Nucleus of atom consists of positively charged protons and uncharged (neutral) neutrons. Protons and neutrons are called nucleons.
- mp = 1.672623 x 10^{-27} kg
- mn = 1.674929 x 10^{-27} kg, slightly heavier than proton

Units

Atomic mass units - a unit of mass based on ^{12}C which is assigned the atomic mass of 12 amu.

m_p = 1.0073 amu m_n = 1.0087 amu

1 eV = energy gained by an electron when it drops through a potential difference of 1 volt.

By Einstein's formula $E = mc^2$ we may also give masses in terms of energy.

Calculate!

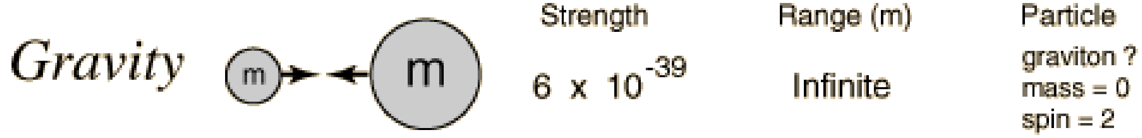
1 amu = 1.6605 x 10^{-27} kg

1 eV = 1.6022 x 10^{-19} J

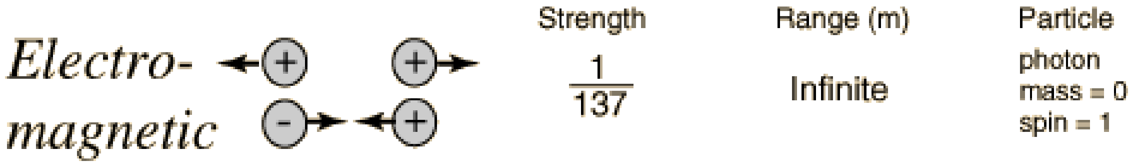
1 amu = 1.6605 x 10^{-27} kg = 1.4924 x 10^{-10} J = 9.315 x 10^{8} eV = 931.5 MeV

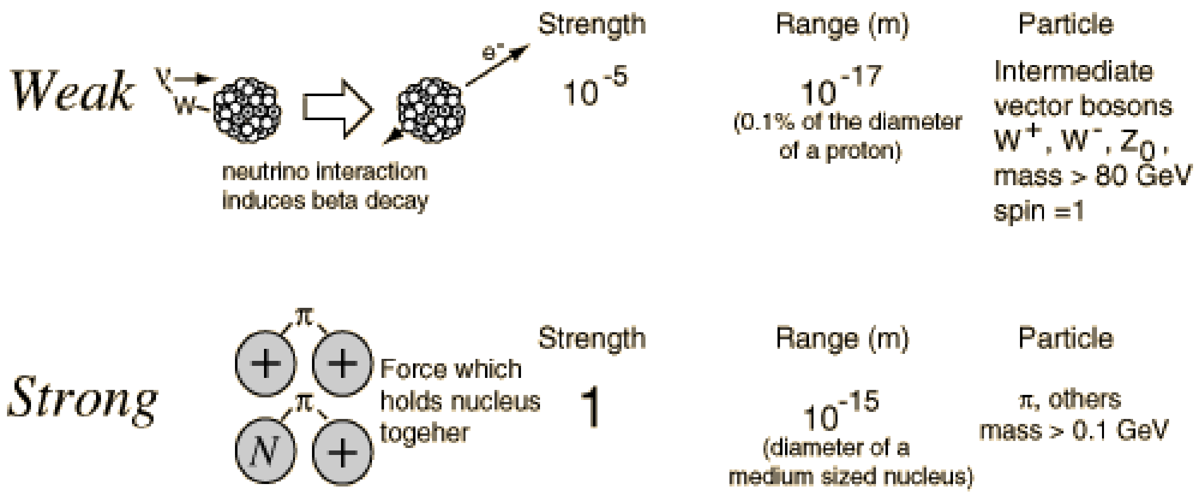
The Four Fundamental Forces:

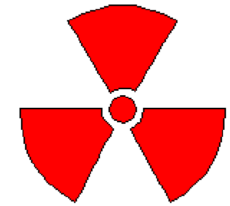
[1] Gravity (weak ,only attractive, long range)

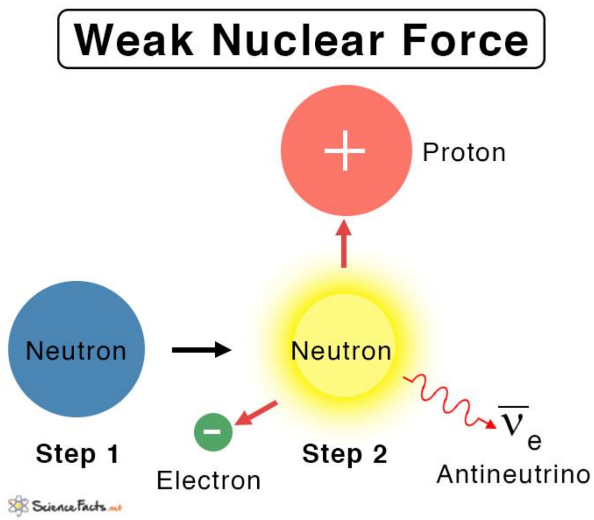


[2] Electromagnetic (stronger, both attractive and repulsive, long range.)







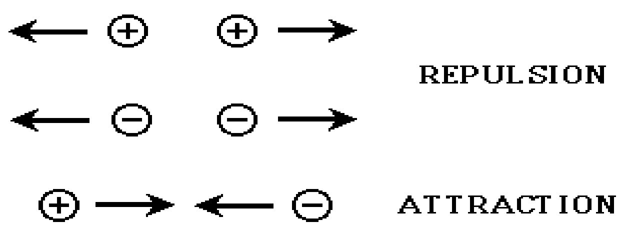


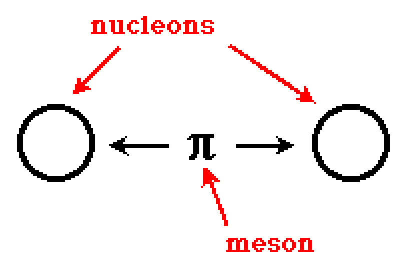
The weak nuclear force (or just the weak force, or weak interaction) acts inside of individual nucleons, which means that it is even shorter ranged than the strong force. It is the force that allows protons to turn into neutrons and vice versa through beta decay.

The strong nuclear force is sometimes referred to as just the strong force or the strong interaction. This force is strong enough that it overcomes the repulsive force between the two positively charged protons, allowing protons and neutrons to stick together in an unimaginably small space.

The Differences of Nuclear Strong force-

- The strong nuclear force **is one of the four basic forces** in nature
- As its name implies, it is the **strongest** of the four.
- It also has the **shortest range**, meaning that particles must be extremely close before its effects are felt.
- It does not depend on the **charge**. By the way the nuclear force between p-p is the same as n-p or n-n.





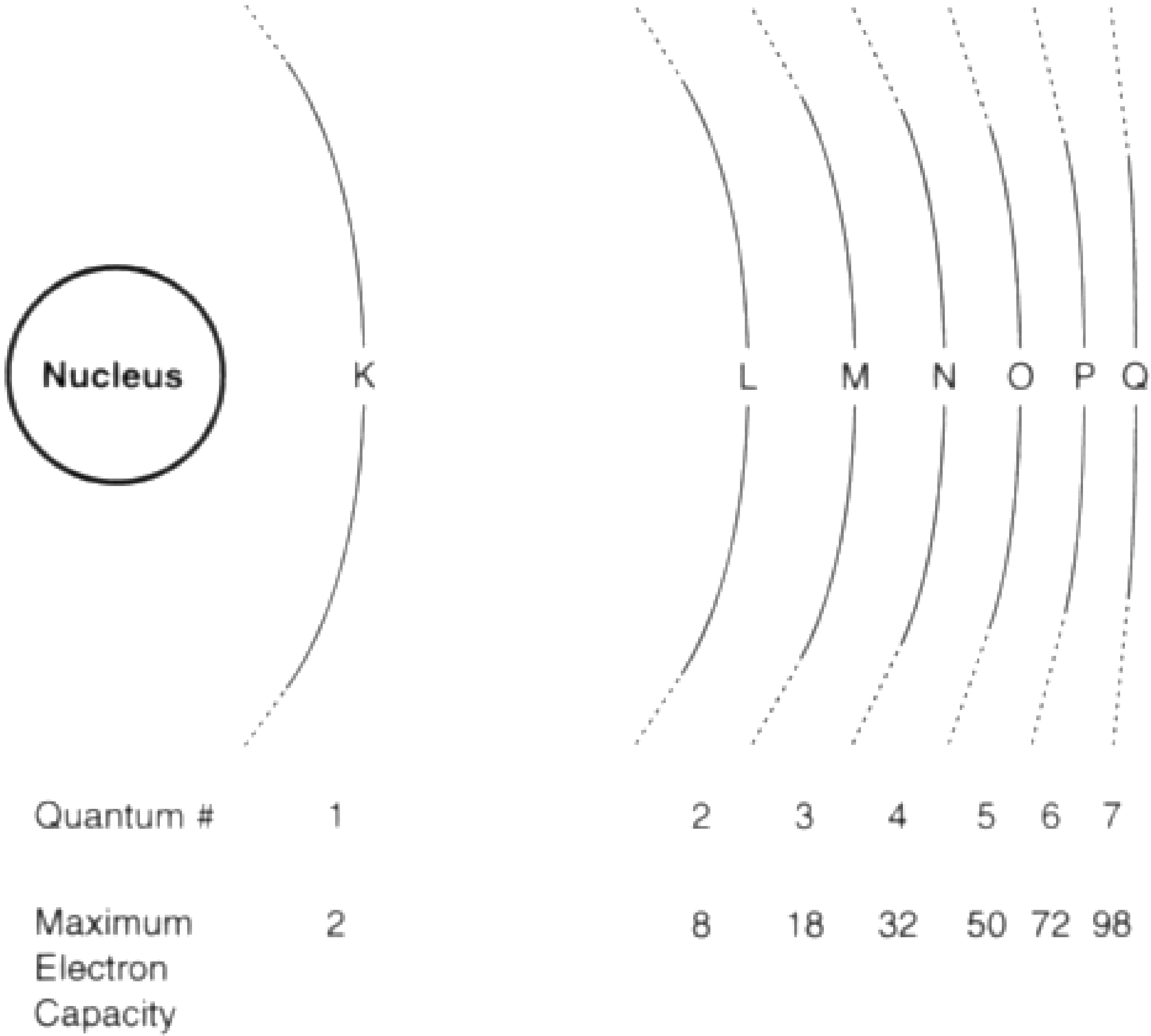
The Differences Between Nuclear Strong force and Other Forces

- The nucleus of all atoms **except hydrogen** contain **more than one proton** in them
- Each proton carries a **positive charge**, why do the nuclei of these atoms **stay together?**
- The protons must feel a repulsive force from the other neighboring protons
- The strong nuclear force is created between nucleons by the **exchange of particles called mesons**.
- **As long as** this meson exchange can happen, the strong force is able to hold the participating nucleons together.
- The nucleons **must be extremely close together** in order for this exchange to happen.

In particle physics, mesons are subatomic particles composed of one quark and one antiquark, bound together by the strong interaction. Because mesons are composed of sub-particles, they have a physical size, with a radius roughly one femtometre, which is about 2⁄3 the size of a proton or neutron. All mesons are unstable, with the longest-lived lasting for only a few hundredths of a microsecond. Charged mesons decay (sometimes through intermediate particles) to form electrons and neutrinos. Uncharged mesons may decay to photons.

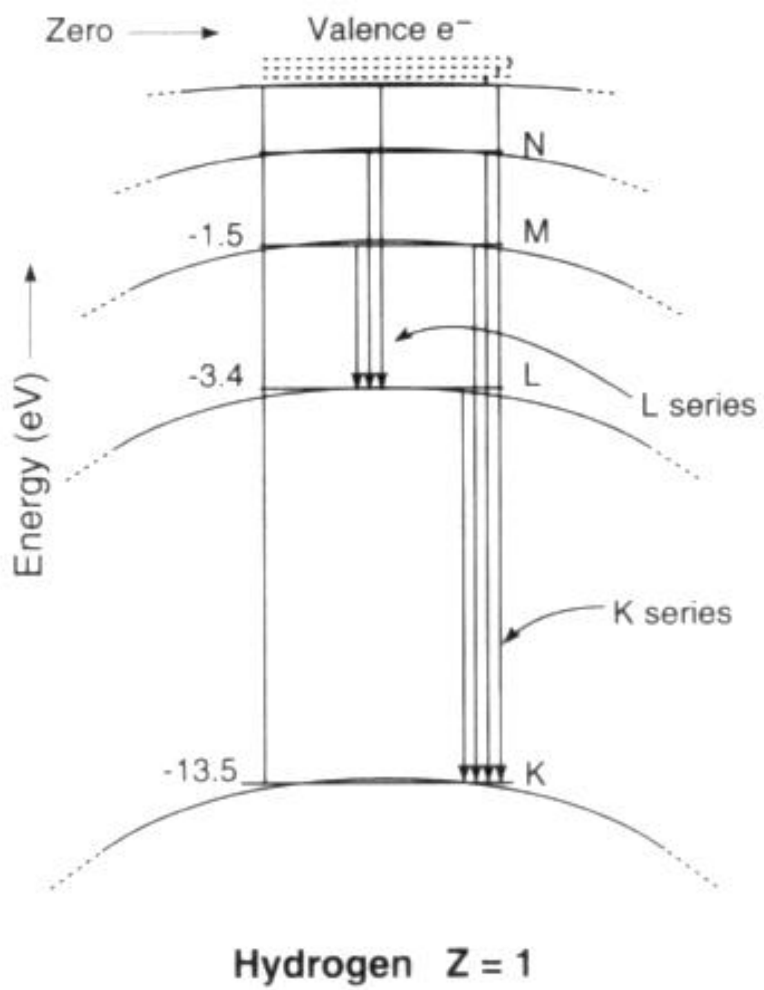
Structure of the Atom

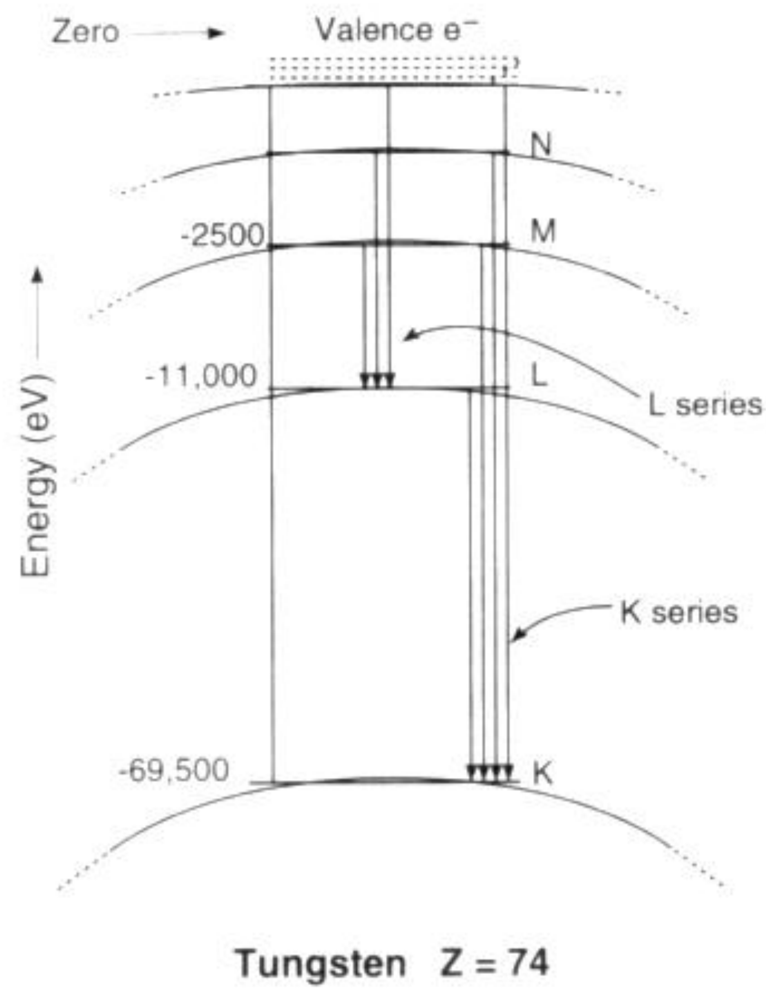
- Atom: Smallest division of an element in which the chemical identity of the element is maintained
- Composed of extremely dense positively charged nucleus containing protons and neutrons and an extranuclear cloud of light negatively charged electrons
- Electrically neutral in its nonionized state


Nucleus
K
L
M
N
O
P
Q
Quantum #
1
2
3
4
5
6
7
Maximum Electron Capacity
2
8
18
32
50
72
98

Binding Energy

- Energy required to remove an electron completely from an atom
- By convention, binding energies are negative with increasing magnitude for electrons in shells closer to the nucleus
- Binding energy of electrons in a particular orbit increases with the number of protons in the nucleus (i.e., atomic number, *Z*)


Zero
Valence e⁻
N
M
-1.5
-3.4
L
L series
K series
-13.5
K
Energy (eV)
Hydrogen Z = 1

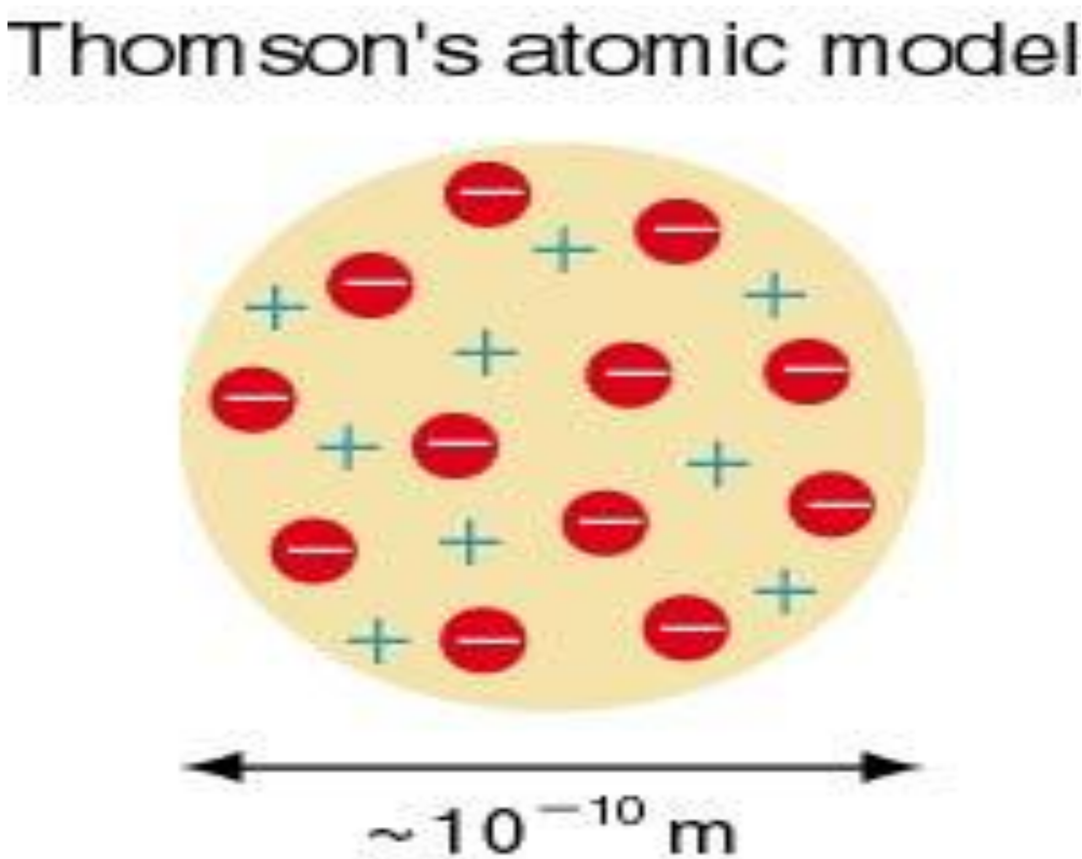

Zero
Valence e⁻
N
M
-2500
-11,000
L
L series
K series
-69,500
K
Energy (eV)
Tungsten Z = 74

Atomic Nucleus

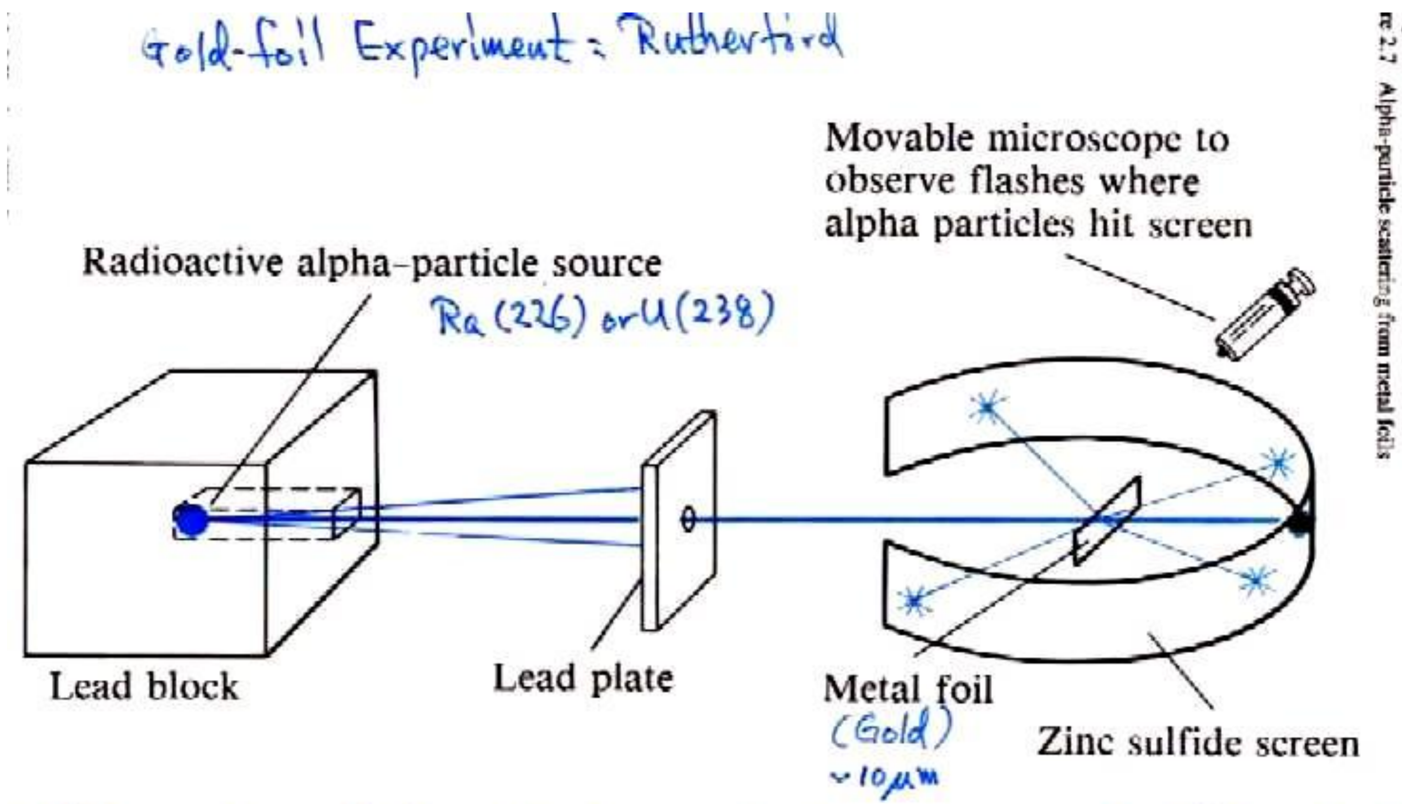
- Composed of protons and neutrons (collectively, *nucleons*)
- Number of protons is *atomic number* (Z); total number of protons and neutrons (N) is the *mass number* (A)
- Notation specifying an atom with chemical symbol X is

$$ {}^{A}_{Z}X_{N} $$

Plum Pudding Model



Rutherford's Experiment



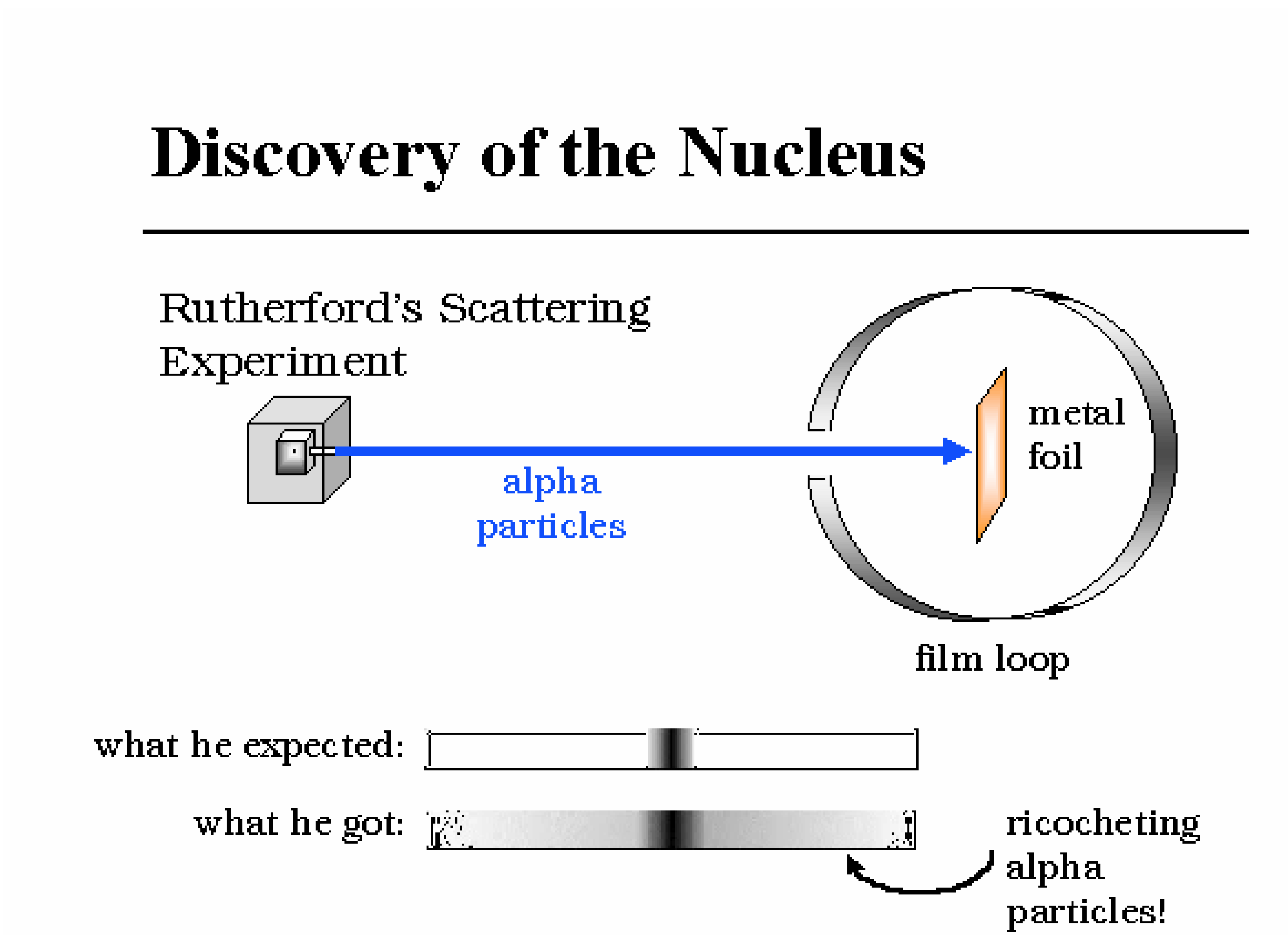
(1) A narrow beam of α particle from a radioactive source was directed to a thin fo

(2) Most of them pass thru the foil; & Many deflected at moderate angles.

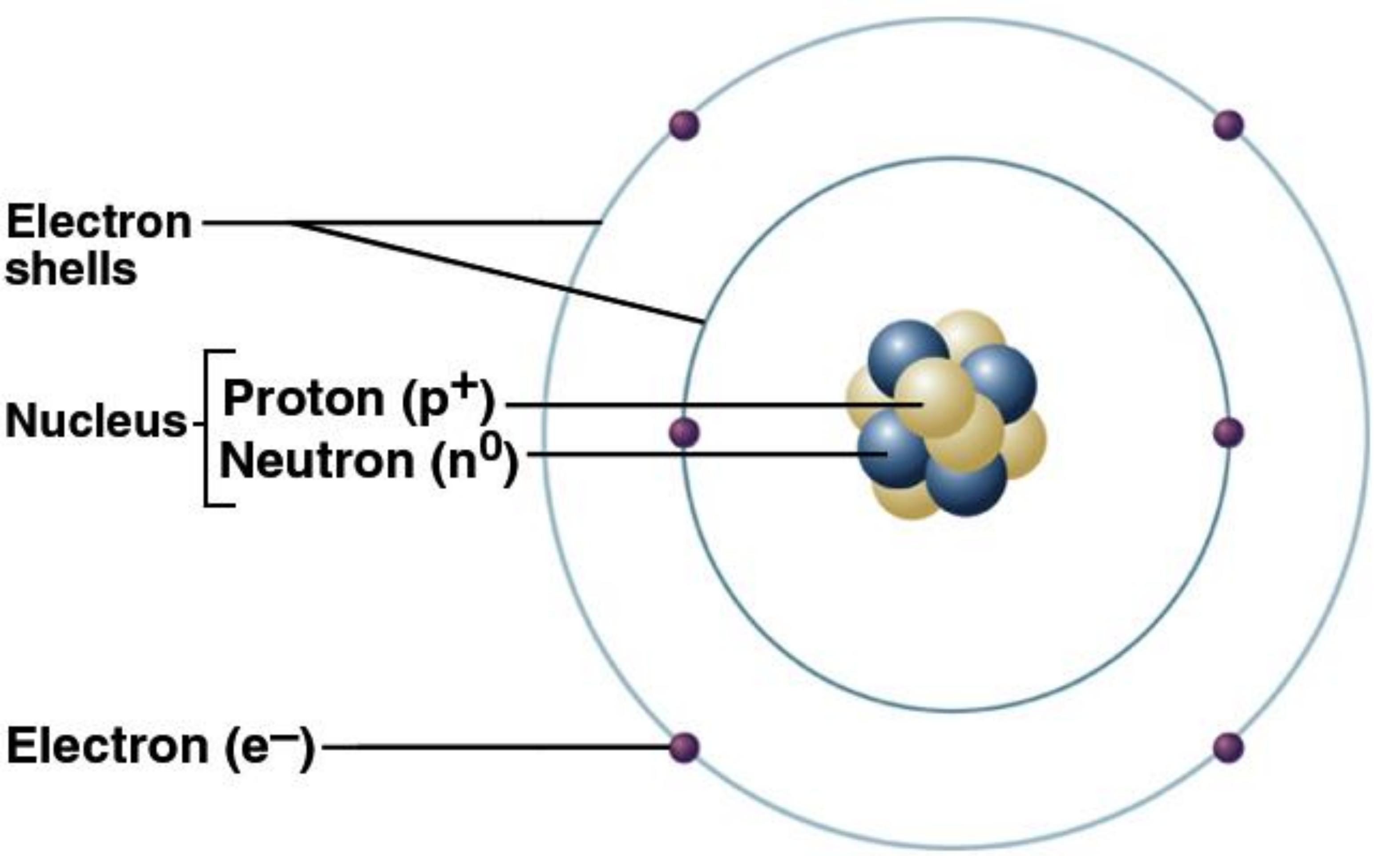
(3) 0.001% of them were deflected at acute angles.

