RADIATION PHYSICS

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Review Course

Thomas Jefferson University

OVERVIEW

- Basic properties of radiation
- Sources of radiation
- Interaction with matter
- Measurement of radiation

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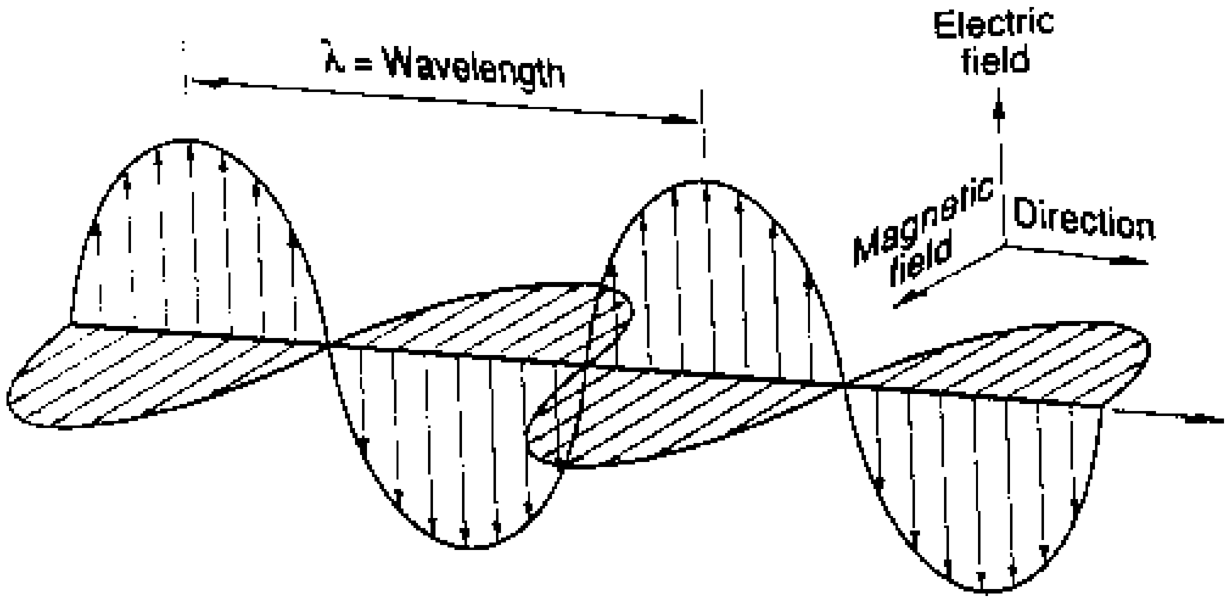
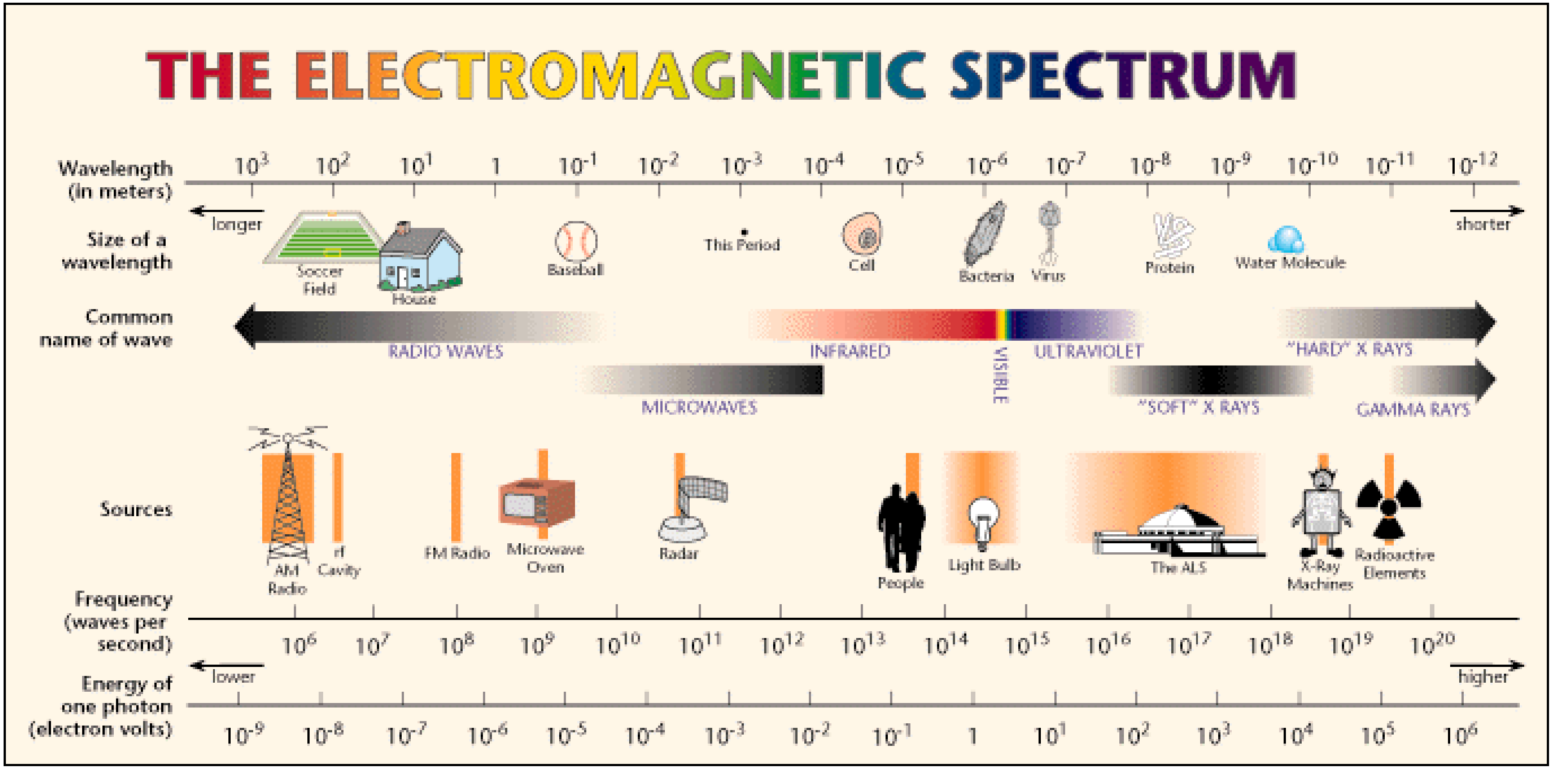
Electromagnetic Radiation

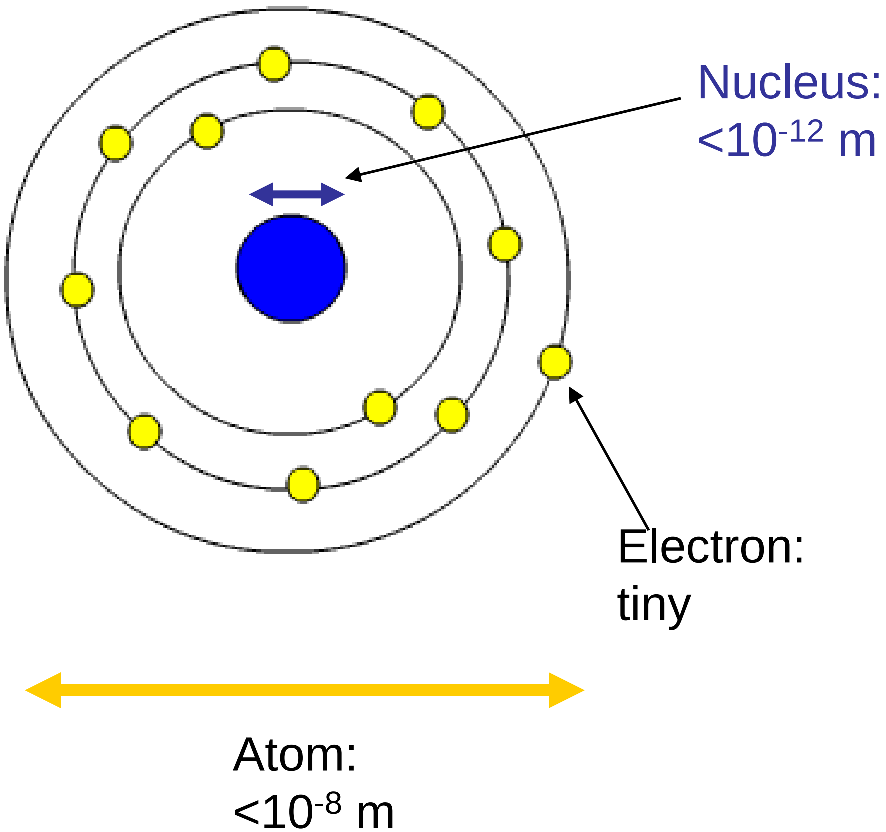


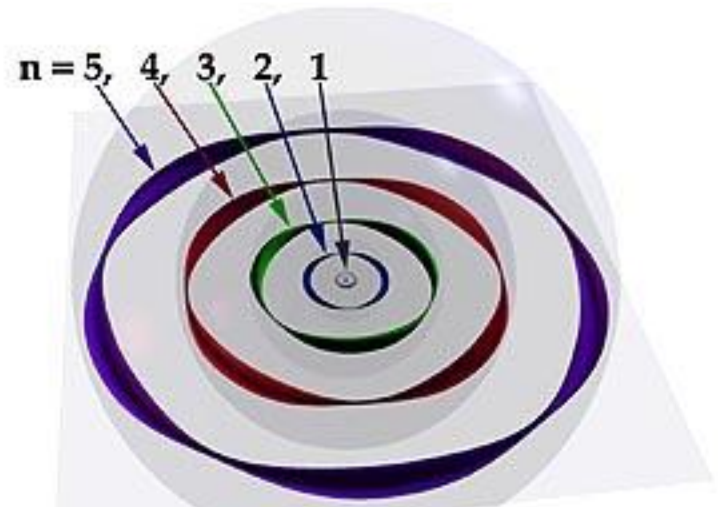
- *Velocity = Frequency × Wavelength*
- Velocity of EM radiation is "c" – speed of light



*Note: (1) Gamma rays refer to photons emitted from the nucleus.
(2) Gamma rays are not necessarily higher in energy than X-rays.
(3) Human eye can only detect a small range of the EM spectrum.

Atomic Structure

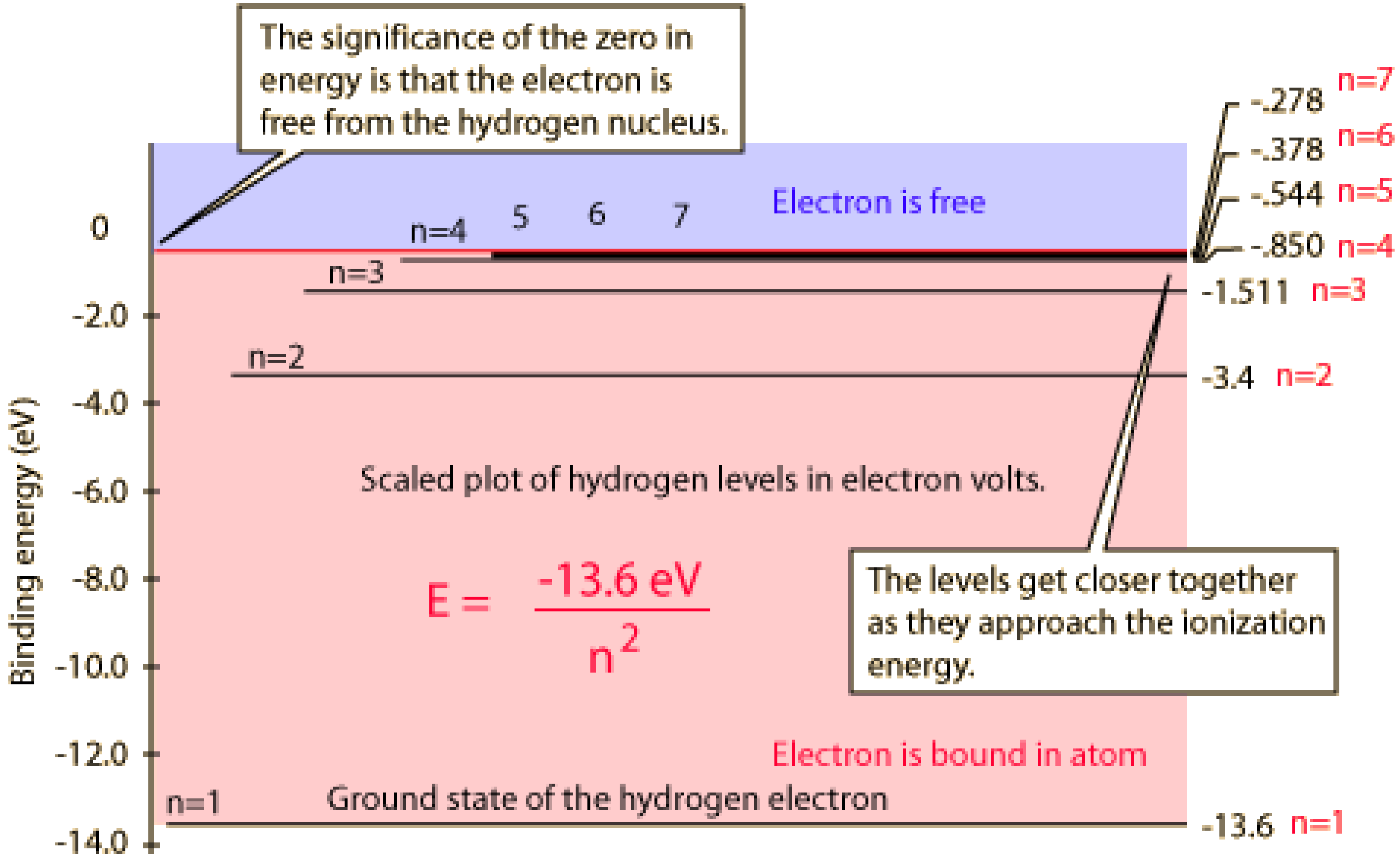




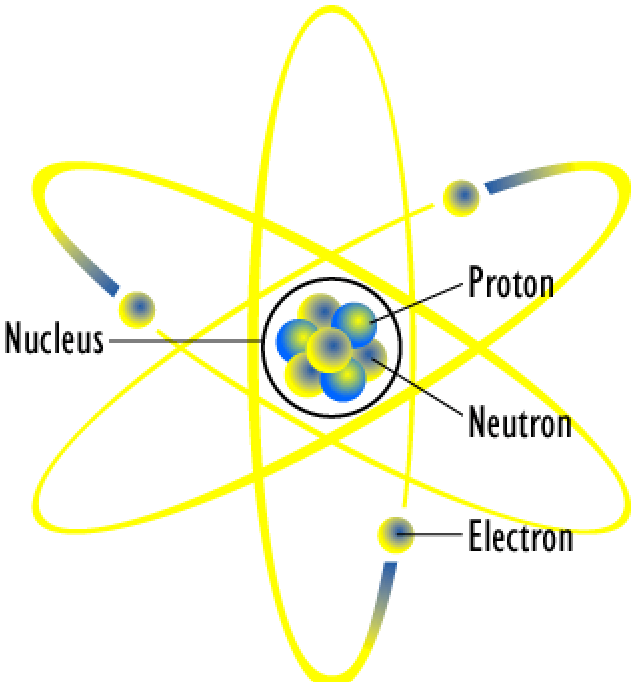
Niels Bohr - Louis de Broglie atom, 1924

The atom is mostly empty space

Energy levels of the hydrogen atom



Nuclear Structure



Subatomic particles

- Alpha particle (α): 2 protons and 2 neutrons bound together.
  - This is just a helium nucleus.
- Beta-minus particle (β^-): electron emitted by the nucleus (rather than from an orbital shell).
  - How does the nucleus produce electrons?
- Beta-plus particle (β^+): positron emitted by the nucleus.
- Gamma ray (γ): photon emitted by the nucleus.
  - How does the nucleus produce photons?

Basic Physical Properties

- Radioactive decay
  - Random process for each atom, but predictable in an ensemble of many atoms
    - Similar to (choose a or b):
      - (a) photon interaction with matter
      - (b) electron interaction with matter
- $T_{1/2}$ Half life: time required for ½ of the source material to decay.
- Decay mode: alpha, beta, e- capture

"electron volt – eV"

- This is an important unit of energy in radiation physics.
- It is defined as energy acquired when an electron falls through 1 volt.
  - 1 electron has 1.6×10^{-19} C
  - Energy through 1 volt = 1.6×10^{-19} C x 1 V

    = 1.6×10^{-19} J

    = 1 eV

Conservation Laws in Physics

1. Total energy is conserved
2. Total momentum is conserved
3. Total charge is conserved

Conservation Laws in Physics

1. Total energy is conserved

   Example:

   - When an electron drifts through a high voltage tube, potential energy (anode to cathode) is converted to kinetic energy (velocity of the electron).
   - When one such fast electron strikes a target, its kinetic energy is converted to
     - X-ray energies
     - heat

Conservation Laws in Physics

1. Total energy is conserved
2. Total momentum is conserved
    - Momentum = Mass x Velocity
    - It is a vector
    - Example:
        - A positron ("anti-matter" of electron: just like an electron, but with positive charge) at rest annihilates with an electron. Two photons are created as a result. These two photons are emitted in opposite directions so that the total momentum is conserved (zero).

Einstein: $E = m c^2$

- Equivalence of mass and energy
  - Expands the energy conservation law to mass and energy
  - Example: Mass of an electron at rest is given as 9.1×10^{-31} kg. What is the energy needed to create an electron-positron pair?
    - Question: Why not creating a single electron?
      - ANS: Conservation of _____
    - Energy = $2 \times 9.1\times10^{-31} \times (3\times10^{8})^{2}$ J
      $= 2 \times 8.2\times10^{-14}$ J
      $= 2 \times 511$ keV $= 1.02$ MeV
- "Electron rest mass": 511 keV

Summary of Fundamental Quantities and Units

Fundamental Units (SI)

– Mass	kg
– Length	m
– Time	s (sec)
– Current	A

Summary of Fundamental Quantities and Units

Derived Units

– Velocity	m/s
– Acceleration	m/s^2 (or $m\ s^{-2}$)
– Force	$N = kg\ m\ s^{-2}$
– Energy (work)	$J = N\ m$

Summary of Fundamental Quantities and Units

Electrical Units

- Charge C = A s
- Potential V = J/C

Summary of Fundamental Quantities and Units

This leads to units of interest to us…

– Absorbed dose gray (Gy) = J/kg

Sometimes 1 cGy is referred to as “1 rad”

– Exposure roentgen (R)

1 R = 2.58×10^{-4} C/kg

– Activity becquerel (Bq) = disintegration/sec

Also “curie” (Ci)

1 Ci = 3.7×10^{10} Bq

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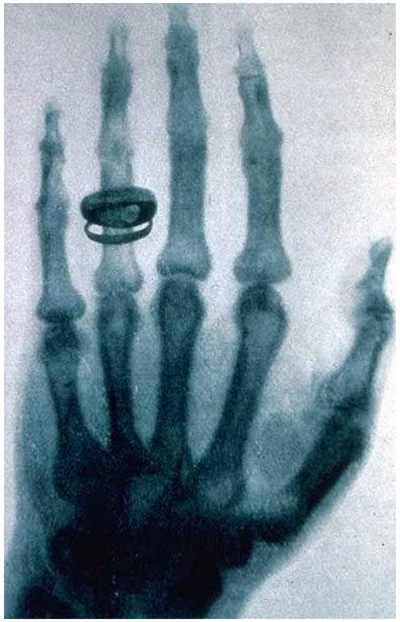
Production of X-rays

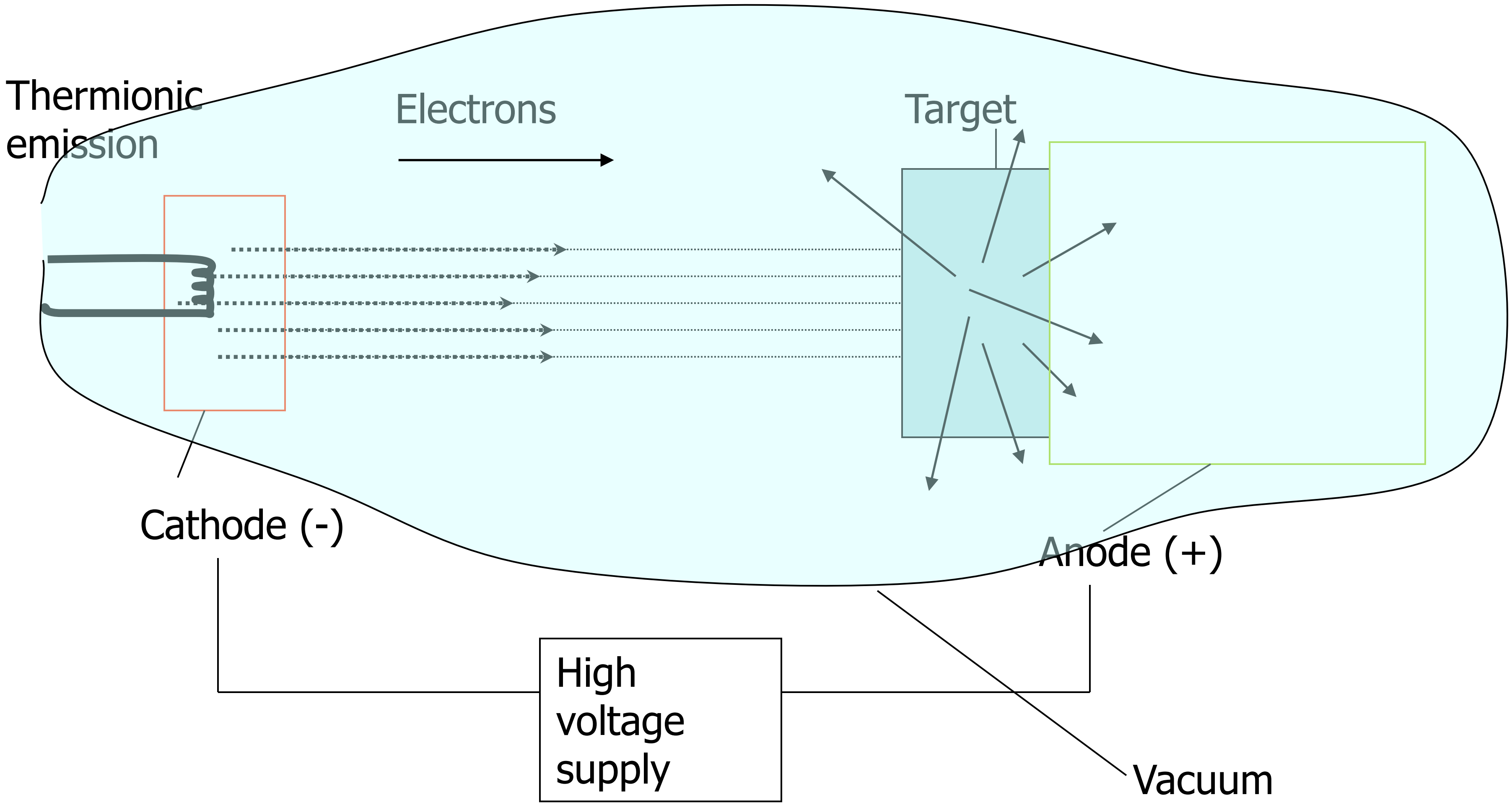
Wilhelm Conrad Röntgen

X-ray was discovered in 1895



Production of X-rays

-- X-ray tube



Production of X-rays: Bremsstrahlung

Brems-strahlung: “breaking radiation”

$$Efficiency = 9 \times 10^{-10}\, Z\, V$$

Tungsten target

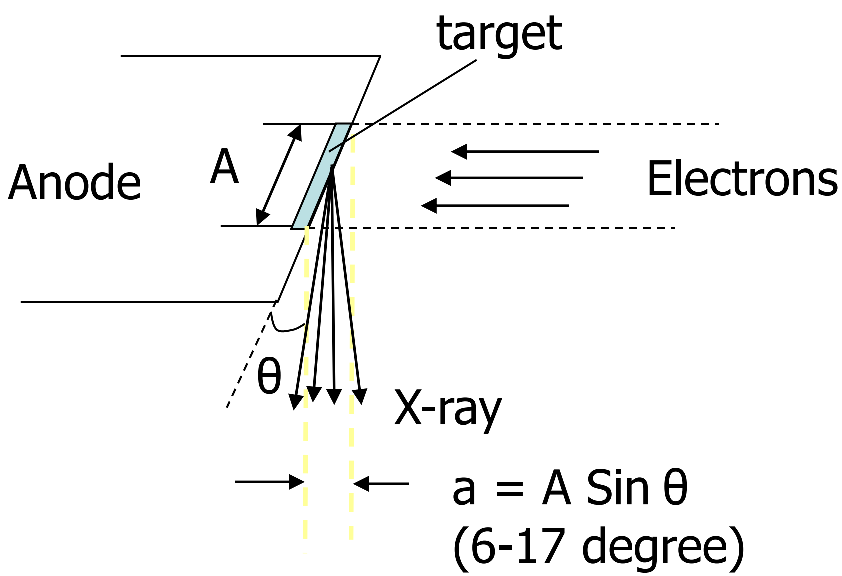
- Z=74 e.g. 100 kV efficiency = 0.7%

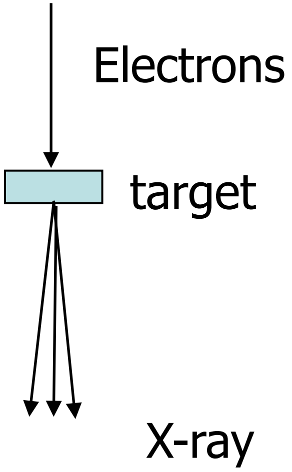
  (heat…)

- melting point = 3370 °C

Production of X-rays

Anode design – line focus principle





MV X-ray production:

Transmission target

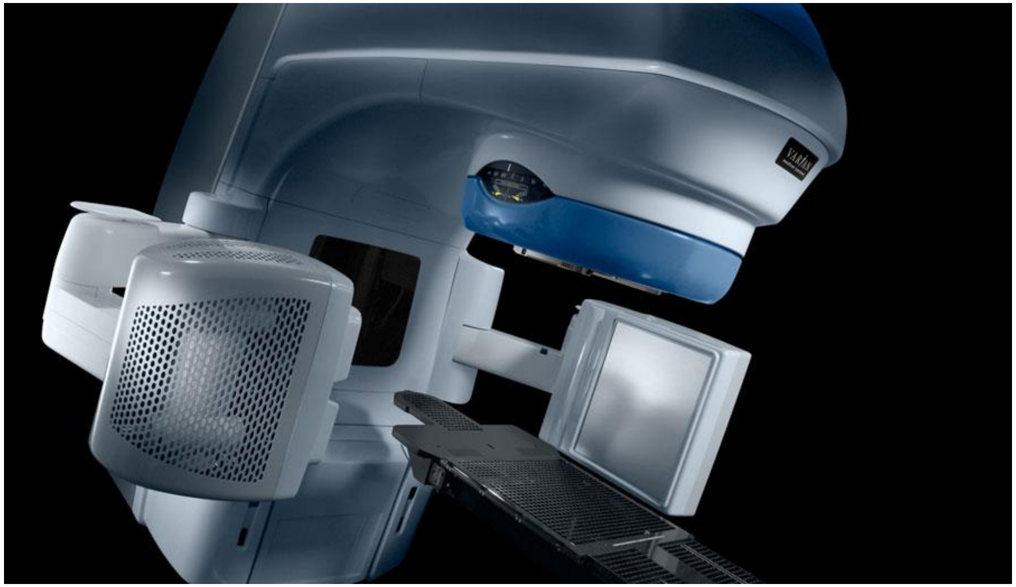
Focal spot: the apparent source of x-rays in the tube

- Small enough to produce sharp image (0.1-2mm)
- Large enough to tolerate a high heat loading

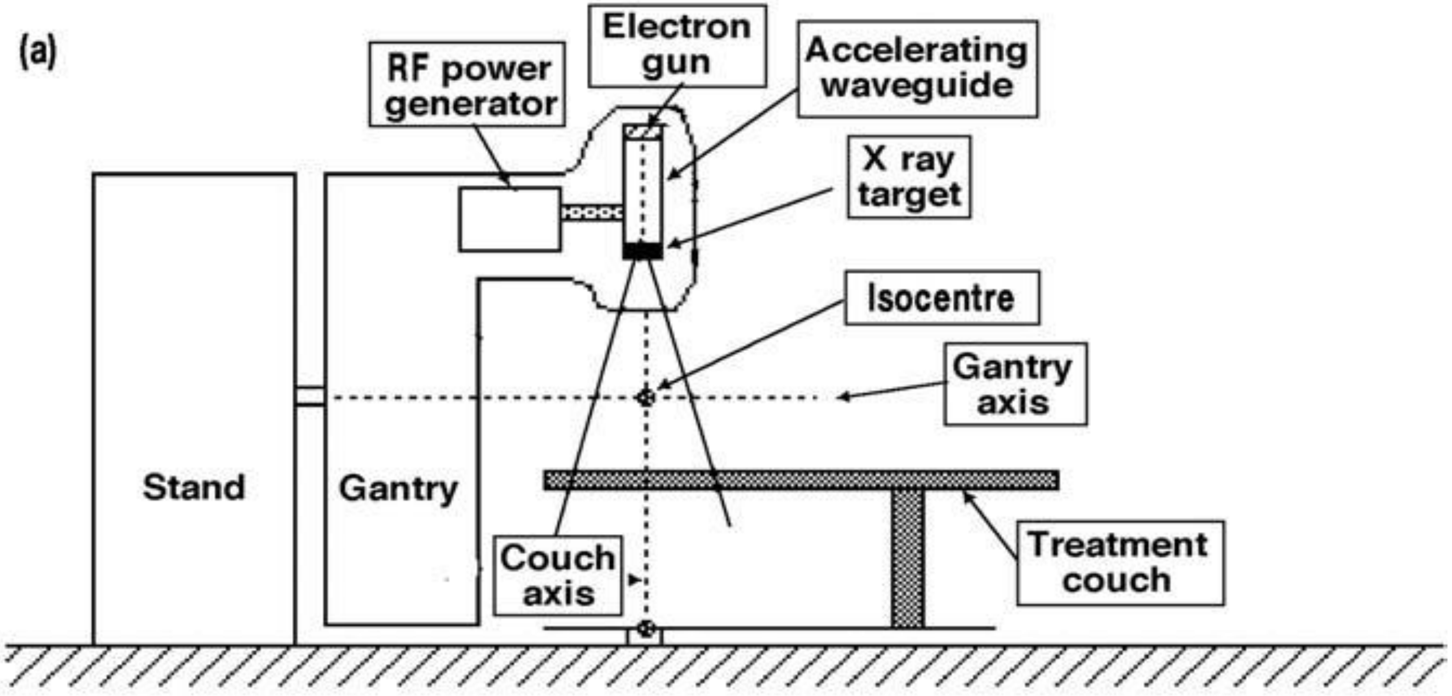
X-ray / Gamma-ray Producing Machines

- Linear accelerator (megavoltage machine)
- Cobalt-60 (“Teletherapy”) machine
- Kilovoltage machines

Linear accelerator (Linac)

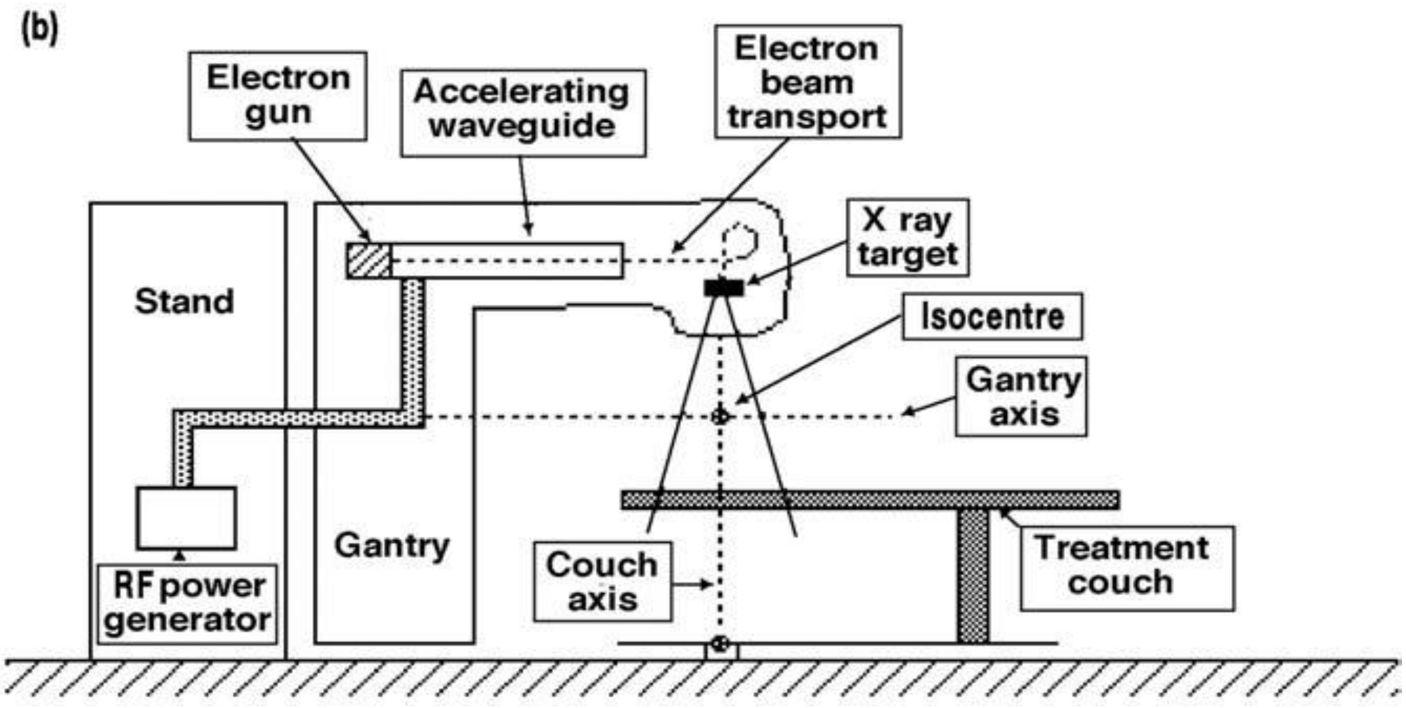


Components of linear accelerator



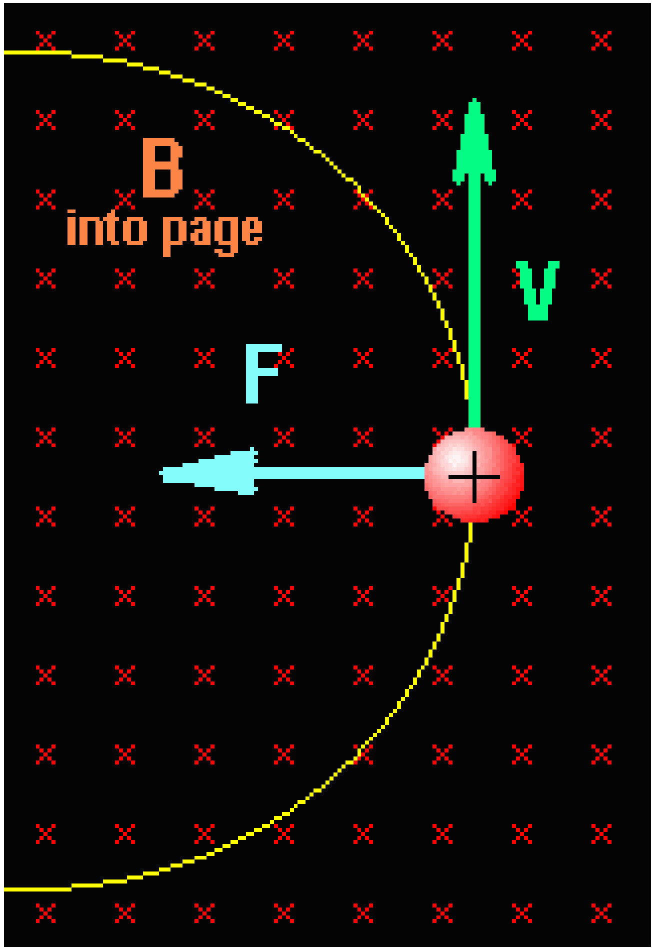
- Straight-through beam design: electron gun and target are permanently embedded into the accelerating waveguide, RF power generator is mounted in the gantry

Components of linear accelerator



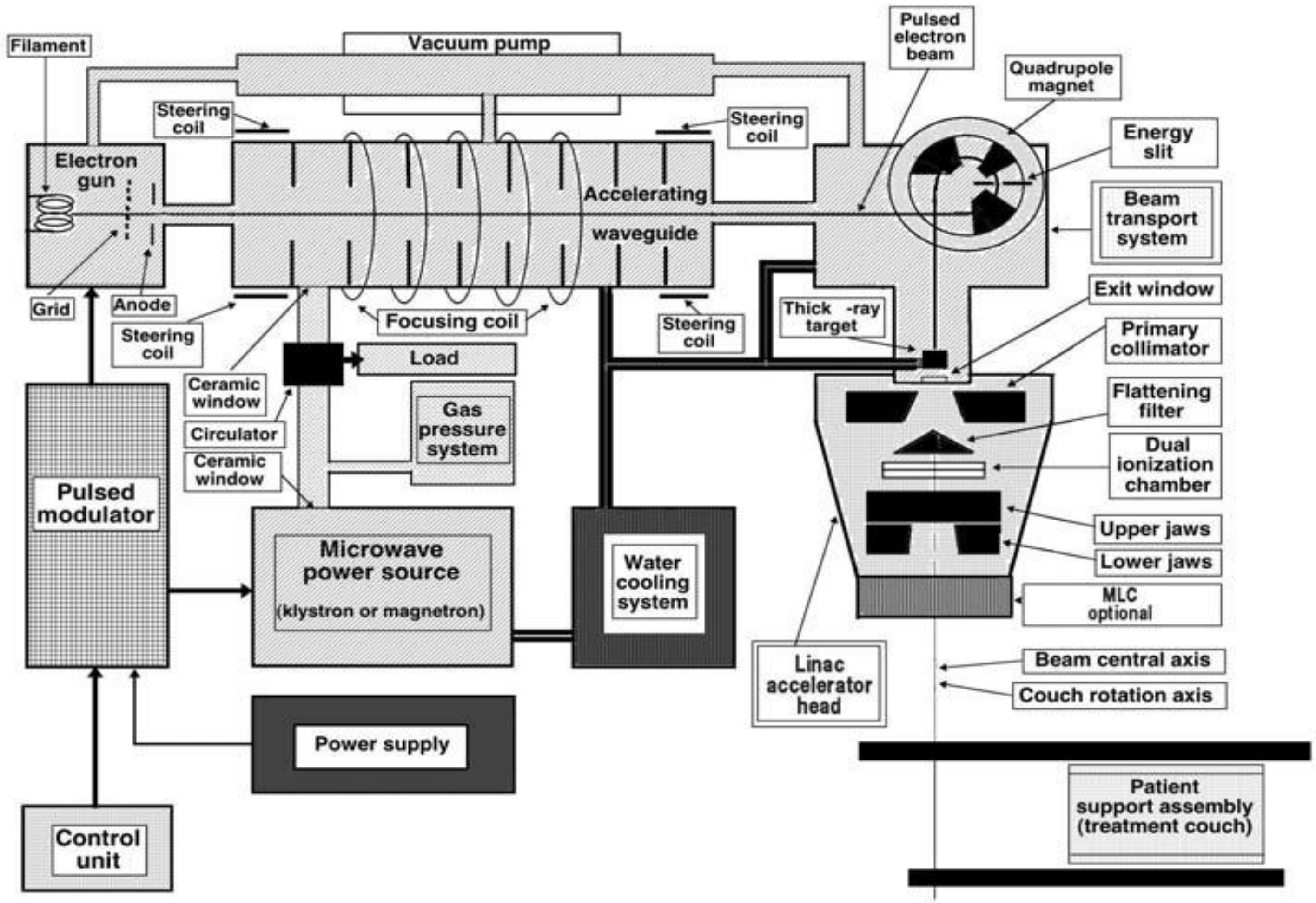
Most common

Charged particles in magnetic field

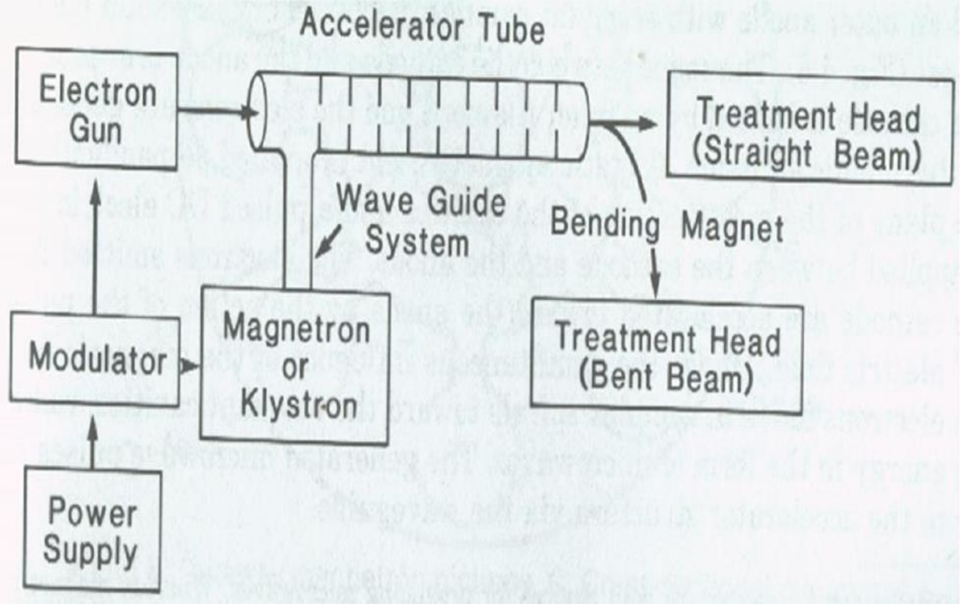


- Charged particle such as an electron or a proton moving in a magnetic field experience a force perpendicular to its motion.
- This force causes its trajectory to bend into an arc.
- The direction of the arc depends on the direction of the magnetic field relative to the velocity of the charged particle, and the charge (+ve or –ve) of the particle.

Components of linear accelerator



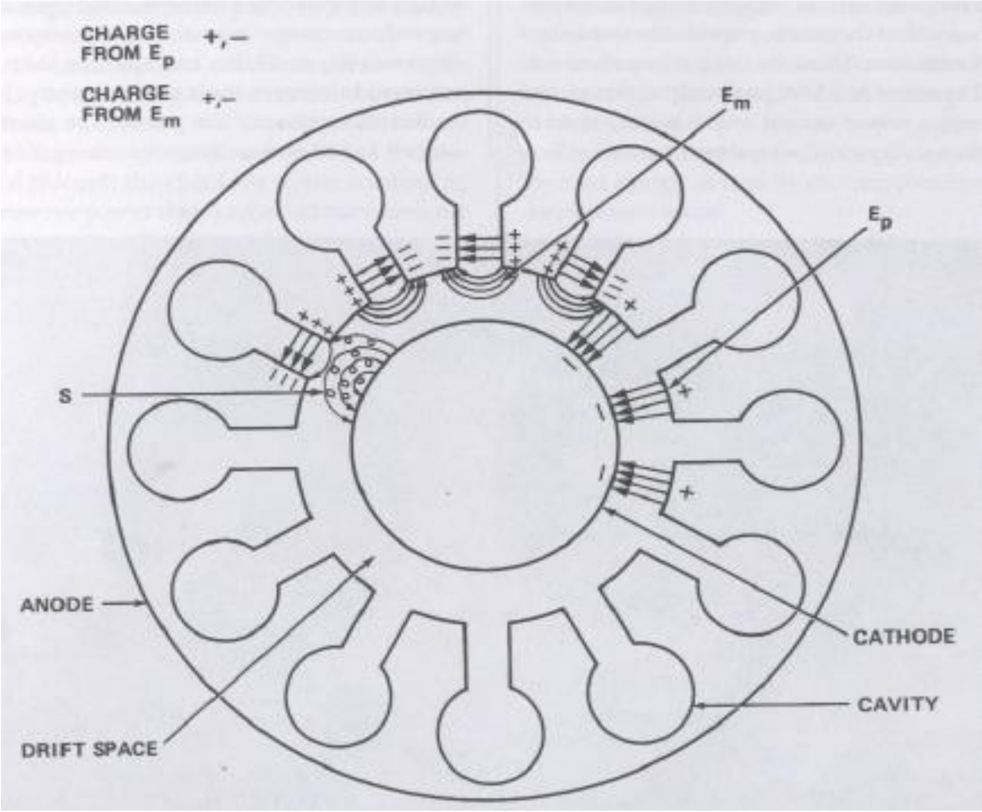
Major components of a linear accelerator



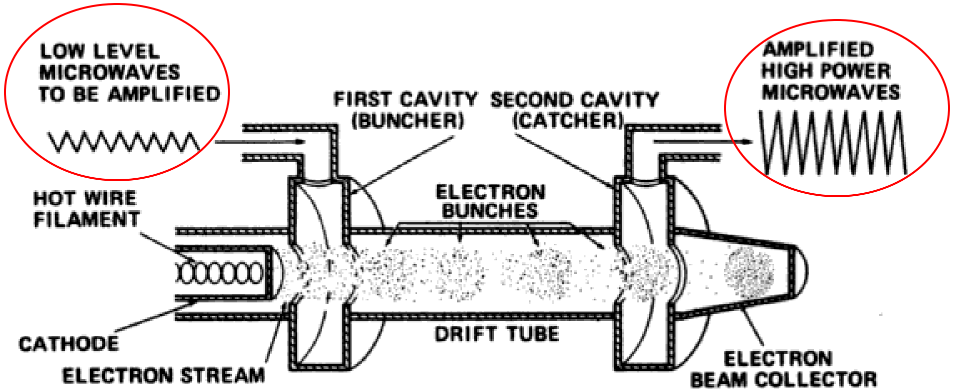
- **Electron gun: source of electron**
- **Klystron or magnetron: microwave power source, provides microwave power to accelerate electron**
- **Waveguide: conveys microwave power**
- **Accelerator tube (accelerating waveguide, or accelerator guide): microwave cavities energized by magnetron or klystron, in which electrons are accelerated**
- **Bending magnet: deflects electron from accelerator tube and focuses them on target**
- **Treatment head: contains beam shaping and monitoring devices**