→ Atoms are mostly empty w/ highly localized positively charged region ("nucleus")

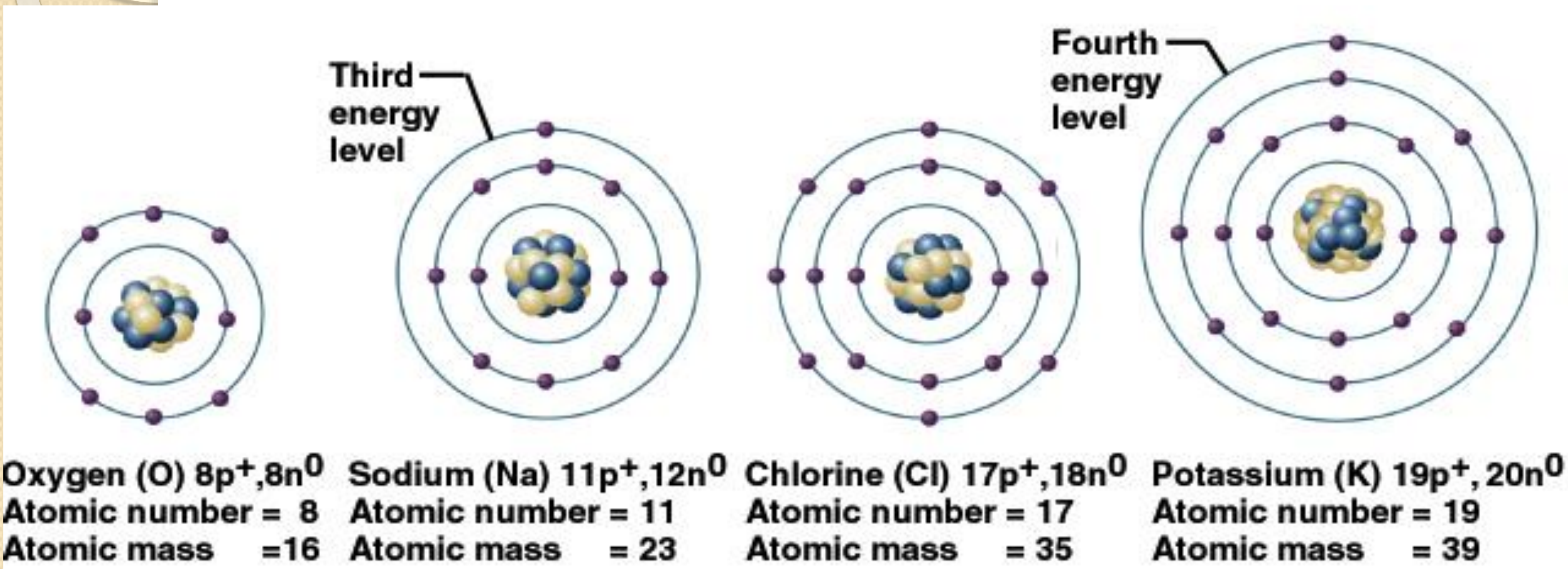
Nucleus Discovered!



Rutherford's Planetary Model of an Atom



Planetary Models of Elements

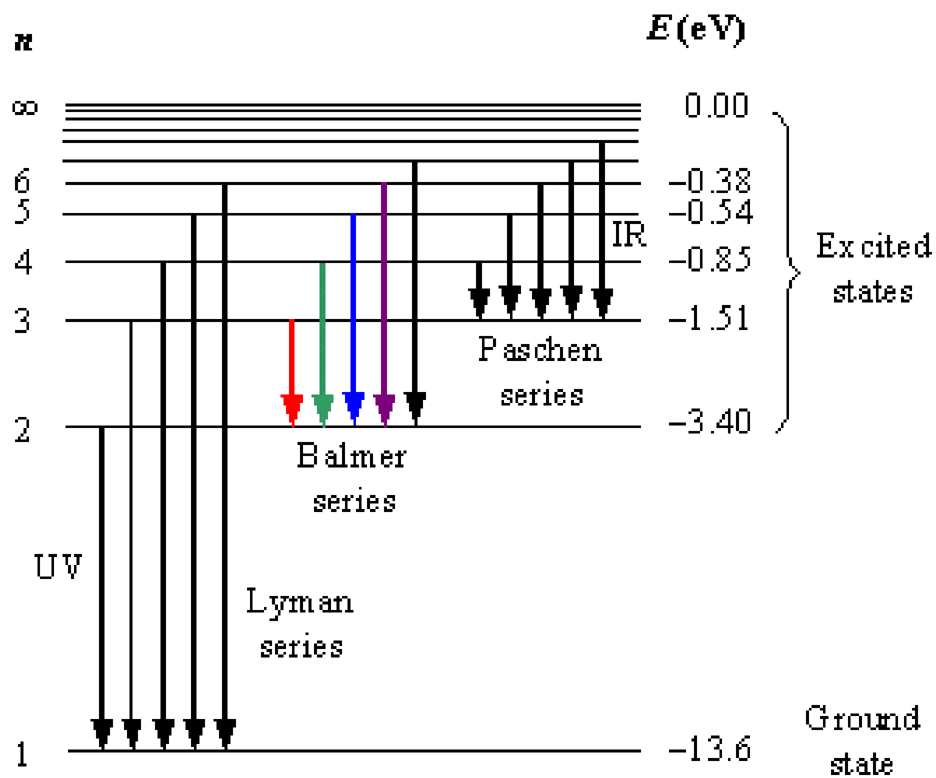


p^+ represents protons, n^o represents neutrons

Bohr Model of the Atom

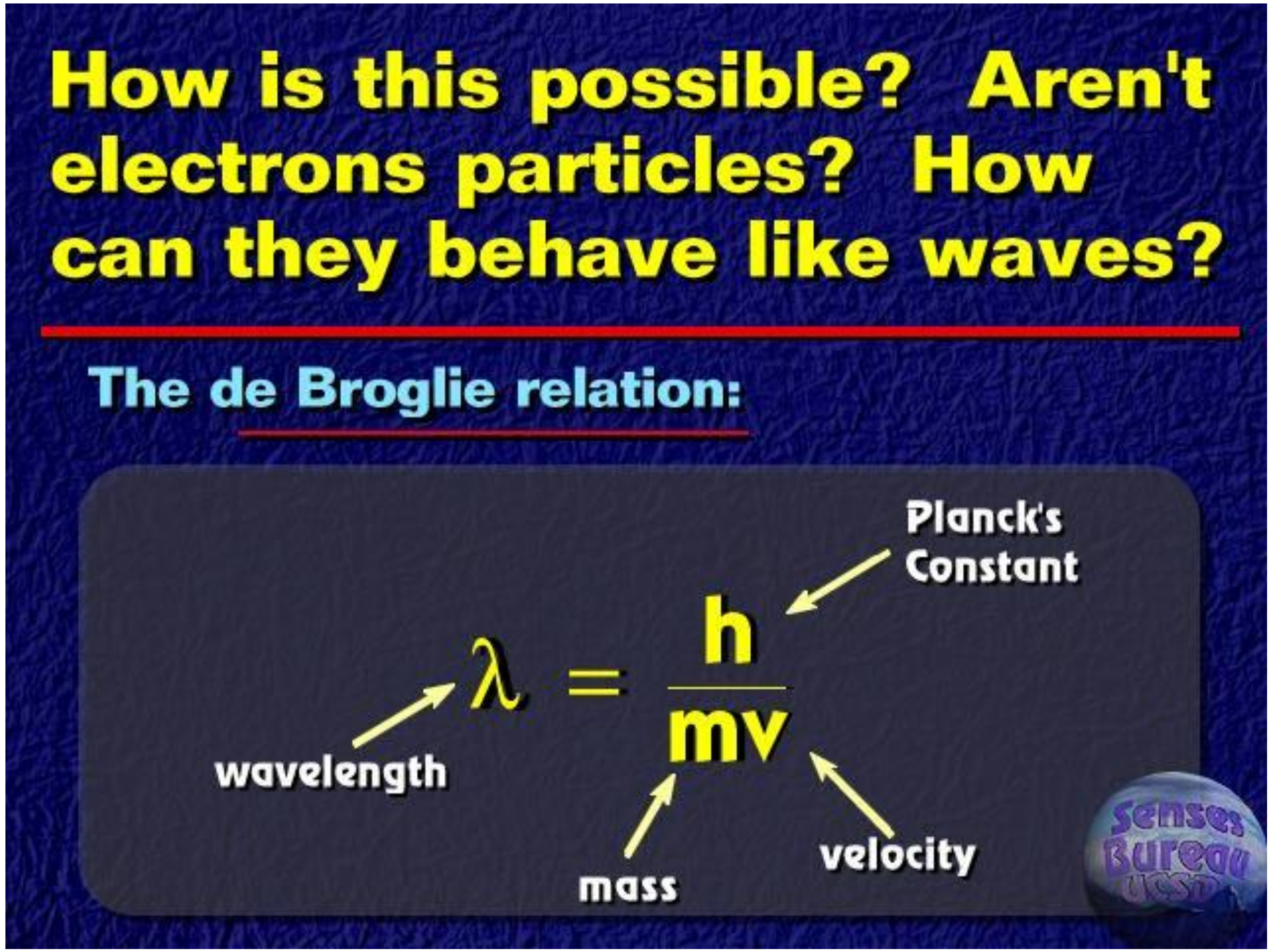
- Electrons orbit around a dense positively charged nucleus at fixed distances
- Each electron occupies a discrete energy state in a given electron shell
- Shells assigned the letters *K*, *L*, *M*, *N*, …, with *K* denoting the innermost shell; also assigned *quantum numbers* 1, 2, 3, 4, …, with 1 designating the *K* shell
- Each shell can contain a maximum of ($2n^2$) electrons, where *n* is the quantum number of the shell

Hydrogen Spectrum

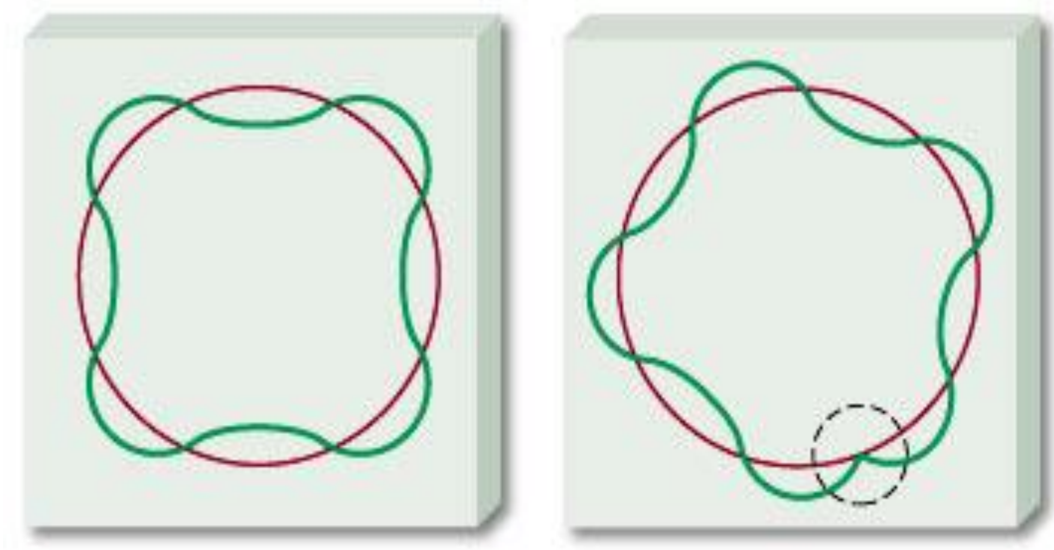


Energy levels of the hydrogen atom with some of the transitions between them that give rise to the spectral lines indicated.

De Broglie Equation



Wave-particle duality



Wave-particle duality states that a particle such as an electron must also have wave properties such as wavelength. In order to maintain a stable orbit, the electron should have an integral number of wavelengths in its travels around the nucleus. If the wavelengths do not match going around the circle, destructive interference between the wavelengths causes the waves to disappear. This observation led scientists to describe electron motion using equations for wave motion.

Electromagnetic Radiation

- Gamma rays, x-rays, UV, Visible light, IR, radio waves (RF)
- No mass; unaffected by electrical or magnetic fields; constant speed in a given medium
- Travels in straight lines; trajectory can be altered by interaction with matter
  - Absorption – removal of the radiation
  - Scattering – change in trajectory

Particulate Radiation

- Protons – found in nuclei of all atoms; single positive charge
- Electrons – exist in atomic orbits; emitted by nuclei of some radioactive atoms (referred to as *beta-minus* particles (β^-), *negatrons*, or simply "beta particles")
- Positrons – positively charged electrons (β^+); emitted from some nuclei during radioactive decay
- Neutrons – uncharged nuclear particle; released by nuclear fission and used for radionuclide production

Mass Energy Equivalence

- Einstein's theory of relativity states that mass and energy are interchangeable

$$E = mc^2$$

where *E* represents the energy equivalent to mass *m* at rest and *c* is the speed of light in a vacuum

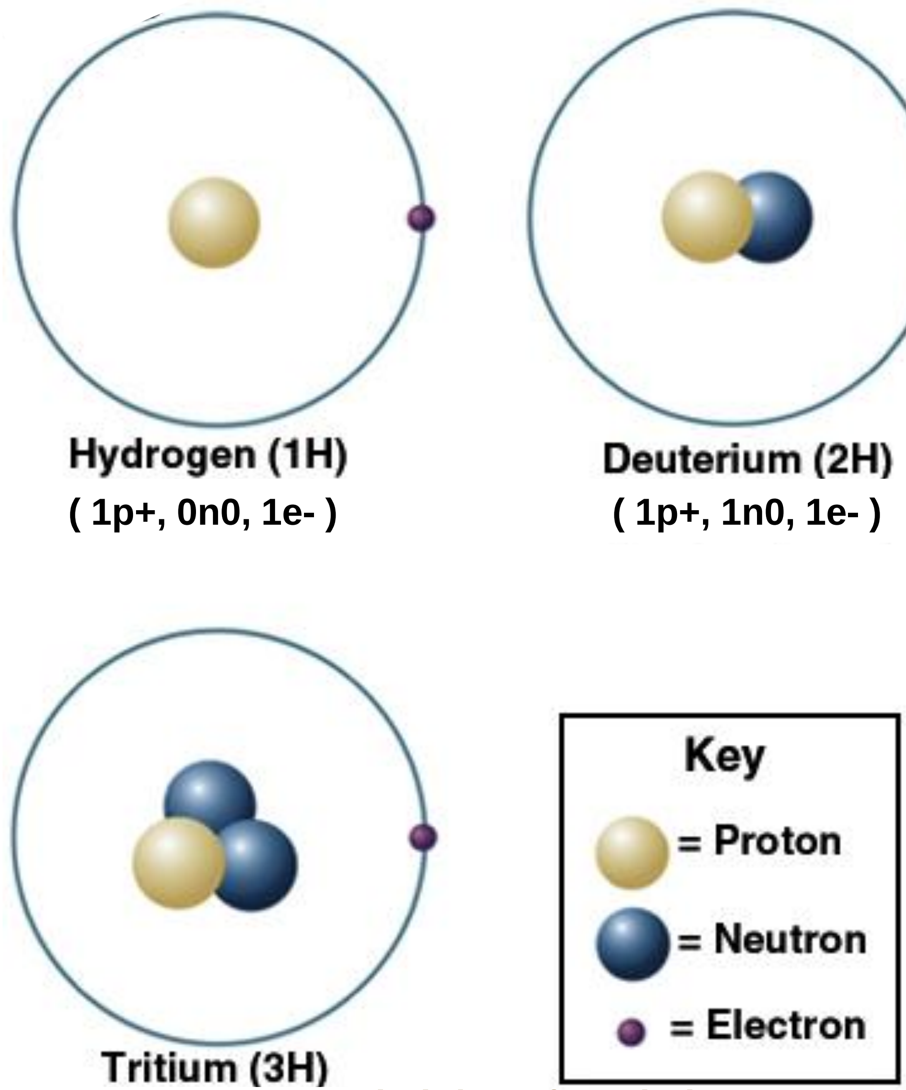
Fundamental Properties of Particulate Radiation

Particle	Symbol	Relative Charge	Approx. *E* (MeV)
Proton	p	+1	938
Electron	e^-	-1	0.511
Positron	e^+	+1	0.511
Neutron	n	0	940

Nuclear Families

Family	Nuclides with Same	Example
Isotopes	Atomic number (Z)	$_{53}$I-131 and $_{53}$I-125
Isobars	Mass number (A)	Mo-99 and Tc-99
Isotones	Number of neutrons (A - Z)	$_{53}$I-131 and $_{54}$Xe-132
Isomers	Atomic and mass numbers but different energy states	Tc-99m and Tc-99; ΔE = 142 keV

Isotopes of Hydrogen



(1p+, 0n0, 1e-)

(1p+, 1n0, 1e-)

(1p+, 2n0, 1e-)

Isotopes

Isotopes

- isotopes: same Z, different M

$^{1}_{1}H$ $^{2}_{1}H$ $^{3}_{1}H$ $^{12}_{6}C$ $^{13}_{6}C$ $^{14}_{6}C$ $^{235}_{92}U$ $^{238}_{92}U$

- isotopic abundance: $\frac{\text{\# atoms of isotope present}}{\text{\# atoms of element present}}$

isotope	natural abundance	mass (amu)
carbon-12	98.89 %	12.000000
carbon-13	1.11 %	13.003354

average mass: 12.01_{11} amu

ENERGY UNITS

A Reminder……..

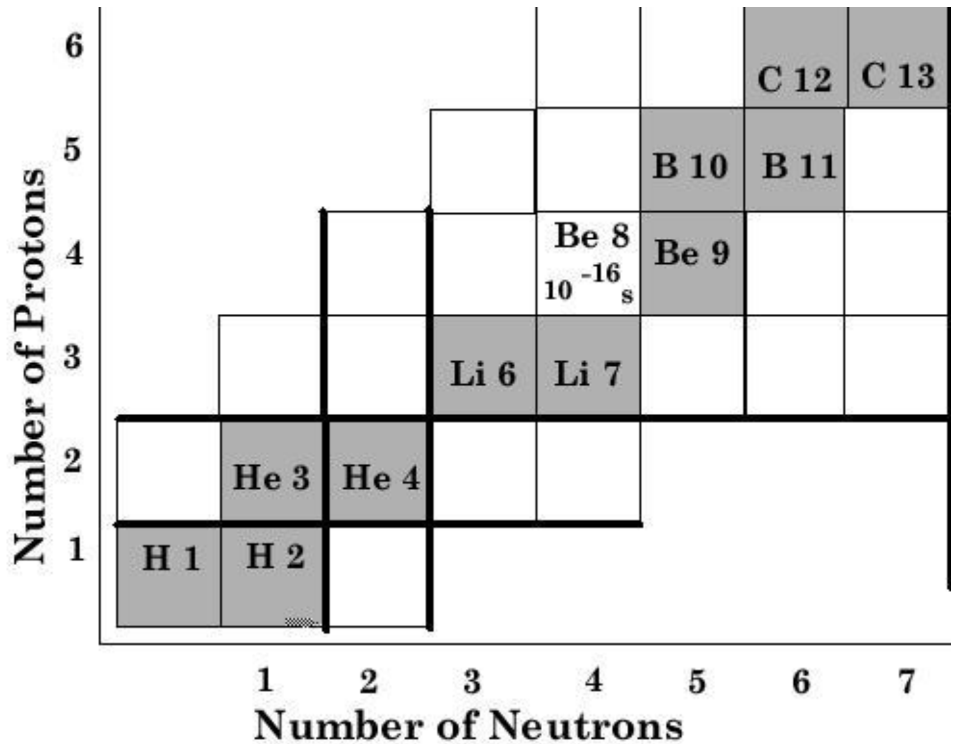
Radiation energies are commonly expressed as Electron Volts (eV).

One eV = 1.6 X 10^{-19} Joules

One electron is said to have energy equivalent to 0.51 MeV according to Einstein's theory of relativity

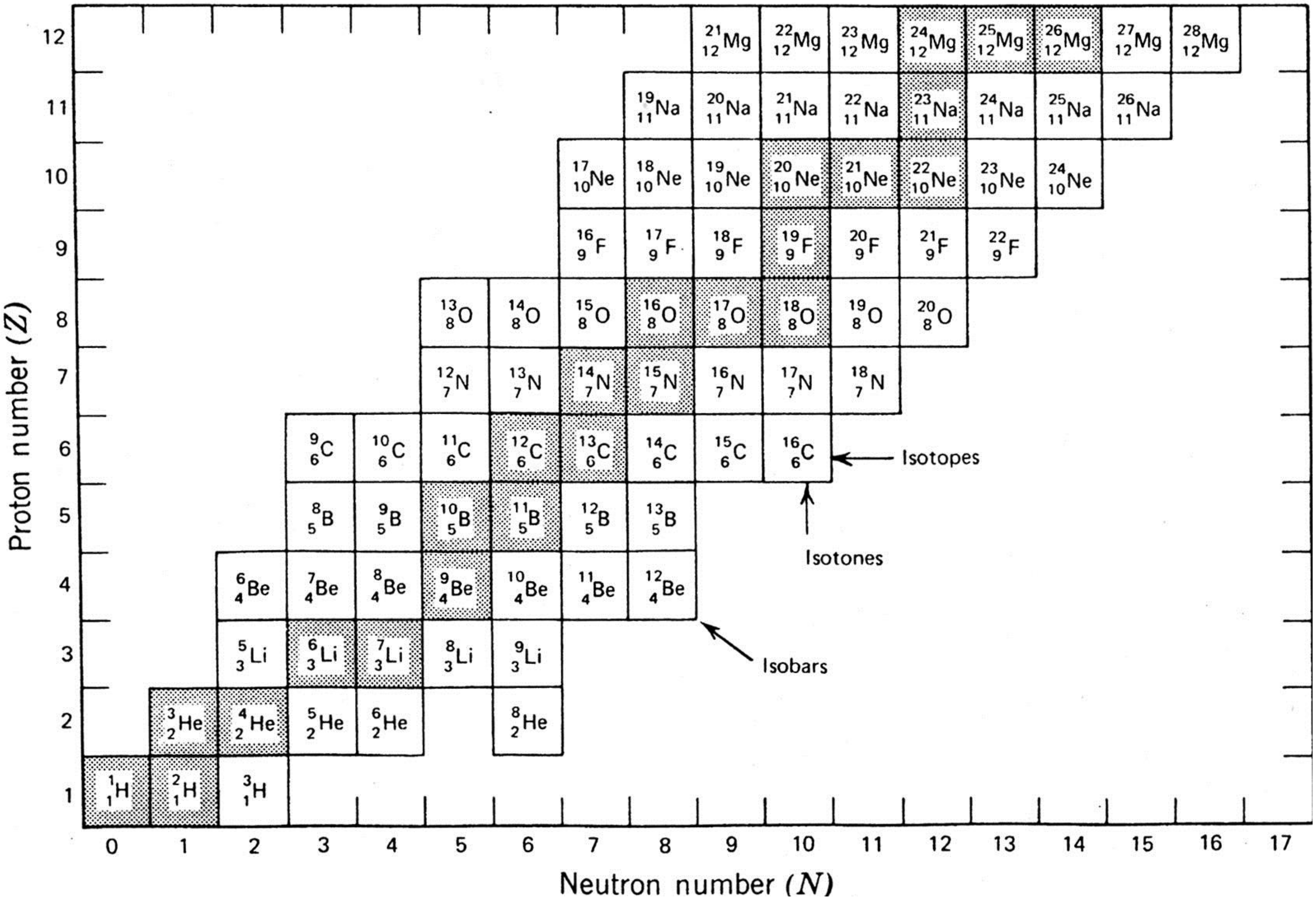
You will commonly see beta and gamma radiations expressed as MeV or KeV.

Line of Stability

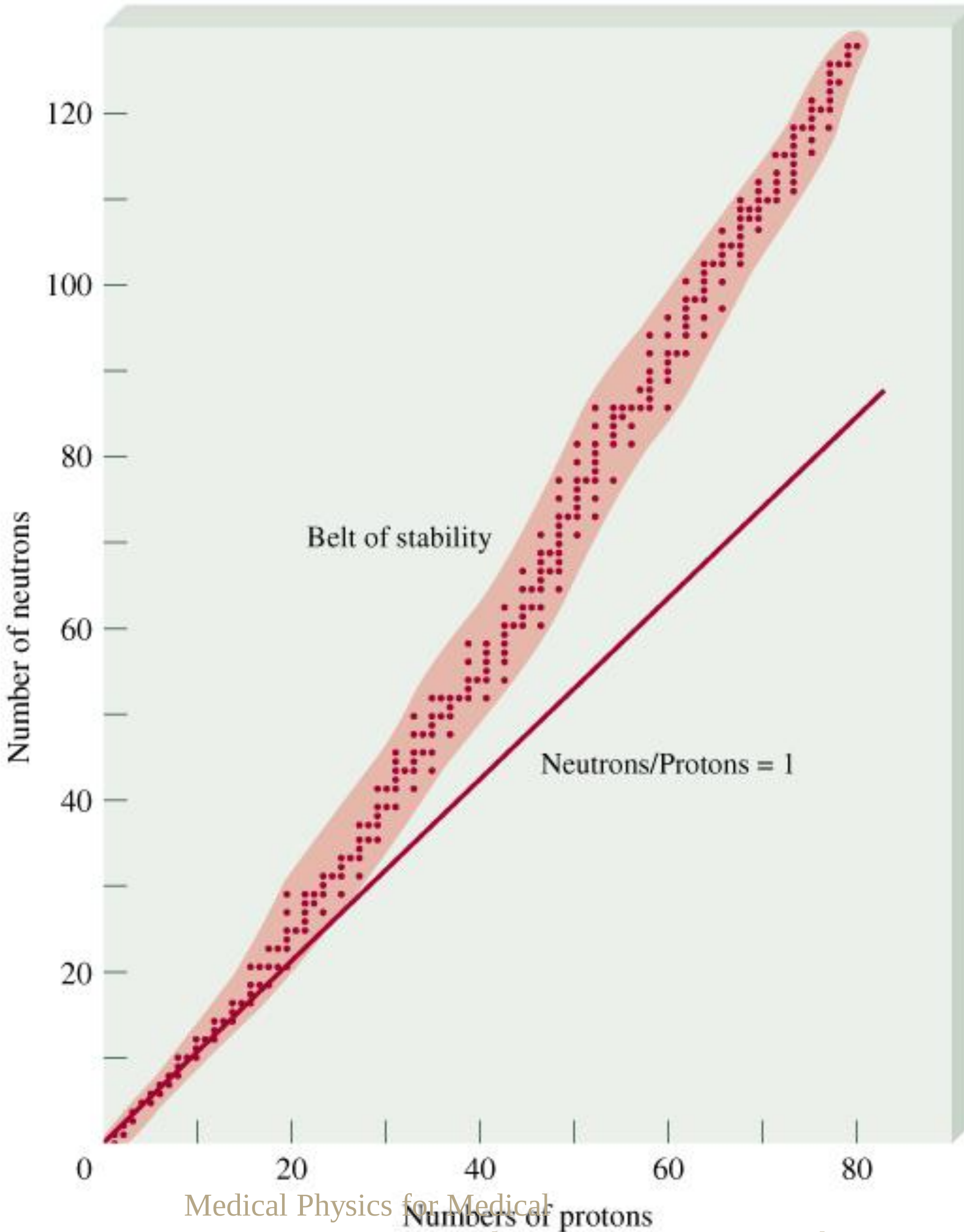


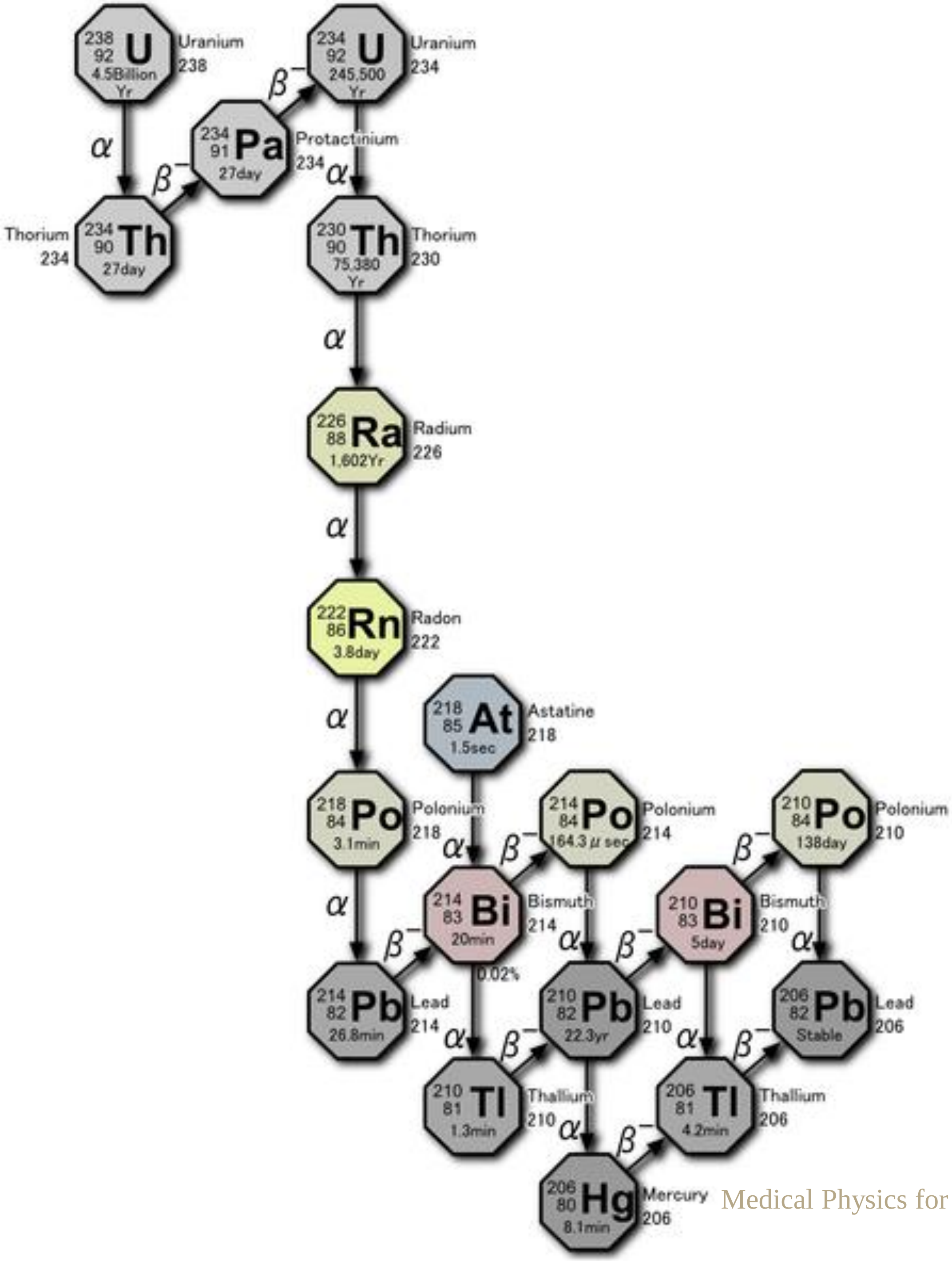
- Number of protons in nucleus determines what kind of element the atom is
- Number of neutrons in the nucleus determines the isotope of that element