Magnetron

- **Functions: microwave generator, generates microwave pulses of several microseconds duration.**
- **Repetition rate of several hundred pulses per second.**
- **Frequency ~3000 MHz.**
- **2-5 MW peak power.**
- **Less costly but less stable than a klystron.**
- **Usually used to power lower energy linacs.**



Klystron



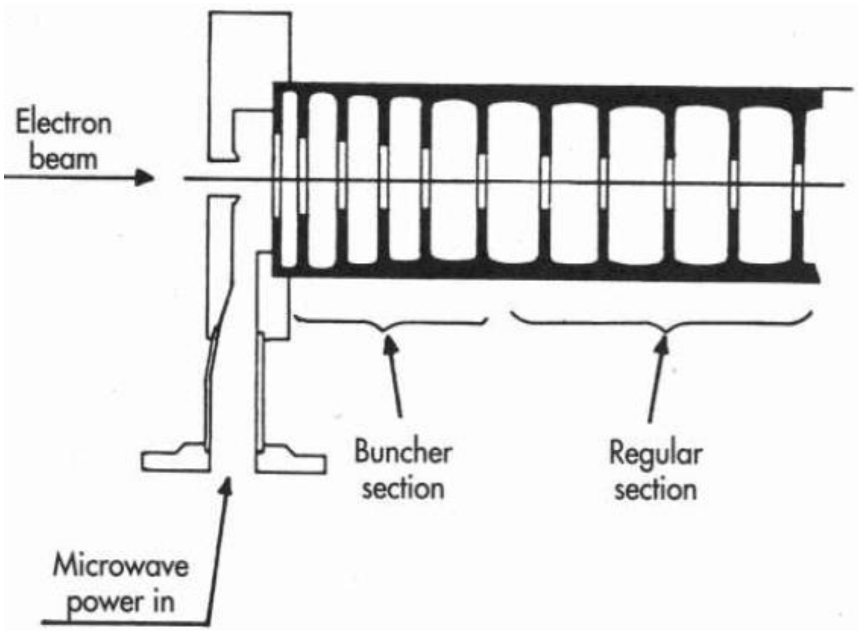
- **Function: microwave amplifier (needs low-power microwave input).**
- **2 cavity structure: Buncher and Catcher.**
- **Electrons are accelerated into buncher, which is energized by low energy microwaves. Microwaves set up alternating E fields across cavity, leading to electron bunching.**
- **Bunches reach catcher cavity, induce charges across ends and generate retarding E field. Electrons decelerate, kinetic energy converted into high-power microwaves.**
- **Operates at 3-7 MW peak power**
- **Usually used in high energy Linacs**

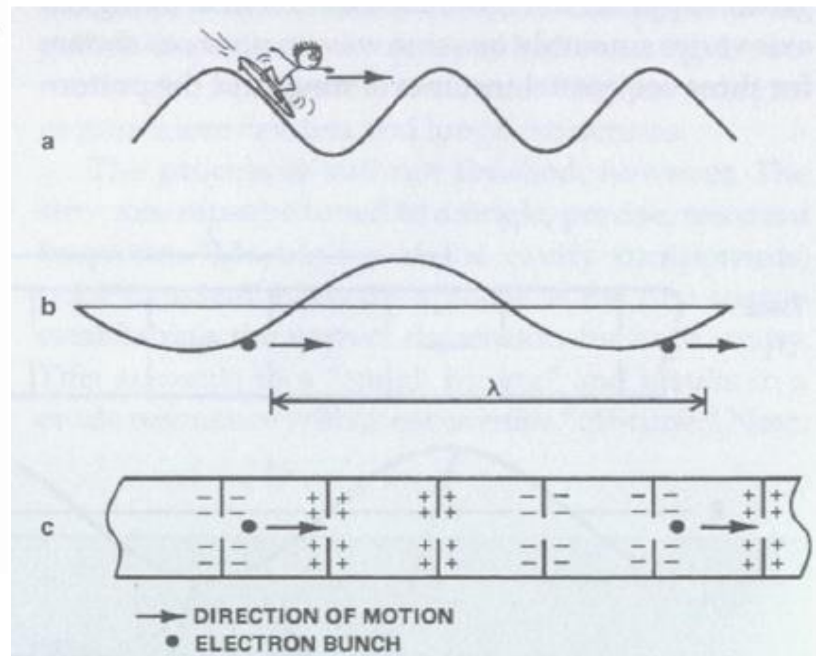
Accelerating waveguide

- General waveguide: “guides” electromagnetic waves from one point to another point
- Accelerating waveguide:
  - **Accelerate electron**
  - **Series of adjacent, cylindrical evacuated microwave cavities**
  - **Range from ~30 cm for 4-MeV units to > 1m for high-energy units**
  - **First few cavities vary in size, accelerate and bunch electron in a similar way as klystron cavities**
  - **Electrons gain energy, approach relativistic velocity**
  - **Two types of accelerator structures: Standing-wave and Traveling-wave.**


ABD

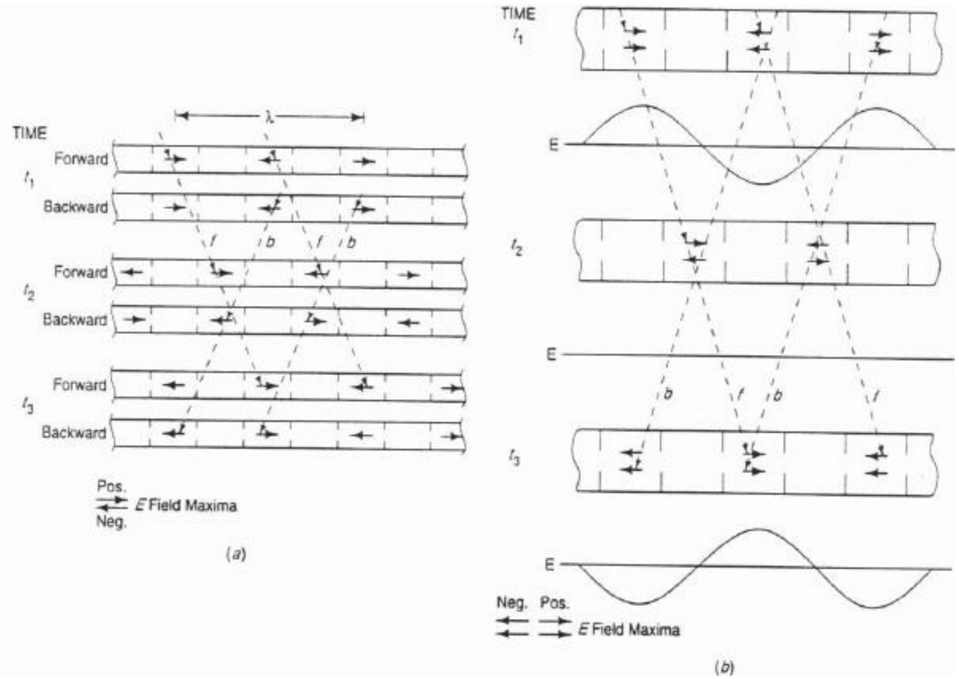
Traveling-wave accelerating waveguide

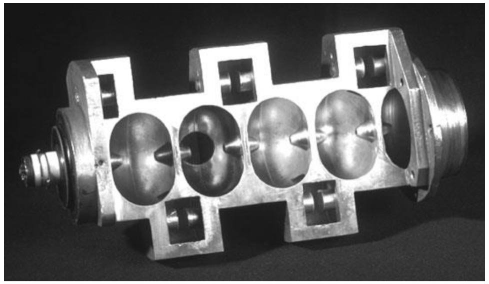




- Microwave travels in one direction
- Electrons “surf” down the traveling wave, accelerated by the moving electric field

Standing-wave accelerating waveguide

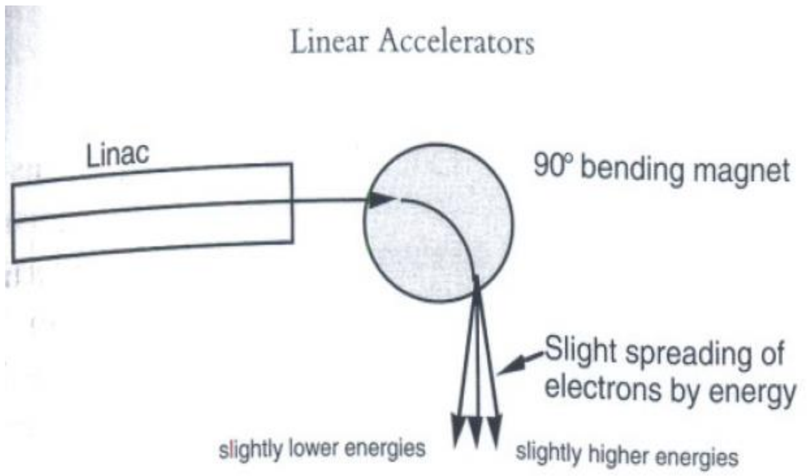


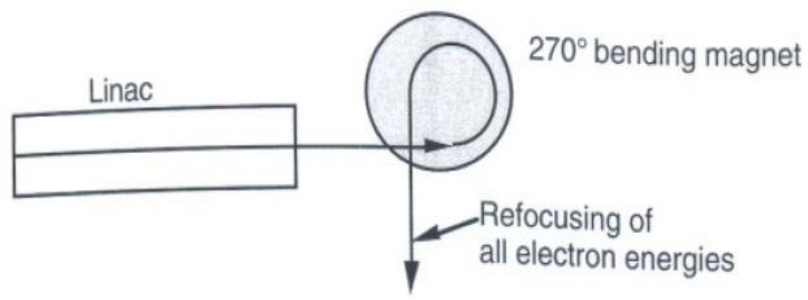


- Microwaves travel in forward and backward (by reflection) directions, forming a standing wave electric field
- Electrons gain energies from the standing-wave electric field. Every other cavity has zero electric field, which does not accelerate electrons and can be moved off axis (side coupling cavity): the accelerator waveguide is short compared to traveling waveguide.

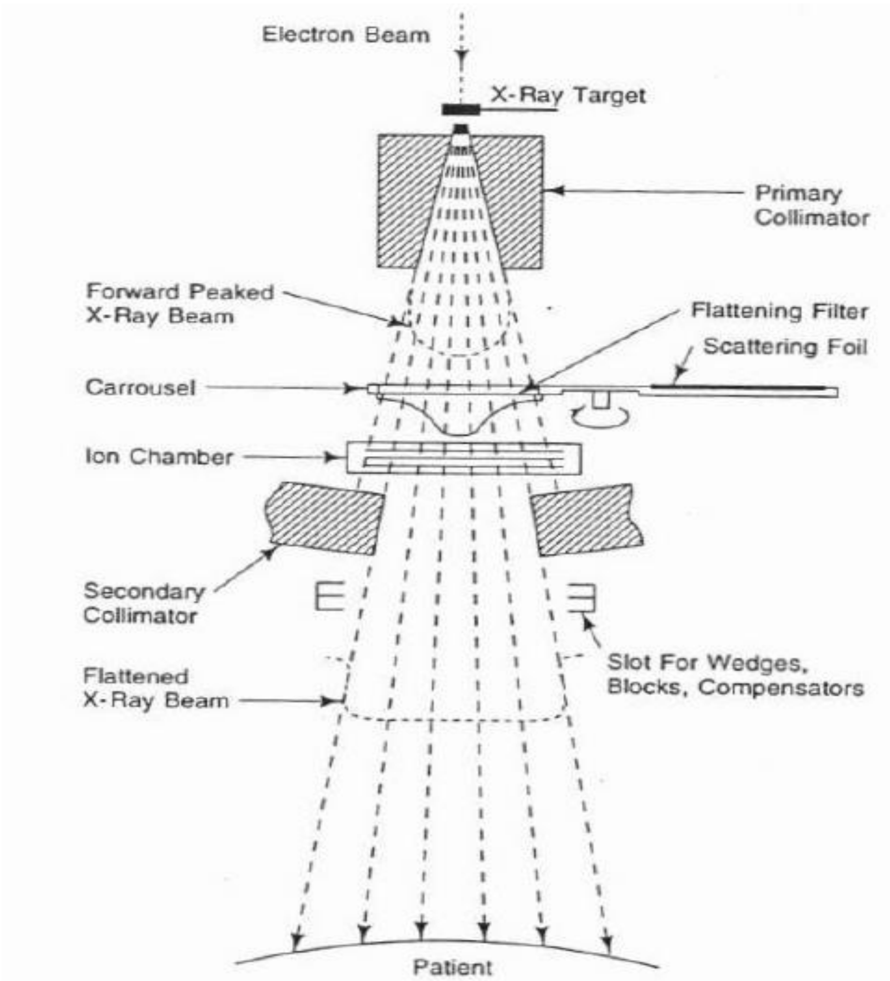
Bending magnet

- After leaving the accelerator structure, electron beam continues through an evacuated bending magnet.
- Electrons are deflected by the bending magnet to either strike a target (x-ray beam) or exit through treatment head via thin window for electron therapy.
- 90º bending magnet (Chromatic magnet): beam is spread (spatial dispersion)
- 270° bending magnet (Achromatic magnet): beam is refocused
- Lower energy linacs have straight-through beam and do not need bending magnet.





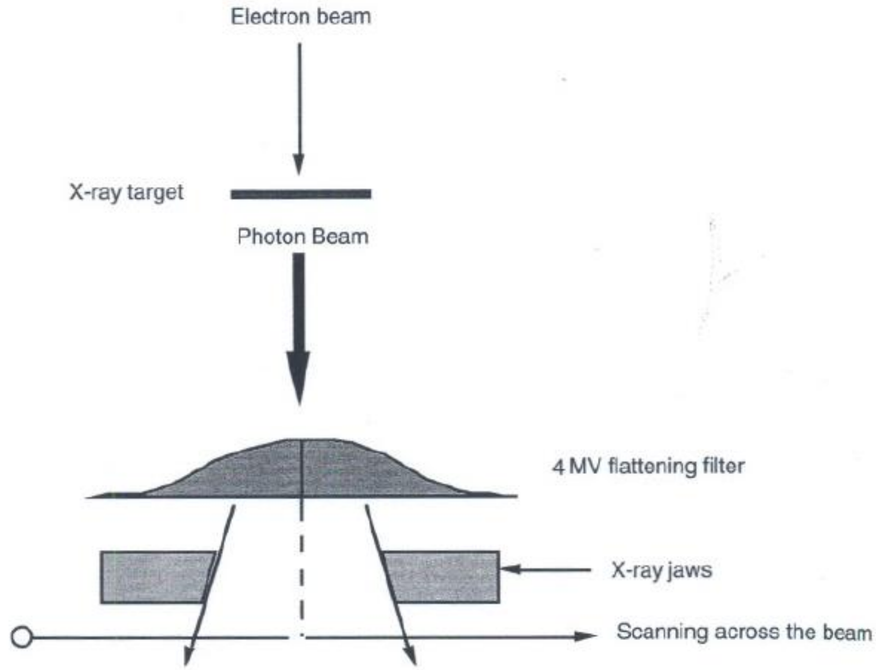
Treatment head (photon therapy)



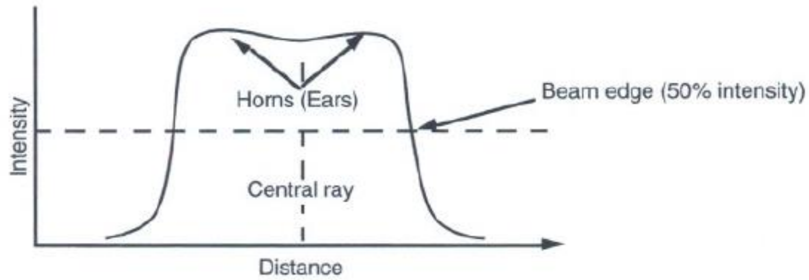
- Target: tungsten
- Flattening filter (lead, steel, copper, brass, etc.)
- Beam collimation by second collimators, which consist of jaws and multi-leaf collimator (MLC)

Flattening filter

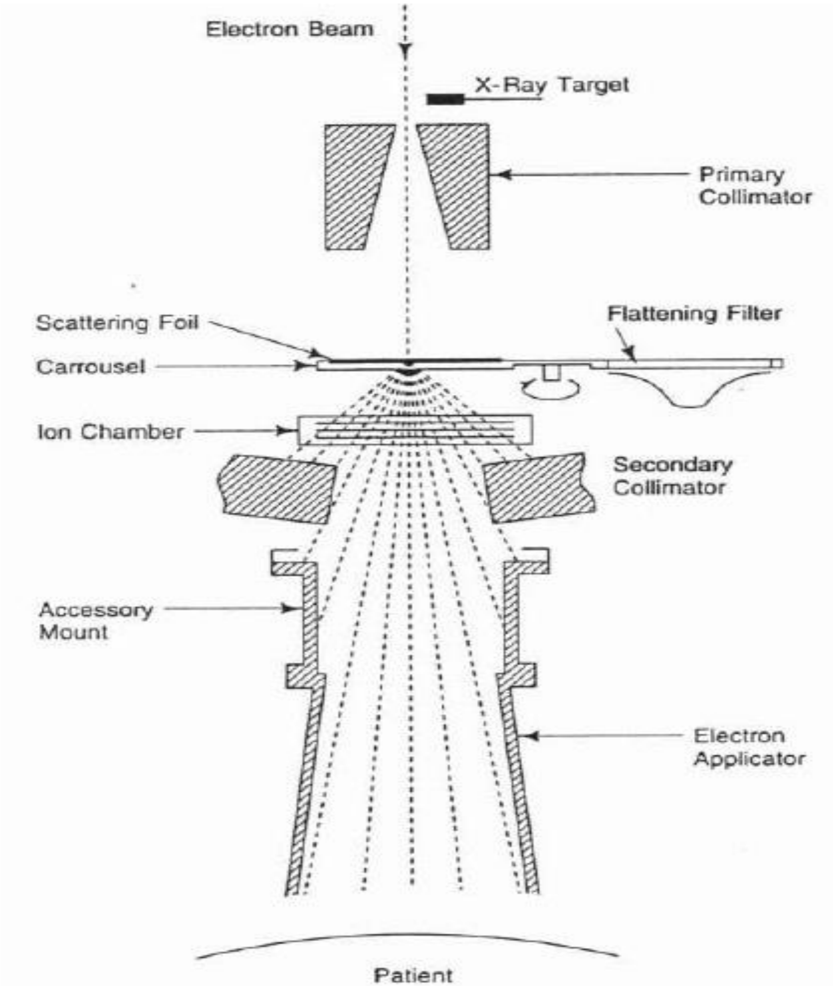
a.



b.

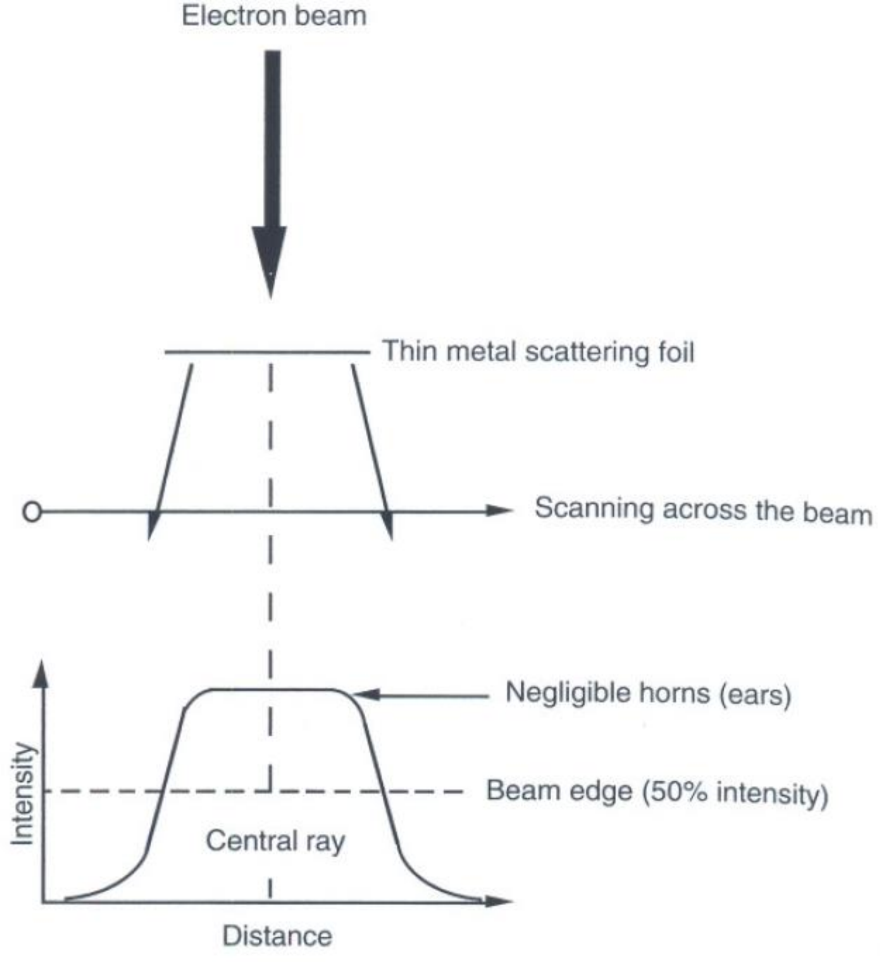


Treatment head (electron therapy)