Line of Stability



Stability Line

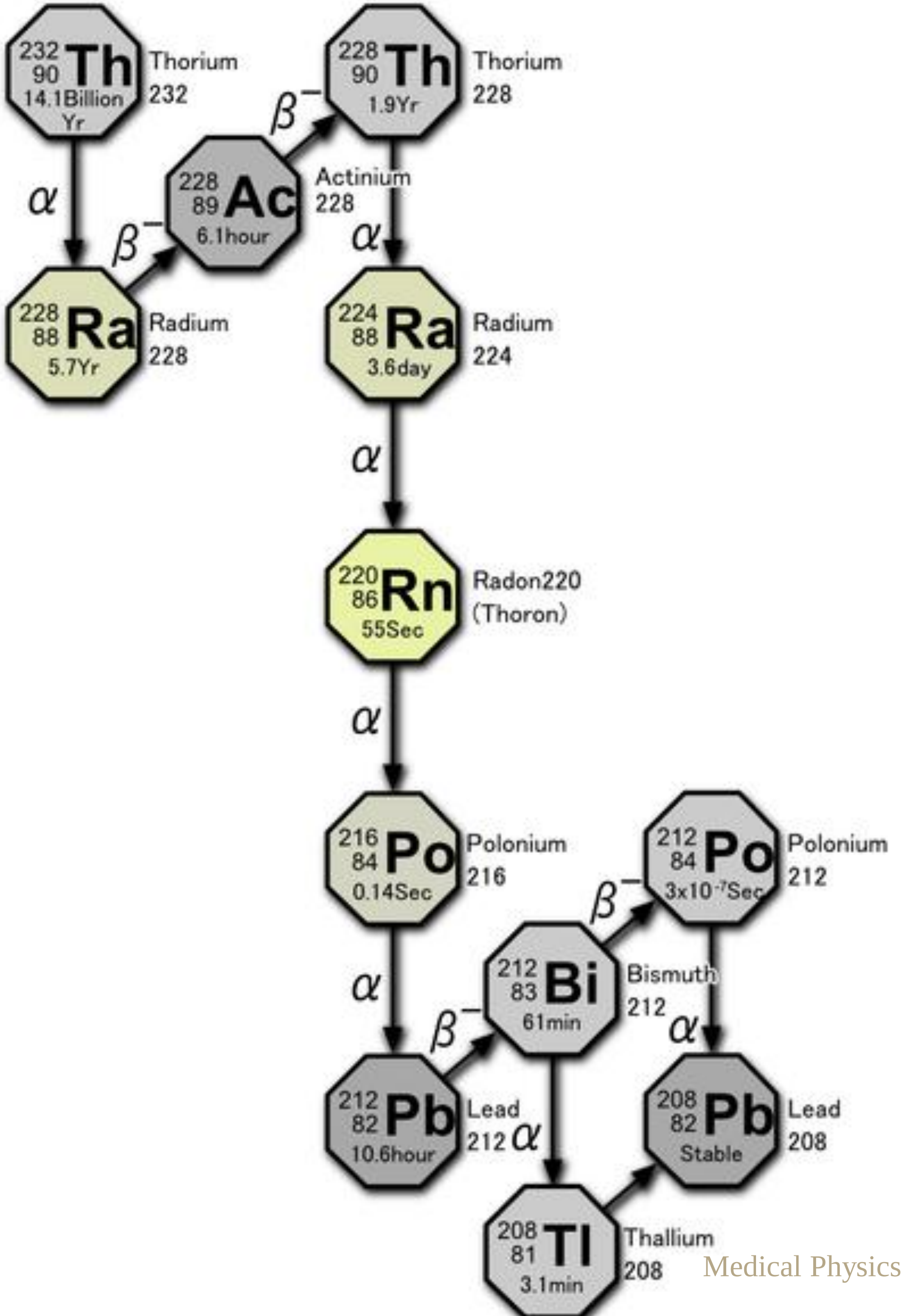




Radioactive Series

Uranium series

The 4n+2 chain of U-238

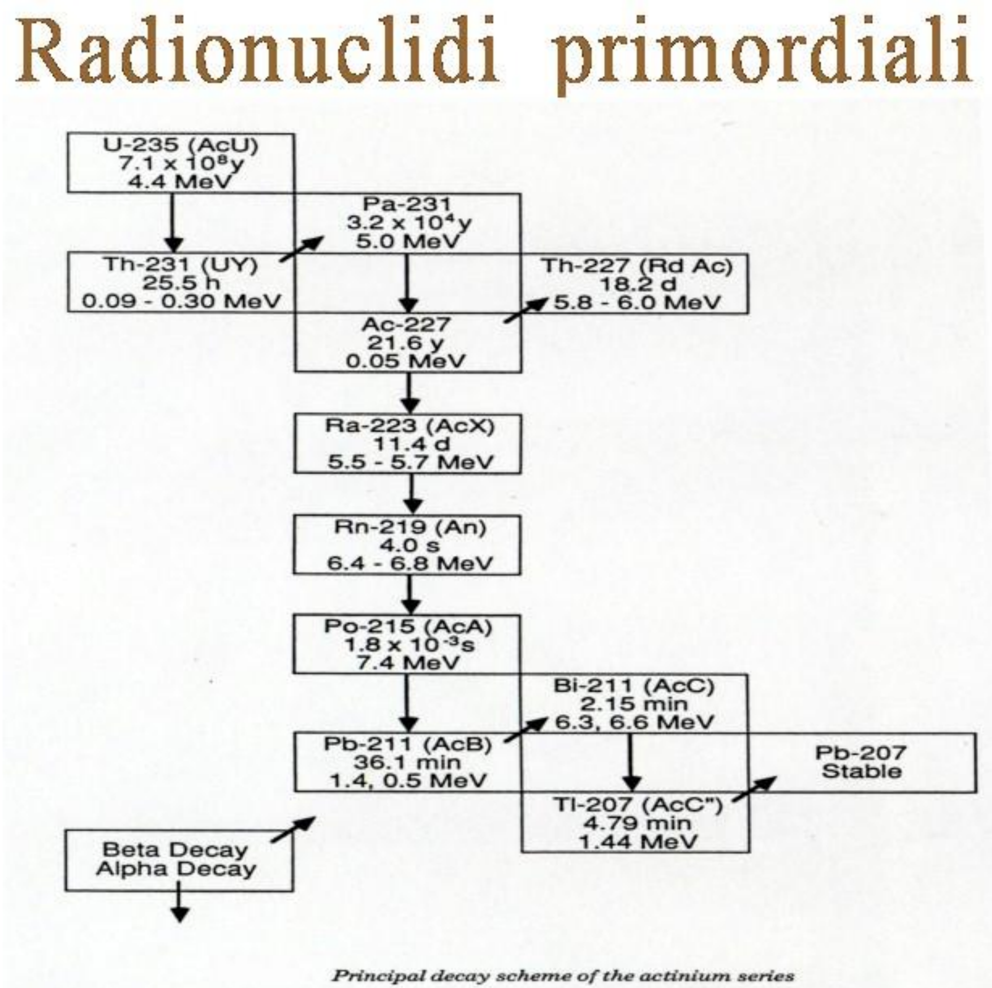


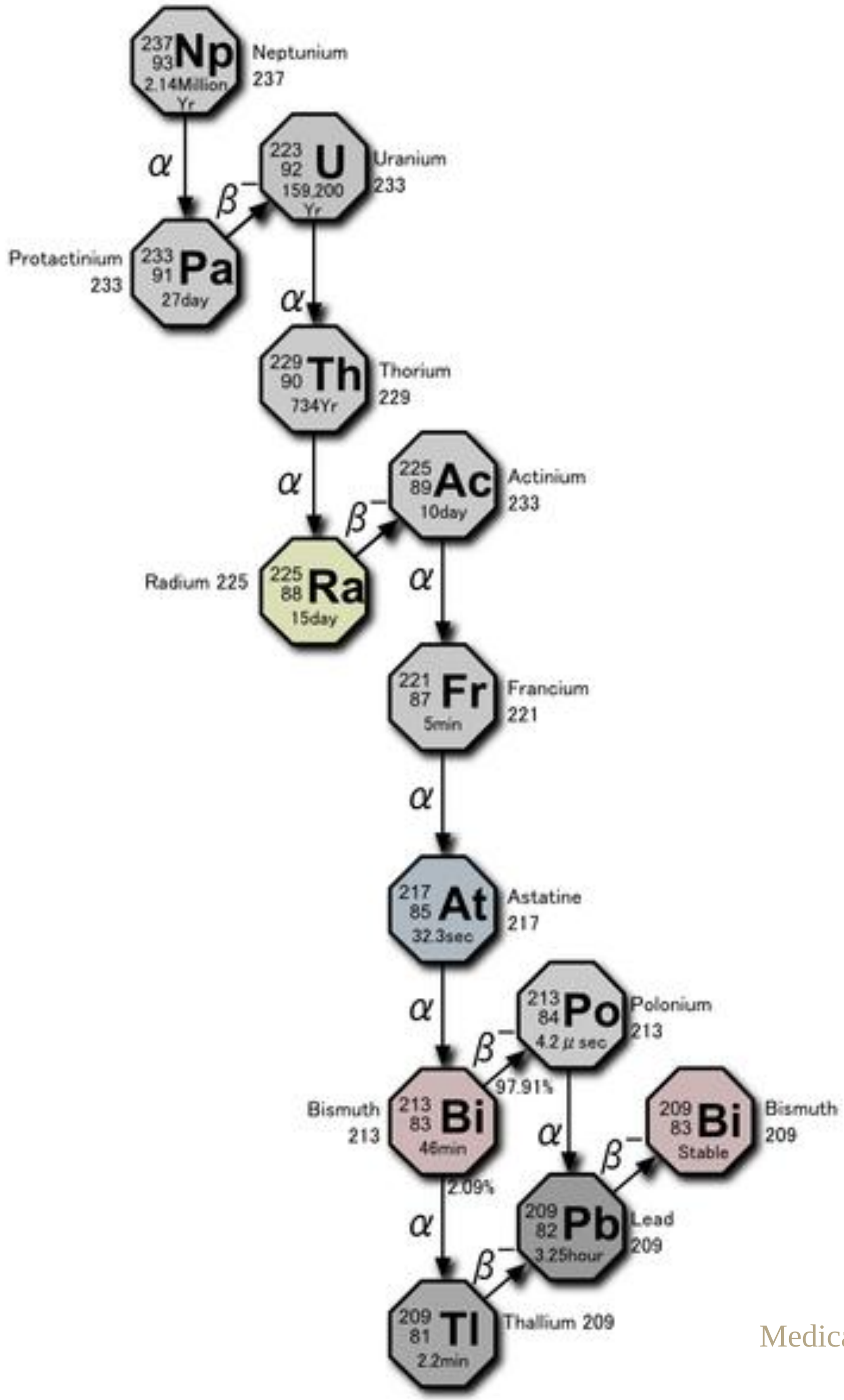
Radioactive Series

Thorium series

The 4n chain of Th-232

Long Half Lives





Radioactive Series

Neptunium series

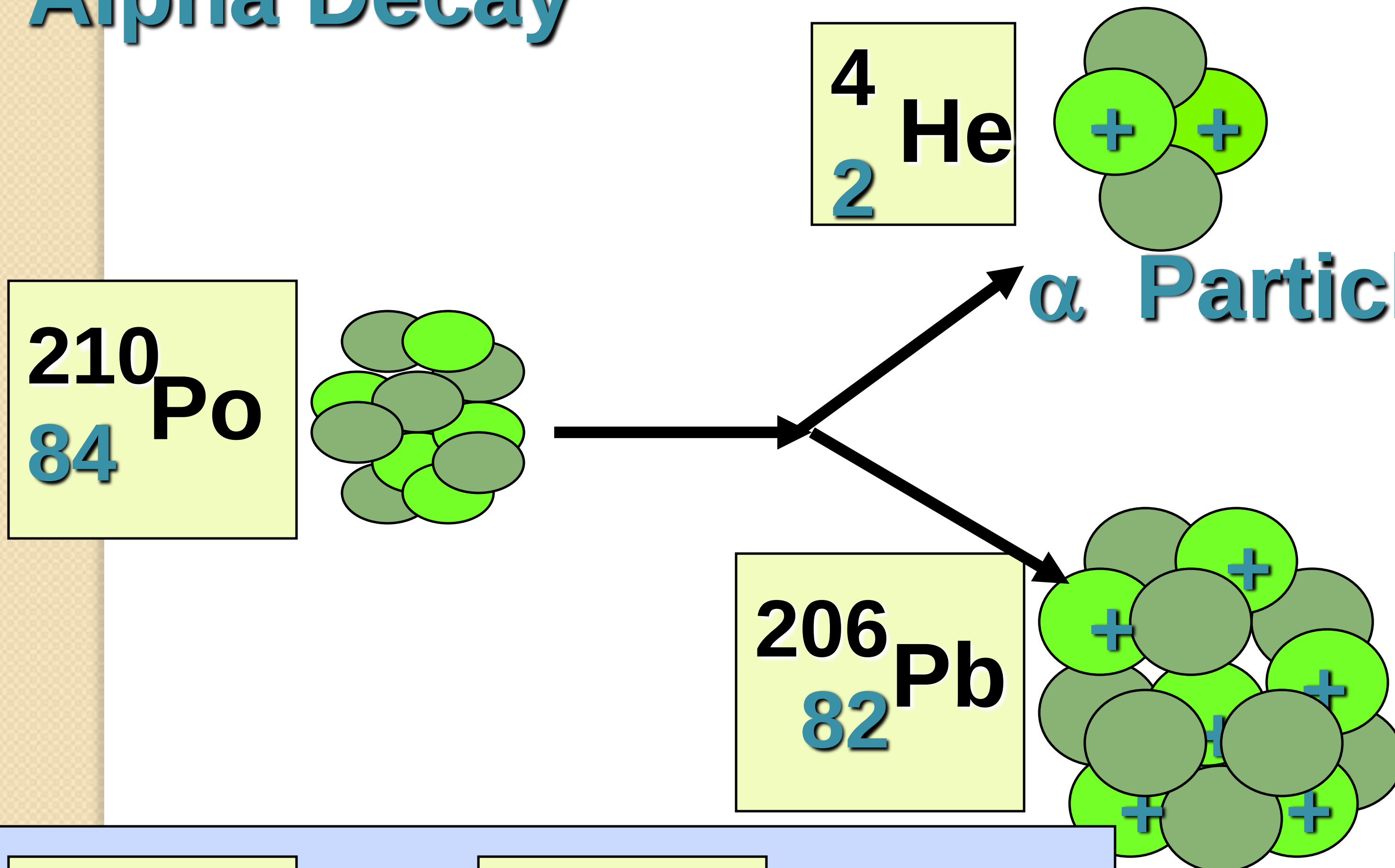
The 4n + 1 chain of Np-237

Types of Radiation

ALPHA DECAY

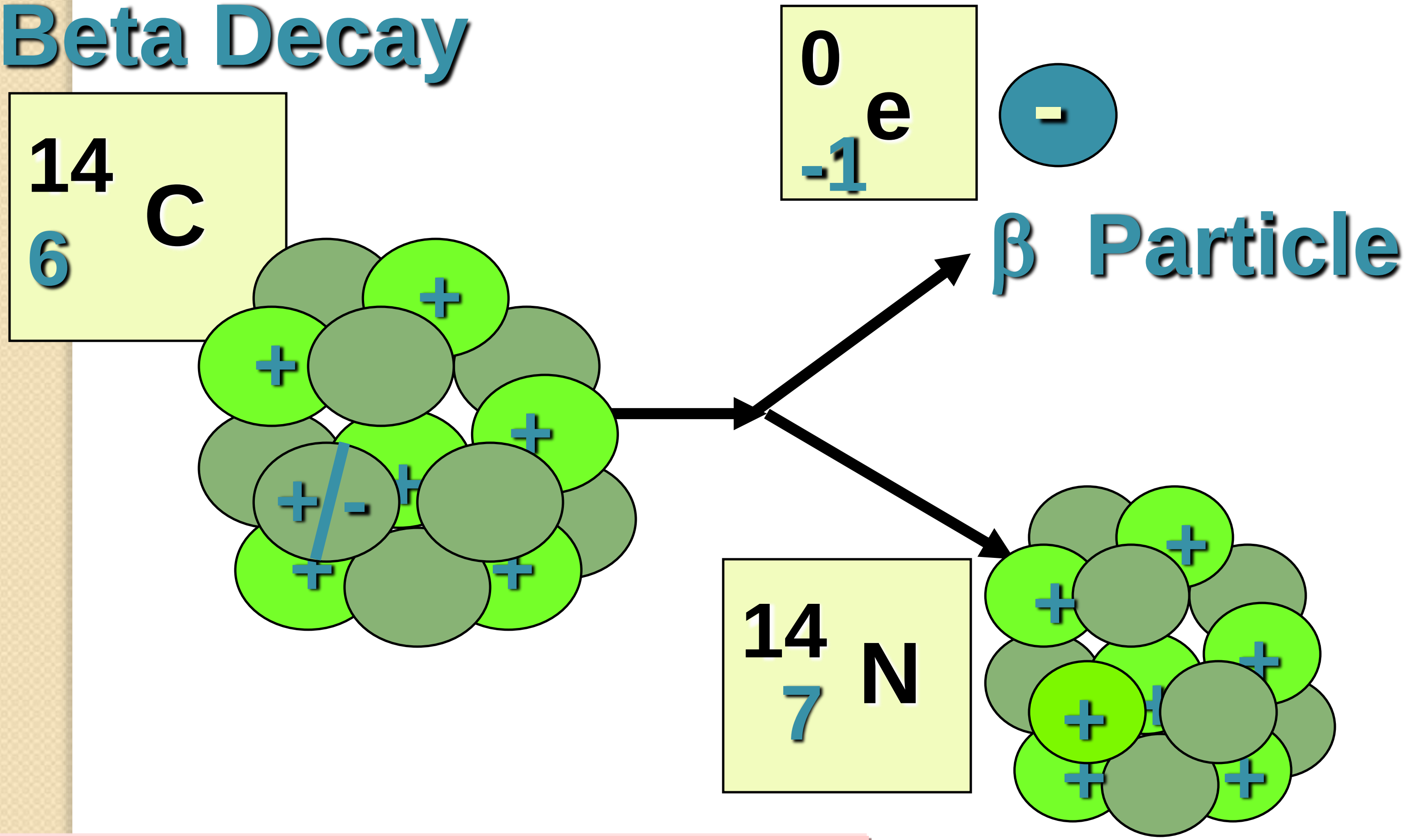
- Alpha decay is generally found in isotopes of the heavy elements.
- Alpha decay is a helium nucleus with 2 protons and 2 neutrons and is ejected from the nucleus of an atom with high kinetic energy, although it may have a relatively low velocity.
- You will not be working with alpha emitters in this course.

Alpha Decay



$$^{210}_{84}Po \rightarrow \, ^{206}_{82}Pb + \, ^{4}_{2}He$$

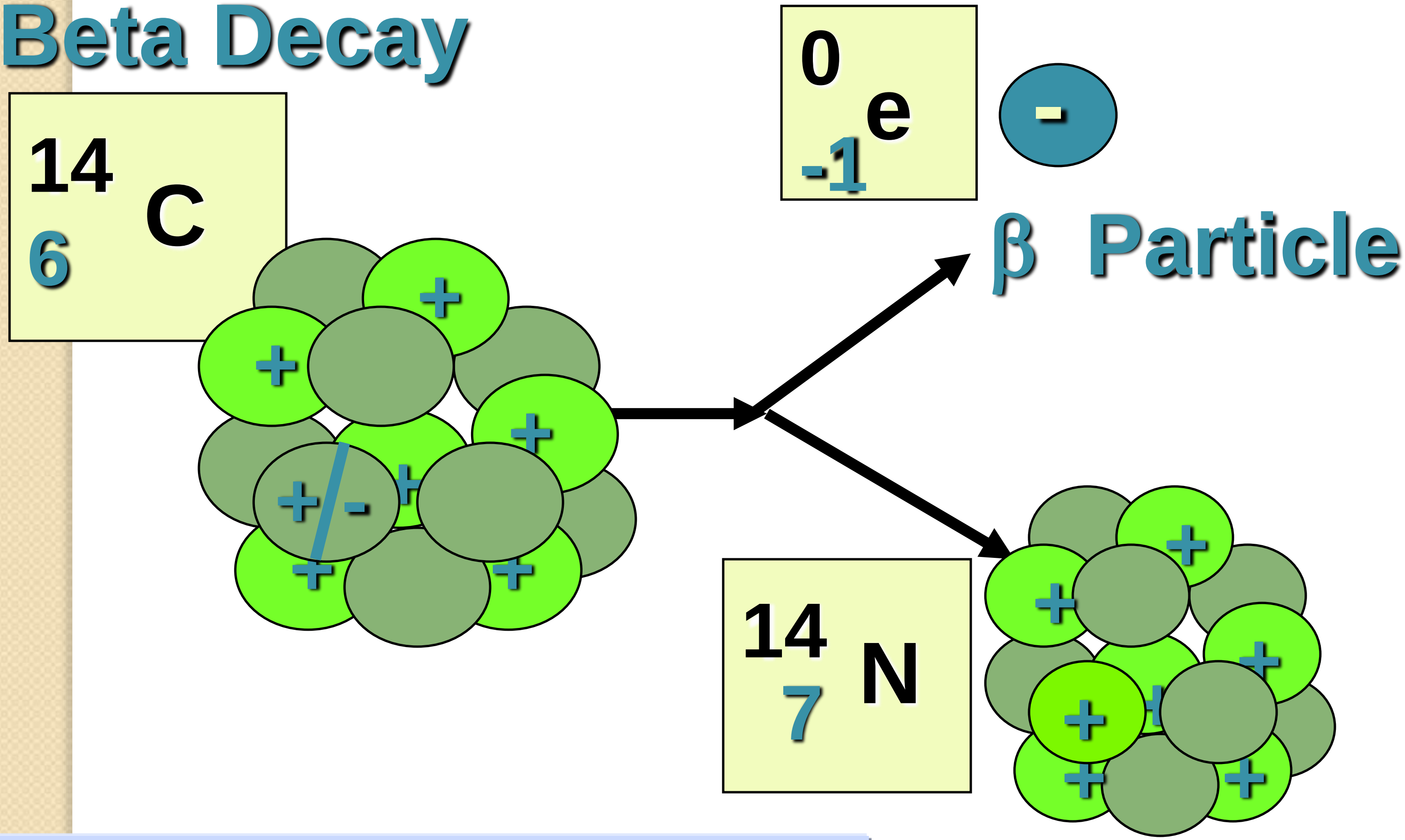
Beta Decay



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

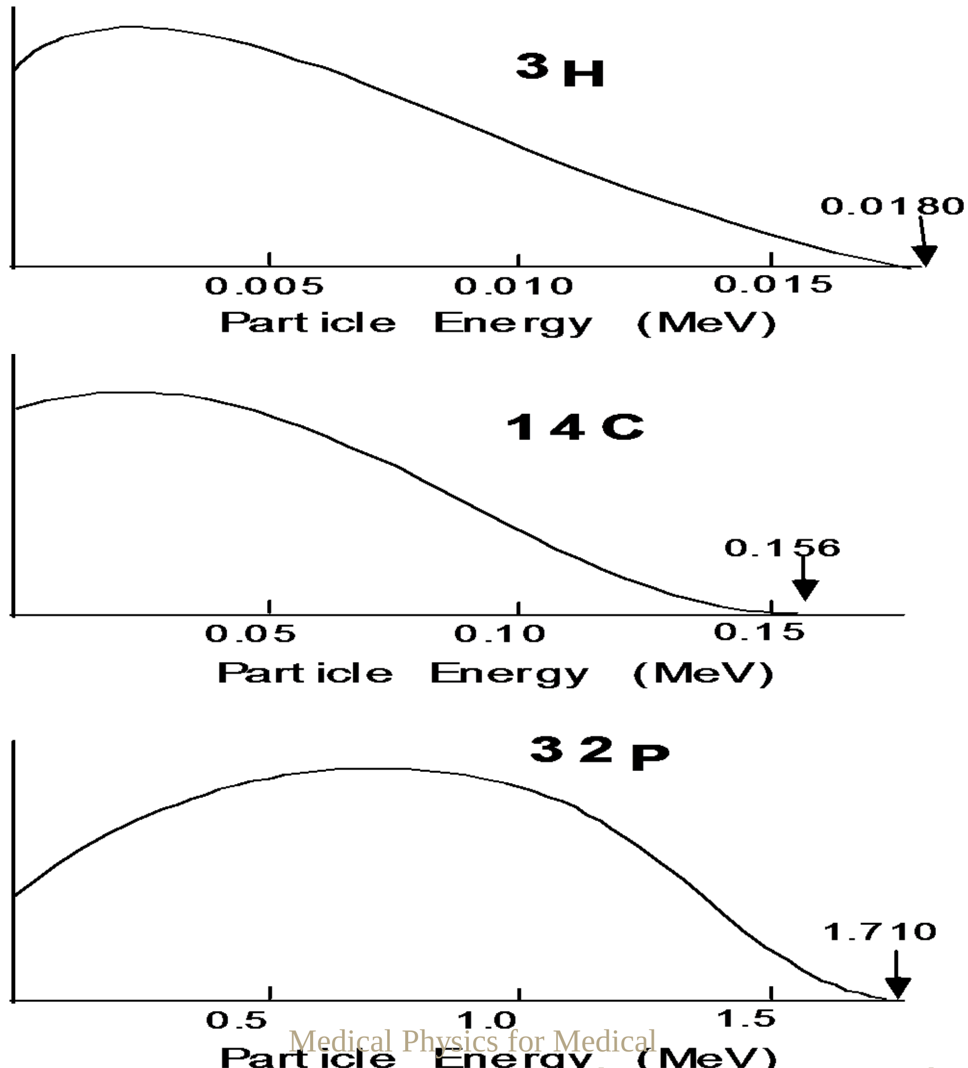
neutron proton electron

Beta Decay

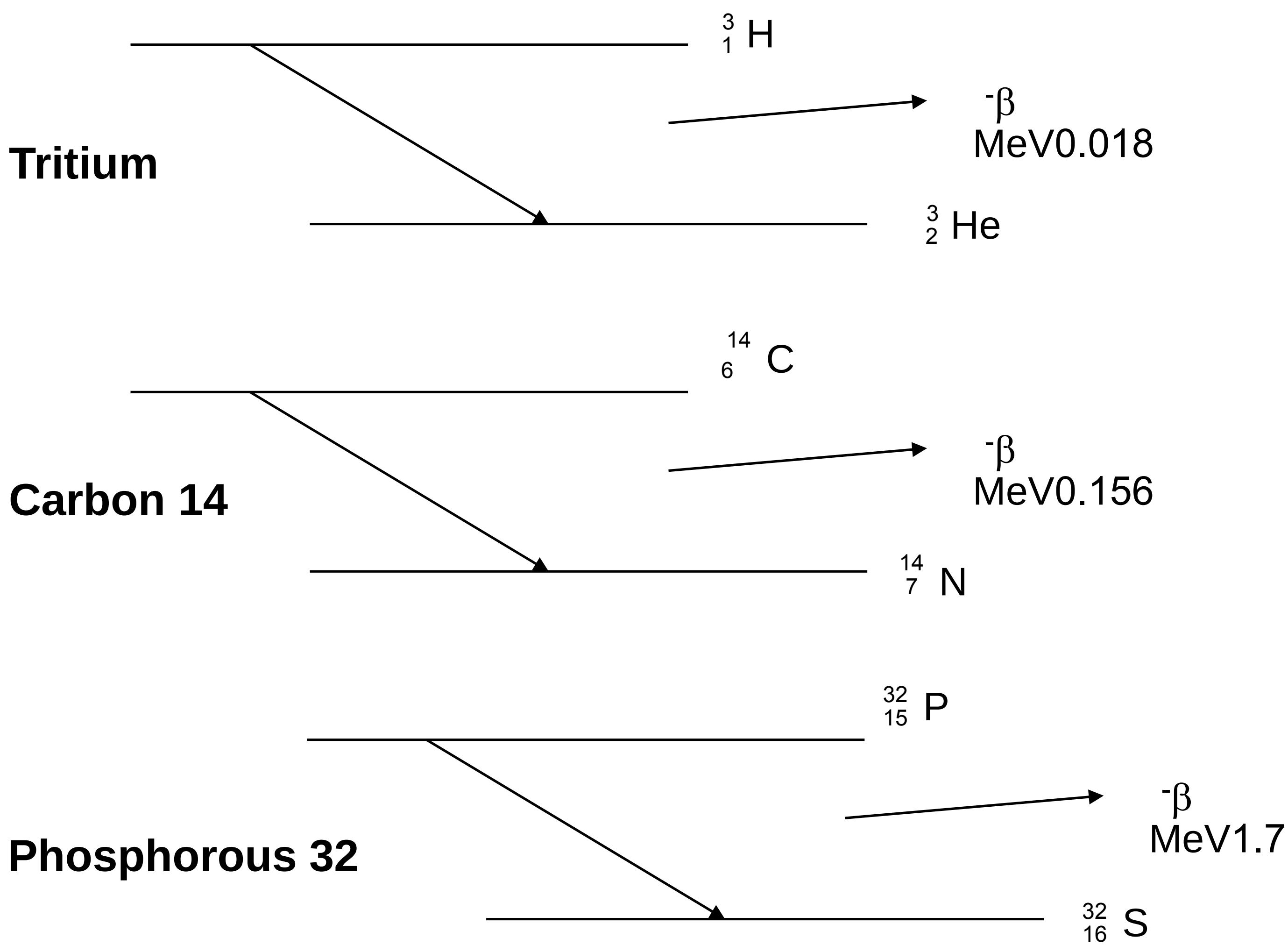


$$^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}e$$

Beta Particle Energy Distributions



Examples of Negative Beta Decay



Beta Emitters of Interest

Tritum (^{3}H)

$${}^{3}_{1}\text{H} \quad <<<< \quad {}^{3}_{2}\text{He} + \text{b-} + \text{antineut} + \text{energy}$$