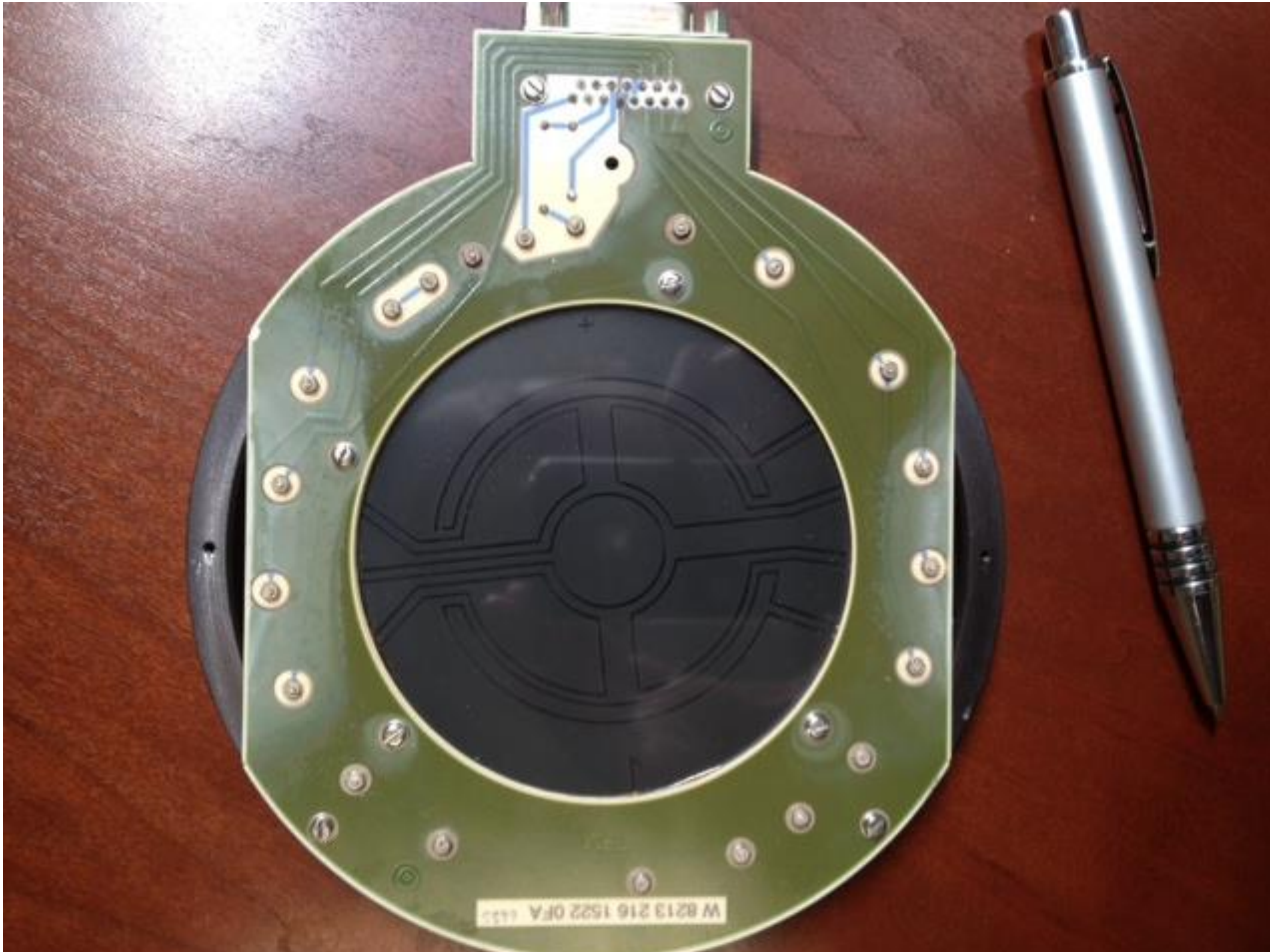
- X-ray target is removed
- Scattering foil (a fraction of millimeter, gold, silver, steel, aluminum, brass, etc) is used instead of the flattening filter used in photon therapy
- Beam collimation by jaws (i.e., secondary collimators) and electron applicator (cone)

Scattering foil



Monitor chamber

- Ionization chambers located in the treatment head to monitor dose, symmetry, energy
- Made of thin, low Z materials (aluminum or plastic), almost no effects on the beam
- Usually consists of two independent chambers: the second chamber is used as a backup to avoid overtreatment if the first one fails; In some machines, a third chamber is used to monitor symmetry or energy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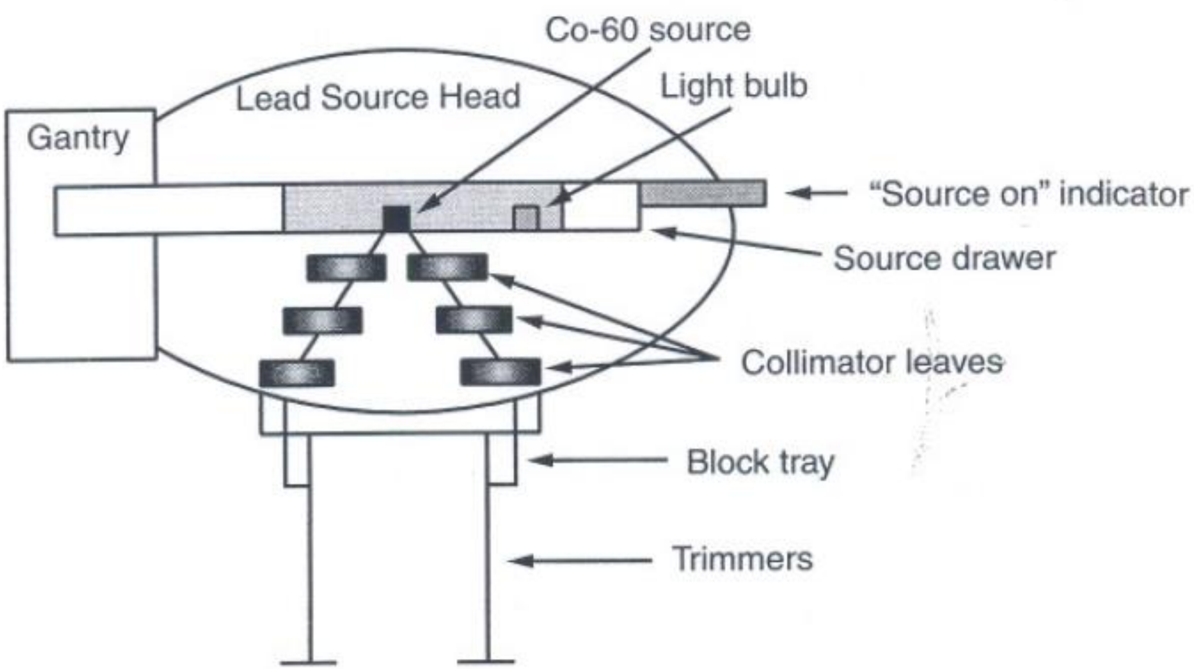
Cobolt-60 machine (“Teletherapy”)

- Co-60: high specific activity (Curies per gram), high average photon energy.
- Source, in form of solid cylinder, discs or pellets, contained in stainless steel capsule welded sealed, to ensure no leakage.
- Beta decay: ^{60}Co decays with half-life of 5.26 years.
- 2 photons (gamma rays) are emitted: 1.17 and 1.33 MeV.
- The average energy is 1.25 MeV.
- Line spectrum, in contrast to the bremsstrahlung X-ray (continuous spectrum)

Cobalt-60 machine head



- Timer error:

  Difference between the beam-on time setting and the time the source is in the treatment position

- Source continues radiating, causing significant level of background radiation

Geometric Penumbra

- Penumbra: region at the edge of a radiation field where the dose rapidly falls as a function of distance from the beam axis

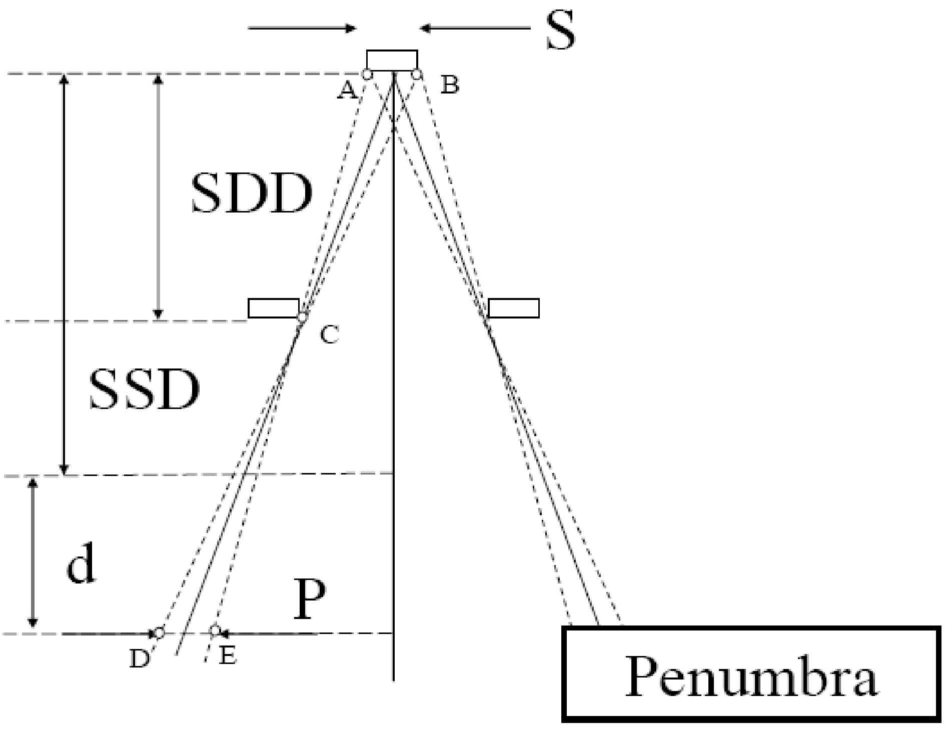
- Geometric penumbra: due to finite source size

- Geometric penumbra size
  at depth of *d*:
  $P = S\ (SSD + d - SDD)\ /\ SDD$,

  on skin (i.e., $d = 0$):
  $\boldsymbol{P = S\ (SSD - SDD)\ /\ SDD}$,

  where *S* is source size, *SDD* is source-diaphragm-distance, *SSD* is source-skin distance

- Penumbra trimmer (increasing SDD) is used in Cobal-60 machine to reduce the penumbra



Kilovoltage machines

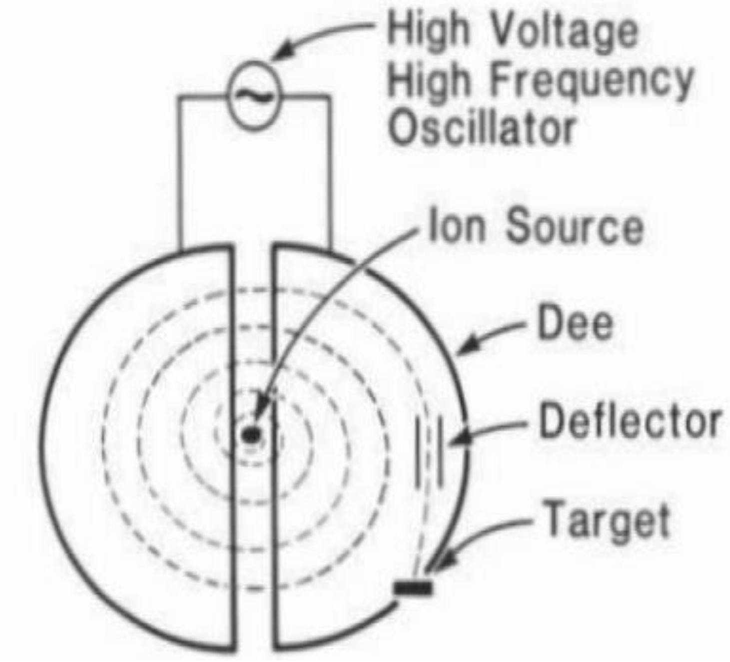
- Contact therapy: 40-50 kV, for irradiation of shallow lesions 1-2mm, almost completely absorbed within 2 cm of tissue. A 0.5-1.0-mm-thick Al filter used to absorb very soft component of energy spectrum.

- Superficial therapy: 50-150 kV. For lesions of about 5 mm depth. Al filters of 1-6 mm used to harden beam.

- Orthovoltage therapy: 150-500 kV. Filters used to achieve HVLs between 1-4 mm Cu. Useful for lesions 2-3 cm deep.

- Supervoltage therapy: 500-1000 kV.

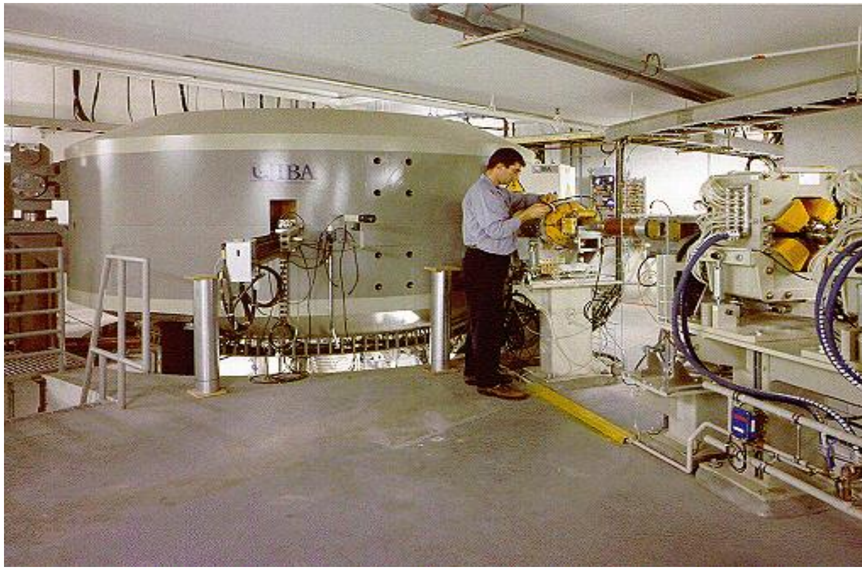
Cyclotron



- Consists of highly evacuated metal half-discs (Dees)

- Accelerate heavy charged particles (proton, deuterons) by an oscillating electric field between the Dees

- Magnetic field confines the charged particles to a circular path



Cyclotron

Synchrotron

Questions

- What is the purpose of a magnetron? Klystron?

Questions

- What is achromatic bending magnet?

Questions

- What is the purpose of a monitor chamber?

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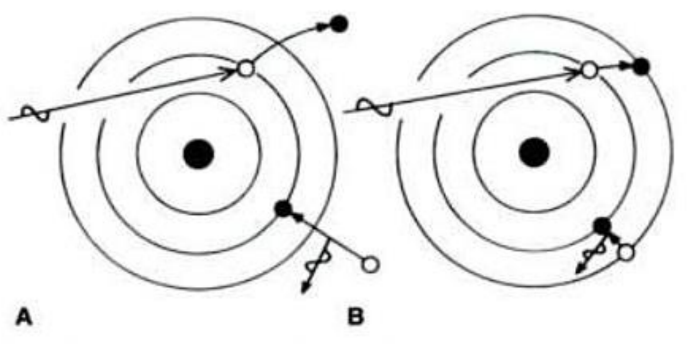
Ionization vs. Excitation

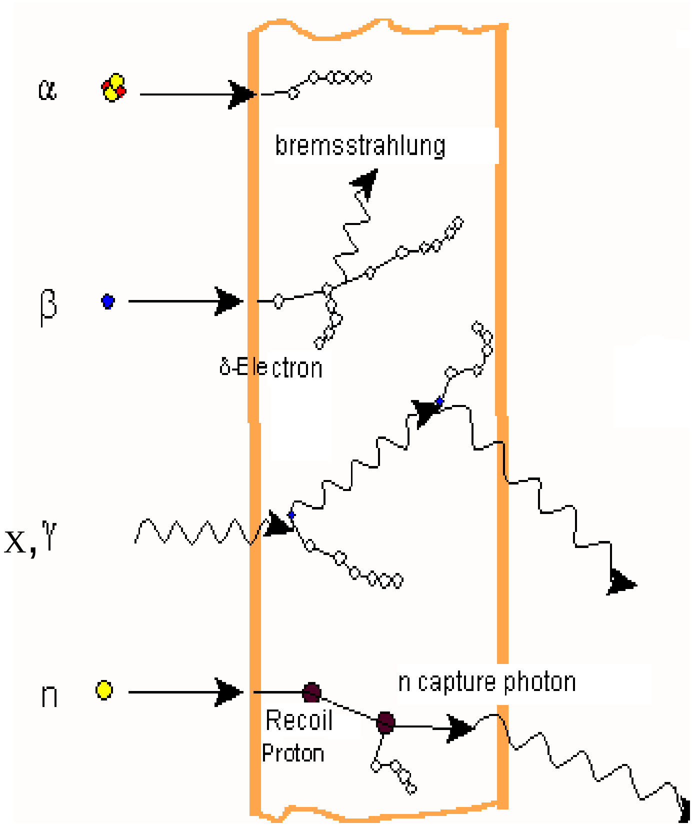


Ionization Excitation

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

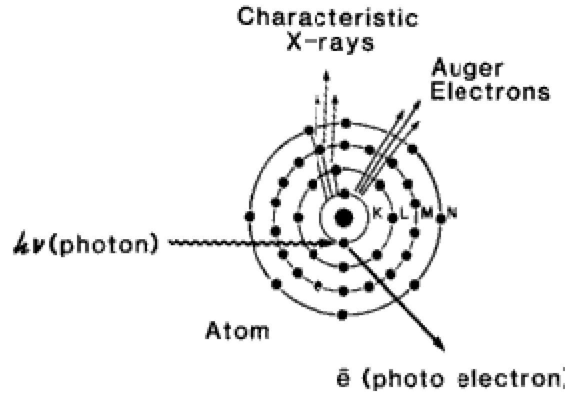
Ionizing Radiation

- Electromagnetic or particulate **radiation capable of producing ion pairs** by interaction with matter:
  - **X** and **Gamma** rays (photons)
  - **Alpha** particles
  - **Beta** particles (electrons)
  - **Neutrons**
  - Charged nuclei

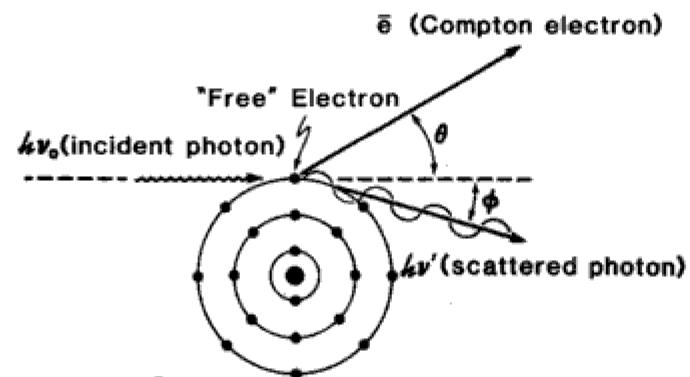


Ionizing radiation interaction by photons

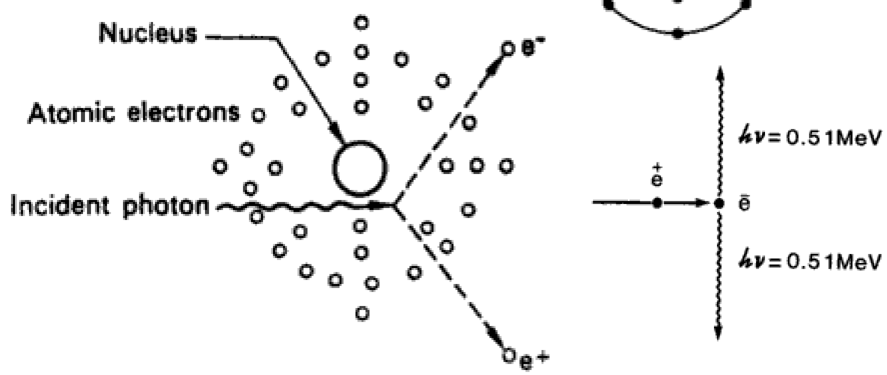
- Photoelectric effect



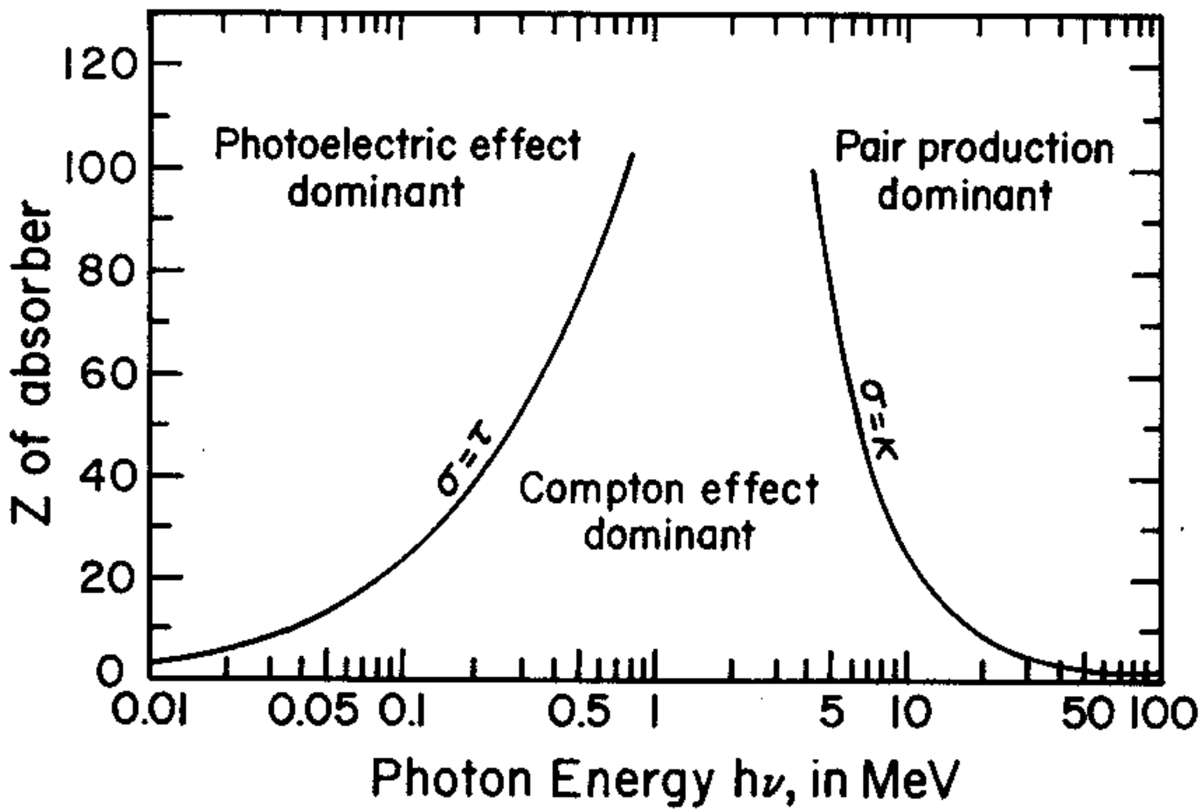
- Compton effect



- Pair production



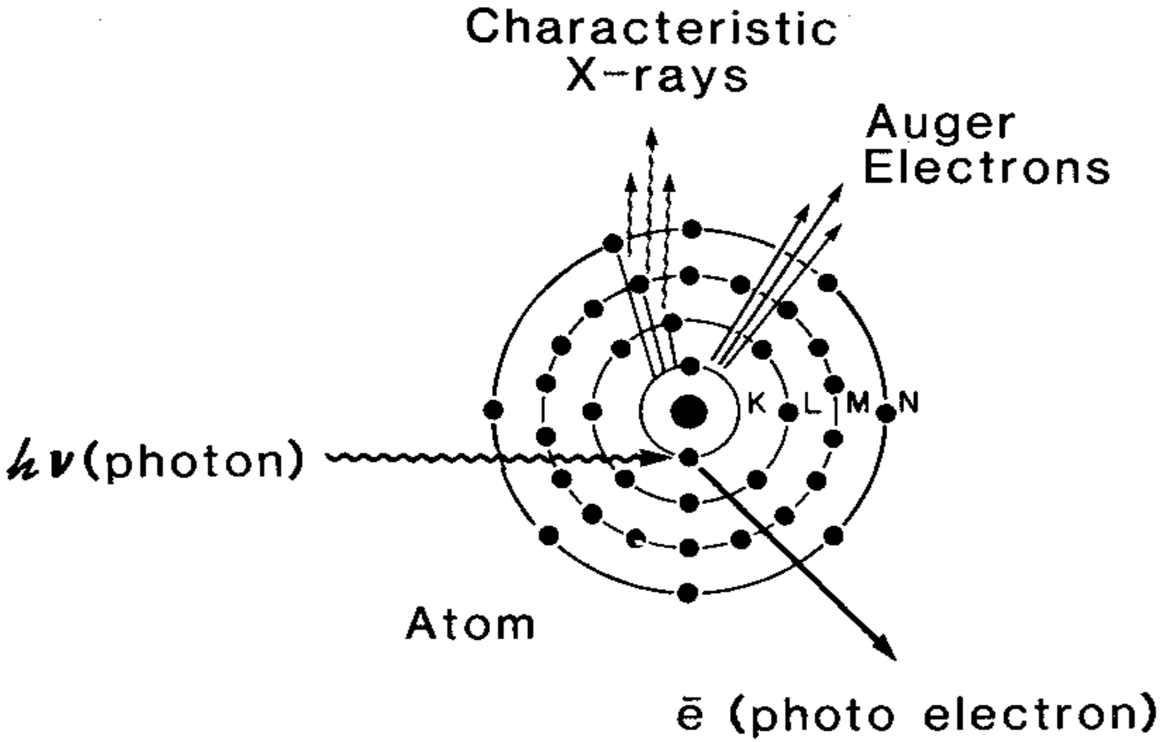
Relative importance of the three major types of photon interactions. The curves show the values of Z and Eγ for which two types of effects are equal



Photoelectric interaction (photo-ionization)

- Incoming photon is completely absorbed by the atom
- Total photon energy is transferred to an orbital electron of the atom
- The electron is ejected from the atom (after overcoming its binding energy)
  - "the photoelectron"
- The atom is left with a shell vacancy
  - Typically, inner shell vacancy
  - Followed by orbital electron downward cascade to reach lower energy state
    - Characteristic radiation
    - Auger emission

Photoelectric interaction (cont.)