Beta particle has energy of 0.018 MeV

Carbon 14 (^{14}C)

$${}^{14}_{6}\text{C} \quad >>>> \quad {}^{14}_{7}\text{N} + \text{b-} + \text{antineut} + \text{energy}$$

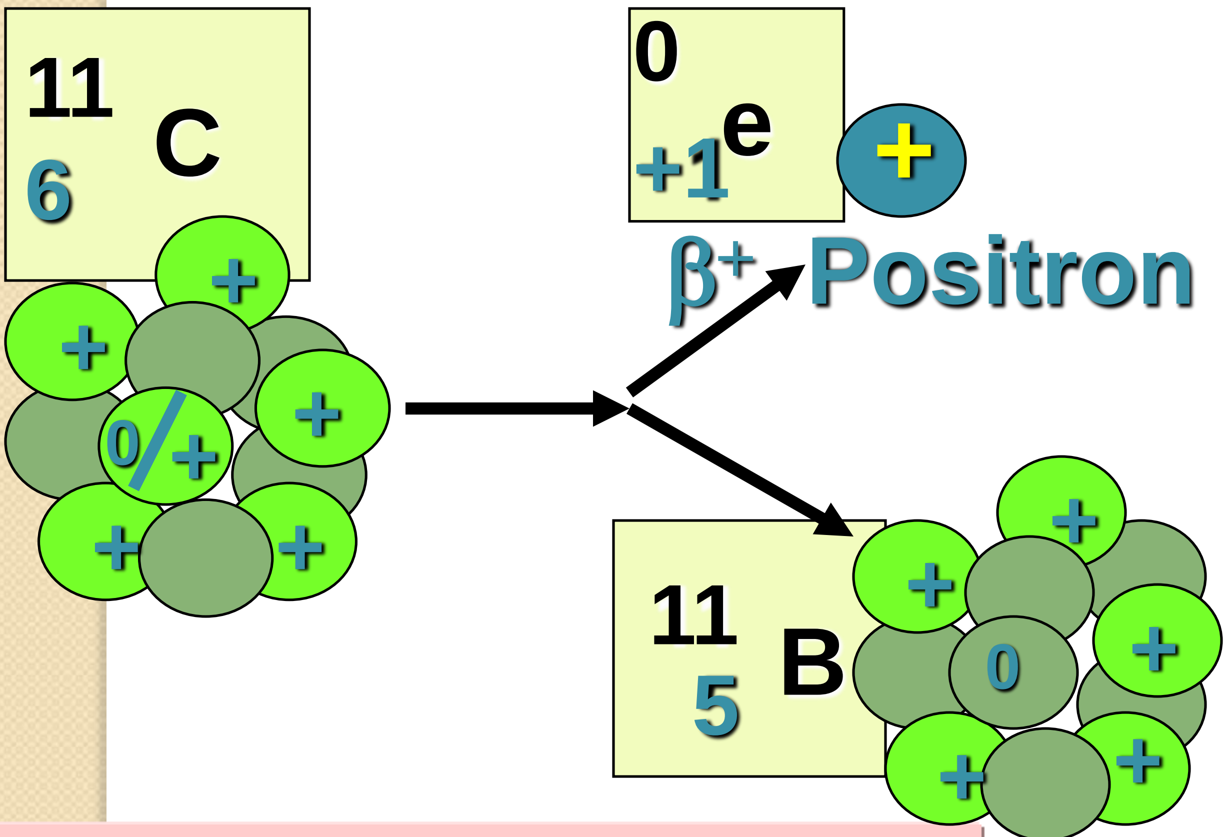
Beta particle has energy of 0.156 MeV

Phosphorus 32 (^{32}P)

$${}^{32}_{15}\text{P} \quad >>>> \quad {}^{32}_{16}\text{S} + \text{b-} + \text{antineut} + \text{energy}$$

Beta particle has energy of 1.7 MeV

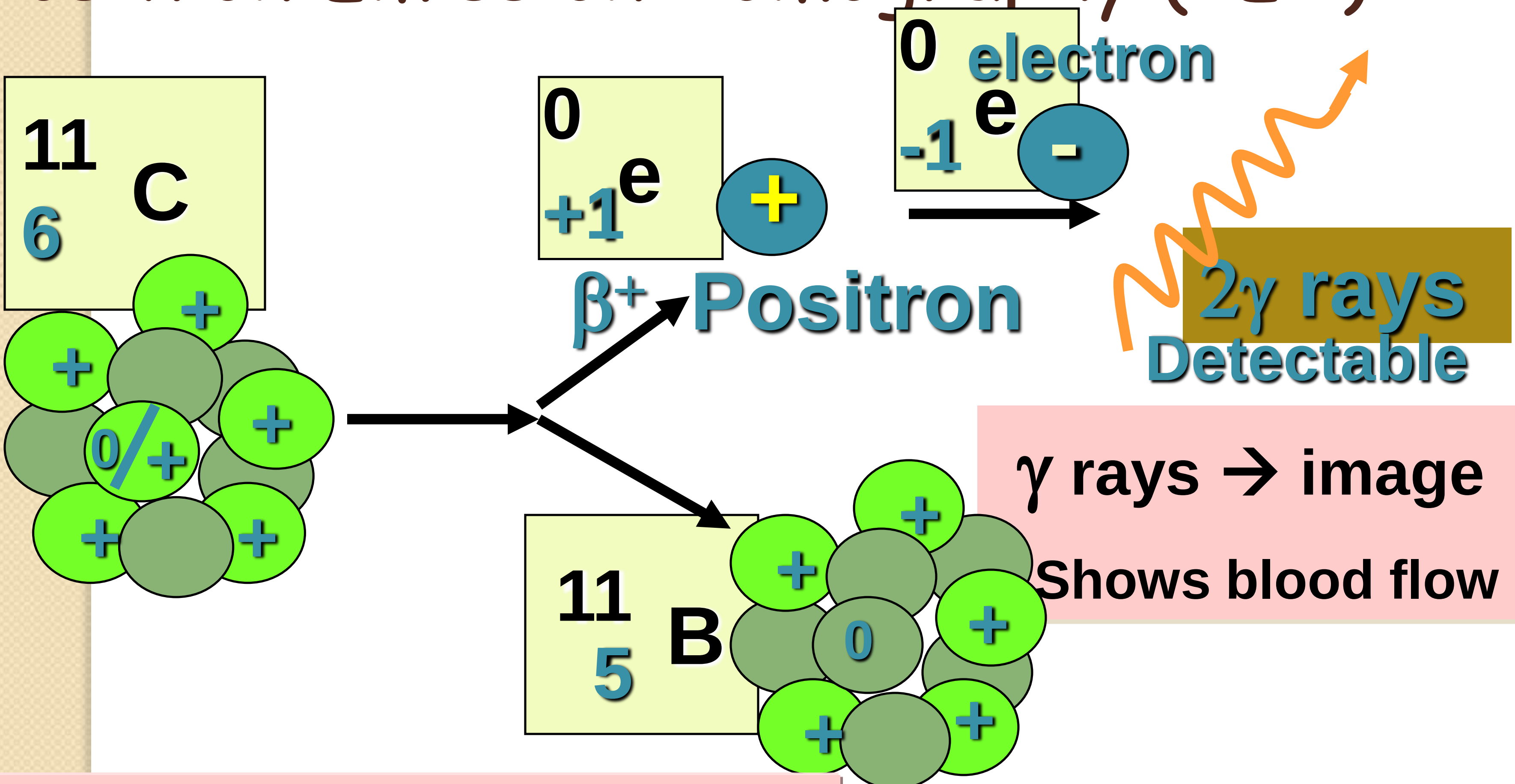
Positron Emission Tomography (PET)



$$^{1}_{1}H \rightarrow\, ^{1}_{0}n +\, ^{0}_{+1}e$$

proton neutron positron

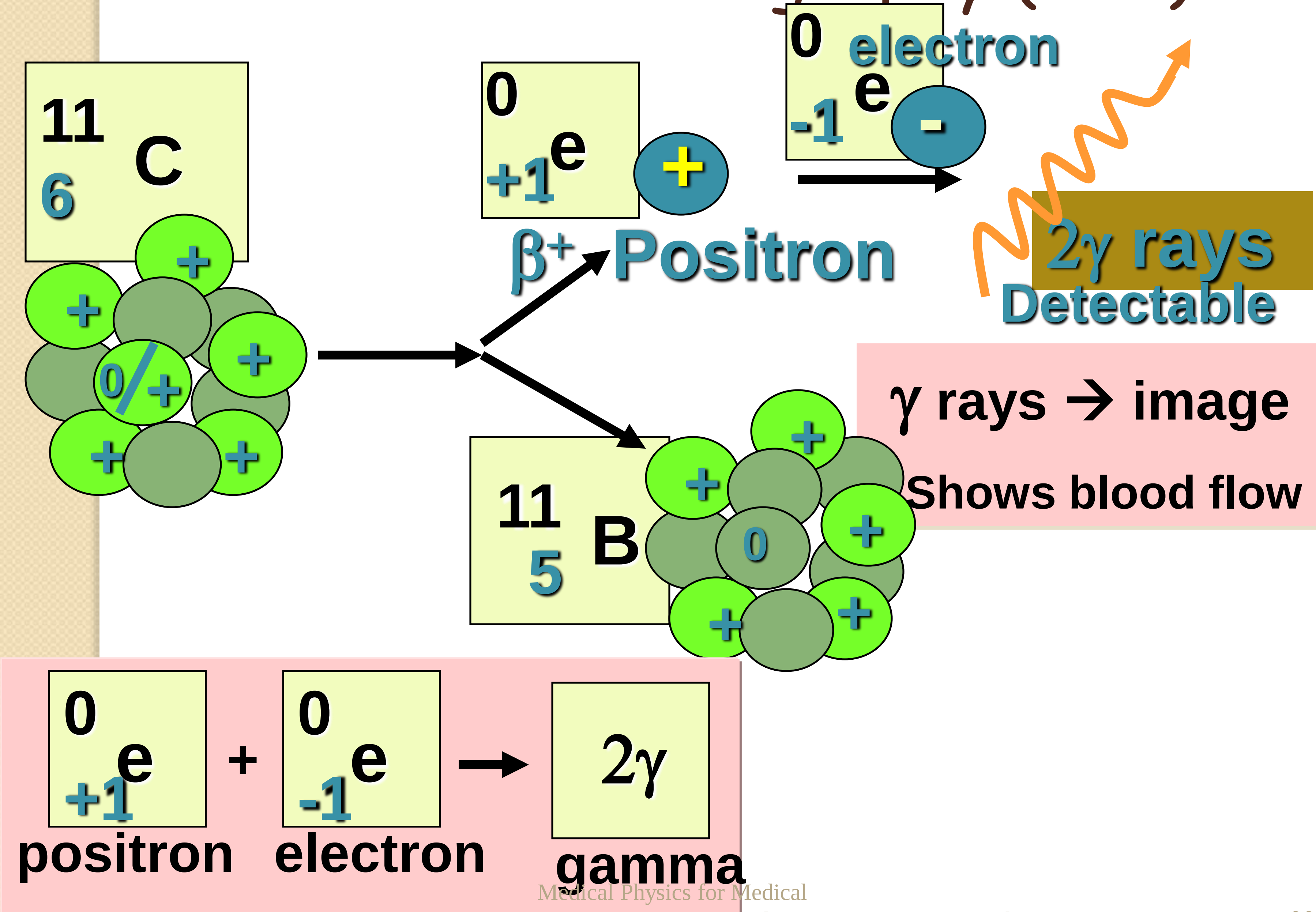
Positron Emission Tomography (PET)



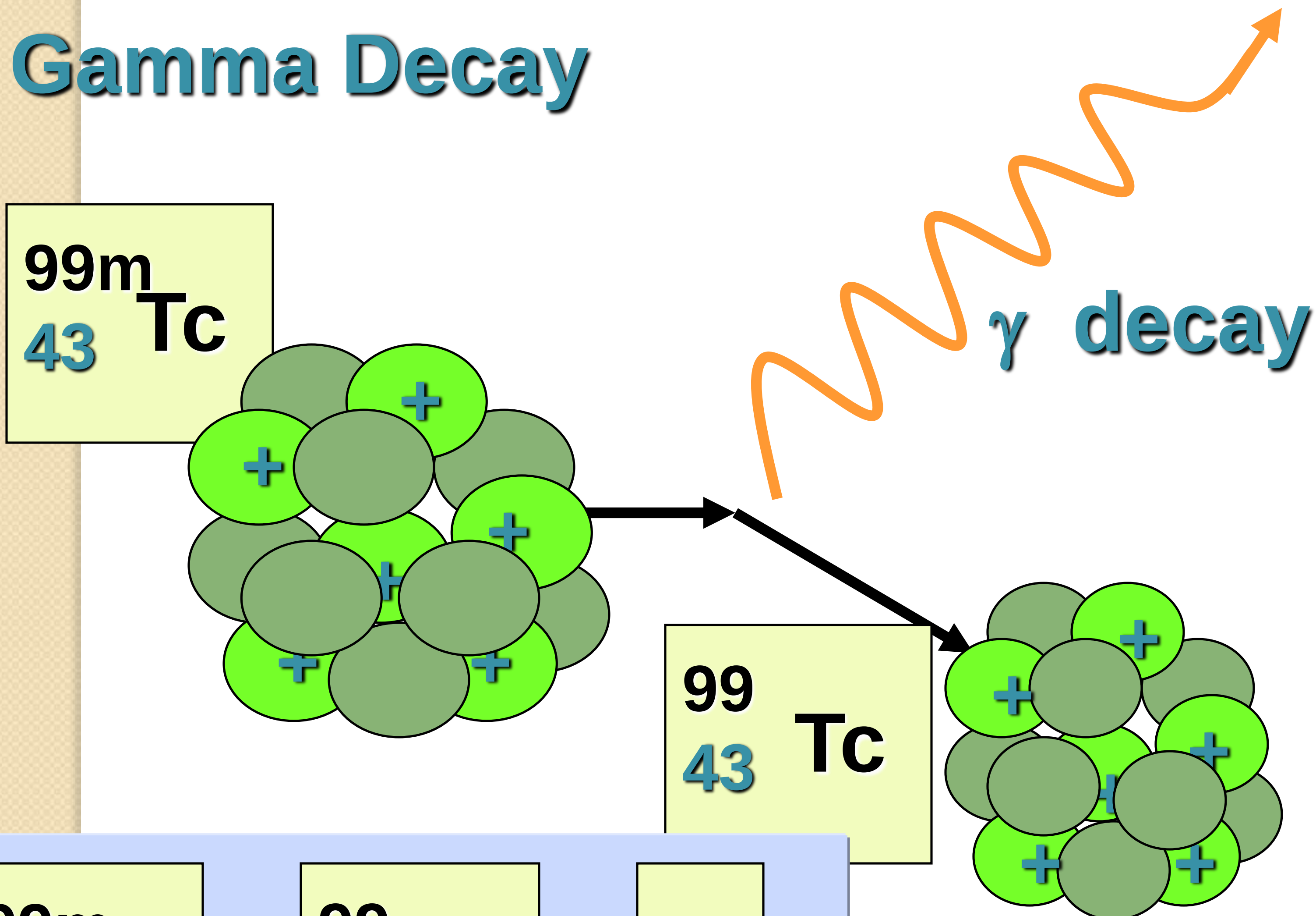
$$^{11}_{6}C \rightarrow \,^{11}_{5}B + \,^{0}_{+1}e$$

positron

Positron Emission Tomography (PET)



Gamma Decay

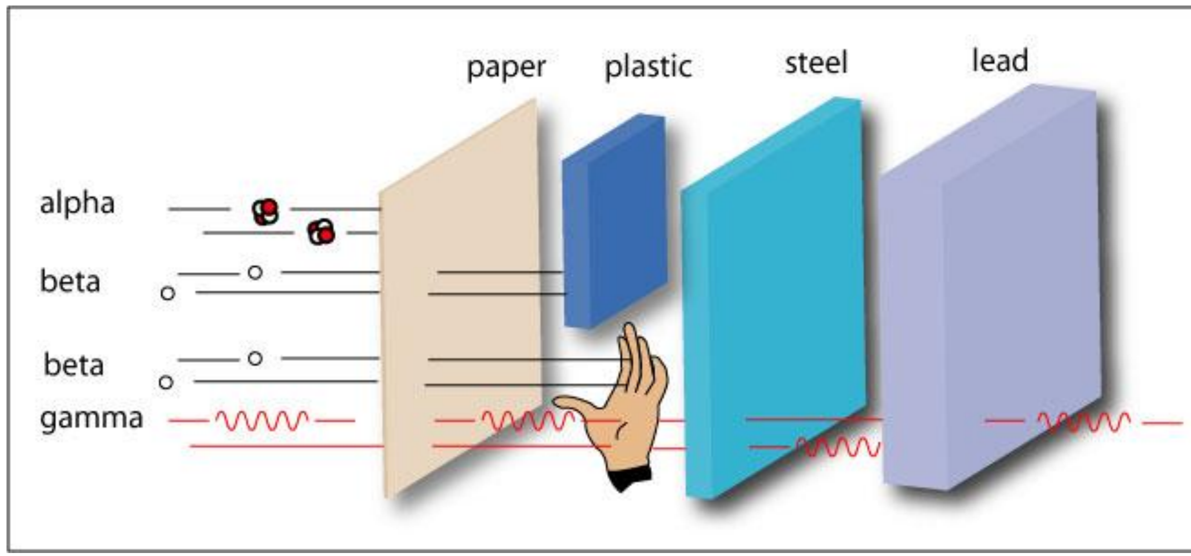


$$^{99m}_{43}Tc \rightarrow {}^{99}_{43}Tc + \gamma$$

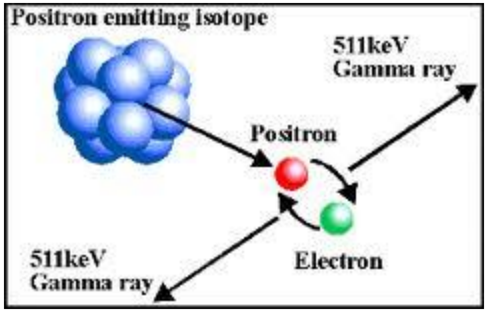
<table>
<tr><td rowspan="3">Unsealed radioactive sources (Radioactive medical products / radiopharmaceuticals / radiotracers)</td><td>For treatment
α and β emissions
(e.g. Ra-223, Sr-89, Y-90,)</td><td rowspan="3">Nuclear Medicine</td></tr>
<tr><td>For diagnosis & treatment
Both β and γ-rays
(e.g. I-131, Re-186, Lu-177)</td></tr>
<tr><td>For diagnoses
γ-rays and positron emissions
Imaging (e.g. Tc-99m, In-111, F-18, C-11 etc.)
Non-imaging (e.g. Cr-51)</td></tr>
</table>

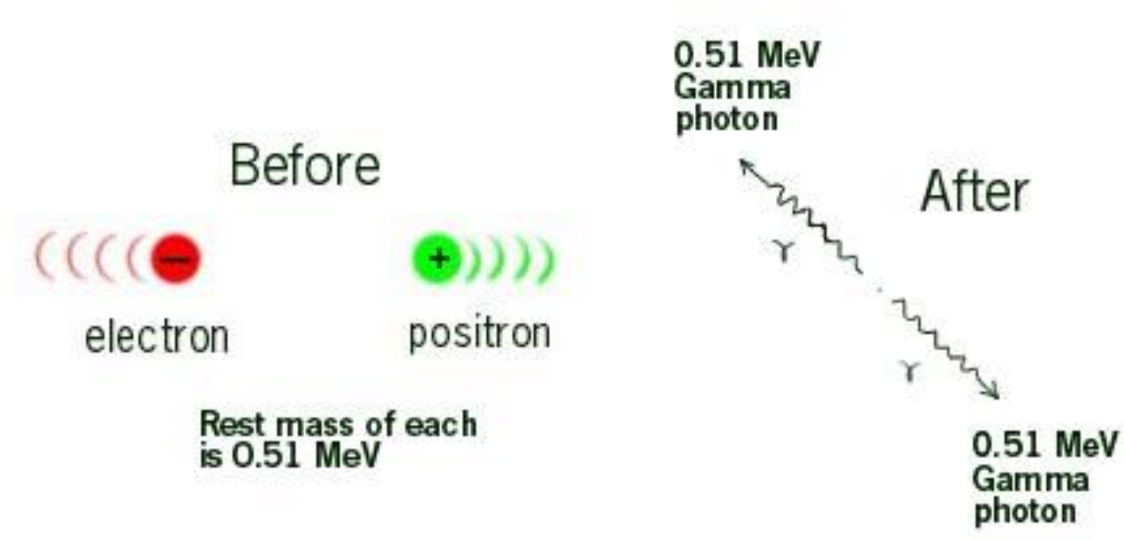
Range of Charged Particles

- Energy
- Mass
- Charge
  - (R ∝ 1/Q²)
- Density



Annihilation



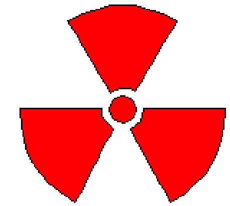


Activity

- Activity is the number of transformations (or disintegrations) per time occurring in a radioactive material
- Conventional unit: curie (Ci)
    - 1 Ci = 3.7×10^{10} disintegrations per second
- International System (SI): becquerel (Bq)
    - 1 Bq = 1 disintegration per second
- 1 Ci = 3.7×10^{10} Bq

[redacted]

Connect ···



یک عکس خانوادگی، چهار جایزه نوبل: داستان خاندان کوری

در نگاه اول، این فقط یک عکس خانوادگی ساده مربوط به سال ۱۹۰۲ است؛ مادر، پدر و دختر کوچک‌شان. اما با دقت بیشتر، میراثی را مشاهده می‌کنید که نظیر آن در تاریخ علم وجود ندارد.

ماری کوری، اولین زنی بود که موفق به دریافت جایزه نوبل شد و تنها فردی در تاریخ است که جایزه نوبل را در دو رشته علمی متفاوت به دست آورد: فیزیک (در سال ۱۹۰۳) و کیمیا (در سال ۱۹۱۱). کارهای پیشگامانه او در زمینه رادیواکتیویته (پرتوزایی) نه تنها یک انقلاب علمی بود، بلکه جهان را دگرگون کرد.

در کنار او، همسر و شریک علمی‌اش، پیر کوری، ایستاده است. او در سال ۱۹۰۳ جایزه نوبل فیزیک را به طور مشترک با ماری و هنری بکرل دریافت کرد و پایه و اساس علم اتمی مدرن را گذاشت.

و اما آن دختر کوچک؟ او ایرن ژولیو-کوری است. ایرن در خانه‌ای بزرگ شد که در آن کنجکاوی و دانش گرامی داشته می‌شد. او نیز راه والدینش را ادامه داد و در سال ۱۹۳۵، به همراه همسرش فردریک ژولیو-کوری، به دلیل کشف رادیواکتیویته مصنوعی، موفق به دریافت جایزه نوبل کیمیا شد.

تنها یک عکس، که سه زندگی و چهار جایزه نوبل را در خود جای داده است. این فقط یک عکس یادگاری نیست؛ بلکه یک بنای یادبود برای نبوغ، پشتکار، و قدرت شگفت‌انگیز میراث علمی است.

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Hassan Bahrami ...

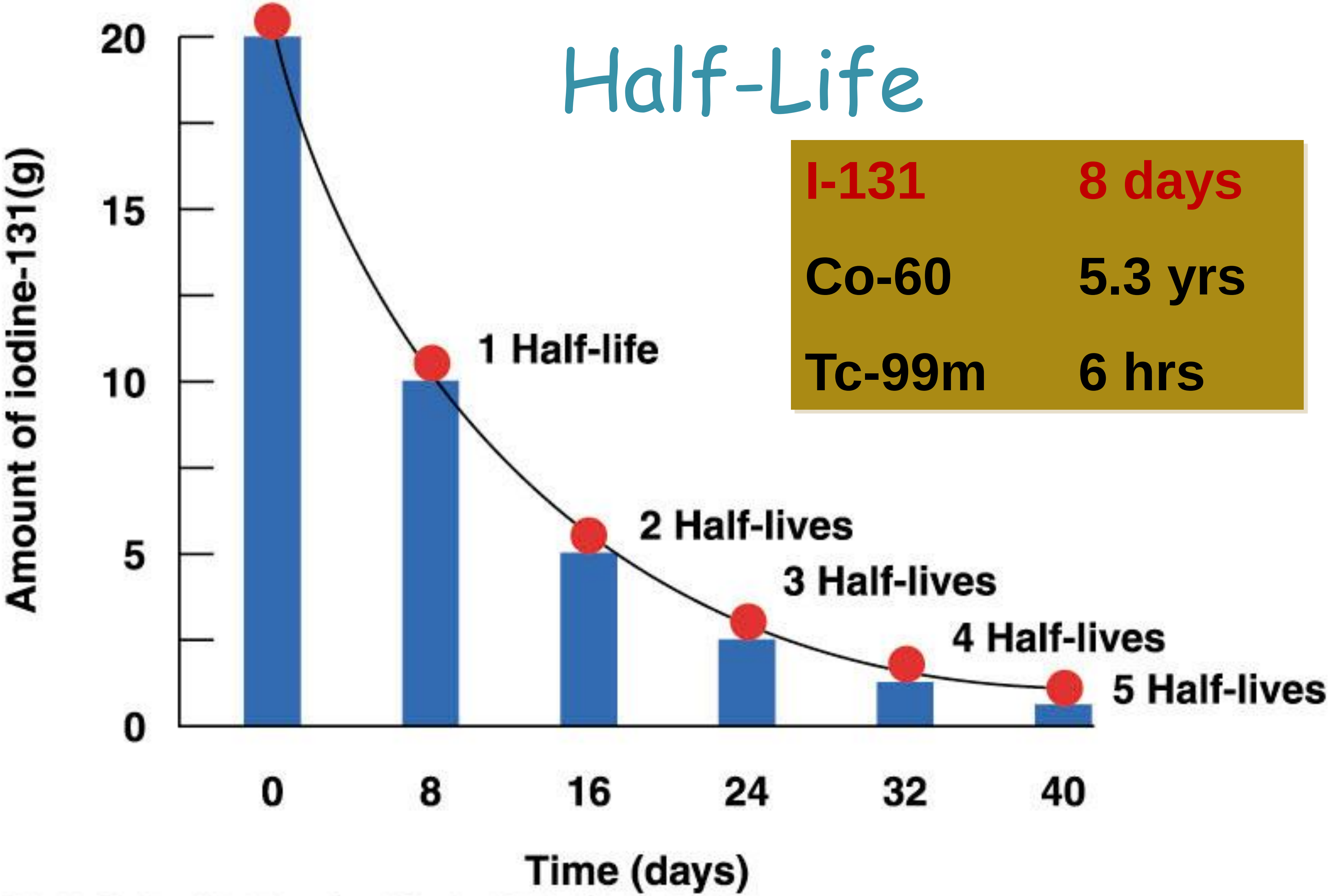
Radioisotopes and Radioactivity

$$A = -dN / dt = \lambda N$$

- Specific Activity Units
  - mCi/mg
  - MBq/mg

Half-Life

I-131	8 days
Co-60	5.3 yrs
Tc-99m	6 hrs



Timberlake, Chemistry: An Introduction to General, Organic, and Biological Chemistry, Eighth Edition.

Retired Person

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Finland discovered bacteria that eat nuclear waste — cleaning radioactive sites in decades instead of millennia

☢ Scientists at University of Helsinki identified extremophile bacteria in ...more

Earning Them the Nickname "Chernobyl Black Frogs."
This Dark Coloration is Believed to be an Adaptive Response to Radiation, as Melanin—The Pigment Responsible for Darker Skin Tones—Absorbs and Dissipates Radiation Energy, Offering Cellular Protection

Mortazavi S, Rabiee S, Fallah A, et al. Adaptive Responses in High-Radiation Environments: Insights From Chernobyl Wildlife and Ramsar Residents. Dose-Response. 2025;23(4). doi:10.1177/15593258251385632

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Half Life of Radioisotopes

$$N = N_o e^{-\lambda t}$$

$$A = A_o e^{-\lambda t}$$

Decay Formula

$$dN = -\lambda N(t)\,dt \qquad (3)$$

Equation (3) may be integrated to give

$$N(t) = N_0 e^{-\lambda t} \qquad (4)$$

where N_0 is the number of nuclei present at time $t = 0$.

A radioactive species is often characterized by its half-life, $T_{1/2}$, which is defined as the time it takes for one-half of the nuclei to decay. Using Equation (4) we see that $T_{1/2}$ satisfies

$$\frac{N}{N_0} = \frac{1}{2} = e^{-\lambda T_{1/2}} \quad \text{or} \quad \ln\frac{1}{2} = -\lambda T_{1/2}$$

$$\lambda = \frac{\ln 2}{T_{1/2}} = \frac{0.693}{T_{1/2}}$$

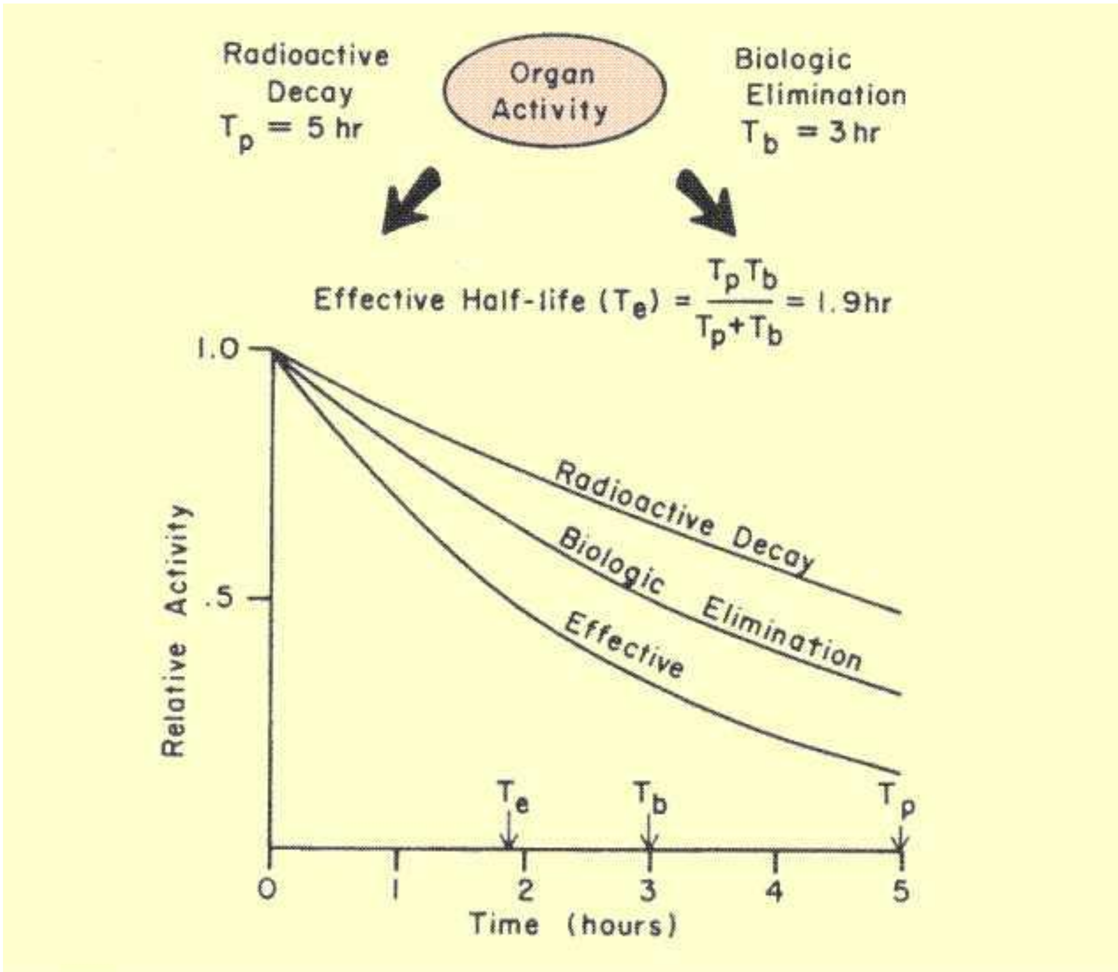
Average Life

- This average lifetime τ is characteristic for each nuclide and doesn't change over time.
- The half-life is shorter than the average life. The specific relationship is
- Thus, the mean life will be the total time it takes for all disintegrations to occur divided by the total number of disintegrations (N_0).
- $\mathbf{T_{avg} = 1.44\ T_{1/2}}$

Biological Half Life

- When a radioactive material is in a living organism, the material can be re moved from a particular organ or location by two mechanisms.
- One is the normal radioactive decay, and the other is biological transport or elimination from the specific site.

Effective Half Life



Physical & Biological Half-Lives

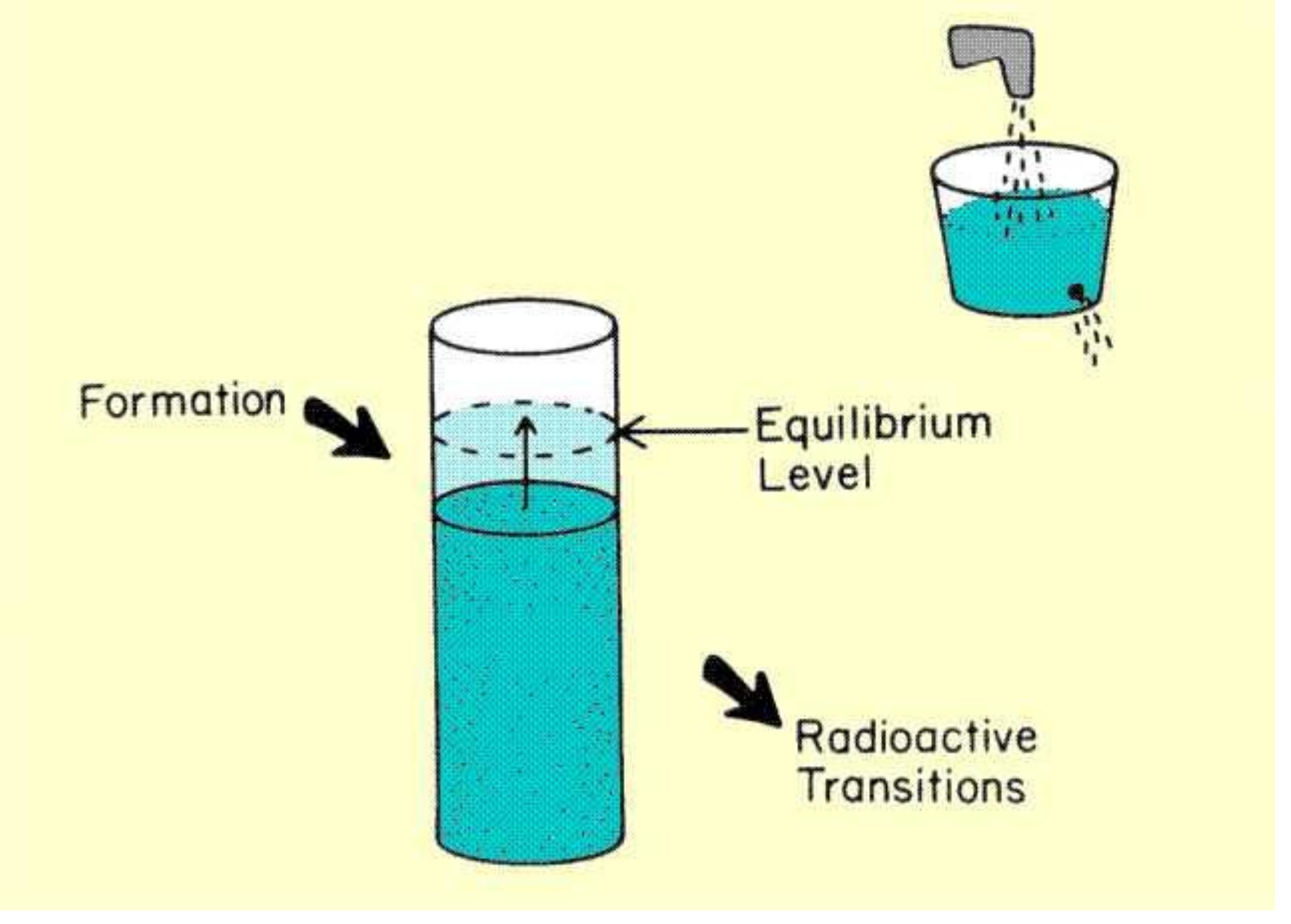
- 1/TEffective = 1/TPhysical + 1/TBiological

Isotope	Half-lives in days		
	$T_{Physical}$	$T_{Biological}$	$T_{Effective}$
^{3}H	4.5×10^{3}	12	12
^{32}P	14.3	1155	14.1
^{90}Sr	1.1×10^{4}	1.8×10^{4}	6.8×10^{3}
^{99m}Tc	0.25	1	0.20

Effective Half Life

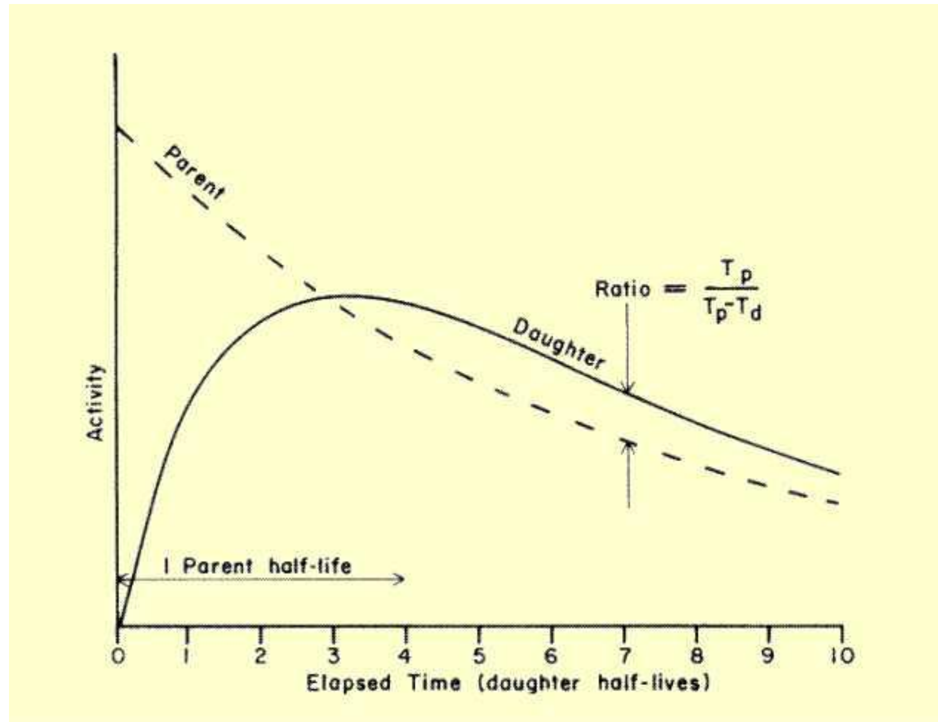
- $T_{eff} = (T_p \times T_b) / (T_p + T_b)$

Concept of Radioactive Equilibrium



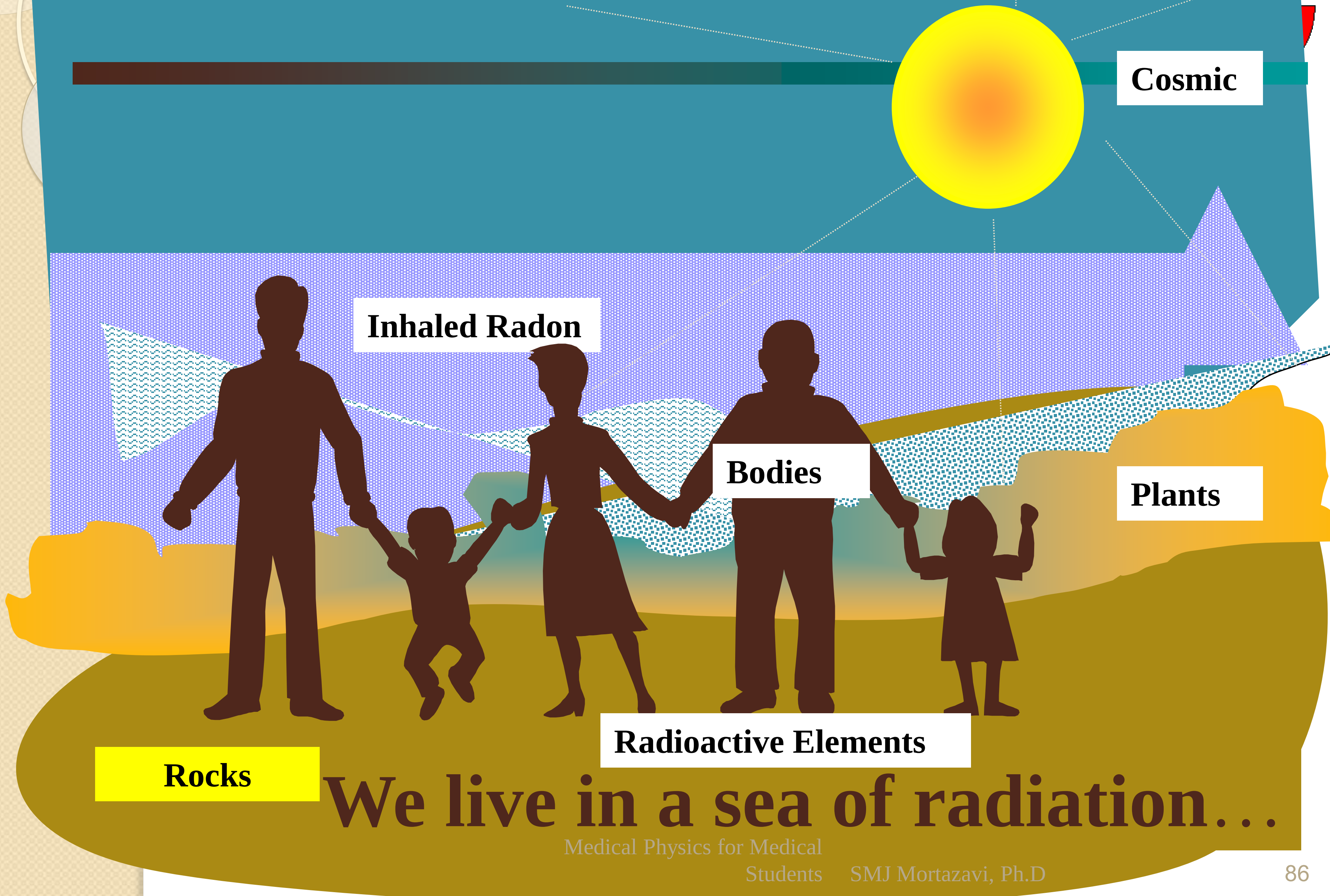
Transient Equilibrium

When the half-life of the parent is only a few times greater than the half-life of the daughter, the condition of transient equilibrium will occur.



$$A_2 = \frac{\lambda_2}{\lambda_2 - \lambda_1} A_1^0 e^{-\lambda_1 t} = \frac{\lambda_2}{\lambda_2 - \lambda_1} A_1$$

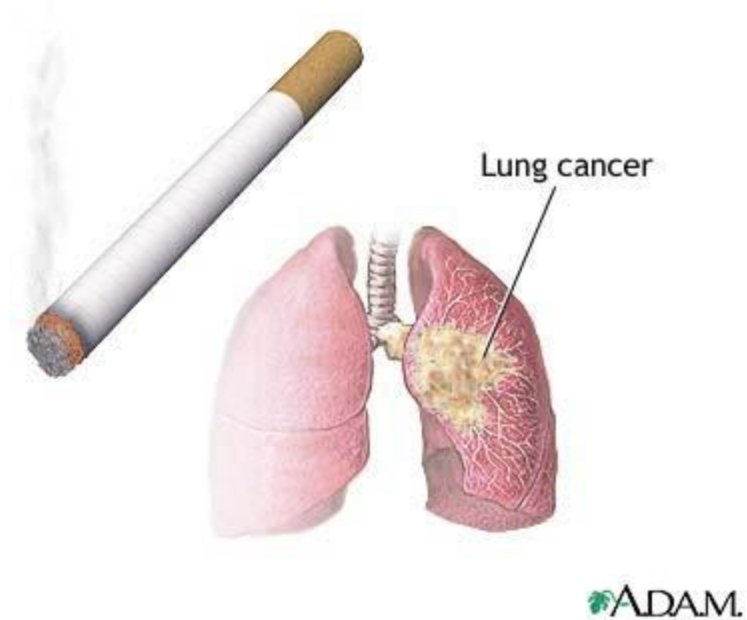
Natural Radioactivity

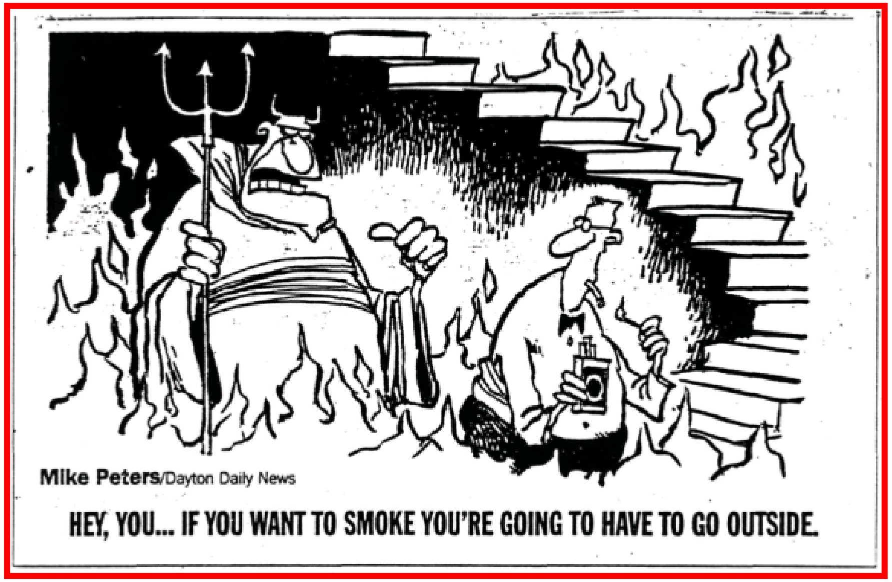


We live in a sea of radiation…

There is considerable exposure due to artificially produced sources!

Possibly largest contributor is tobacco which contains radioactive ^{210}Po which emits 5.3 MeV α particles with an half life of $T_{1/2}$=138.4days.





Natural Radioactivity

- Light radioactive nuclides (H-3, C-14)
- Radioactive series

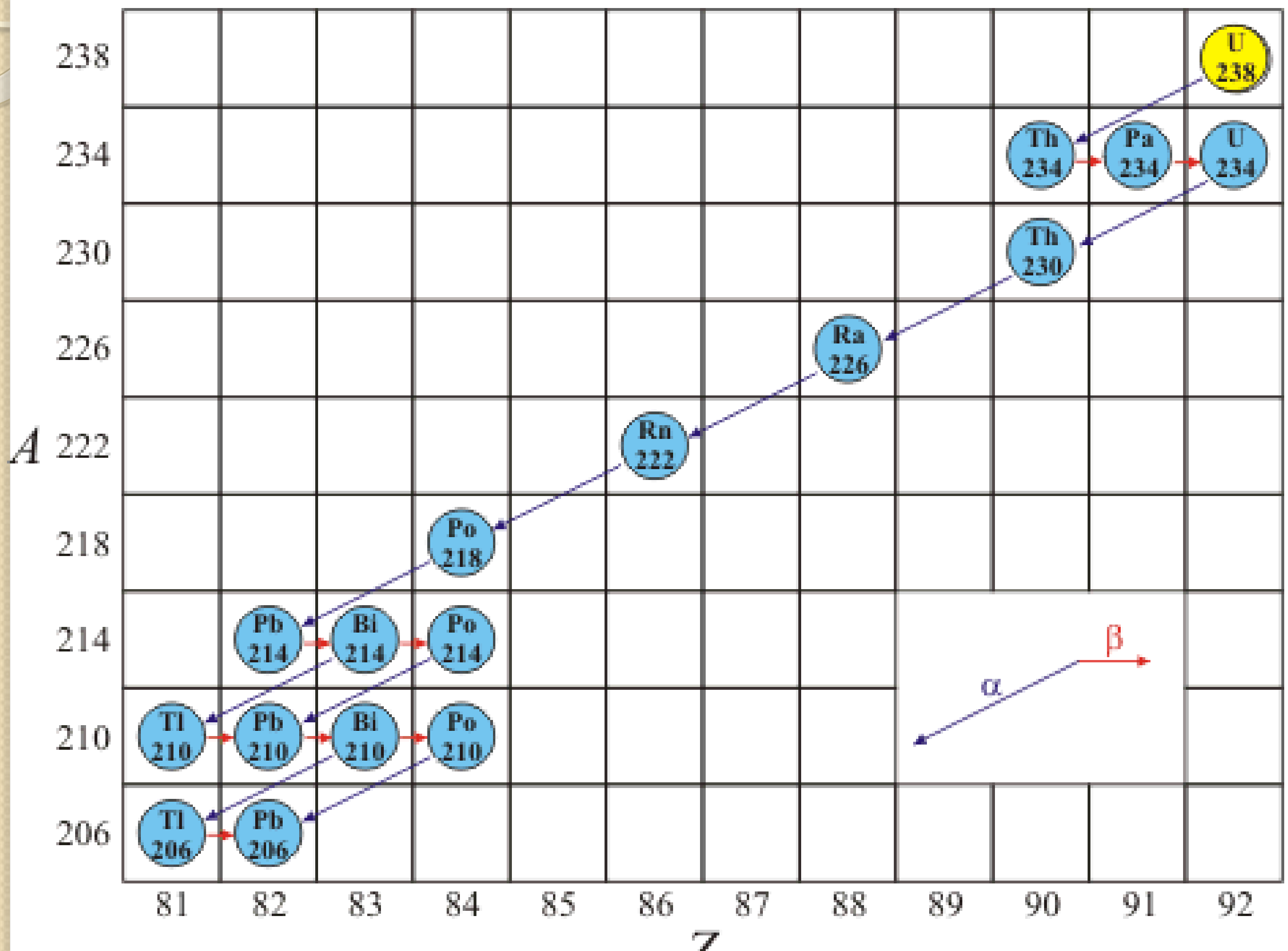
• Natural or classical series:

  - Thorium series
  - Uranium series
  - Actinium series

• The fourth set, the Neptunium series, is headed by neptunium-237.

• Its members are produced artificially by nuclear reactions and do not occur naturally

Uranium Series

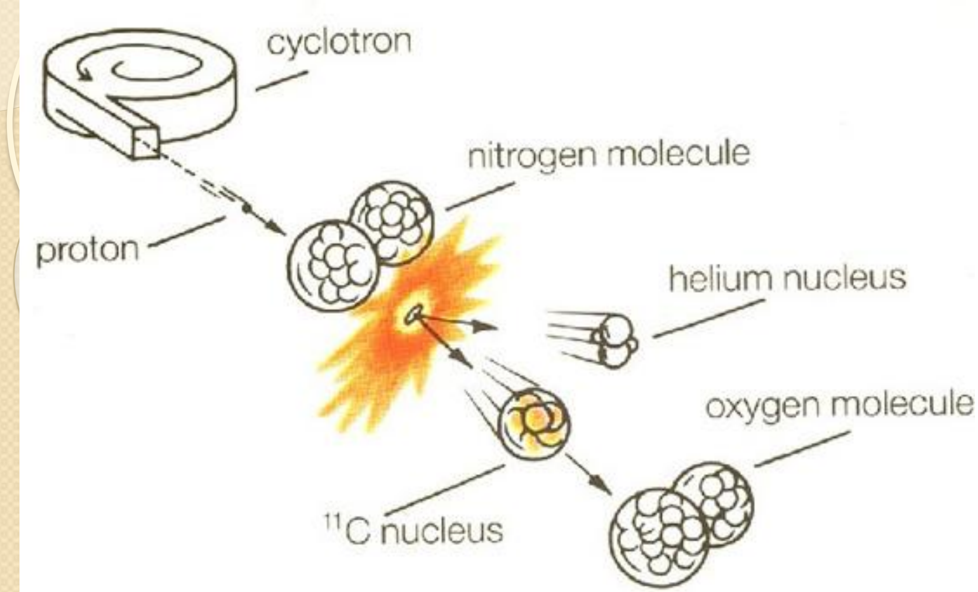


Production of Radionuclides

- Reactor (Fission Fragments)
- Reactor (Neutron Bombardment)
- Cyclotron
- Generators

Neutron Bombardment

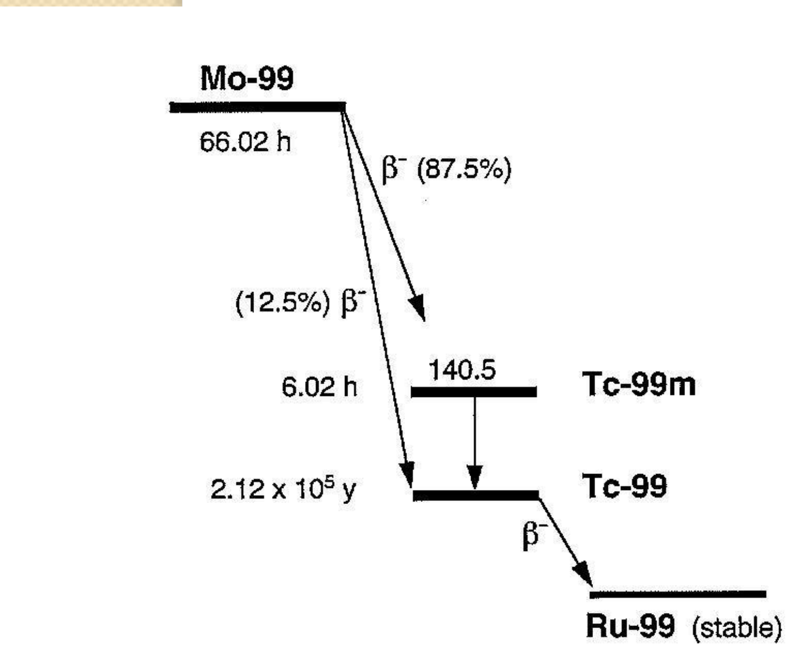
$^{59}_{27}Co + n \rightarrow {}^{60}_{27}Co \rightarrow {}^{60}_{28}Ni + e^{-} + \text{gamma rays}$

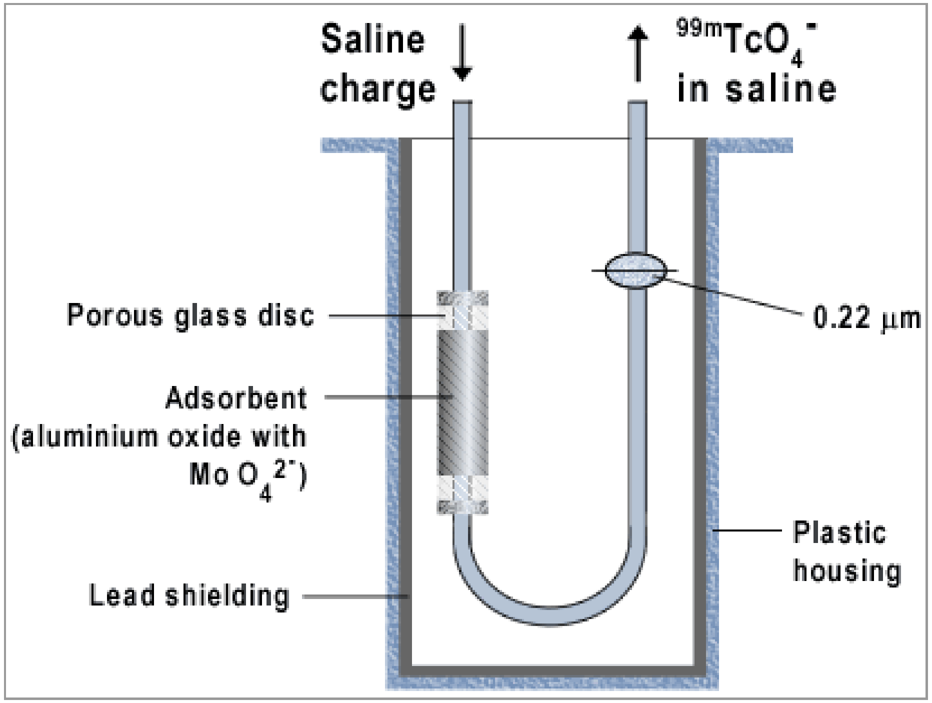


Cyclotron

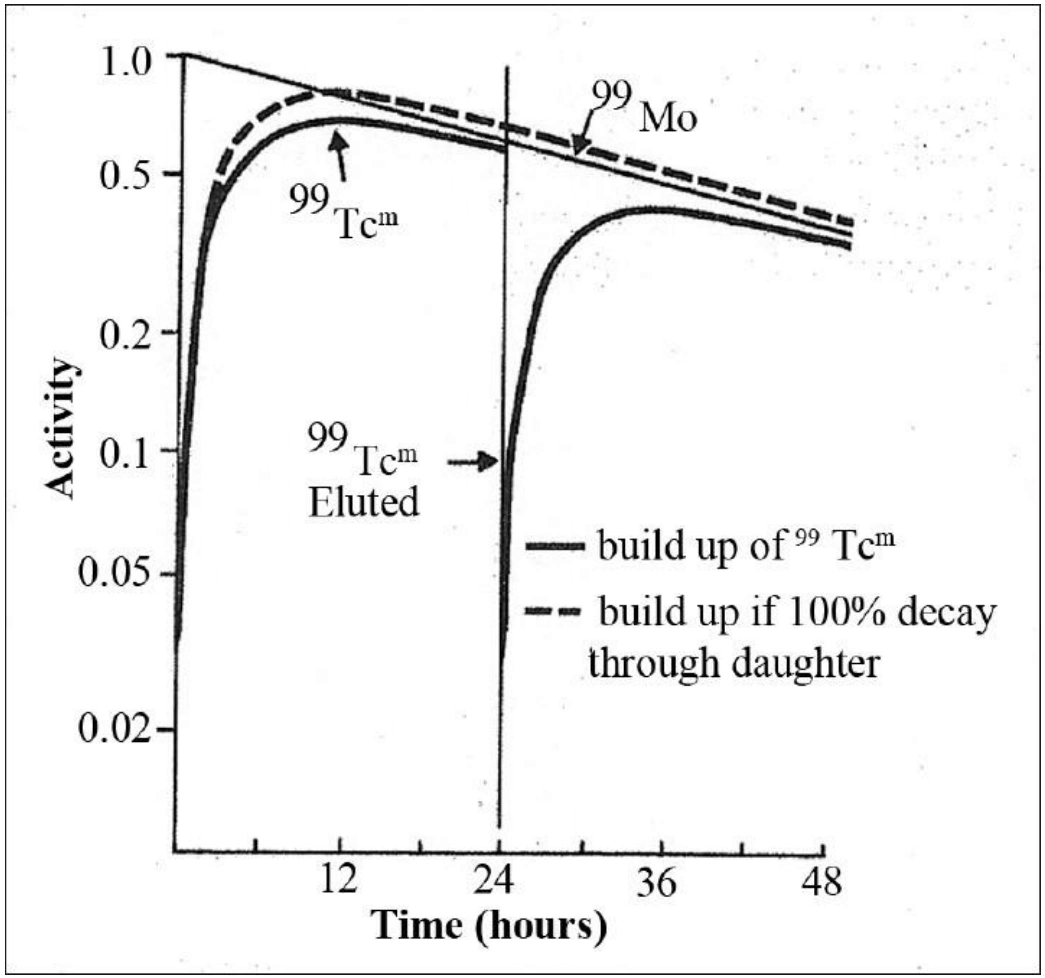
Radionuclide	Half-life	Chemical Form	Nuclear Reaction(s)
^{11}C	20 min	$^{11}CO_2$ / $^{11}CH_4$	$^{14}N(p,\alpha)^{11}C$
^{13}N	10 min	$^{13}NH_4^+$/ $^{13}NO_x$	$^{16}O(p,\alpha)^{13}N$
^{15}O	2 min	$^{15}O_2$	$^{15}N(p,n)^{15}O$ $^{14}N(d,n)^{15}O$
^{18}F	110 min	$^{18}F^-$ or $^{18}F_2$	$^{18}O(p,n)^{18}F$ $^{20}Ne(d,\alpha)^{18}F$

99Mo → 99mTc radionuclide generator





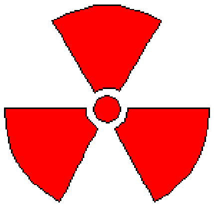
Molybdenum and Technetium Activity in a Generator