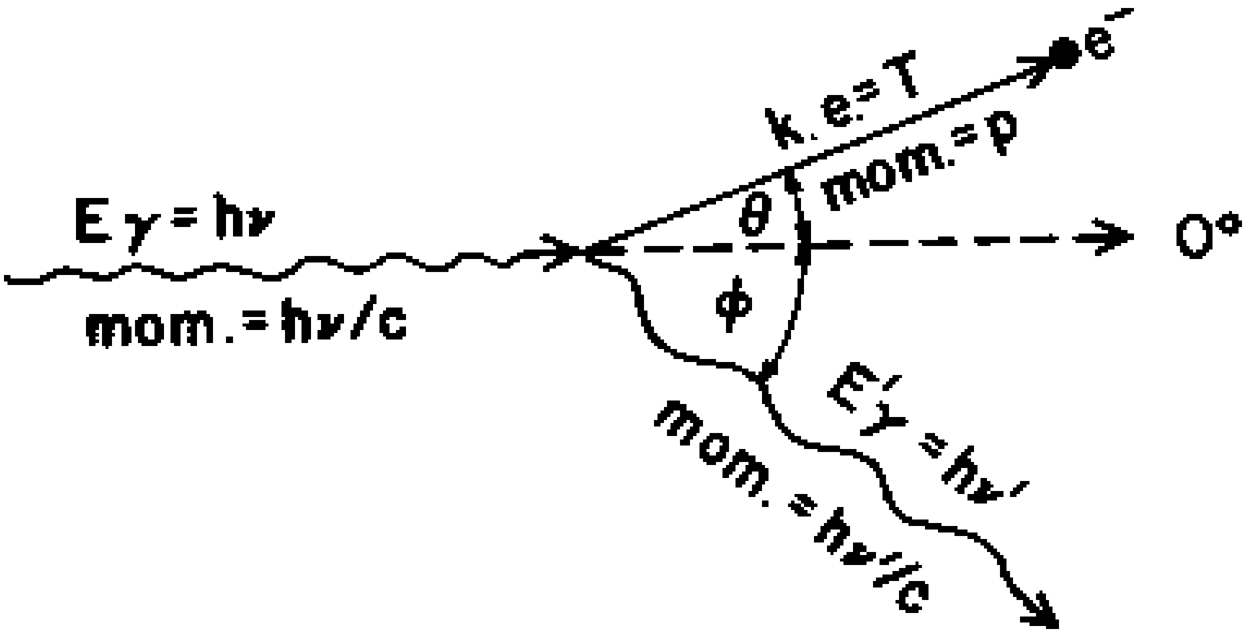
P.E. Effect: Points to remember

- P.E. involves bound electrons
- Probability is highly dependent on Z
  - Therefore a good discriminator of tissue composition in diagnostic imaging
- Probability decreases rapidly with E
  - Important when photon energies are $< \sim 100$ keV
  - Principle of dual energy imaging (inc. DEXA, dual-E CT/chest x-ray)
- Direction of photoelectron emission
  - At low energy, likely towards 90°
  - At high energy, forward directed

Compton Scattering

- "Inelastic scattering"
- Involves "free electrons", or loosely bound outer shell orbital electrons
- Photon transfers part of its energy to the electron, setting the latter in motion ("Compton electron")
  - Compton electron moves in the forward (hemisphere) direction
  - Scattered photon can be in any direction (incl. backscatter)
- Is the most dominant interaction in RT
  - Between 100 keV to 10 MeV, it is the most probable process
- Cross section can be determined from Klein-Nishina formula

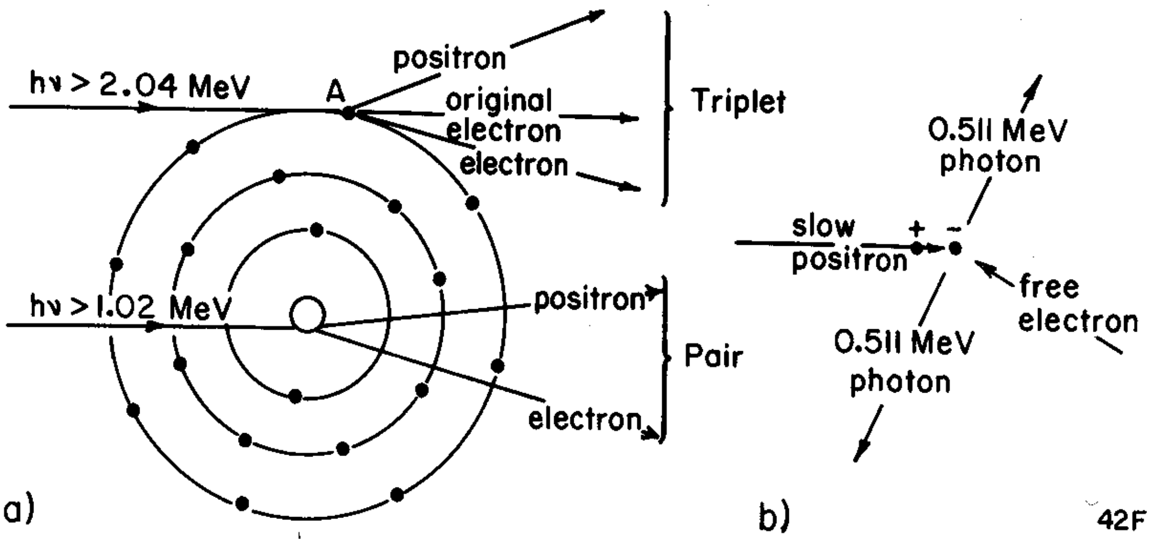
COMPTON EFFECT



Compton Scattering
Points to Remember

- Cross section decreases at high energies
- Proportional to electron density
  - Electron density per gram of any medium is approximately the same (except for hydrogen-rich – why?), so Compton energy transfer per gram is approximately constant in different types of tissues
    - RT “Dose” is relatively uniform in tissues of different compositions
- Compton process is less efficient towards low photon energies
  - Eventually will need P.E. to remove the photon from the beam

Pair Production

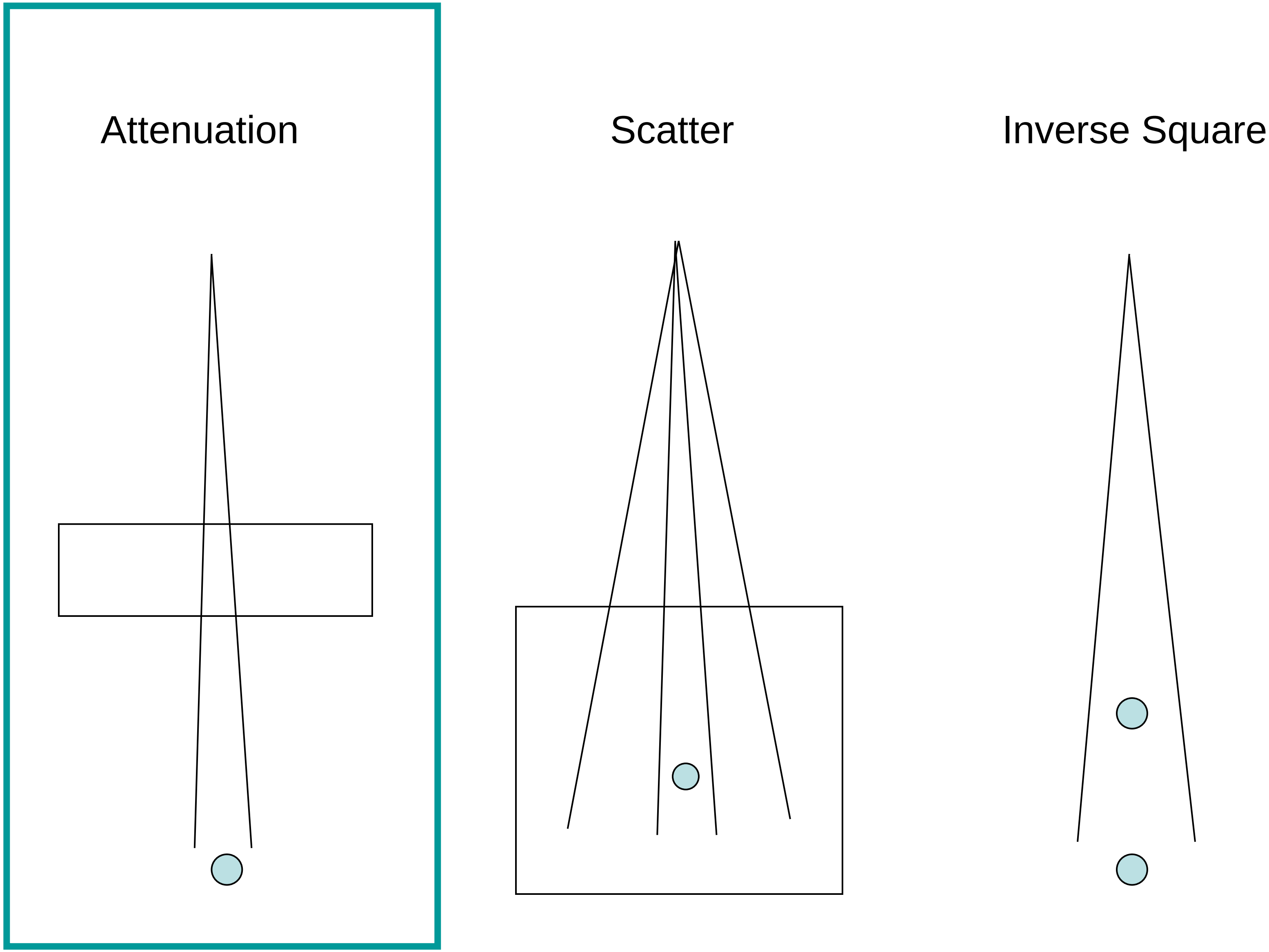


$h\nu = e_{+} + e_{-} + 1.02$ MeV

Threshold: 1.022 MeV (equal to rest mass of 2 e)

Energy distribution between e+ and e- ranges from 0 – 50% each.

Momentum is conserved between all 4 species (inc. nucleus).


Attenuation
Scatter
Inverse Square

Attenuation

- Photon may be
  - Absorbed- deposit all their energy
  - Scattered- direction and energy changed
  - Transmitted- unaffected
- If absorbed or scattered
  - Removed from beam = Attenuated
  - Attenuation is the removal of energy from the beam

What can be an attenuator?

- Patient
- Table
- Block
- Tray
- Others?

Attenuation coefficient

- Represents the probability per unit thickness (or per unit mass) that any one photon will be attenuated
- Is a function of the material
- Is a function of the energy of the photon beam

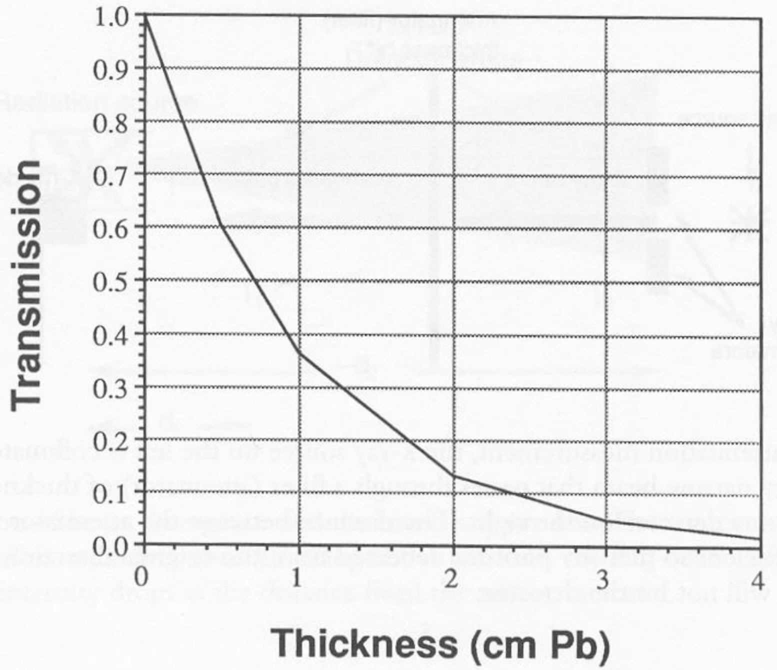
HVL

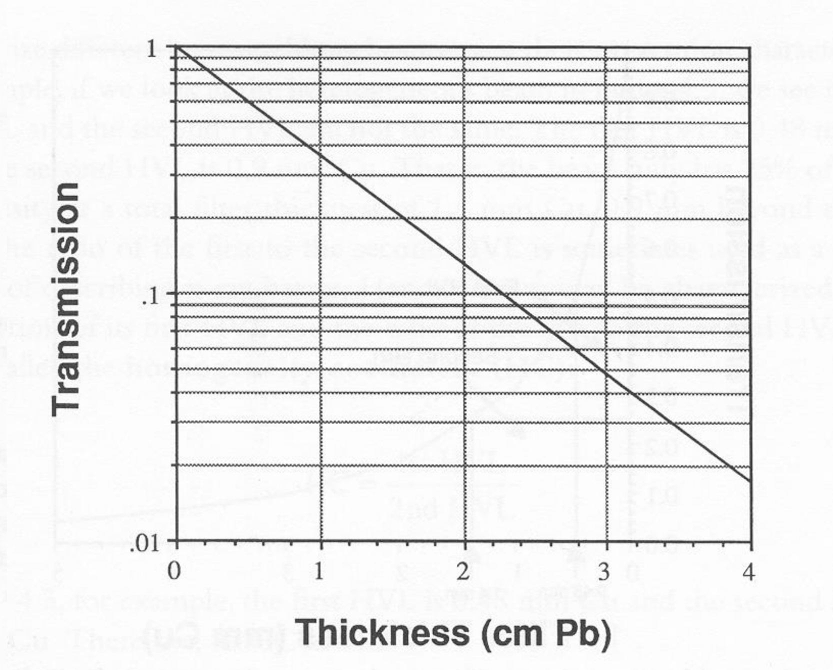
- Half value layer: is the thickness of material required for a particular material to cut the beam’s intensity in half.

- HVL is dependent on beam energy and material

Transmission of Cs-137 beam

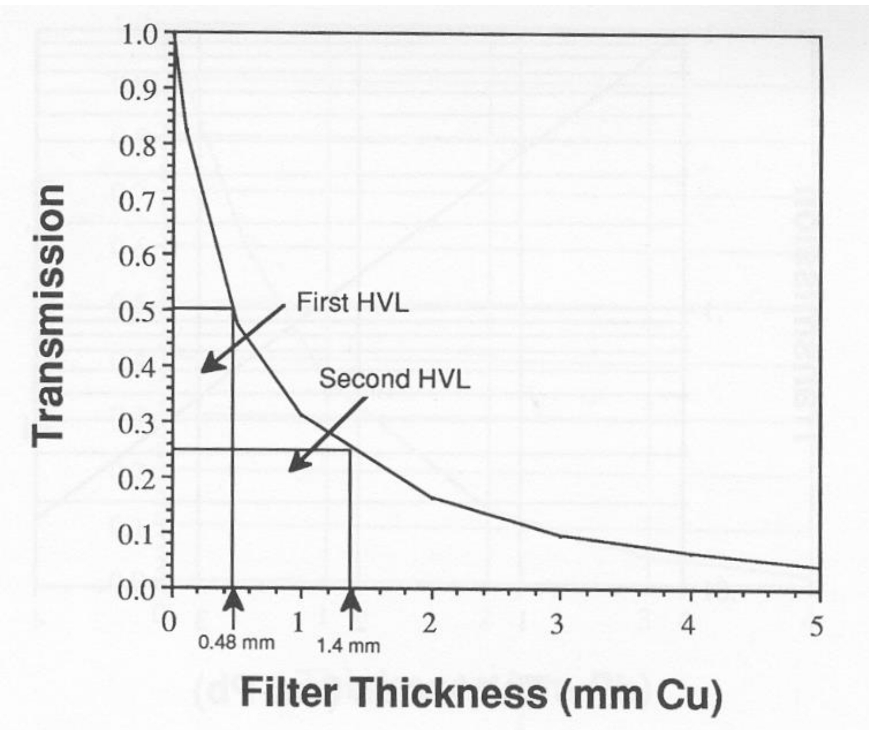
(Mono-energy beam)

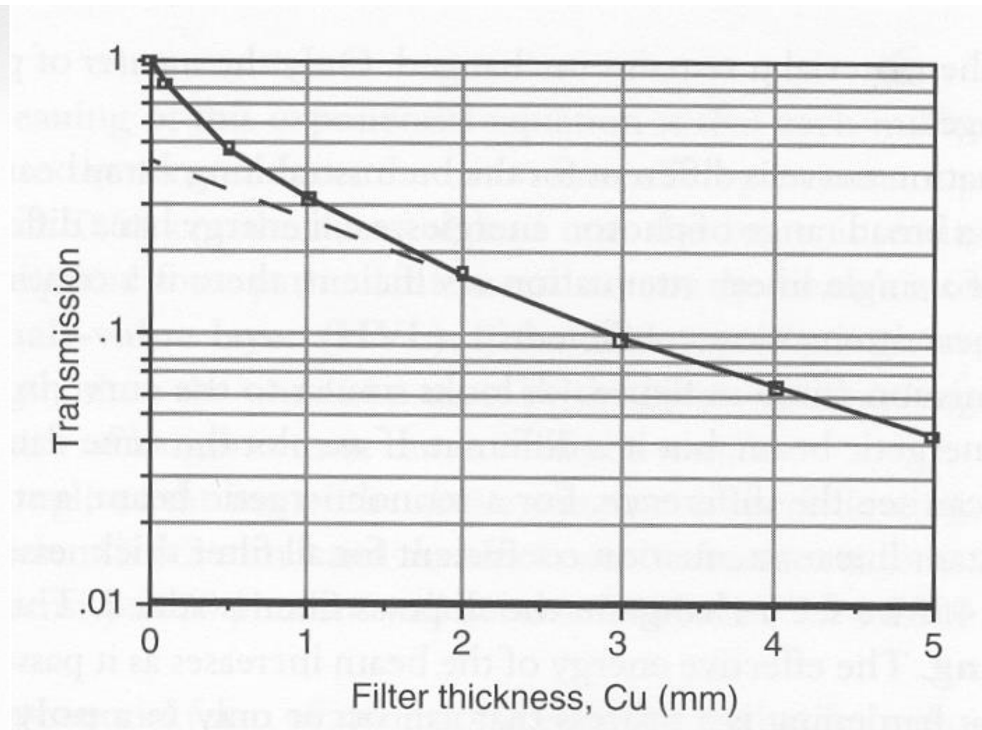




Transmission of bremsstrahlung beam

(Poly-energy beam)





"Beam Hardening"

Question

• An orthovoltage beam has an HVL of 2 mm Cu. What percentage will be transmitted through 8 mm Cu?

a. 25%
b. 50%
c. 6.25%
d. 75%
e. 93.75%

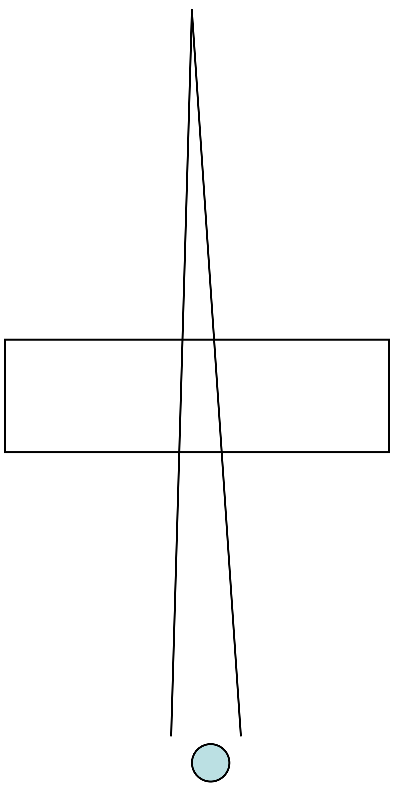
1 HVL: 50%
2 HVL: 25%
3 HVL: 12.5%
4 HVL: _____

Question

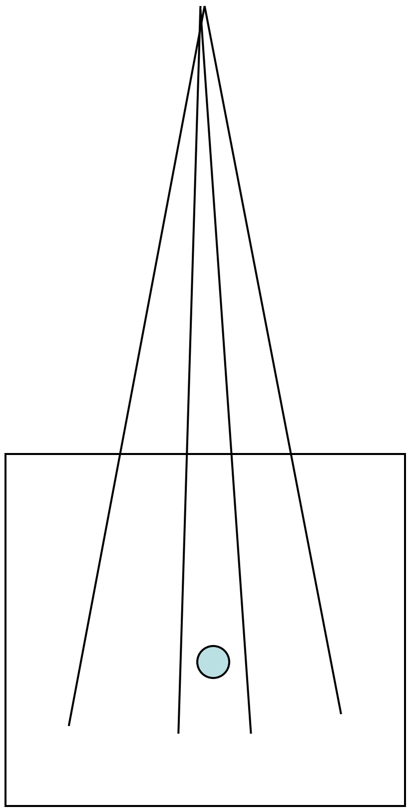
- Add 1 mm Cu filtration to the beam. HVL will increase or decrease? Why?