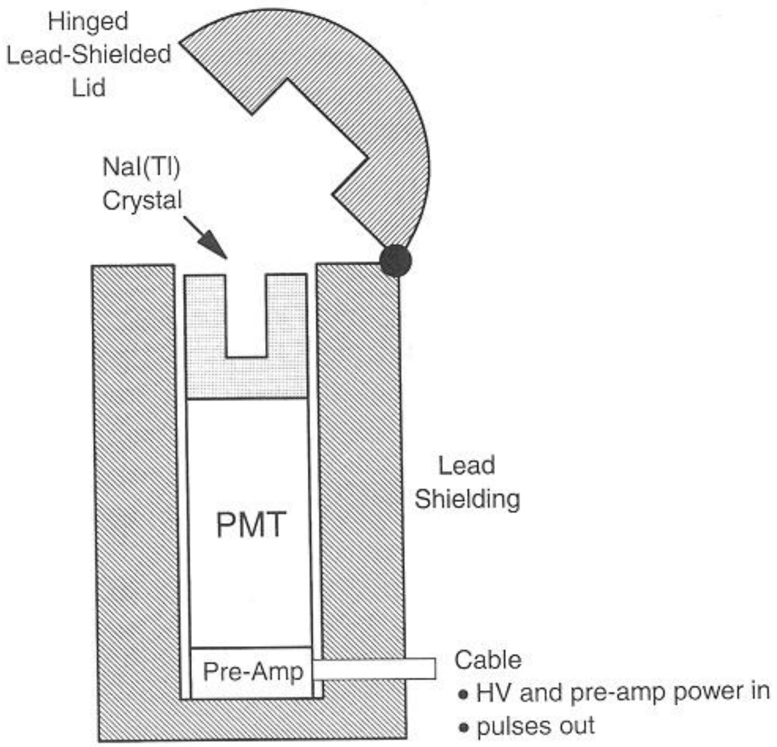
Sodium iodide well counter

- Consists of a cylindrical NaI(Tl) crystal with a hole in the crystal for insertion of samples
- Extremely high efficiency, permitting it to assay samples containing activities of less than 1 nCi

- Sodium iodide well counter



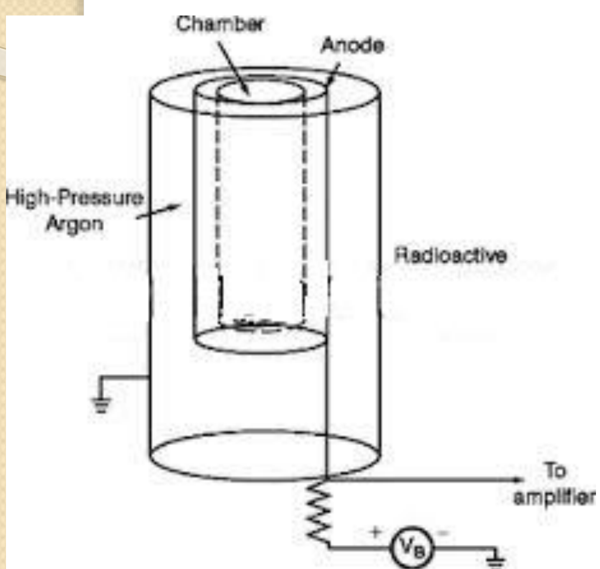
1.5” Sodium Iodide (NaI) drilled-well crystal detector



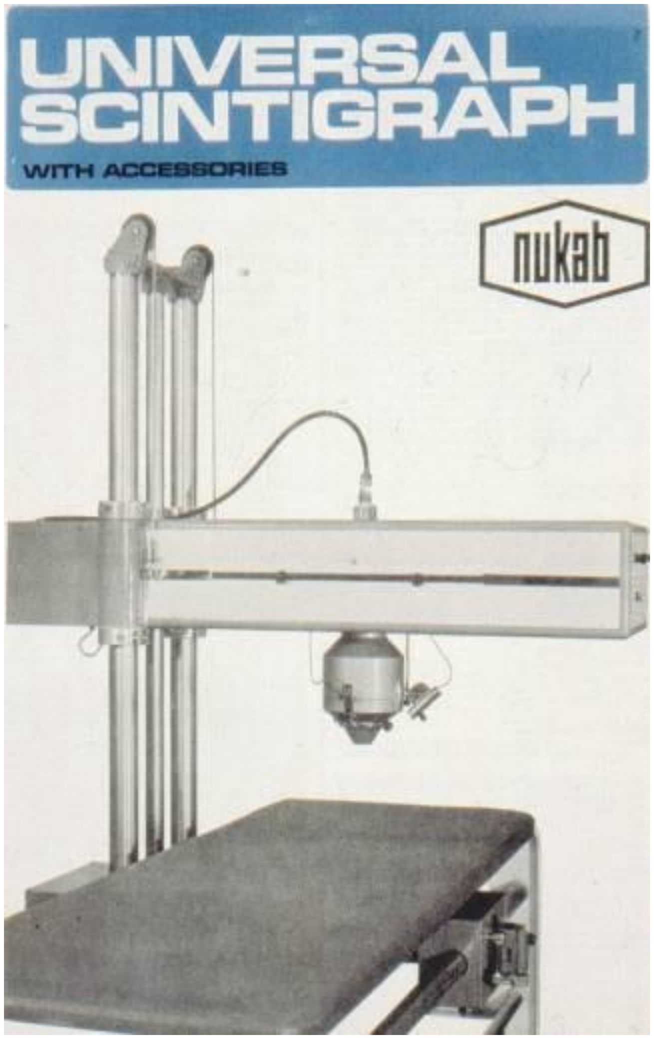
Dose calibrator

- Most dose calibrators are well-type ionization chambers filled with argon (Z = 18) and pressurized to maximize sensitivity
- Cannot directly measure activity – measures intensity of radiation emitted by a dose of a radiopharmaceutical
- Manufacturer determines calibration factors relating the intensity of the detector signal to activity for specific radionuclides commonly used in nuclear medicine

- # Dose calibrator

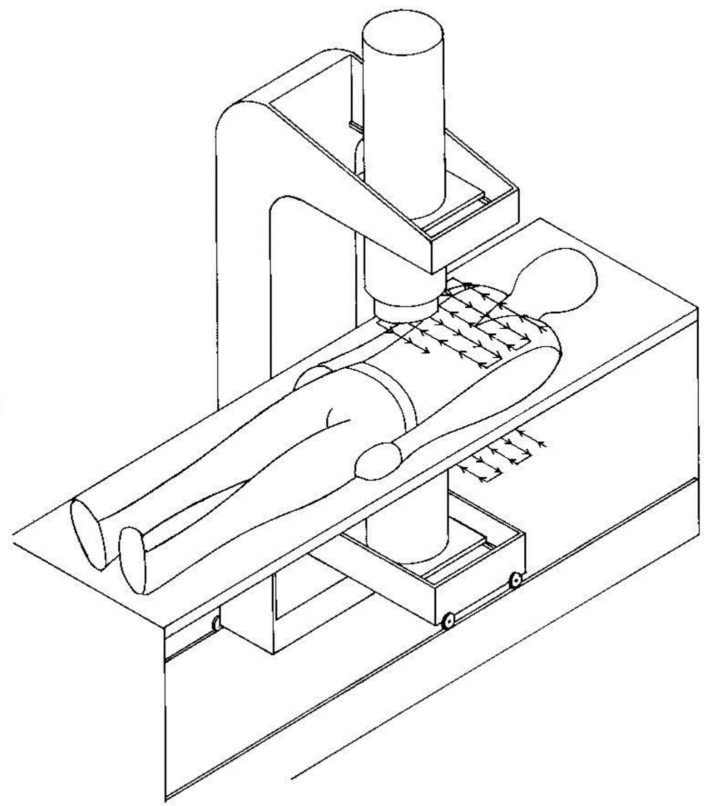


RECTILINEAR SCANNER



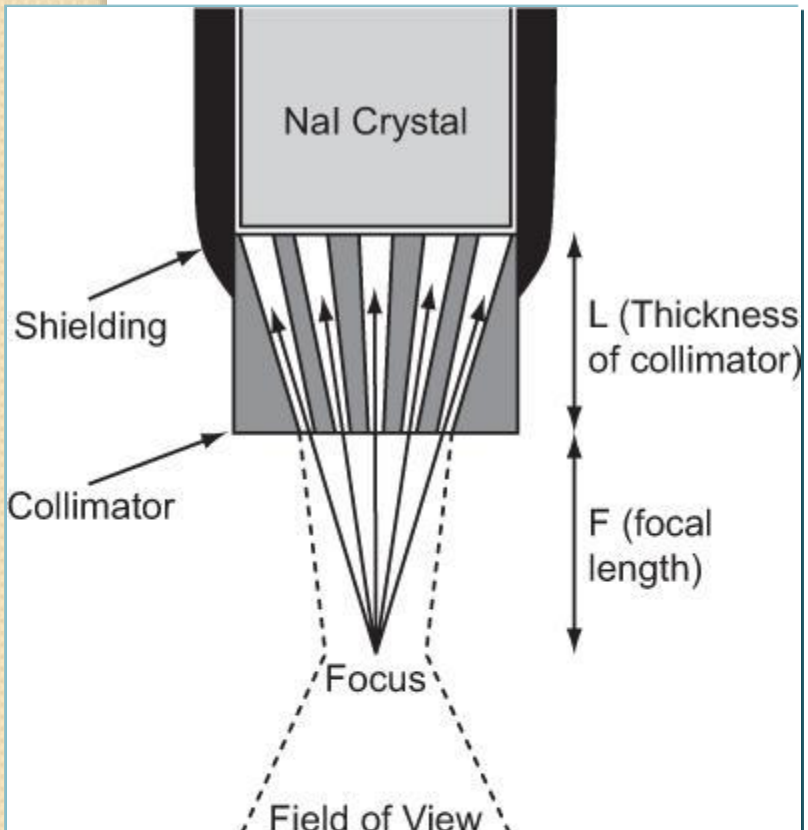
Used to measure the spatial distribution of a radiopharmaceutical

B



Rollo 1977

SMJ Mortazavi, Ph.D

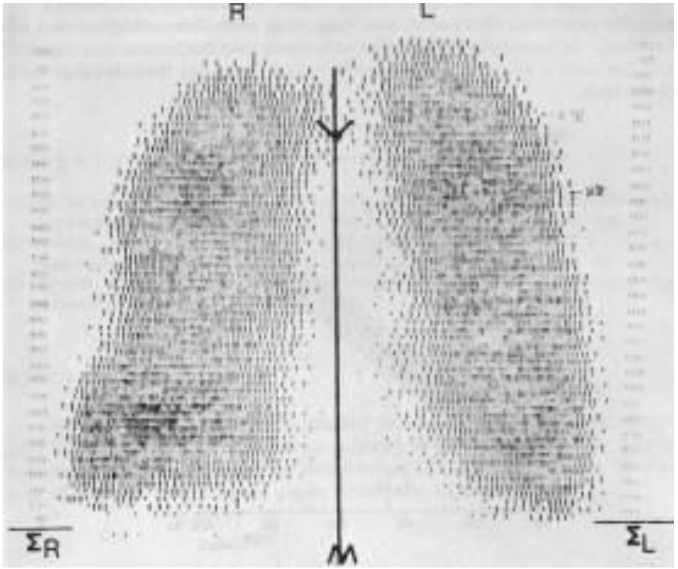


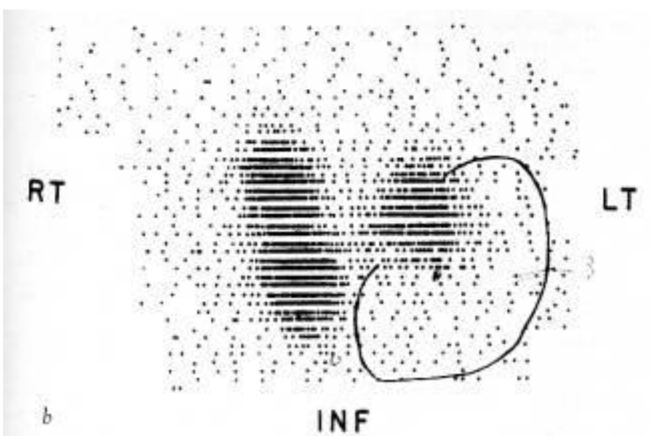
The development of large area scintillator crystals led to the development of the **Gamma Camera** which allowed to scan over larger areas with high spatial resolution.

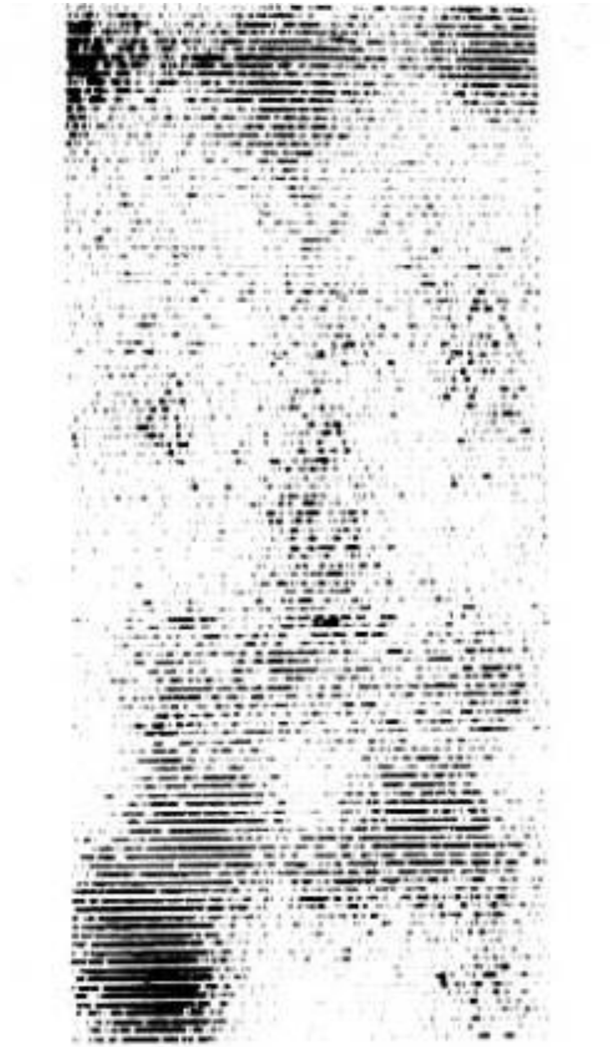
The Gamma camera consists out of a large area NaI crystal with a lead collimator which allows only transmission of γ radiation from a particular point.

The detector device can be moved (rectilinear or linear) to cover larger areas.

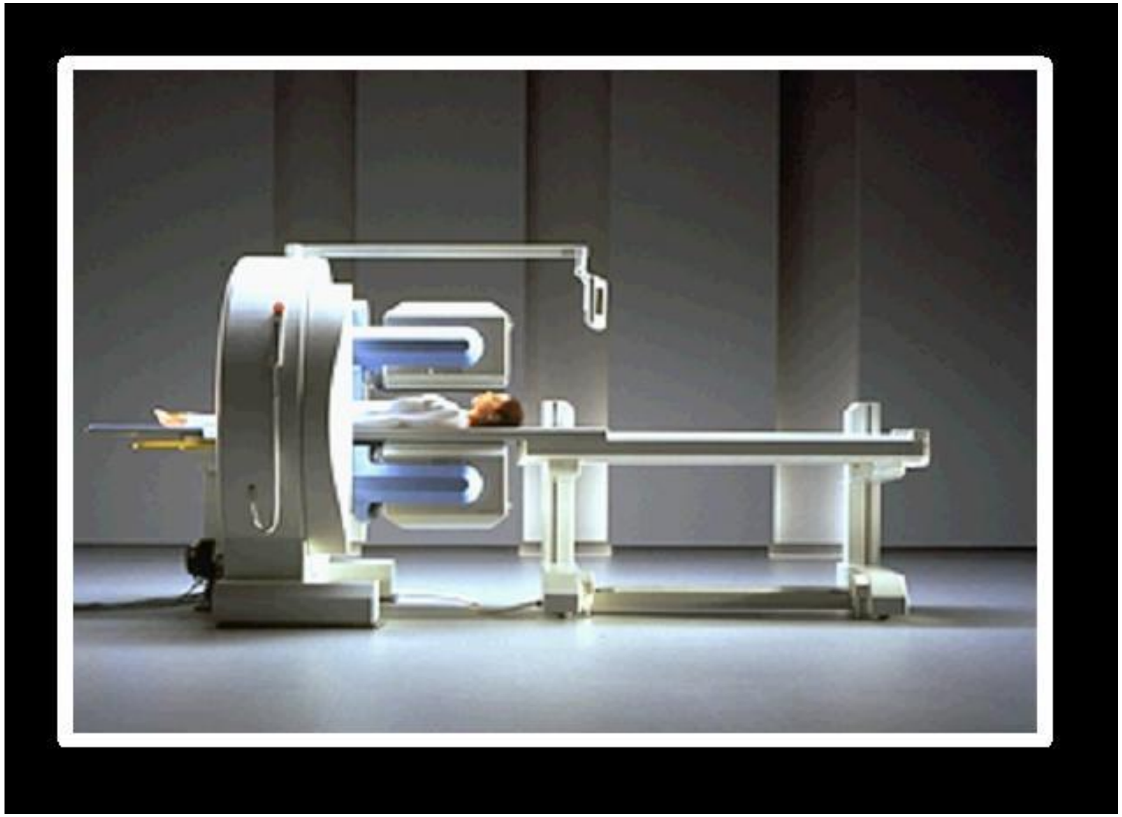
SCANNER IMAGES







Gamma camera

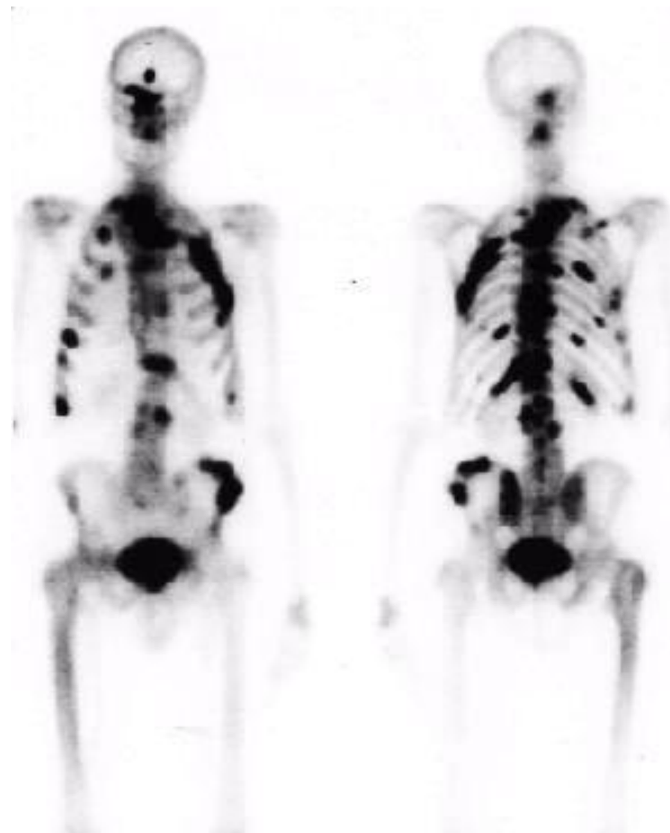


Siemens

Used to measure the spatial and temporal distribution of a radiopharmaceutical

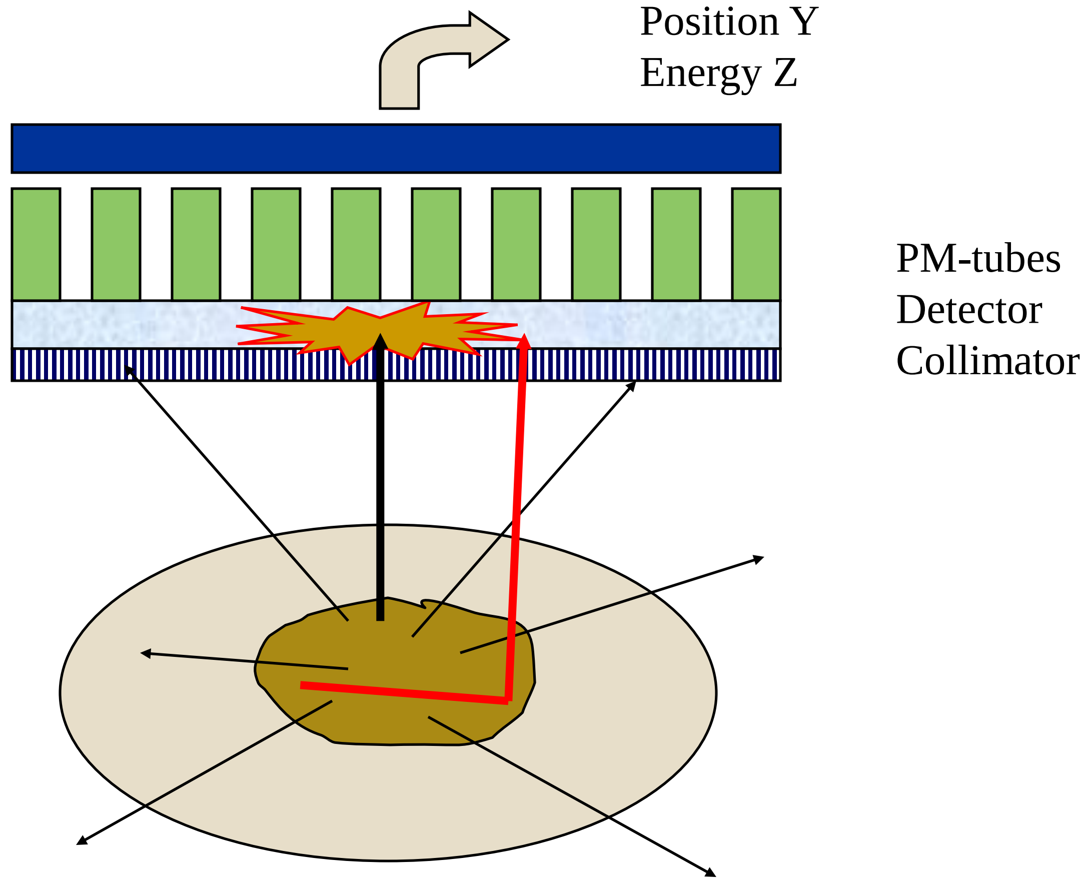
Structure of Gamma Camera

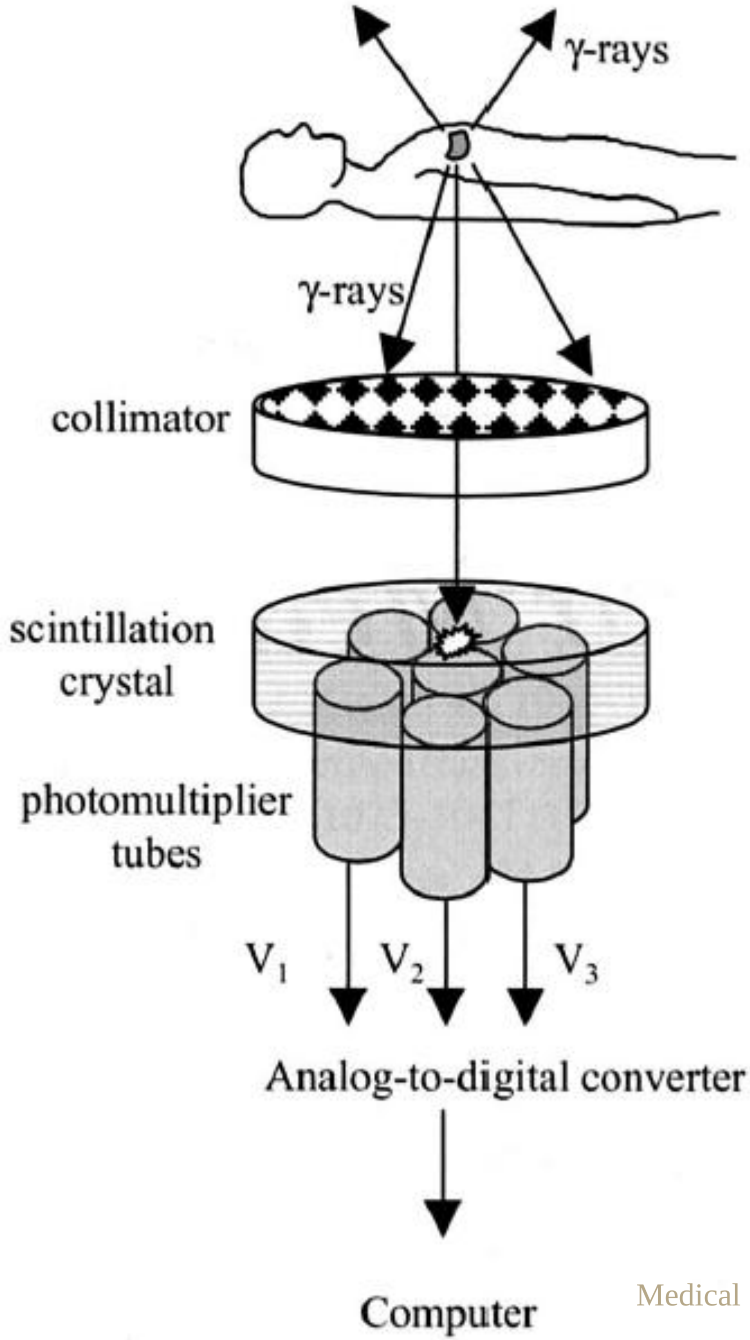
- A bone scan is used to find bone problems, such as cancer, infections, or fractures, to check joint replacements, and to find joint problems, such as arthritis.
- A small amount of injected radioactive matter (tracer) and a camera to form an image.

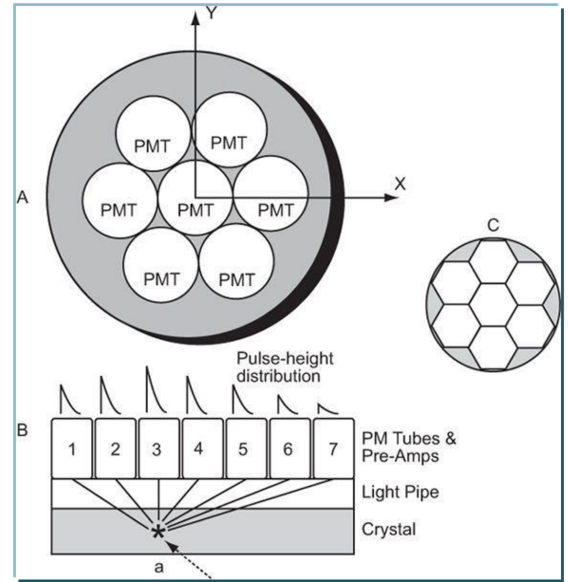


Bone scan looking for metastatic bone cancer.

Gamma camera
(principle of operation)





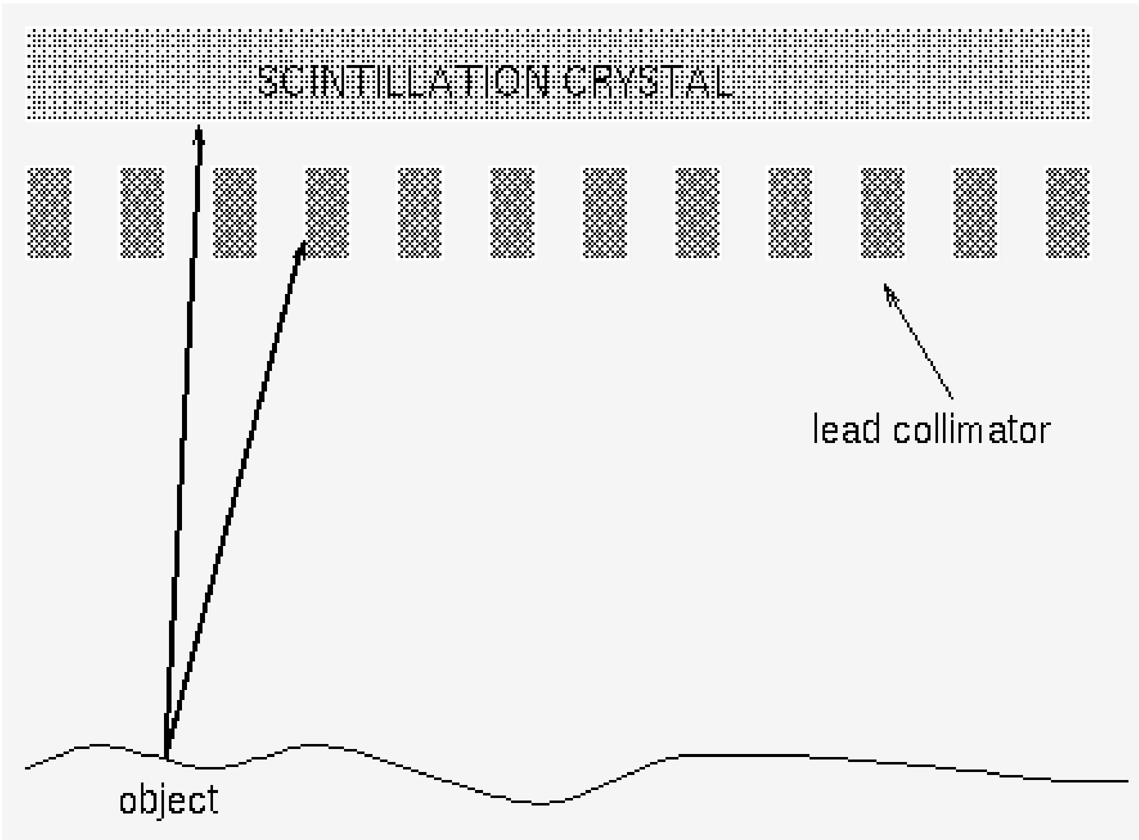


The intensity of radiation incident on a detector at range r from a radioactive source is

$$I = \frac{AE}{4\pi r^2}$$

A: radioactivity of the material;
E: energy of each photon

A crucial component of the modern gamma camera is the **collimator**. The collimator selects the direction of incident photons.



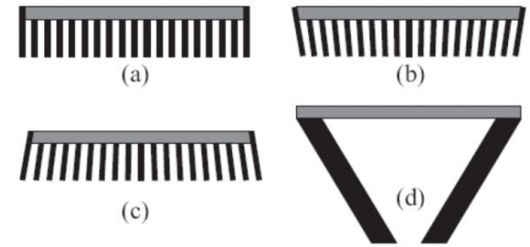
The action of a parallel hole collimator

Collimators

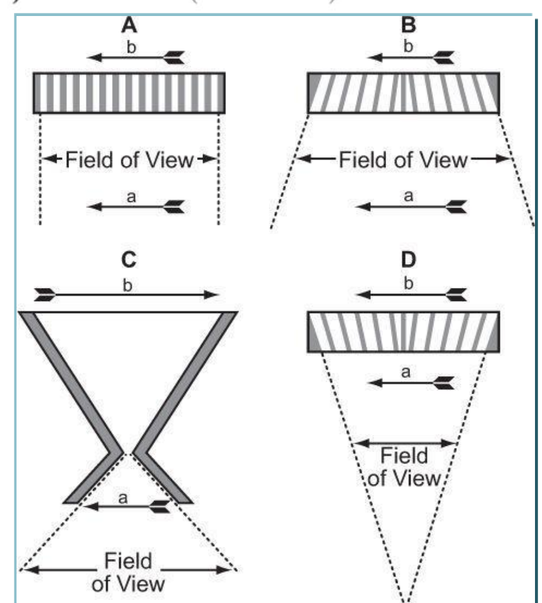
pinhole collimator often used in the imaging of small superficial organs and structures (e.g thyroid,skeletal joints) as it provides image **magnification**.

Fan beam (diverging) collimators are often used for whole body imaging. Such collimators are useful because they increase the detection efficiency because of the increased solid angle of photon acceptance.

Cone beam (converging) collimators are often used for medium sized organ imaging.



(a) Parallel hole
(b) Converging hole (magnifies)
(a) Diverging hole (minifies)
(a) Pin-hole (2–5 mm)

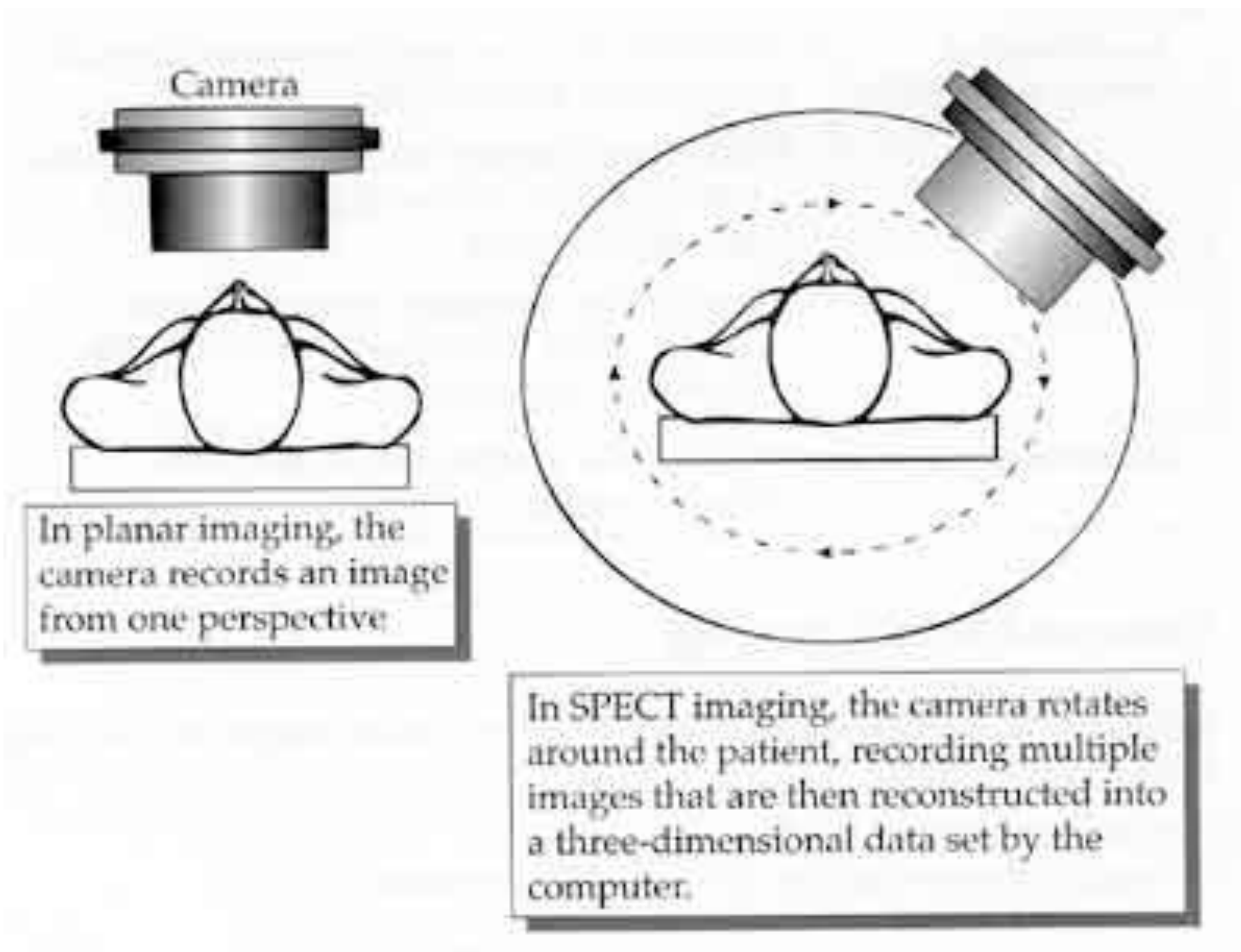


SPECT

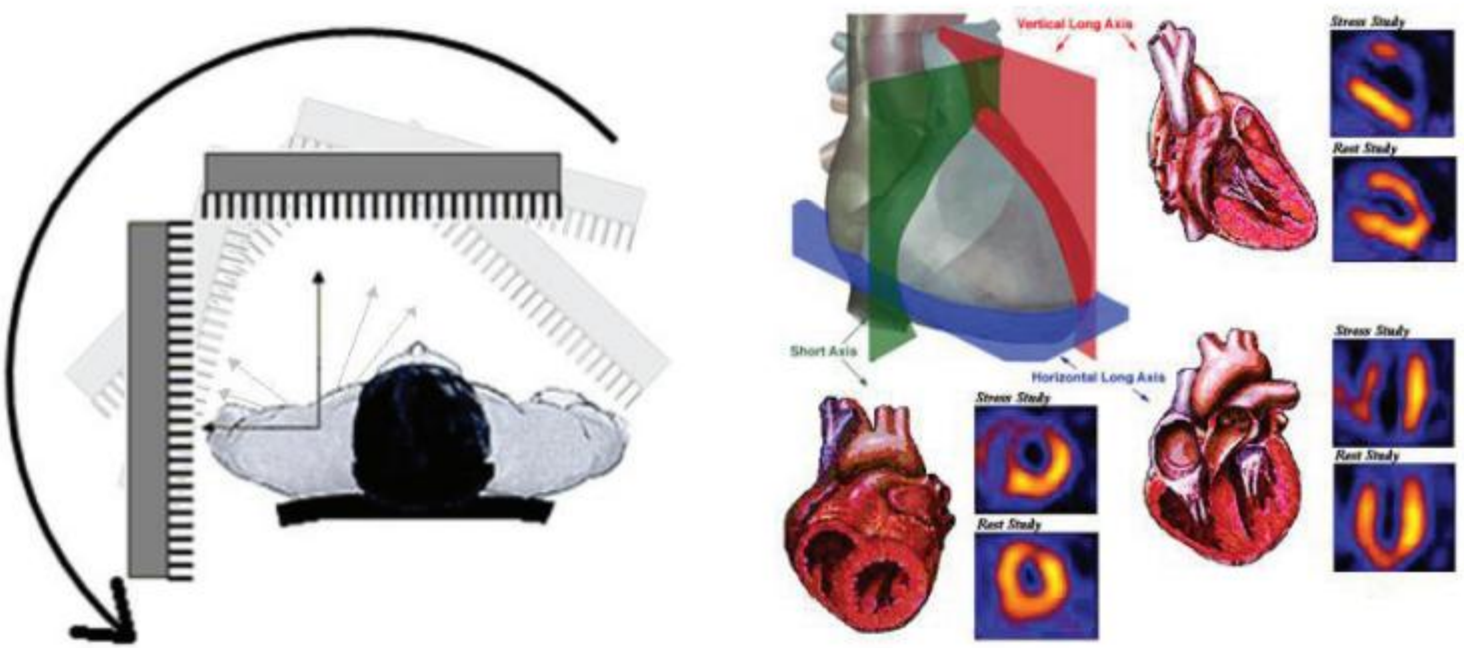
SPECT Instrumentation

- Similar to CT, uses a rotating Anger camera to detect photons traversing paths with different directions
- Recent advances uses multiple Anger cameras (multiple heads), reducing scanning time (below 30 minutes)
- Anger cameras in SPECT must have significantly better performances than for planar scintigraphy to avoid reconstruction artifacts

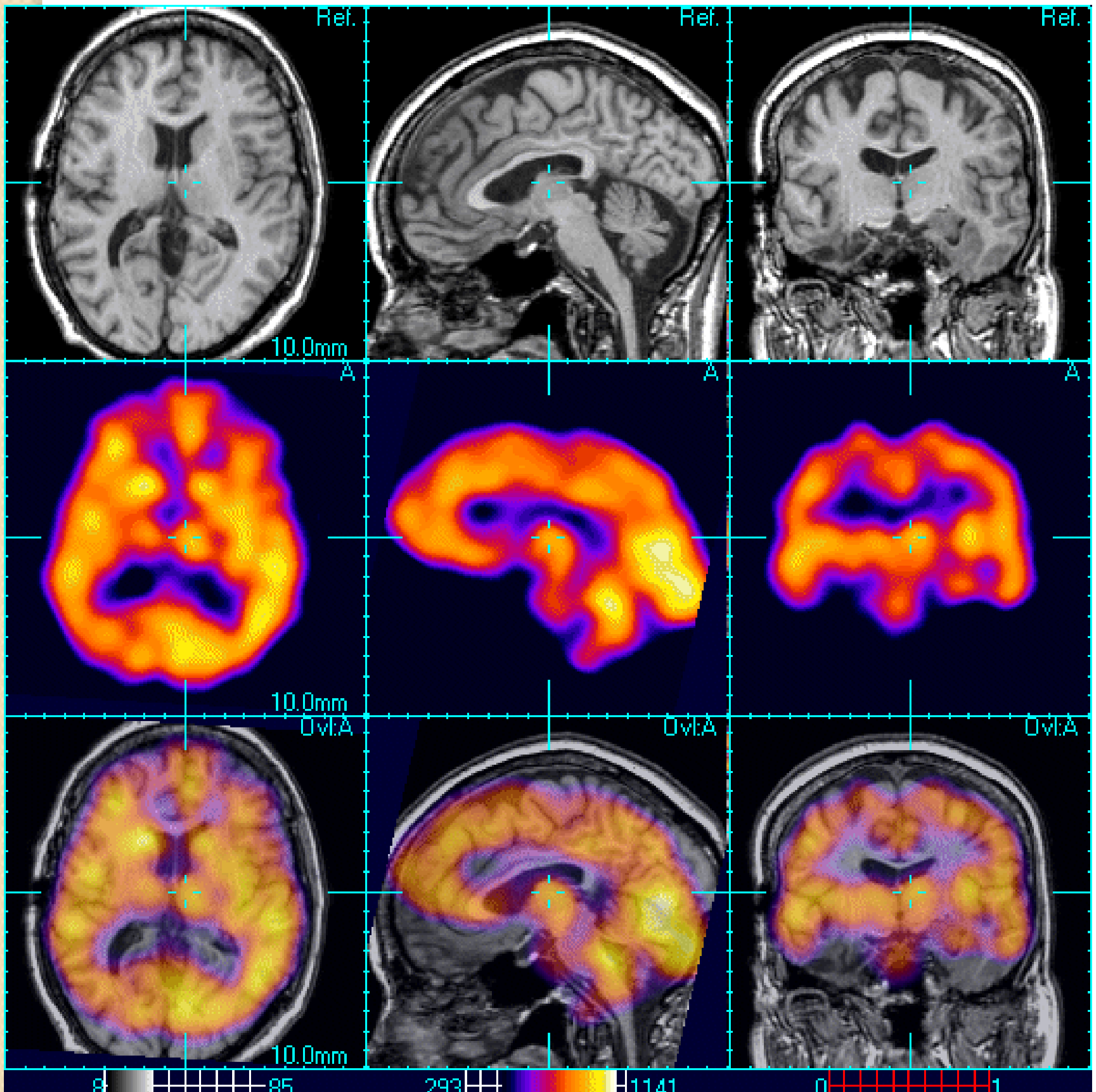
SPECT Instrumentation



SPECT Instrumentation

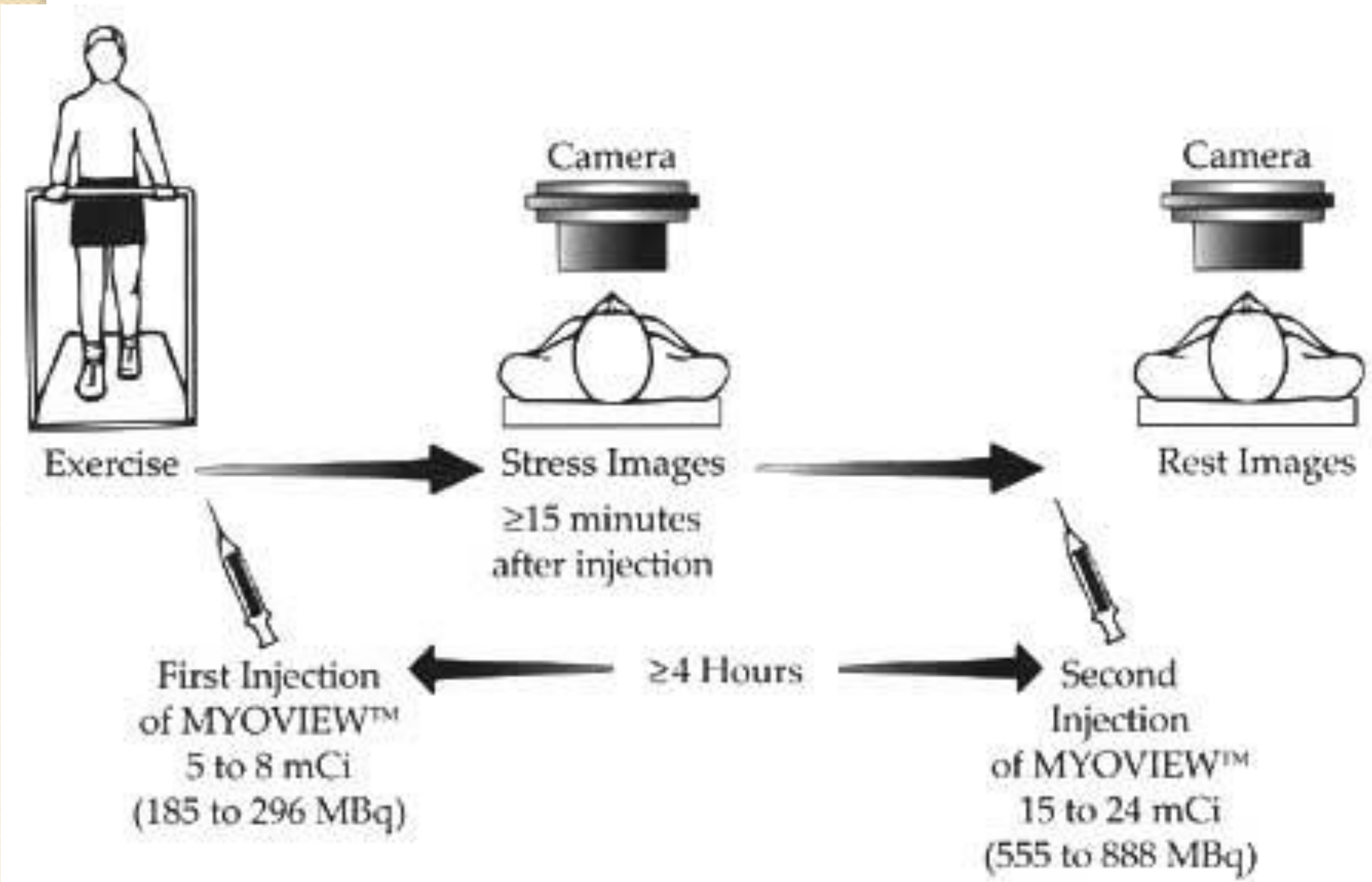


Adapted from: Essential Nuclear Medicine Physics 2nd Edition by Rachel A. Powsner & Edward R. Powsner



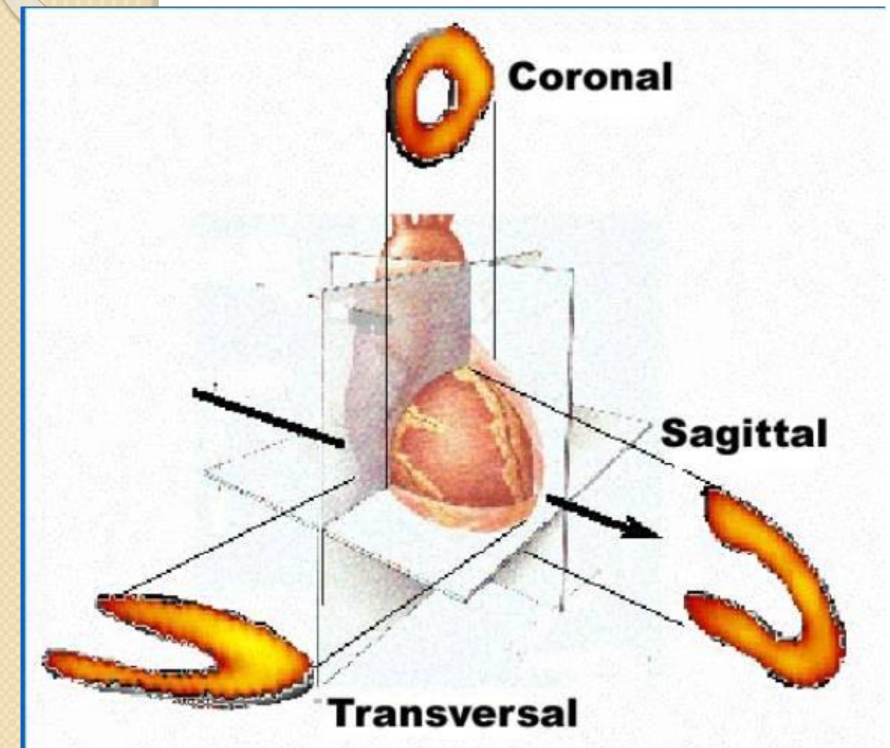
MR and SPECT Hybrid System

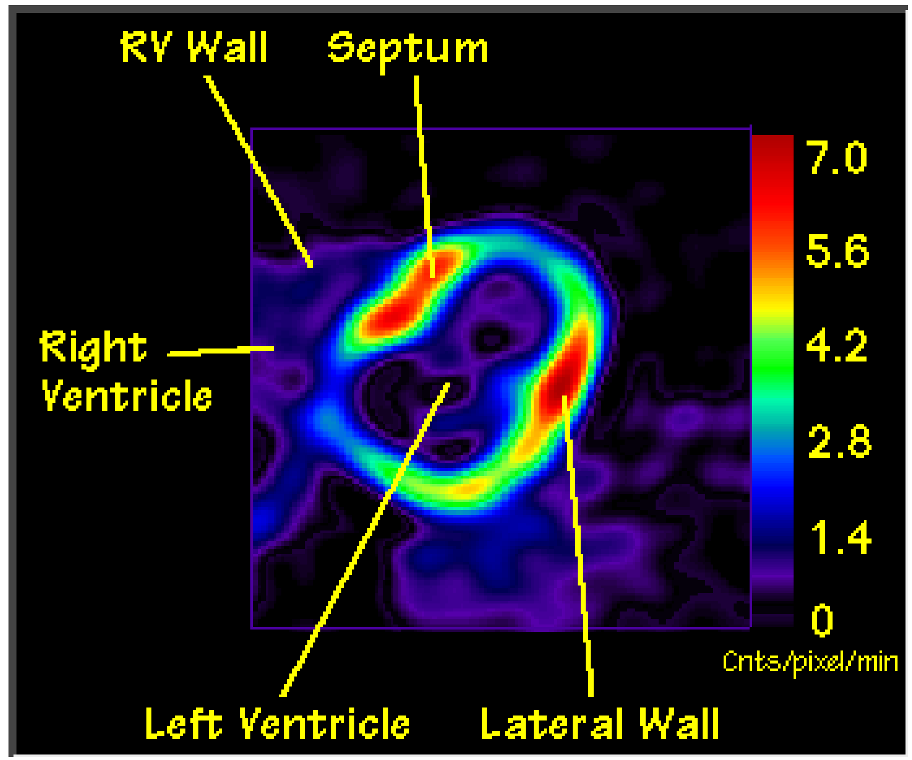
With advancement made in science and technology, it is now possible to combine physiological imaging technologies in Nuclear Medicine (e.g. SPECT and PET) with the anatomy imaging (e.g. CT and MRI) in radiology, constituting a hybrid imaging systems like SPECT-CT, PET-CT and PET-MRI.

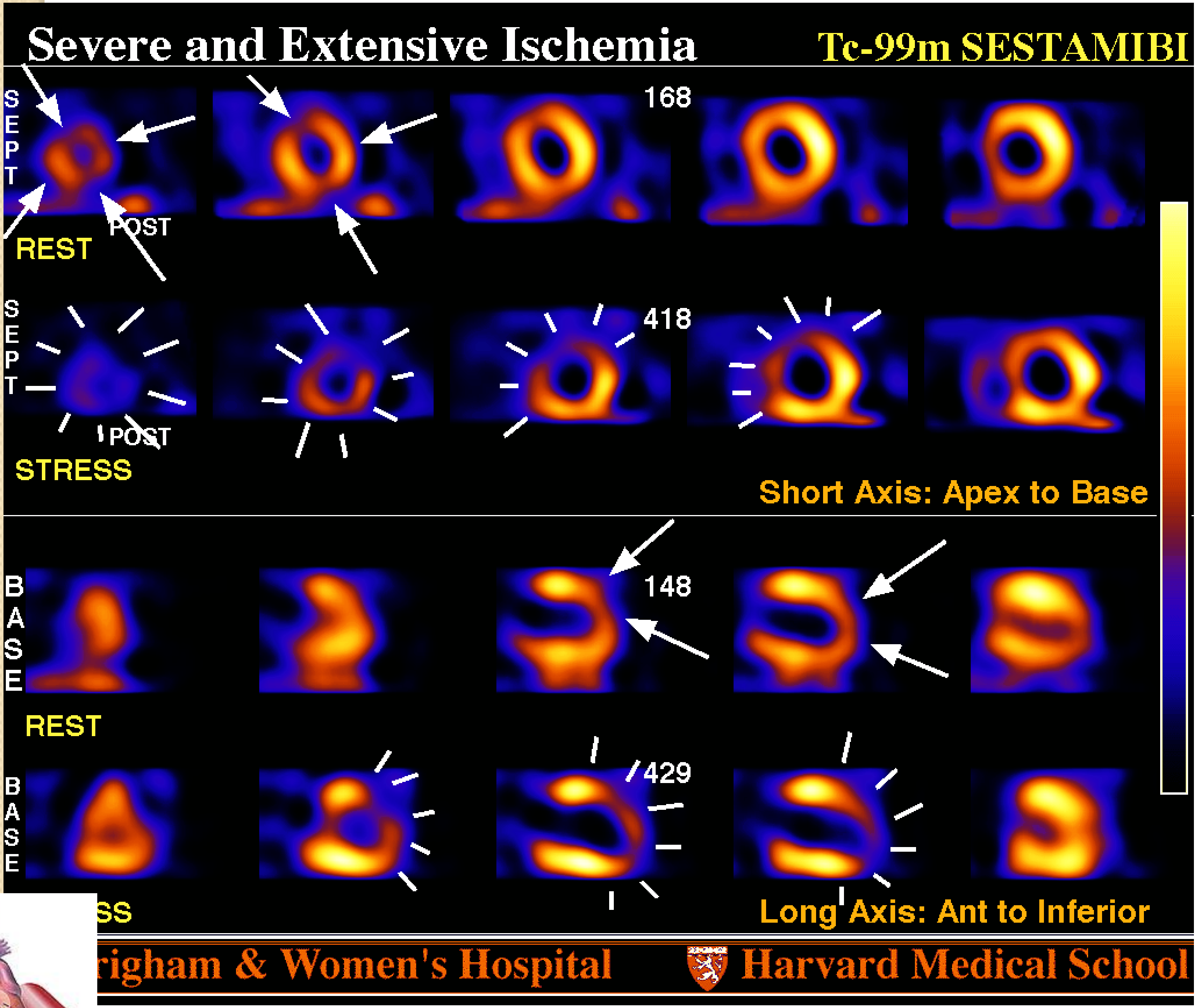


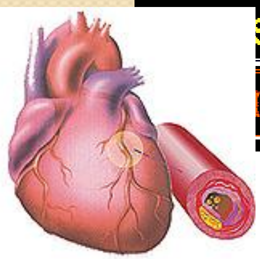
Images taken when the patient is at rest show the baseline state of myocardial perfusion. However, rest images may appear within normal limits even when perfusion defects are present.

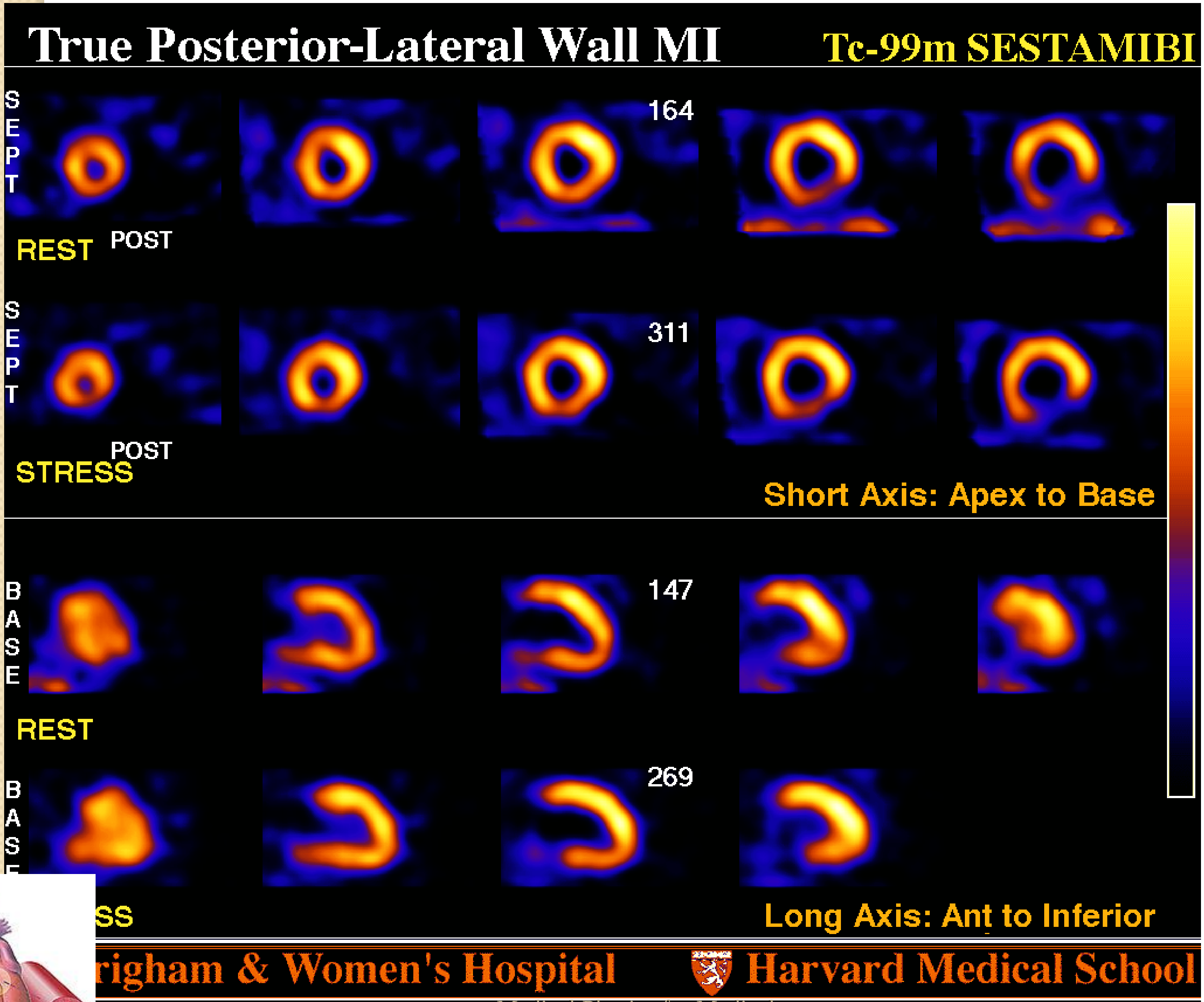
Tomographic planes



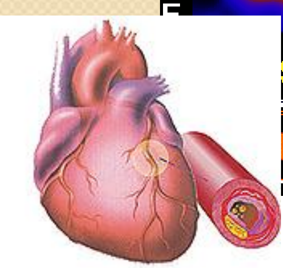



Severe and Extensive Ischemia
Tc-99m SESTAMIBI
SEPT
REST
POST
168
SEPT
STRESS
POST
418
Short Axis: Apex to Base
BASE
REST
148
BASE
429
SS
Long Axis: Ant to Inferior
righam & Women's Hospital
Harvard Medical School

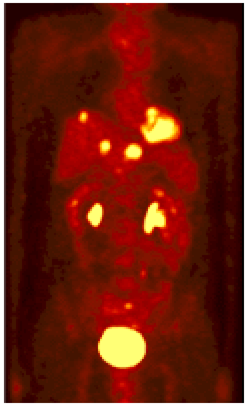




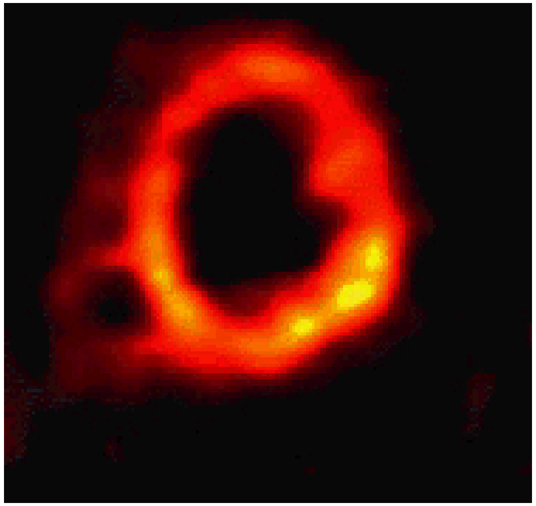
True Posterior-Lateral Wall MI
Tc-99m SESTAMIBI
SEPT
164
REST
POST
SEPT
311
POST
STRESS
Short Axis: Apex to Base
BASE
147
REST
BASE
269
SS
Long Axis: Ant to Inferior
righam & Women's Hospital
Harvard Medical School