Beam hardenening…

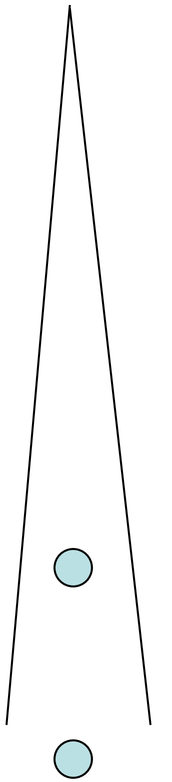
Attenuation

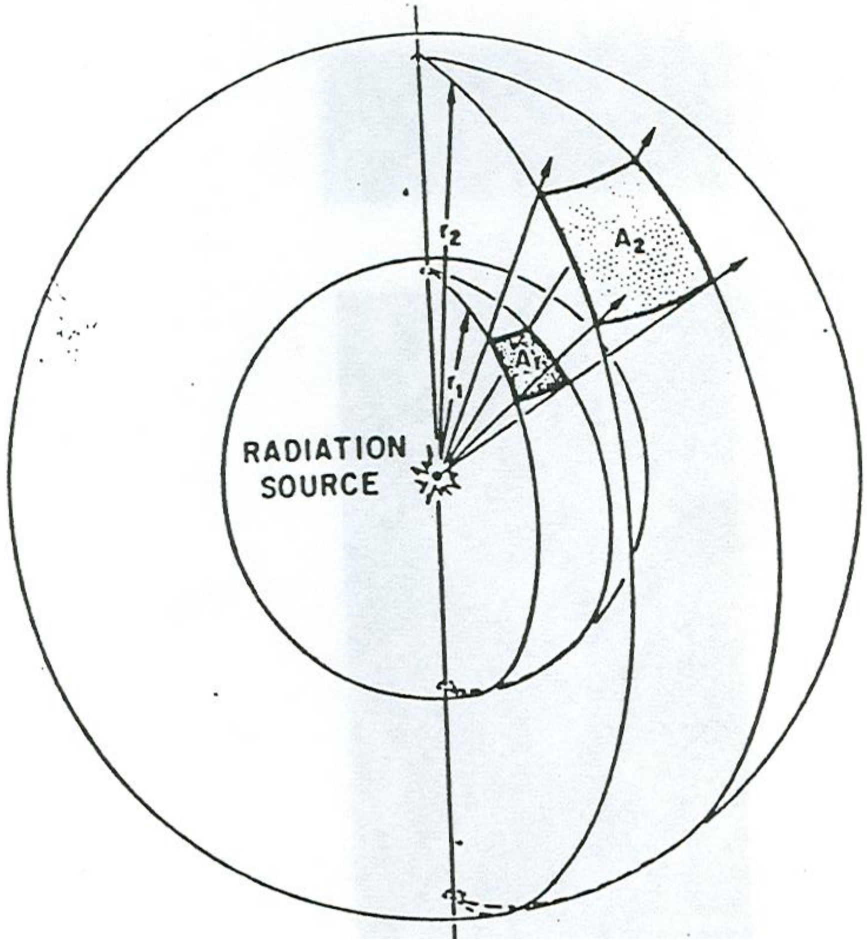


Scatter

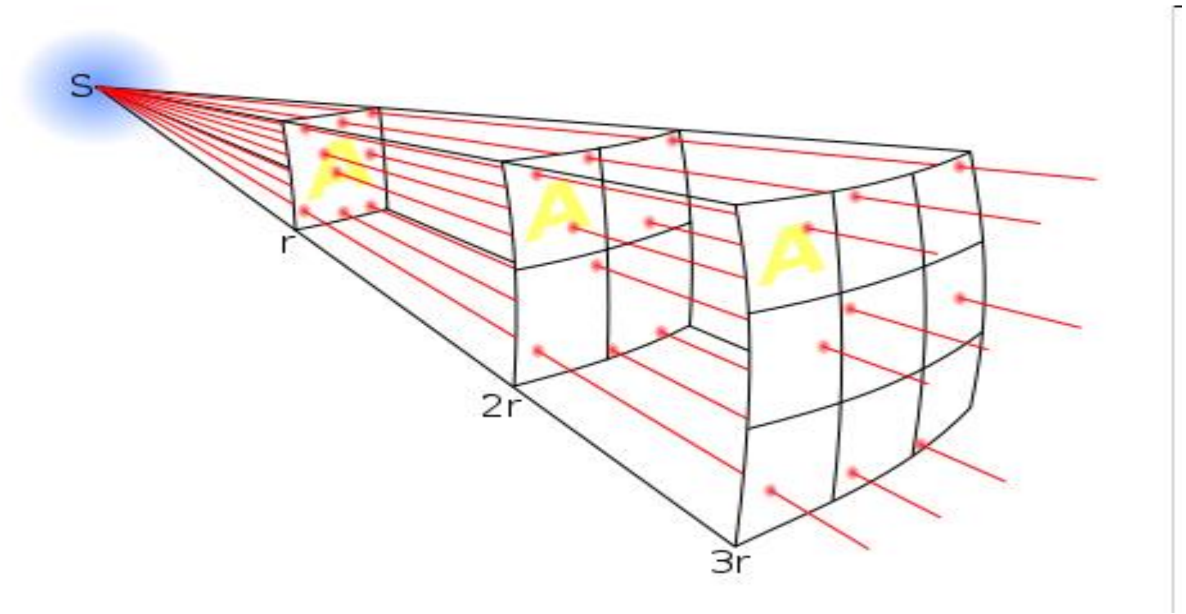


Inverse Square




r_2
A_2
A_1
r_1
RADIATION
SOURCE

Inverse Square Factor



$$\frac{I_2}{I_1} \square \frac{D_1^2}{D_2^2}$$

Example Calculation

- The dose rate in air of a Co-60 teletherapy machine is 80 cGy/min at 80 cm from the source. What is the the dose rate in air at 100 cm?

$$\frac{\text{Dose rate}_{100cm}}{80 \text{ cGy/min}} = \frac{(80 \text{ cm})^2}{(100 \text{ cm})^2}$$

$$\text{Dose rate}_{100cm} = 0.64 \times 80 \text{ cGy/min} = 51.2 \text{ cGy/min}$$

Photon vs. Electron Interaction

Photon	*Electron*
Indirect energy deposit	Direct energy deposit
No interaction, or One interaction	Continuous interactions and loss of energy
Impossible to predict length of travel of individual photon	Characterized by “Range”

Electron Interaction Summary

- Soft and Hard Collision
  - Collision with atomic electrons (ionization and excitation)
  - Collisional Losses
- Bremsstrahlung
  - Collision with nuclei
  - Radiation Losses

Dominant Interactions

- Low Z media (i.e. Water or Tissue)
  Collisional ionization

- High Z media (i.e. Lead)
  - Bremsstrahlung
  - Electron is very small. Two important effects observed for electrons:

    Large changes in energy and angle

    Rapid deceleration $\rightarrow$ bremsstrahlung

Problem 1

Electrons lose energy when passing through matter by

1. production of bremsstrahlung
2. photoelectric interactions
3. collision with other electrons

A. 1 & 2 only

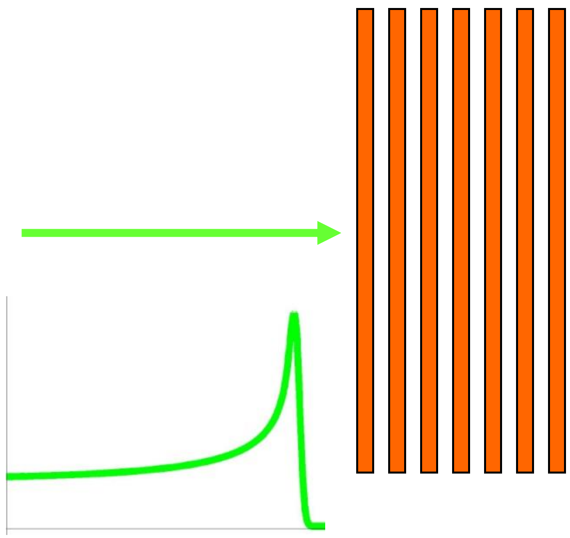
B. 3 only

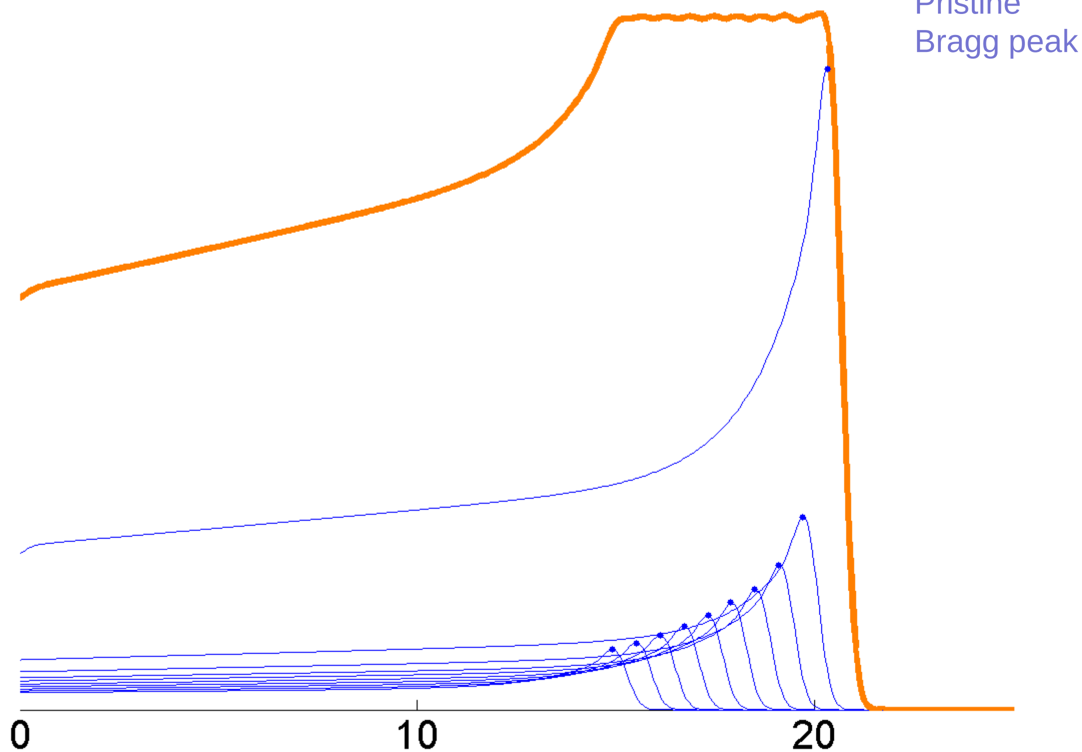
C. 1 & 3

D. All are correct

Proton Beam

Absorbers of pre-determined thicknesses added successively into beam to “pull back” individual pristine Bragg peaks





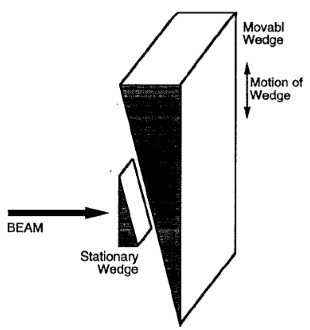
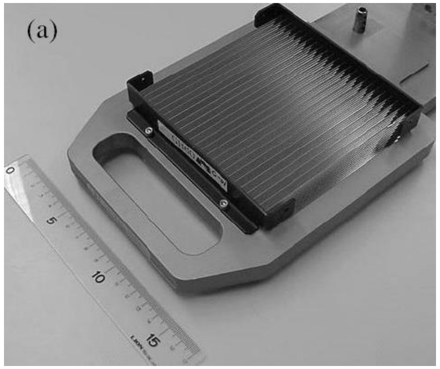
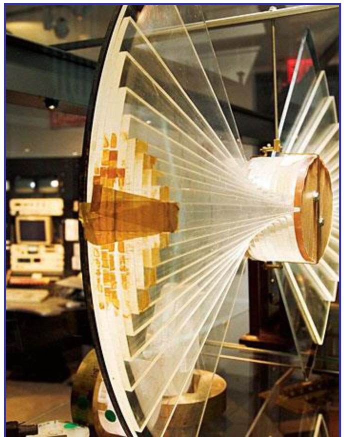


FIG. 18. Schematics of a double wedge system which is used to shift the range of the beam.





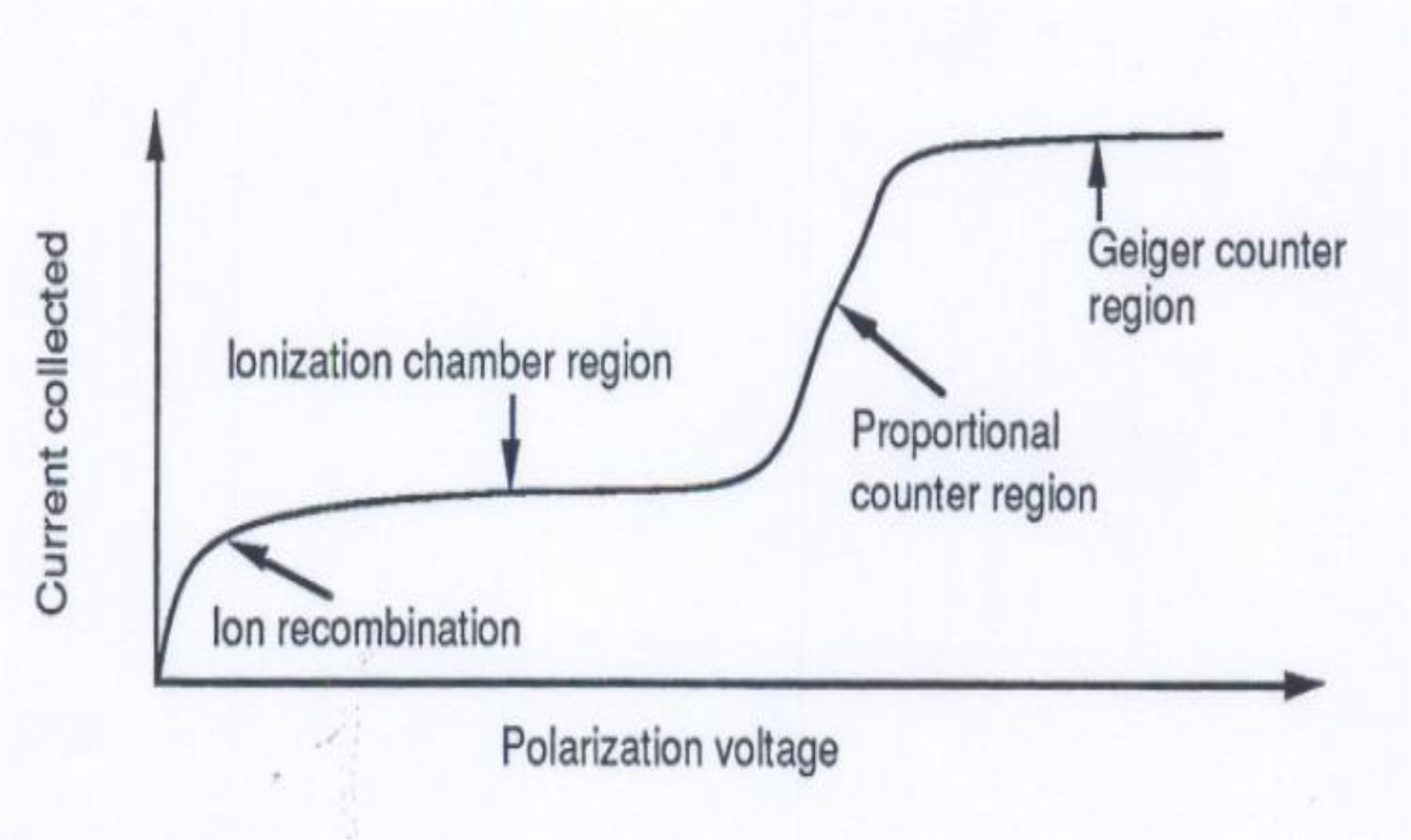
OVERVIEW

- Basic properties of radiation
- Sources of radiation
- Interaction with matter
- Measurement of radiation

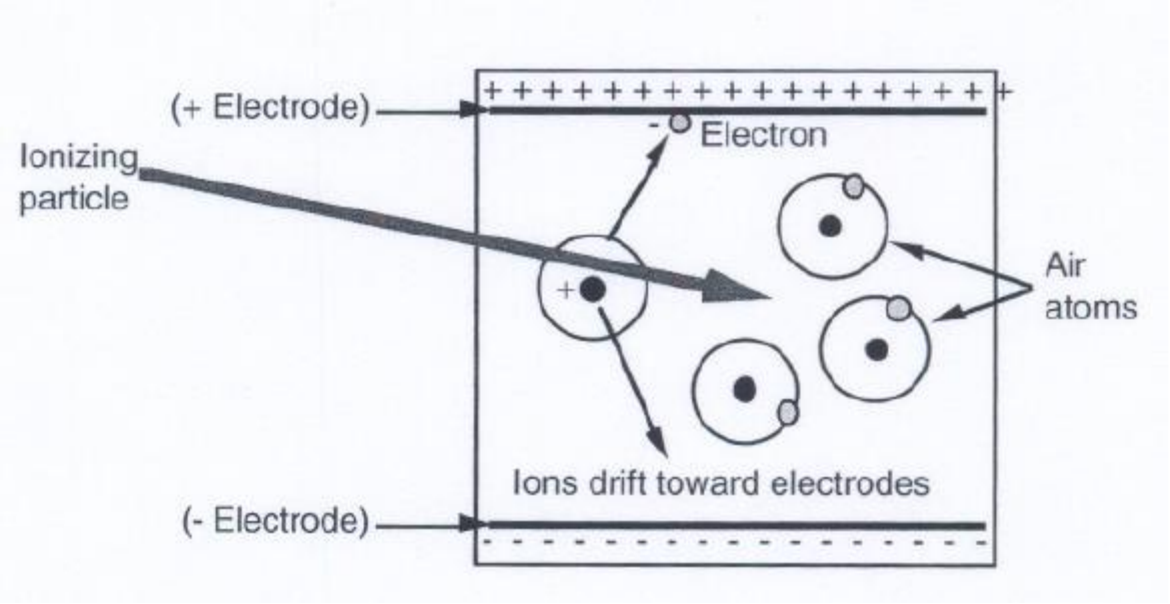
Radiation Detectors

- Ionization chamber
- Geiger-Mueller (G-M) counter
- Proportional counter

Operational regions of gas ionization detectors



Gas ionization detector example : **parallel plate** ionization chamber



- **Chamber** with a fixed volume of gas (e.g., air)
- **Ionization** of the gas by photons or particles
- **Electrodes** with polarization voltage collect ions

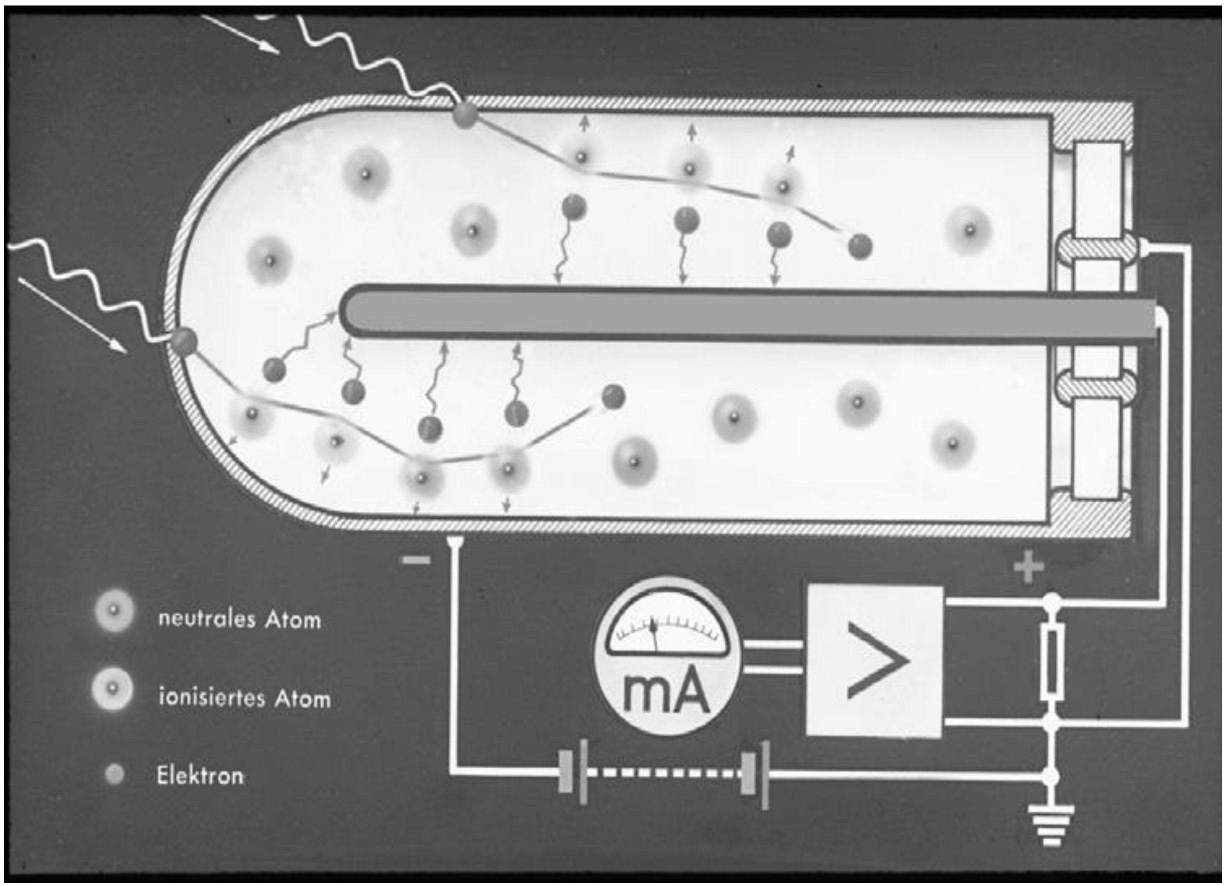
Ion collection

- Ion recombination: $e^- + ion^+ \rightarrow$ neutral atom (no net charge, therefore measurement signal lost)

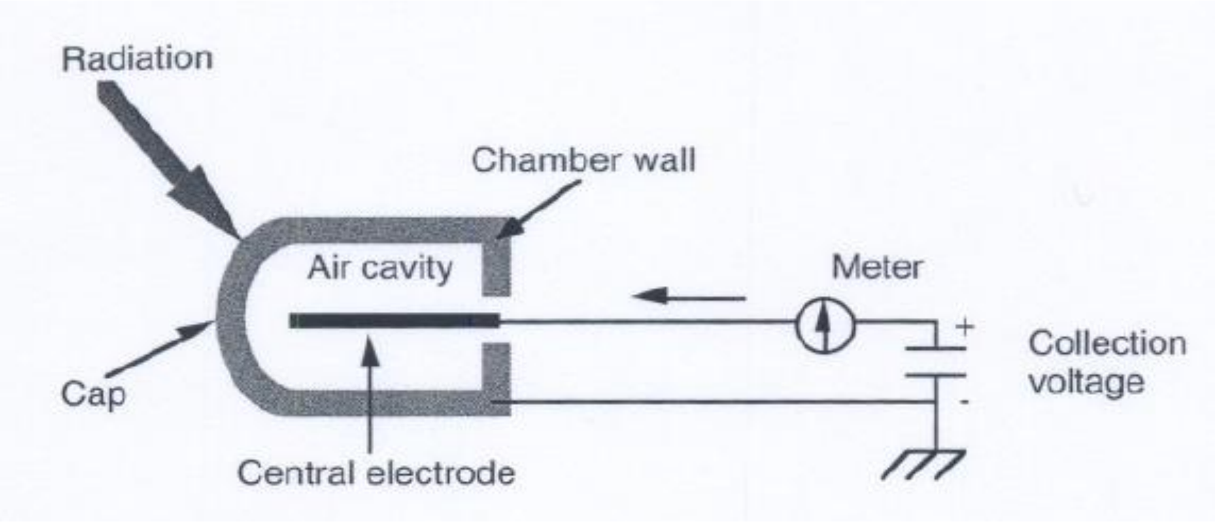
- Collection Efficiency

  = charge collected / charge liberated by initial ionization

Ionization chamber: example -- thimble chamber



Ionization chamber: example -- thimble chamber



- Chamber wall has effective atomic number close to air
- Build-up cap is usually added for high energy photon beams to establish “electron equilibrium”
- Voltage: typically >= 300 volts

Farmer Chamber

Farmer Chamber

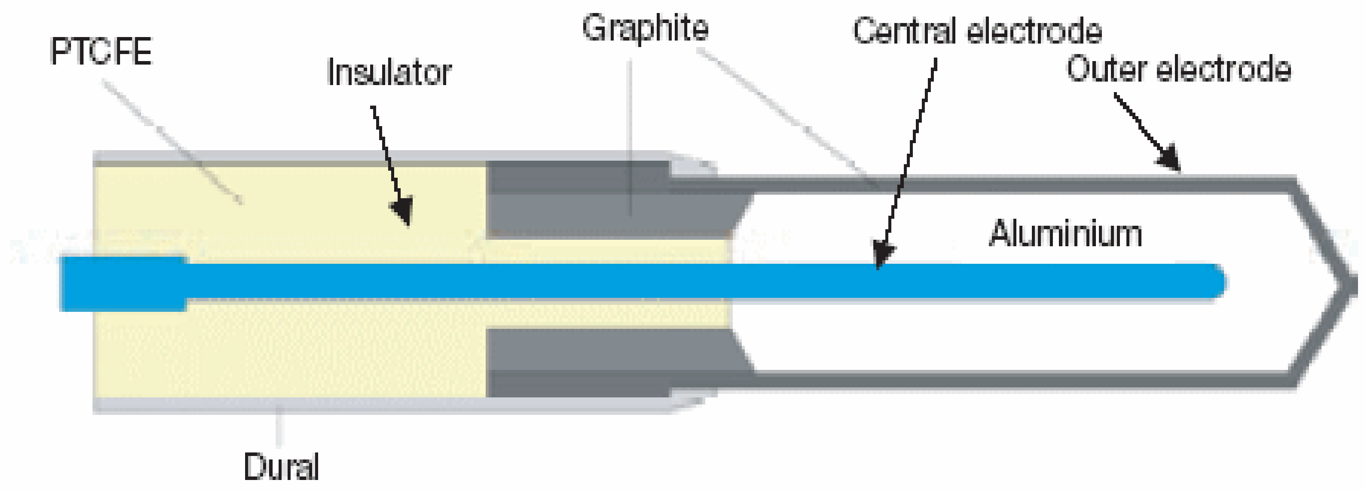
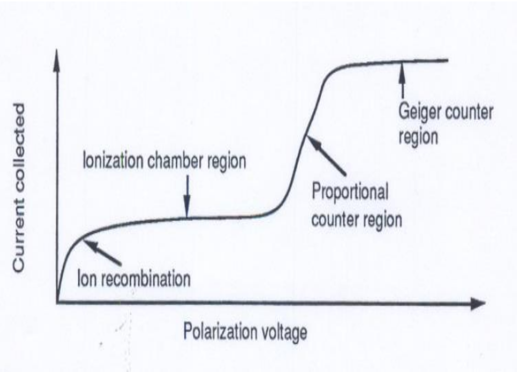
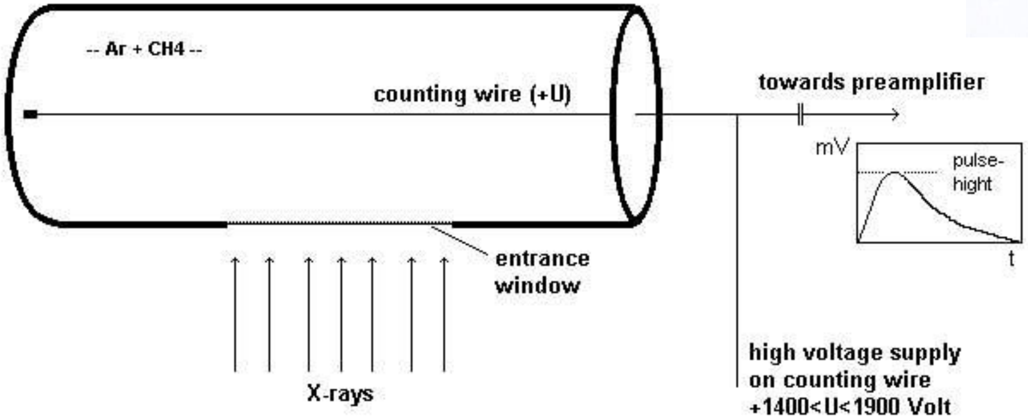


FIG. 3.2. Basic design of a cylindrical Farmer type ionization chamber.

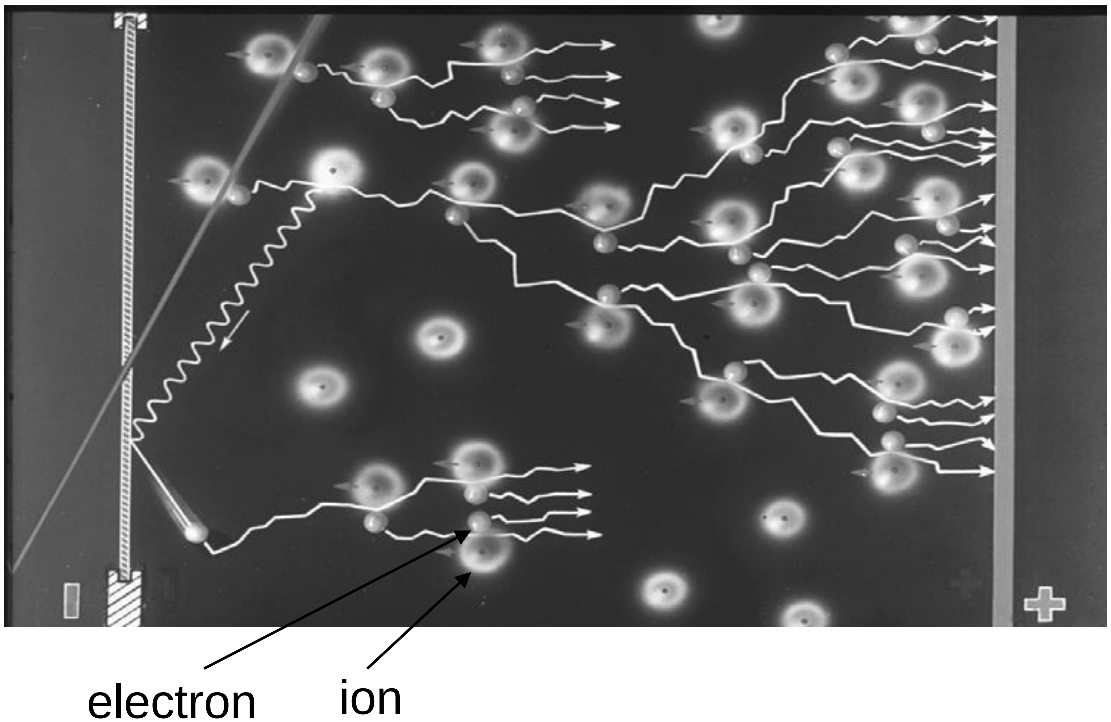
Proportional counter



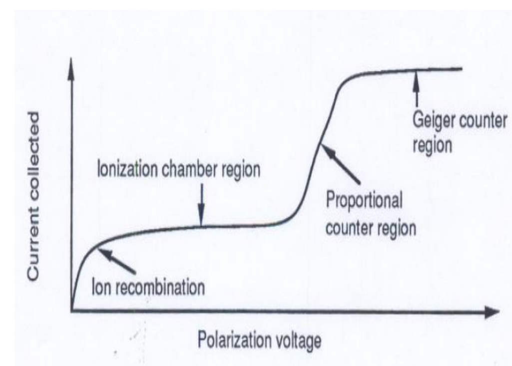


- Operated in pulsed mode
- Detected count rate is proportional to the number of ion pairs formed in an interaction
- Can measure low-intensity radiation and discriminate alpha and beta particles - can be used in radiation safety work

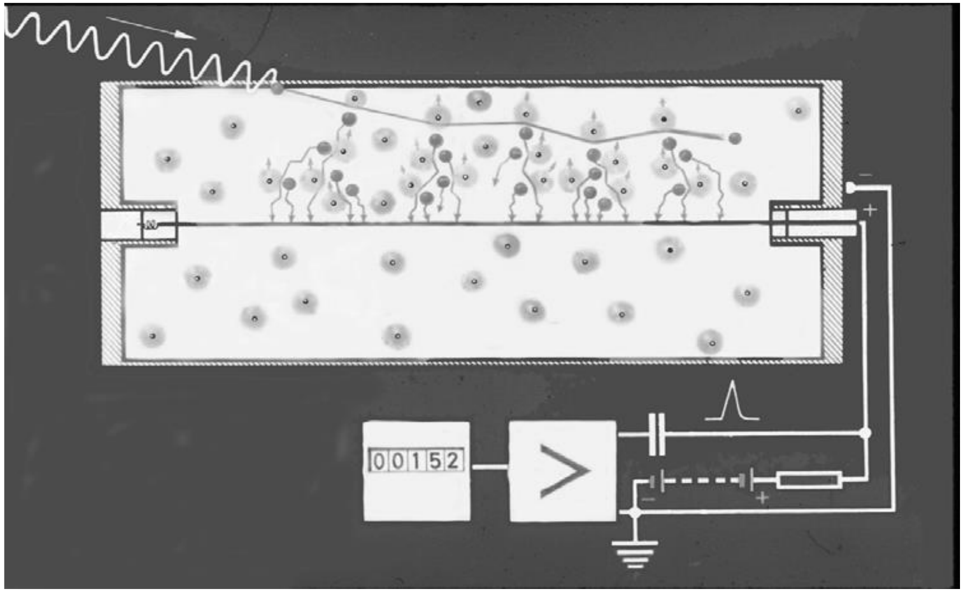
Geiger-Muller (G-M) counter



- Operates in pulsed mode- with very high voltage
- Cascade effect



Geiger-Muller counter

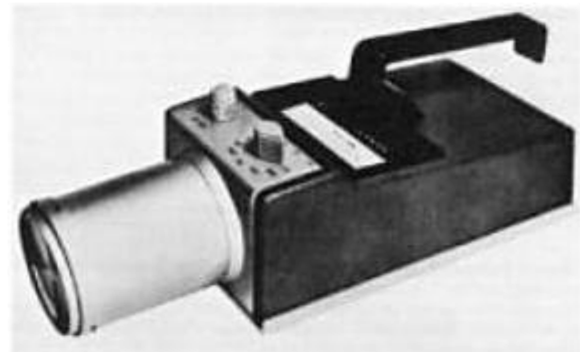


- Large charge amplification: 9–10 orders of magnitude
- Output current pulse
- Can detect single ionization event

Geiger-Muller counter

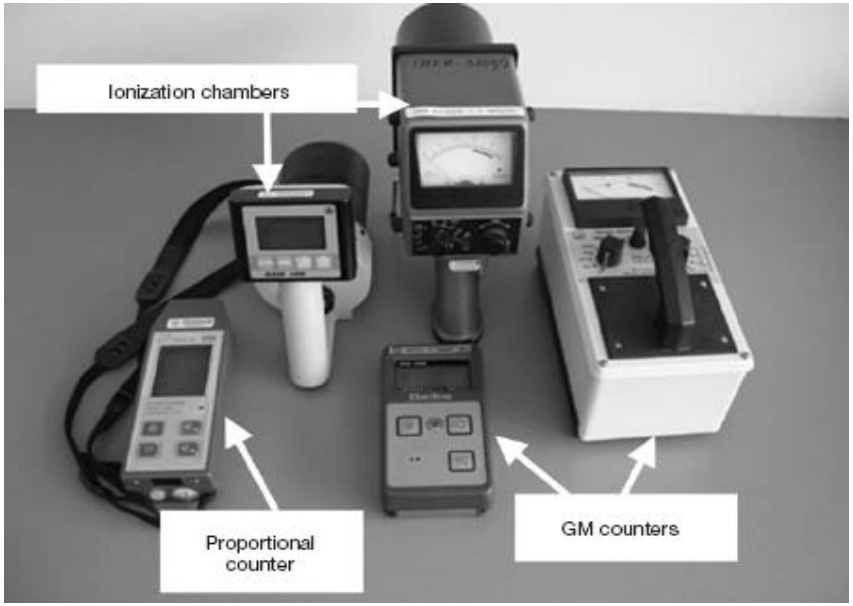
- **Dead time**: a period during which G-M cannot respond to radiation until the polarization voltage is re-established (tens to hundred of milliseconds) : cannot be used for count rates of a few hundred counts per second

Portable ionization chamber:



- Large collection volume (0.5 liter)
- Can measure relatively low-intensity radiation levels but less sensitive than G-M detector
- Can give accurate measures of radiation exposure rates (mR/hr or R/hr)

Survey meters



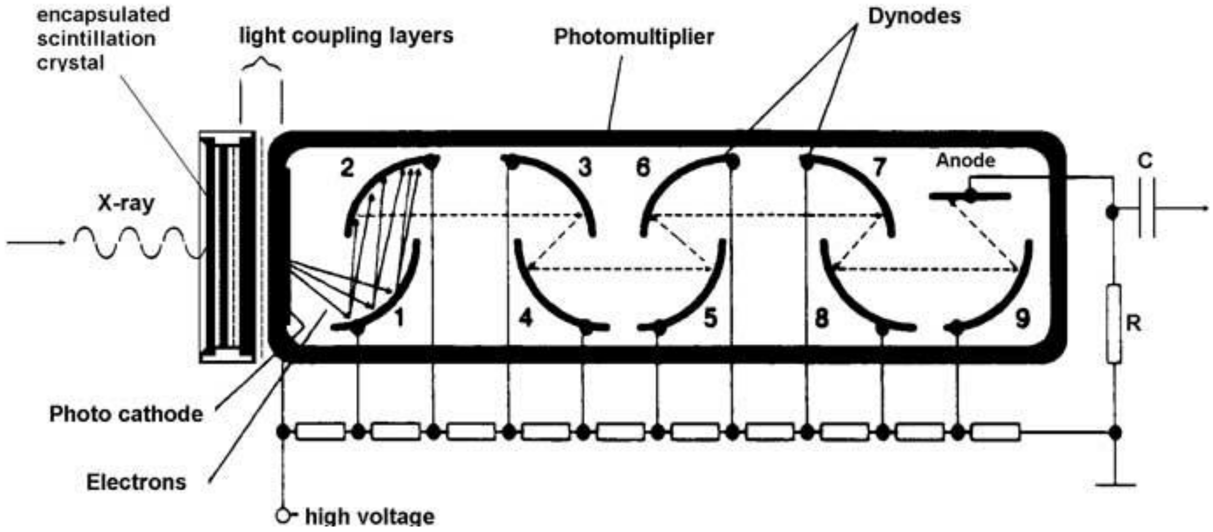
- Large volume ion chamber: Cutie Pie
- G-M counter
- Proportional counter

How to use a survey meter

- Check battery
- Check with radioactive check sources

  (e.g., < 10 μCi of ^{137}Cs)
- Read correctly:
  - Multiplication scales (i.e., x1, x10, …)
  - Units: counts per minute (cpm) or exposure per hour (mR/hr or R/hr)
  - Modes: rate (e.g., mR/hr) or integrate (e.g., mR)

Scintillation detector



- Scintillation crystal (NaI, CaF_2) absorbs photon (x- or gamma-ray) -> ionization -> light emission
- The amount of light produced is proportional to the energy of the absorbed photon
- Used for measuring activity of nuclides, discriminating isotope, measuring brachytherapy source leakage (wipe test)

Neutron detector

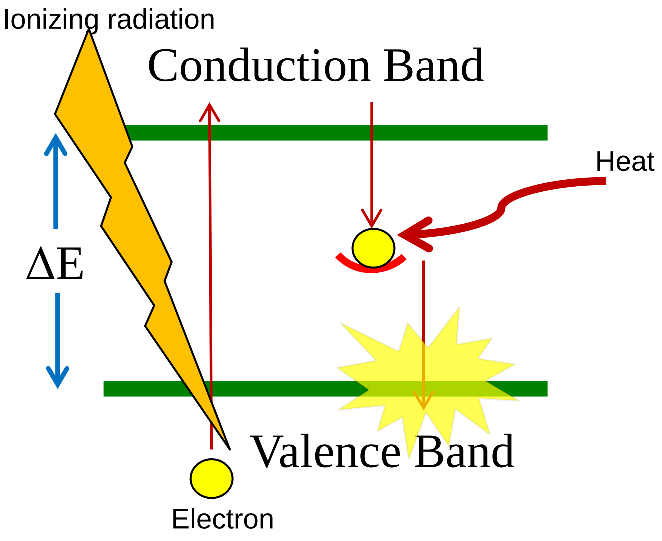
- Moderated gas ionization detector: slow down neutron by using low Z materials (e.g., hydrogen or boron) then detect neutron presence
- Used in survey of linear accelerator (> 10 MV)

Thermoluminescent dosimeter (TLD)

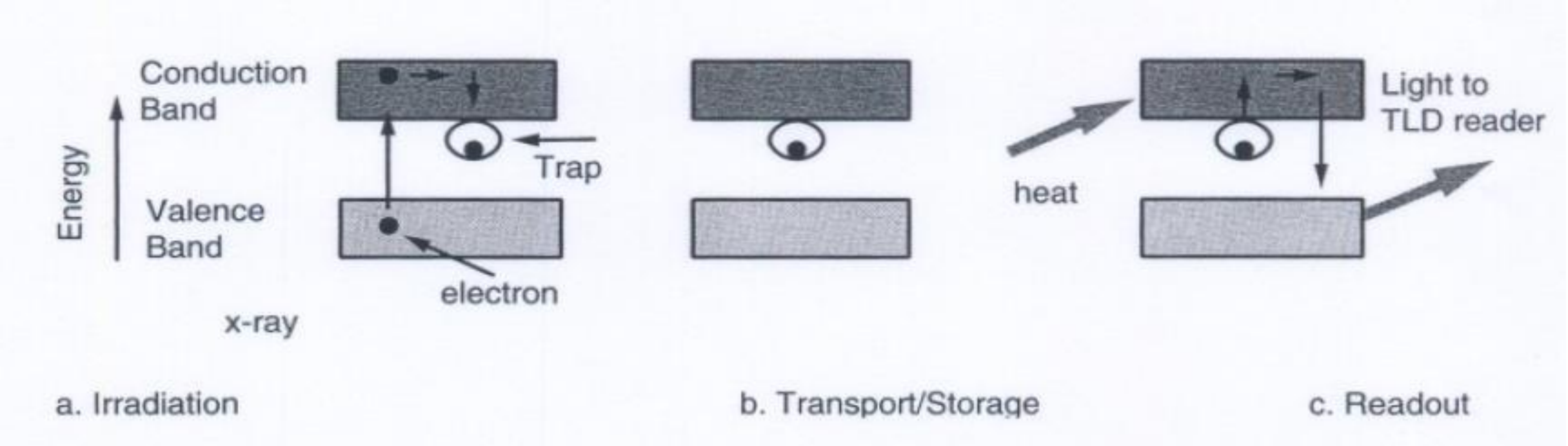
- Lithium fluoride (LiF) or CaF_2:Mn, in the forms of rods or chips
- Used in measuring patient skin dose or abutting field dose, or used in personnel radiation protection monitoring (badges)

Dosimeters – TLD

- Electrons are sitting in the valence band
- Ionizing radiation excites them to the conduction band
- There are intrinsic impurities in the TLD
- Electrons can become trapped in these impurities
- The TLD can then be heated which causes the trapped electron to gain enough energy to jump back to the valence band
- This causes a release of light photons that can be detected by photomultiplier tube