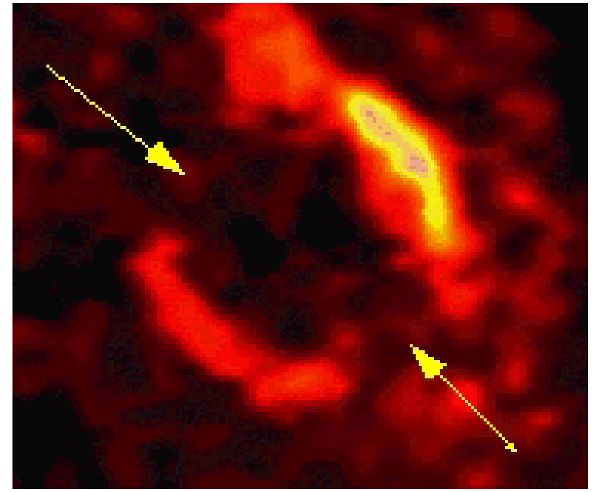


PET



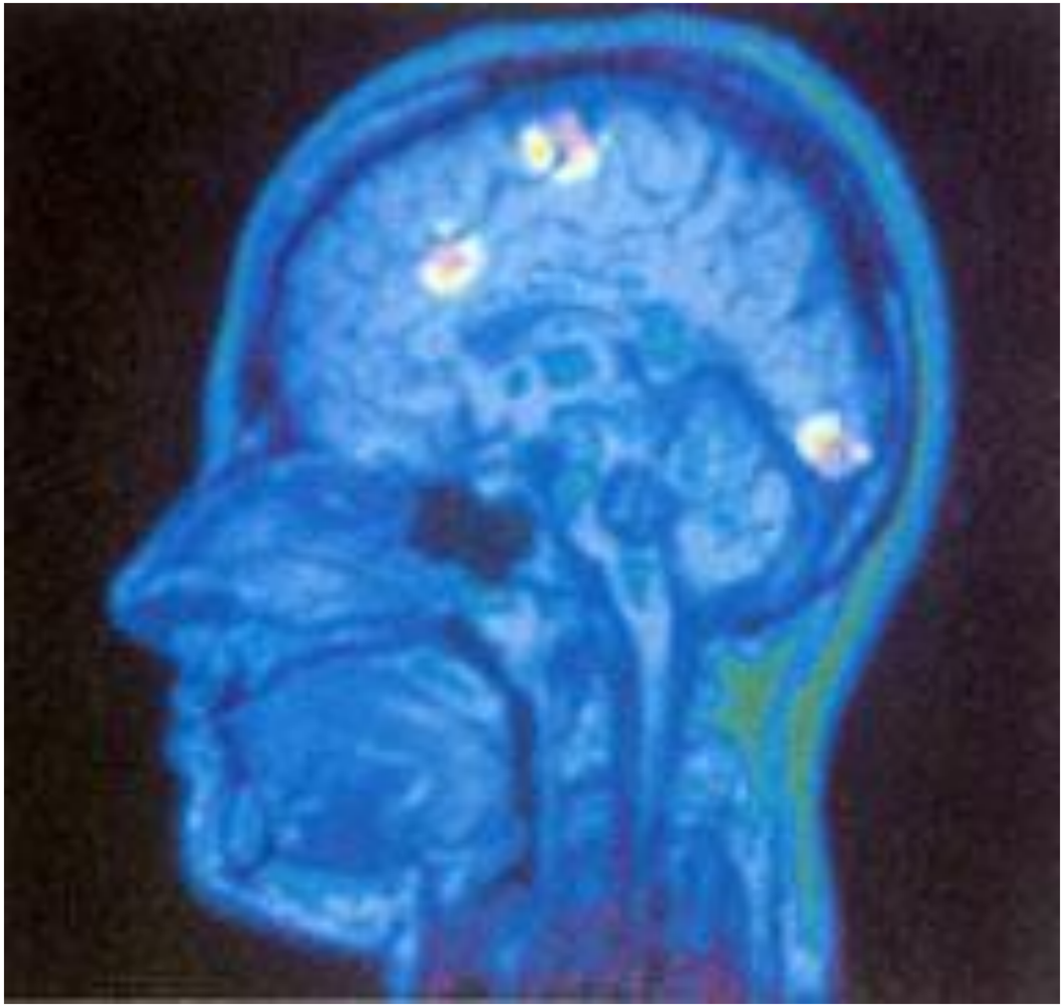
whole-body 3D PET



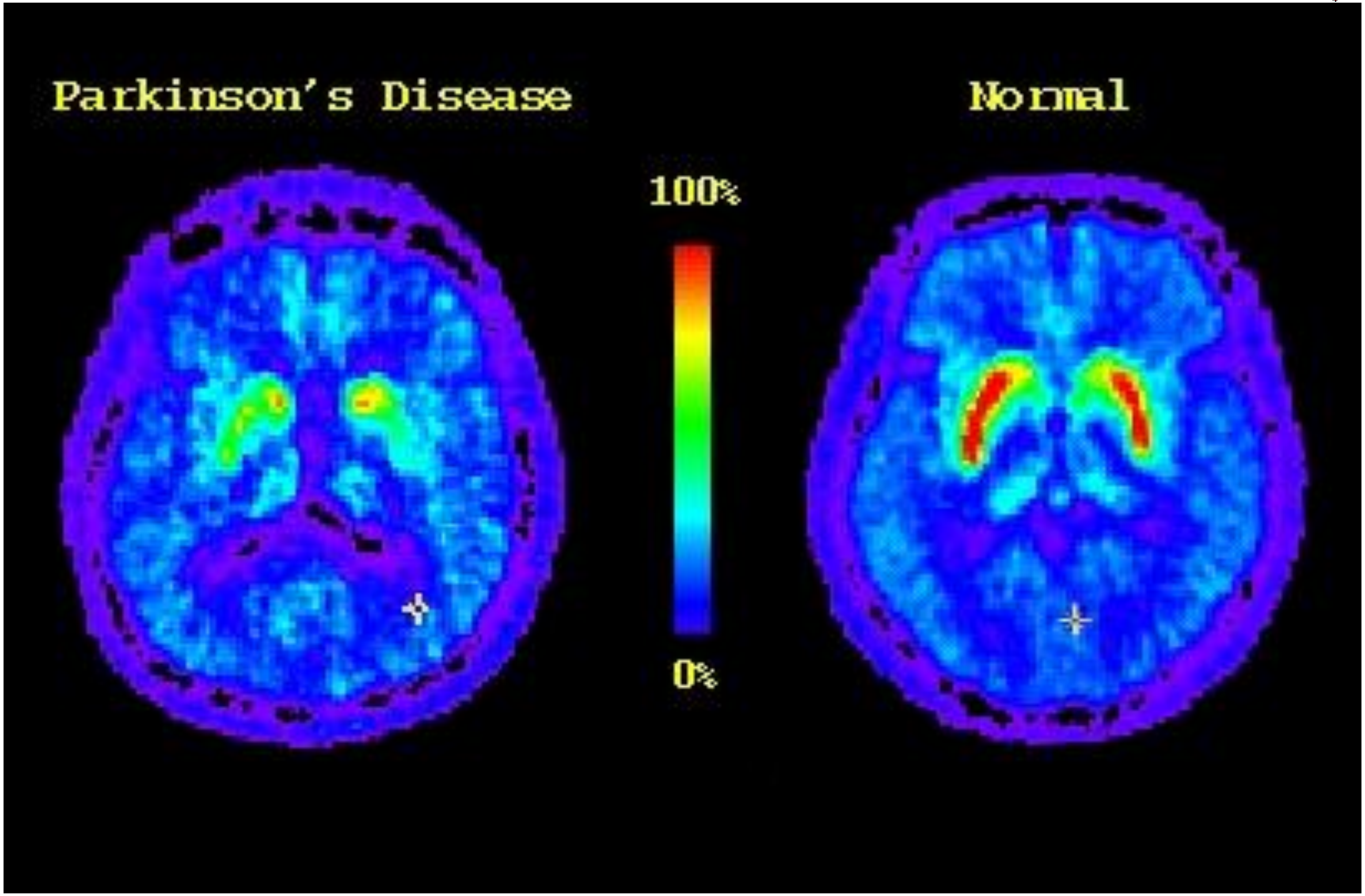


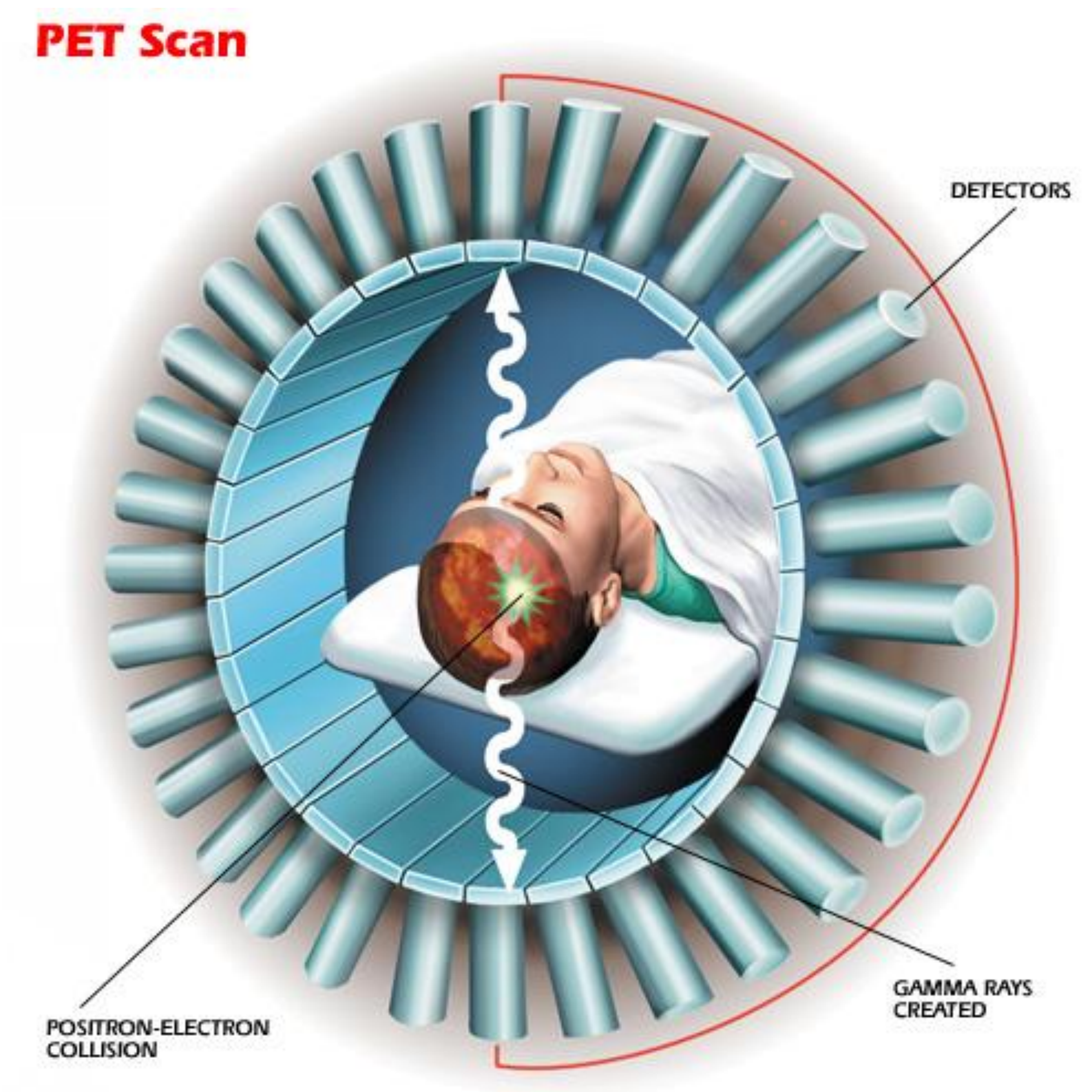
- Normal PET scan of a heart.

- Image of heart which has had a mycardial infarction.
- The arrow points to "dead" myocardial tissue.
- Therefore, the patient will not benefit from heart surgery, but may have other forms of treatment prescribed.

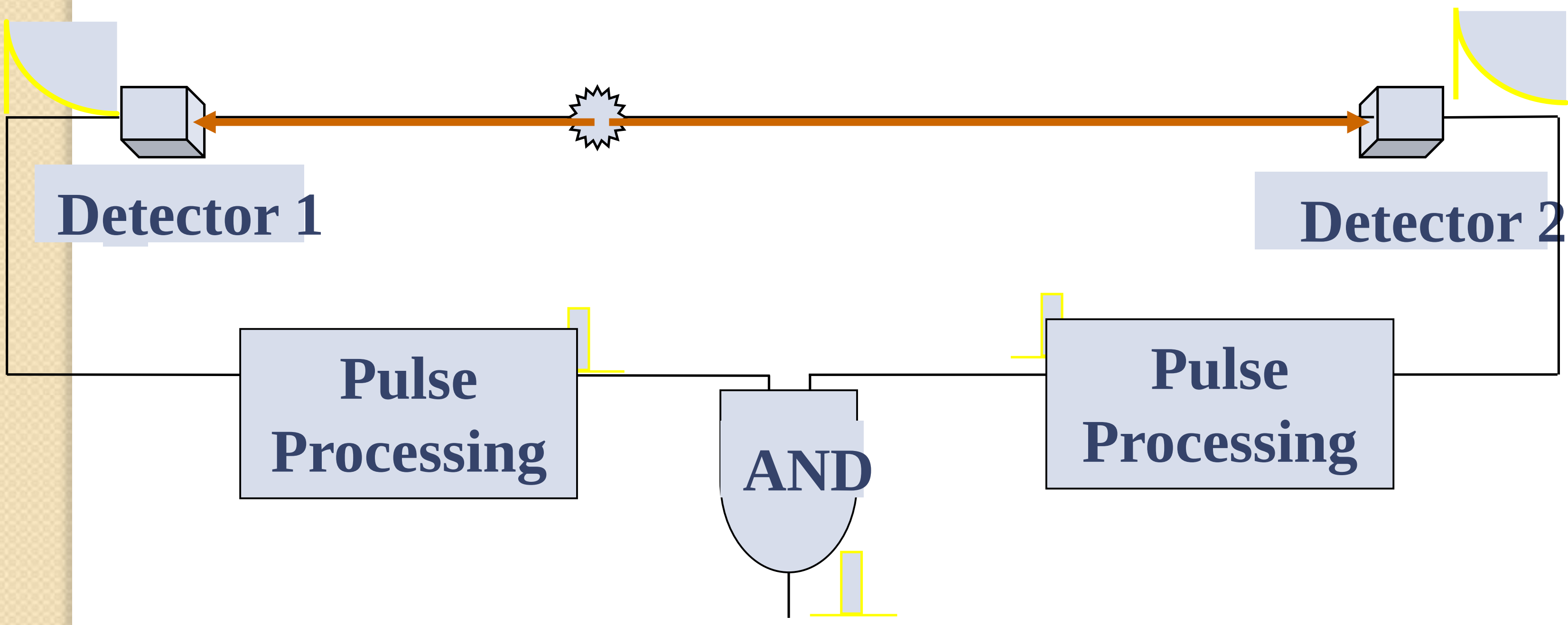


65 year old male with brain tumors imaged here with a PET scan.


Parkinson's Disease
Normal
100%
0%


PET Scan
DETECTORS
GAMMA RAYS CREATED
POSITRON-ELECTRON COLLISION

Coincidence circuit - I



- All the events that happen on the same line contribute to count frequency revealed by the same pair of detectors, and are recorded on the same *line of response*
- The sum of counts recorded on a line of response is proportional to the integral of activity distribution along this line

Positrons

- When a positron meets an electron the collision creates two gamma rays that have the same energy but go in opposite directions.
- PET detects the gamma rays as they leave the patients body. The information is fed to a computer and makes a picture.

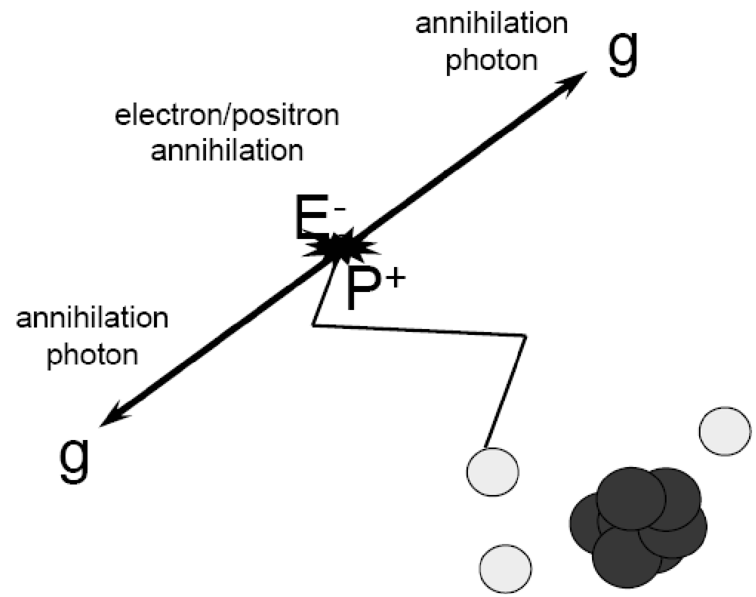
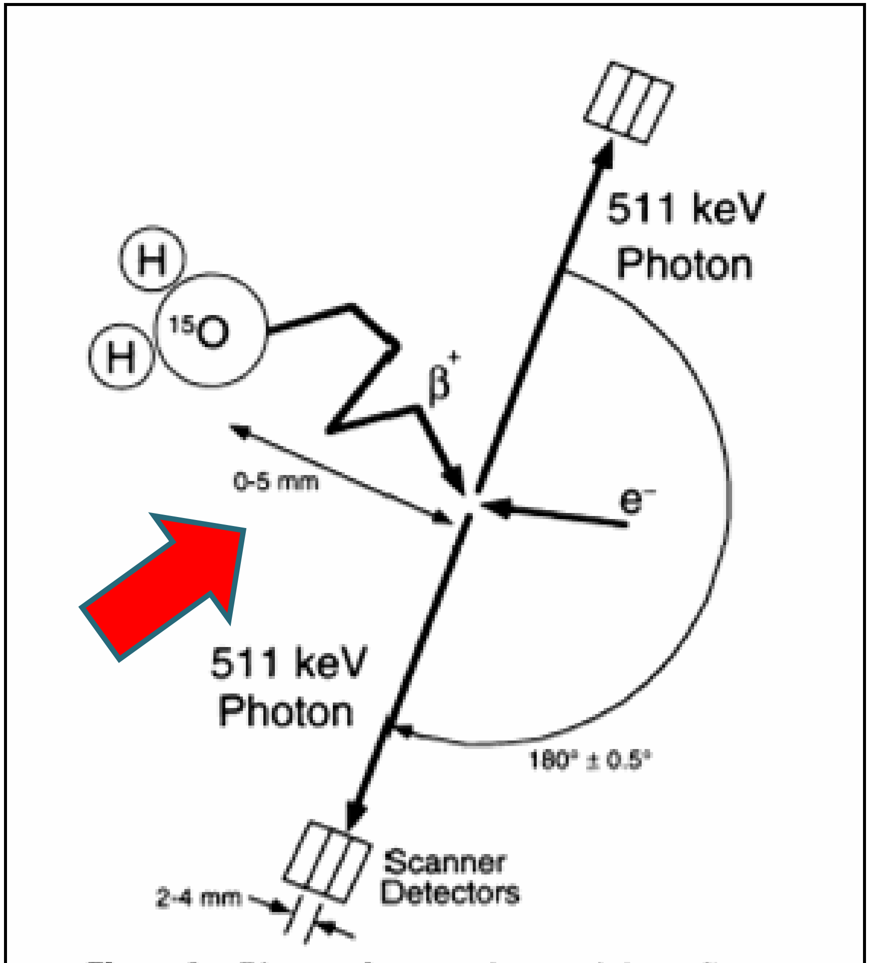


Figure. Demonstration of PET Imaging Detection



PET = positron emission tomography.

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Radiographics. 1995;15:1179-1190.[8]

PET Imaging

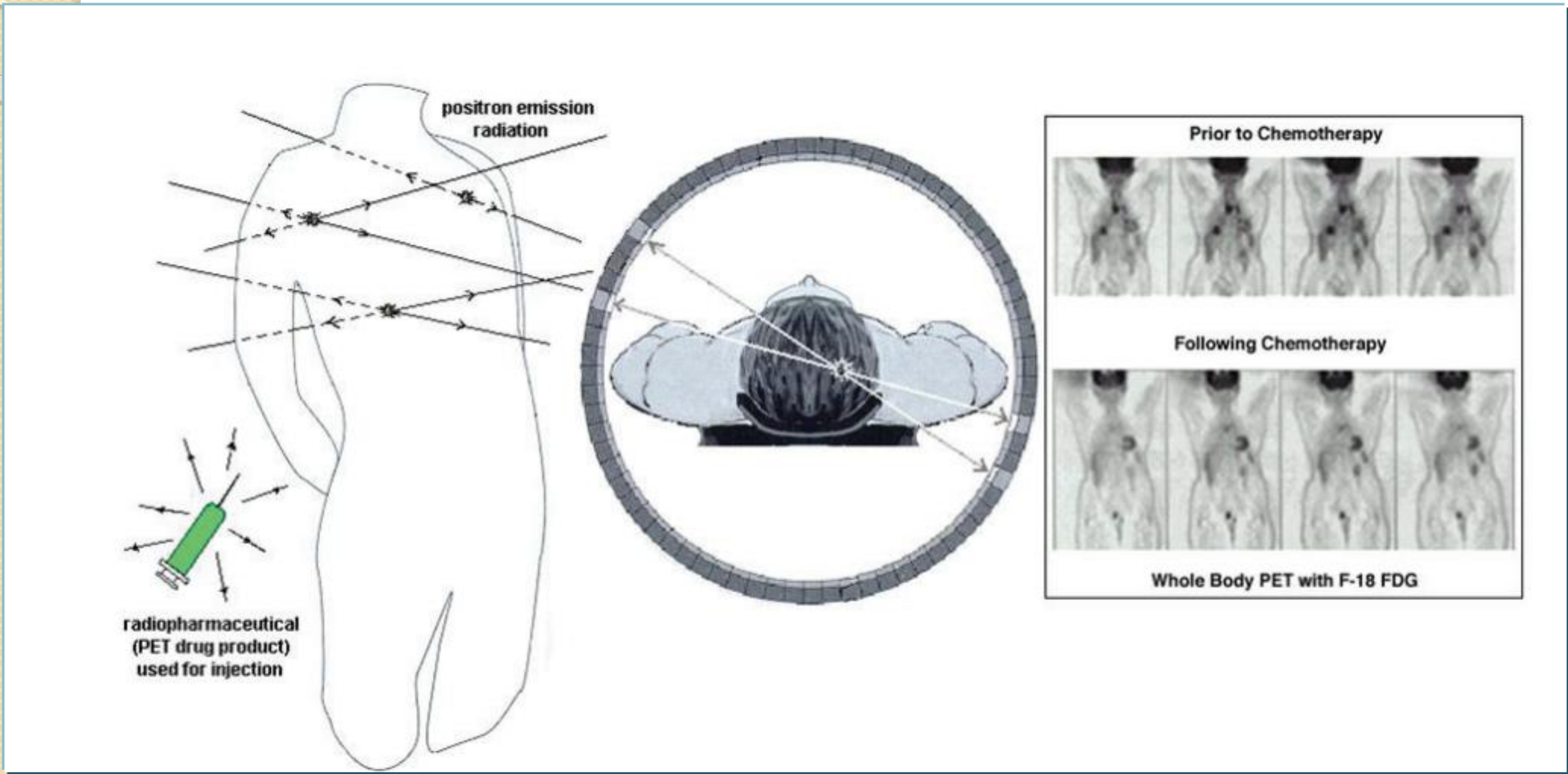
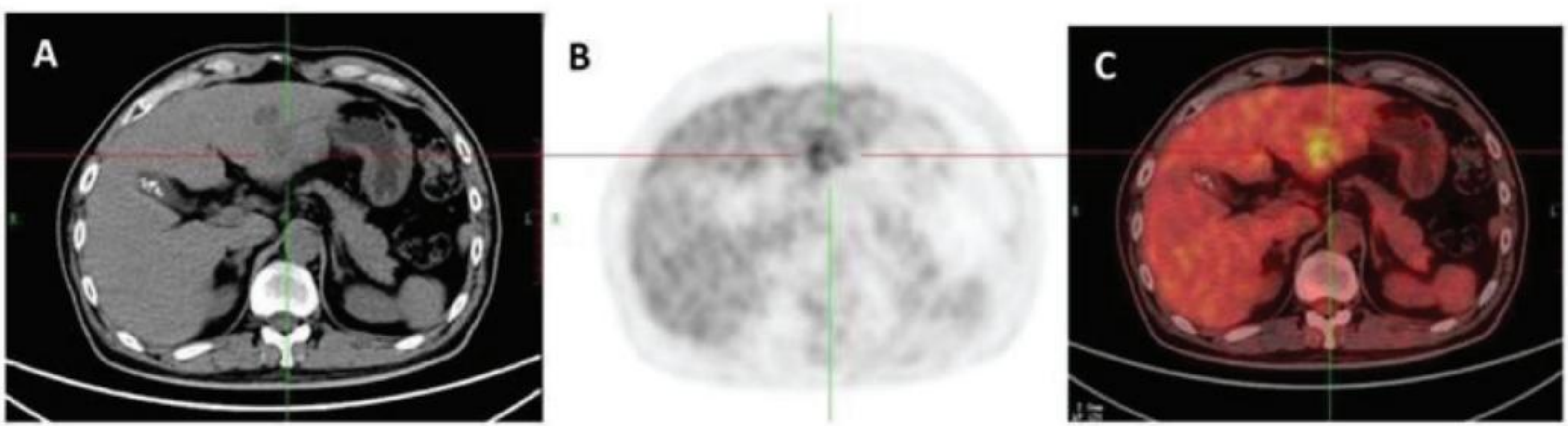

positron emission radiation
radiopharmaceutical (PET drug product) used for injection
Prior to Chemotherapy
Following Chemotherapy
Whole Body PET with F-18 FDG

Image of GEMINI TF PET/CT

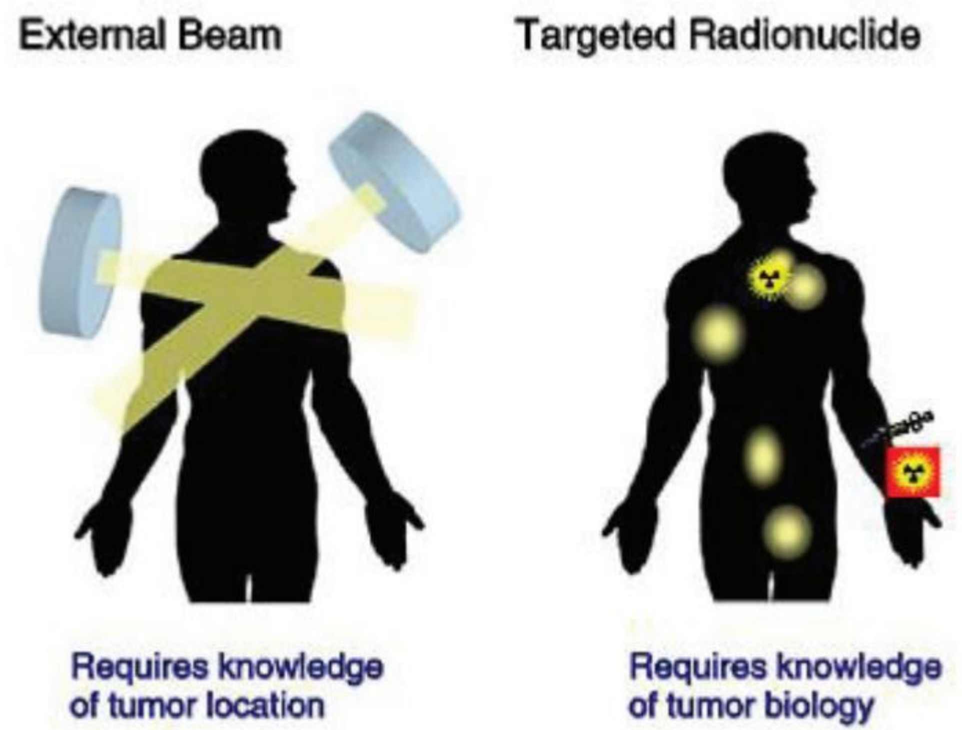


A: Non-contrast CT-scan

B: ^{18}FDG PET image

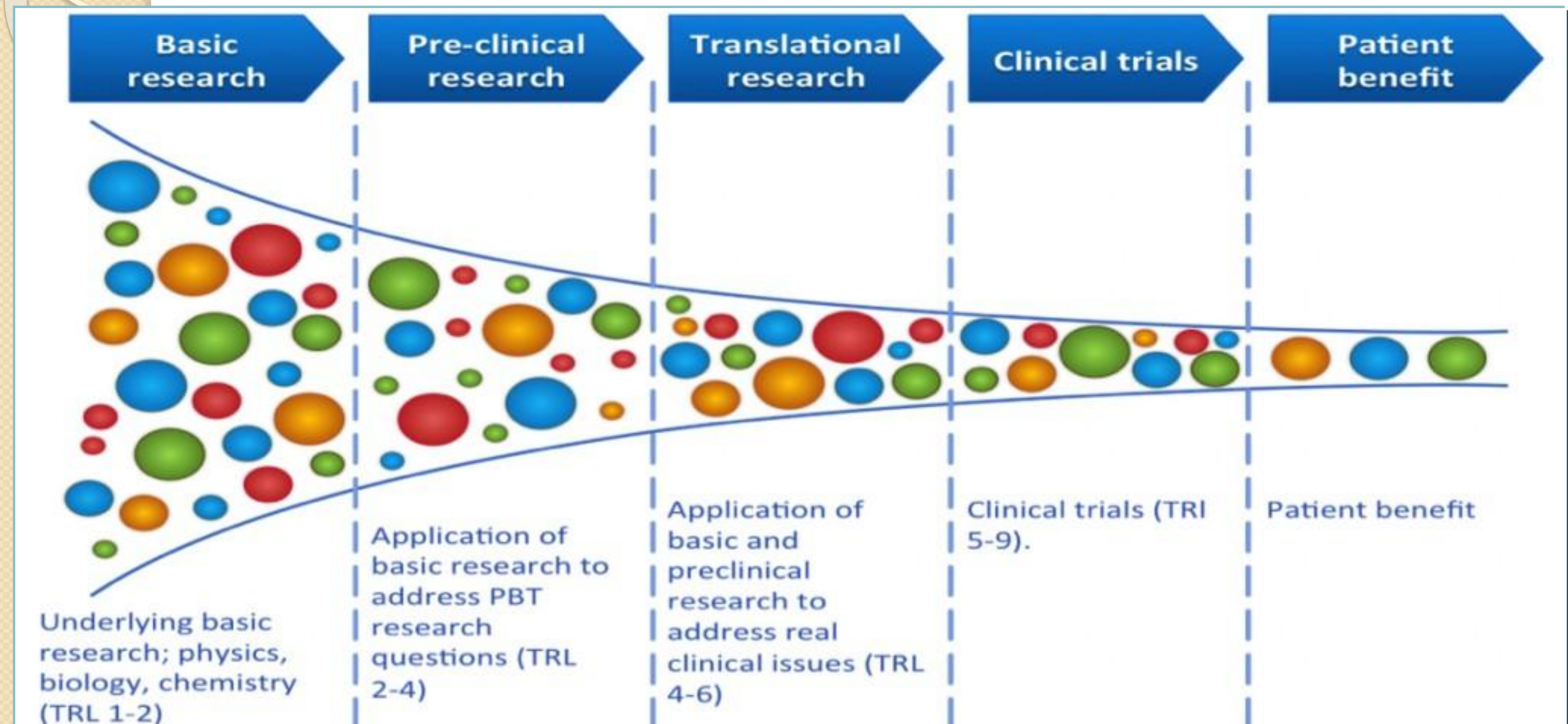
C: ^{18}FDG PET/CT fusion image

Targeted Radionuclide Therapy



Adapted from: Institute of Medicine and National Research Council. 2007. Advancing Nuclear Medicine Through Innovation. Washington, DC: The National Academies Press. https://doi.org/10.17226/11985.

Advanced Radiotherapy



Thank you for your attention!