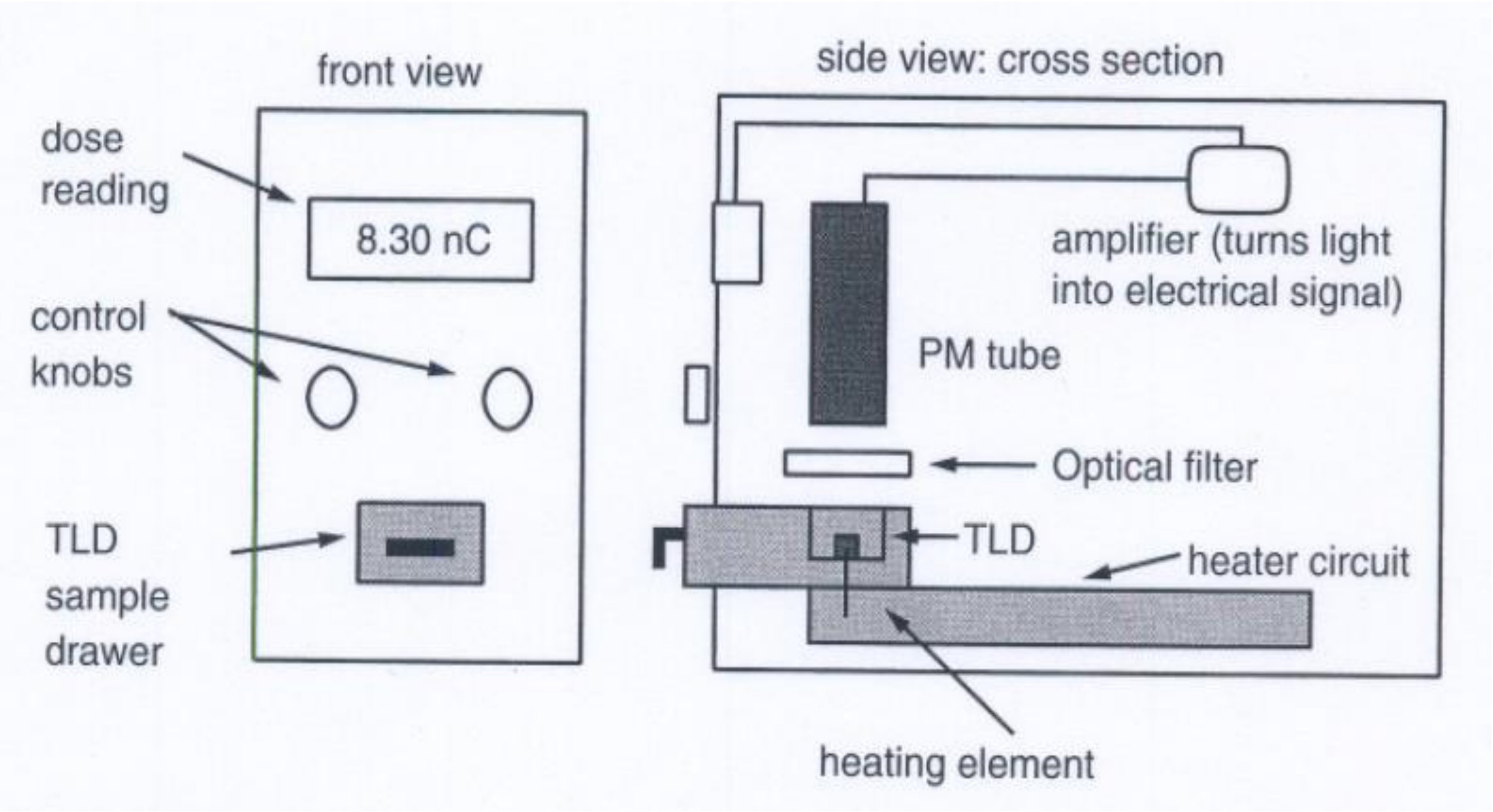


TLD process



- Intensity of light emitted is proportional to absorbed dose

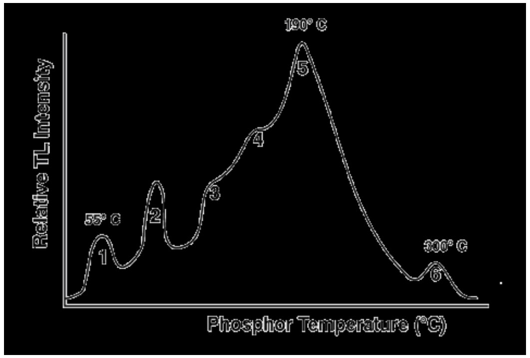
TLD reader



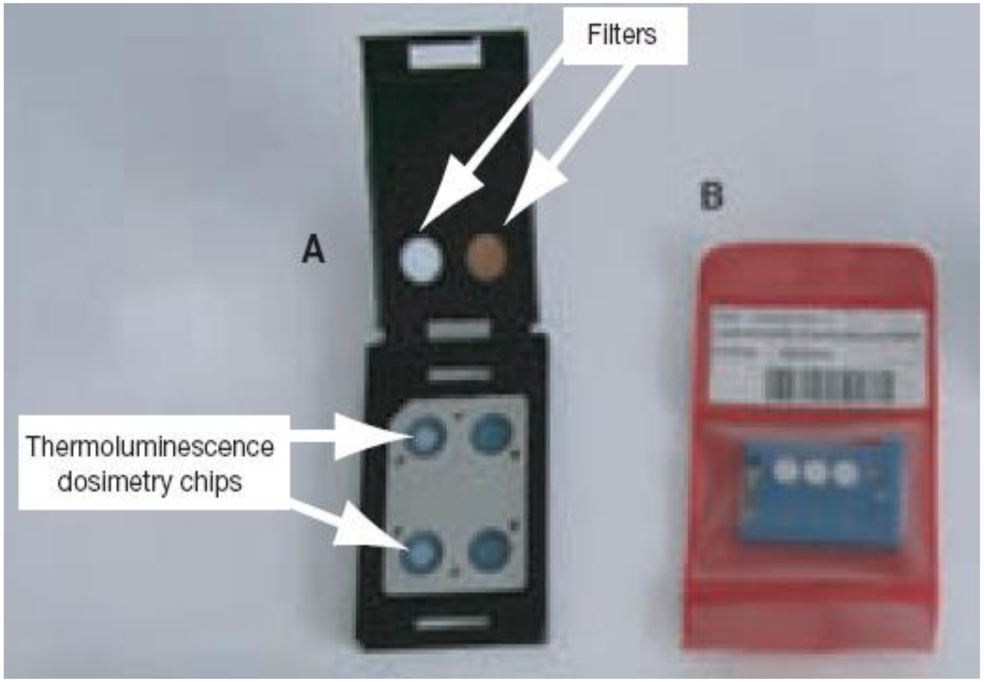
front view
dose reading
8.30 nC
control knobs
TLD sample drawer
side view: cross section
amplifier (turns light into electrical signal)
PM tube
Optical filter
TLD
heater circuit
heating element

Dosimeters – TLD

- The amount of light released is proportional to the dose
- Advantages:
  - Small
  - Large dose range
  - Dose rate independent
- Disadvantages:
  - Not a permanent record
  - Not real-time readout
  - Labor intensive (annealing)



TLD badge



Dosimeters – OSL

- Optically stimulated luminescence
- Same principle as TLD but the trapped electrons are released using laser light as opposed to heat
- Doped aluminum oxide
- Simpler process
- No annealing
- Still need a calibration curve

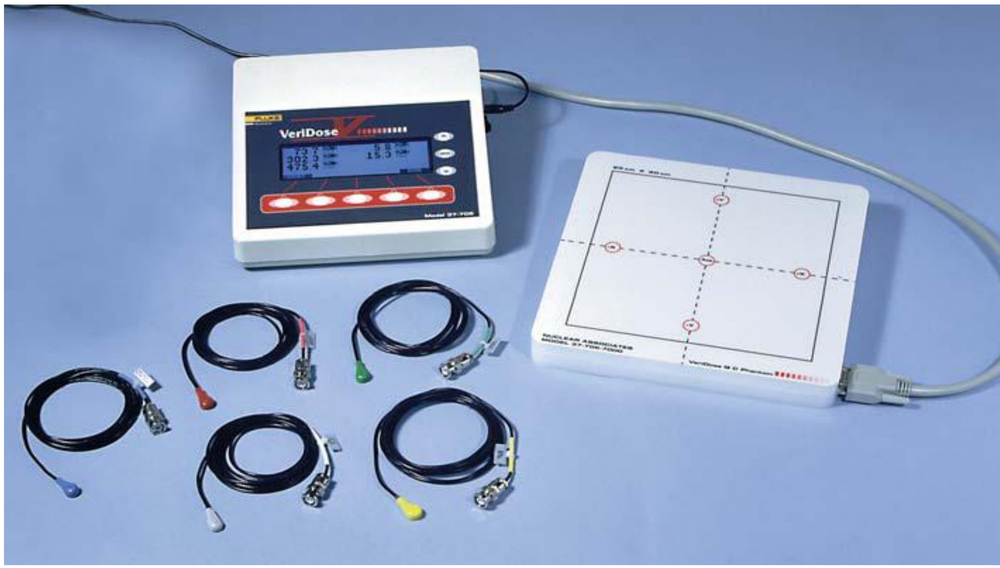
Diode detector

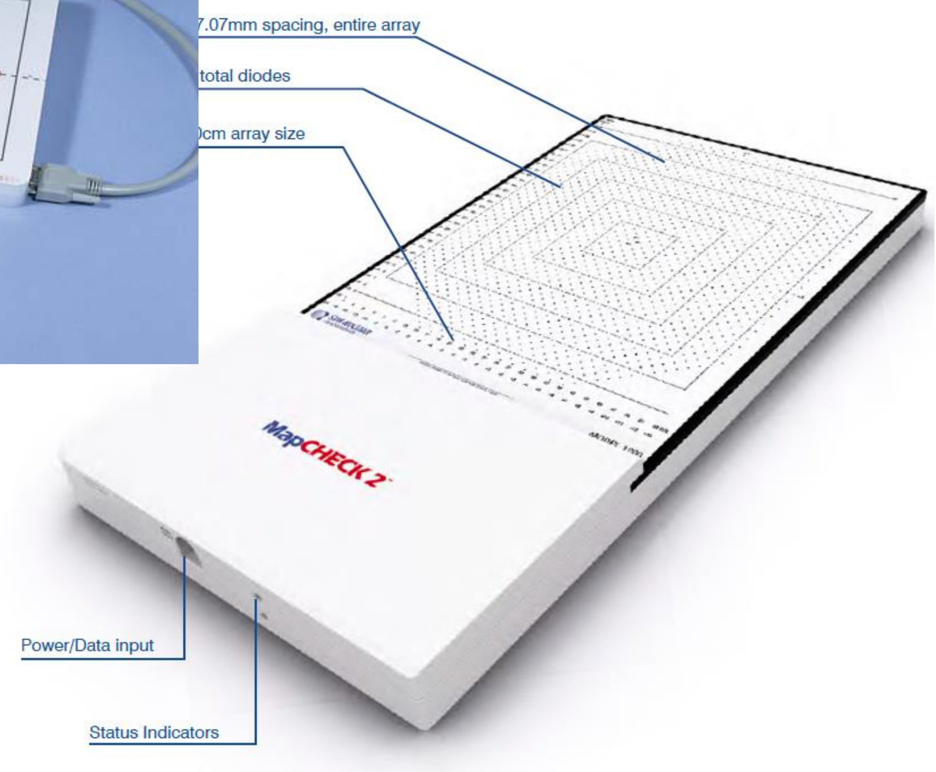
- Unlike TLD, diode is capable of reading and displaying dose immediately (real-time measurement)
- Can be used in patient dosimetry to measure patient surface dose
- Can be used in machine quality assurance to measure beam flatness and symmetry

Diode detector used in patient dosimetry

Separate diodes are designed for electron and photon beams, and are designed for photons of different energies (e.g., 6 MV, 18 MV).

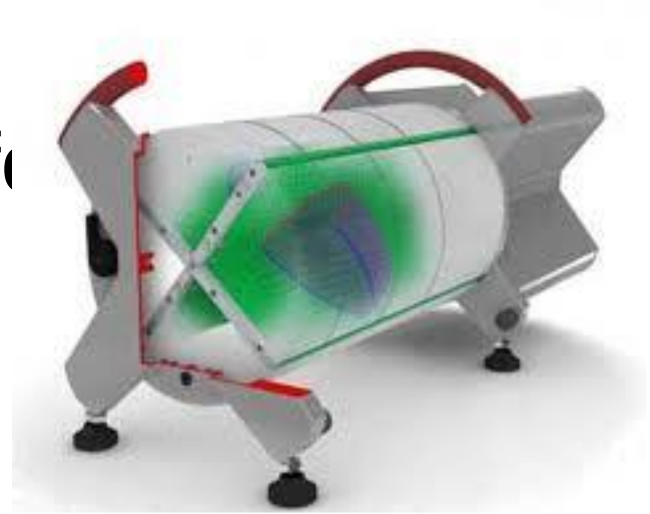
Single diode, diode reader, and diode array

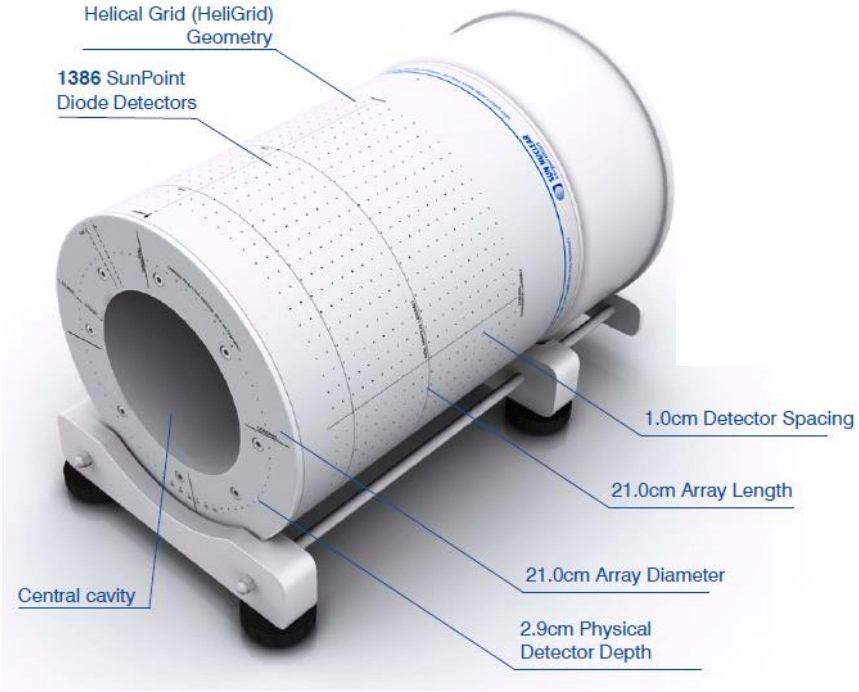




Dosimeters – Arrays

- Patient Specific QA
- Have non-planar arrays f





Film Dosimetry

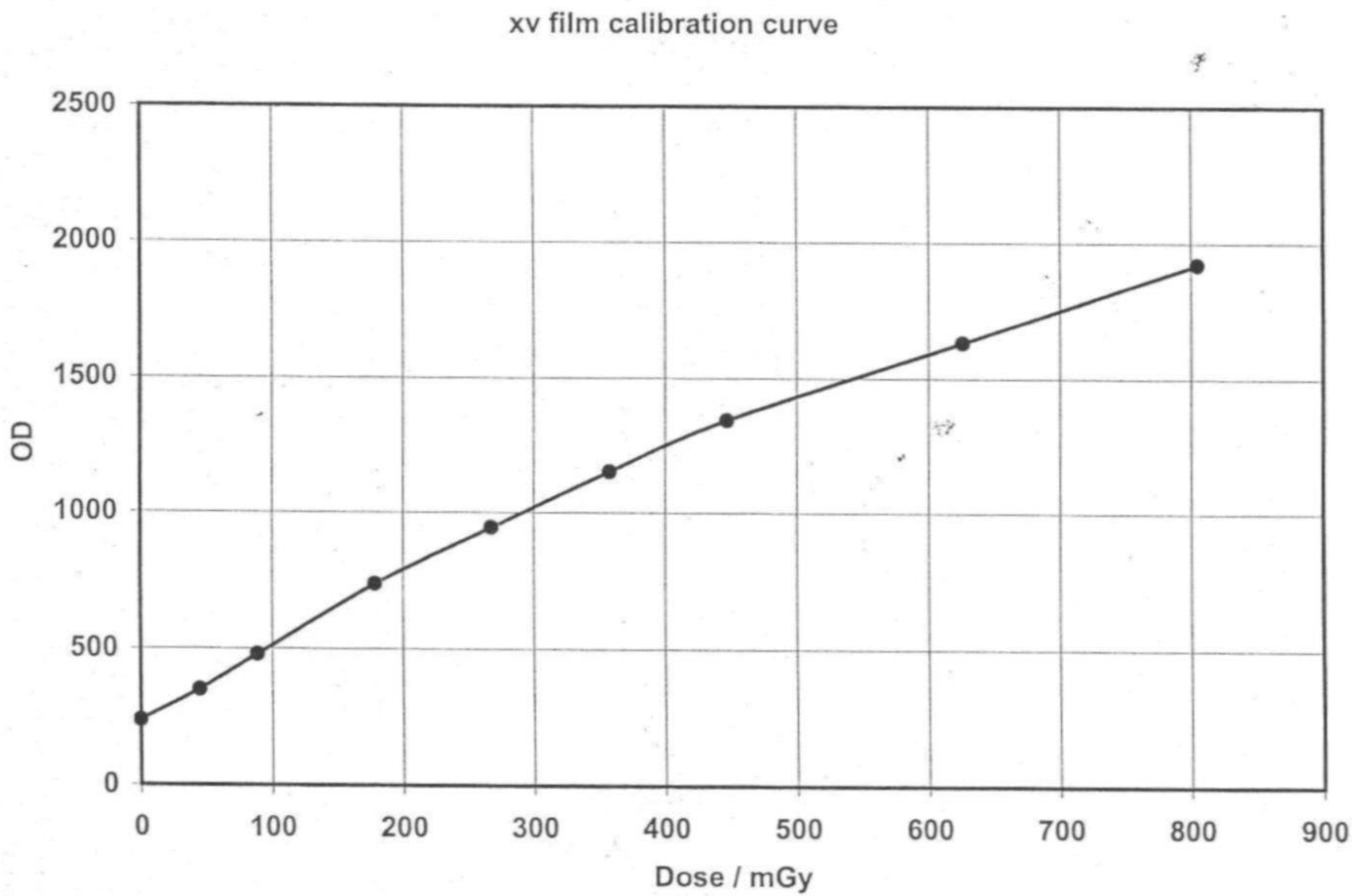
Relationship between dose and film darkening (film's optical density) is established through calibration process:

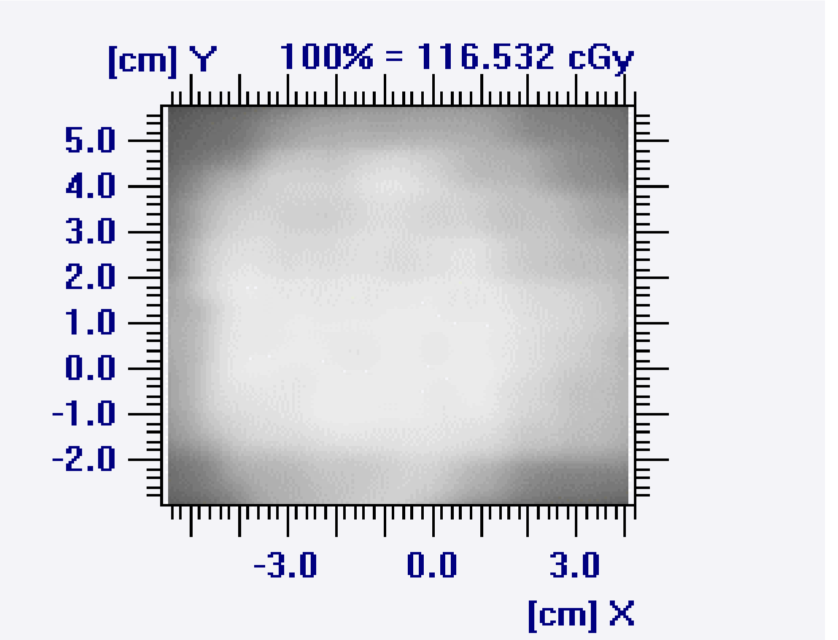
- Dosimetry films are typically semi-linear with dose over specified range of doses;

- Typically used films are: XTL films (1- 5 cGy), XV films (5 – 100 cGy) and EDR films (50-400 cGy);

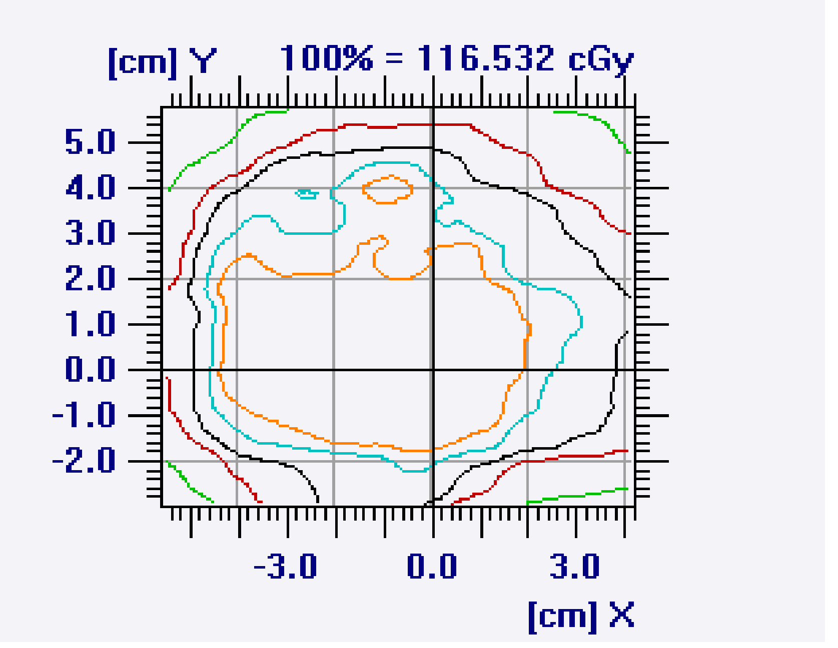
-Radiochromic films: do not need chemical processor;

- Films are not used for accurate dose measurements; they are usually used for dose distribution mapping on a plane.


xv film calibration curve
OD
Dose / mGy
0
500
1000
1500
2000
2500
0
100
200
300
400
500
600
700
800
900


[cm] Y
100% = 116.532 cGy
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
0.0
3.0
[cm] X

1 Film 1


[cm] Y
100% = 116.532 cGy
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
0.0
3.0
[cm] X

Question

- What kind of detector should you use to determine the exposure rate around a 6 MV linear accelerator?

Ion chamber survey meter…

Question

- If you lost a ^{125}I source in operating room during a prostate implant, what instrument would you use to locate its position?

G-M counter
Scintillation detector

Question

- Does an ionization chamber read too high or too low if an insufficient ionization potential is used?

+ve and –ve ions recombine: read too low

Question

- The reading of a Farmer chamber measurement should be corrected upwards when:

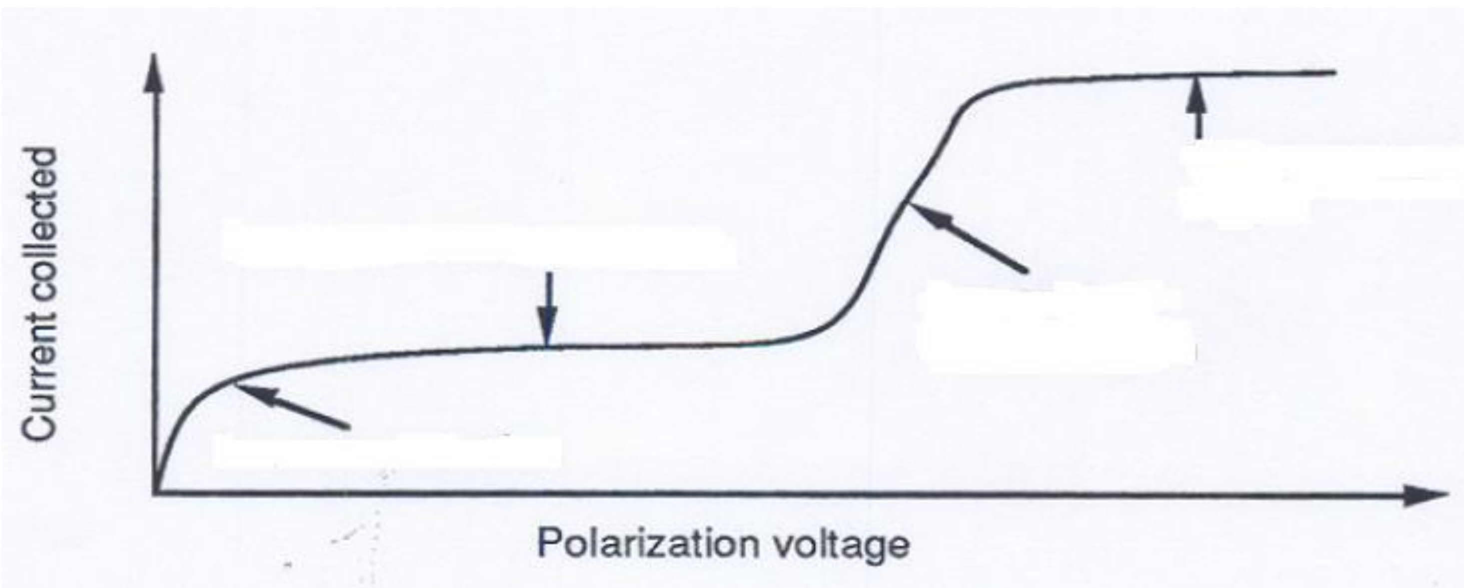
(reading too low…)

1. Temperature is higher than the standard value
2. Temperature is lower than the standard value
3. Pressure is higher than the standard value
4. Pressure is lower than the standard value

Standard values: T = 22 C (273 Kelvin); P = 760 mm Hg

Question

- Which region is the region of operation of G-M counter, ionization chamber, and proportional counter?



Ionizing Radiation

alpha beta gamma

Which picture represents x-ray interaction with medium?

THANK YOU!

Yan.Yu@jefferson.edu