Radiographic Physics Review

Presented By:

Dawn Sturk, M.S.,R.T.(R) RCIS

- Currently serve as the Administrative Director of Radiologic Services at Hurley Medical Center in Flint, MI
- Physics and Radiation Protection Instructor at the Hurley School of Radiologic Technology
- Former Program Director
- Radiographer and Cath Lab Technologist

Atomic Structure

- Knowledge of basic atomic structure is essential to understand how radiation affects us at the atomic level.
- Atoms of various elements may combine to form molecules.
- Radiation may break those molecular bonds and cause damage.

Fundamental Particles

- Nucleons
  - Neutrons (mass 1, no charge)
  - Protons (mass 1, + charge)

- Electrons (virtually 0 mass, - charge)

Nucleus

- Protons: provide the + charge that keeps the electrons attracted.
- Neutrons: contribute only to the atomic mass
- Atomic mass: sum of the protons and neutrons
- Atomic number: number of protons

Electrons

- Electrons rotate around nucleus in “shells”

- Each shell has its own binding energy which is dependant on:

  - Proximity to the nucleus
    - Closer the shell, higher the binding energy

  - Atomic number of the element

Stability

- Atoms that have an equal amount of protons and neutrons are electrically stable
- Removal of an electron is called ionization.
- Hole will eventually fill with a free radical electron

Electron Arrangement

- Shells are named K, L, M, N, O
- K closest to nucleus (highest binding energy)
- Maximum number of electrons in a shell is 2n squared
- Maximum number of electrons

Forces

- Two forces hold the electrons in orbit
  - Centripedal: The force that keep an electron in orbit (- electron attracted to + nucleus)
  - Centrifugal: electrons keep their distance from the nucleus by traveling in a circular path (spinning force)

Variations of Atoms

- Isobars: same atomic mass number but different atomic numbers
- Isotones: same number of neutrons but different numbers of protons.
- Isomers: same atomic number and the same atomic mass number.
- ***Isotopes: same atomic number but different atomic mass numbers.***

Radioactivity

- Emission of particles and energy by atoms to become stable.
- Decay results in the emission of alpha, beta, and gamma.
- Half life the is time required for a quantity of radioactive material to be one half its original value.

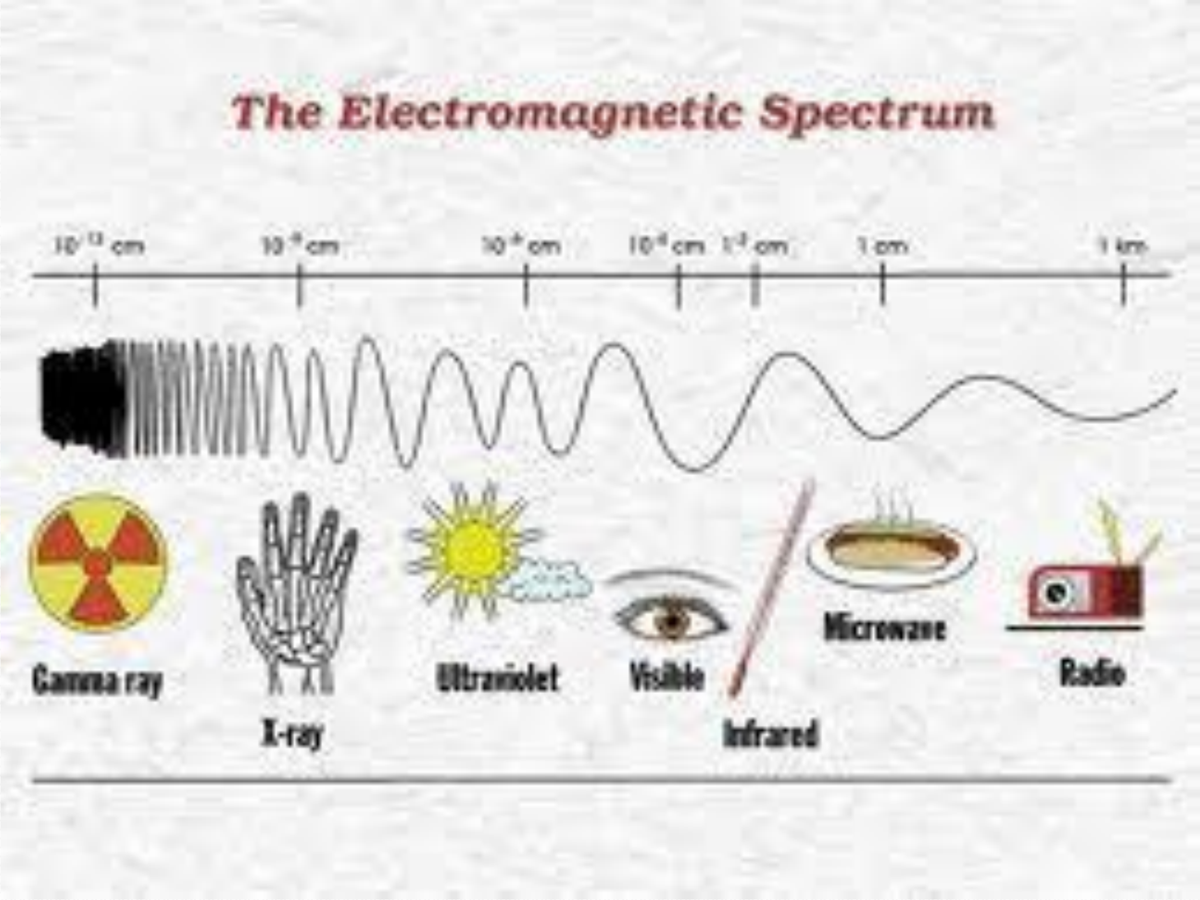
Particulate Radiation

- Alpha: consists of two protons and two neutrons. (heavy, cannot travel far, transfers its energy as soon as it can) (Most harmful)

- Beta: electron emitted from the nucleus of a radioactive atom.

Electromagnetic Radiation

- X-Rays: produced when we set the process in motion
- Gamma: product of radioactive decay.
- Identical except their origin.


The Electromagnetic Spectrum
1 cm
1 km
Gamma ray
X-ray
Ultraviolet
Visible
Infrared
Microwave
Radio

- Properties of electromagnetic energy are:
  - Velocity (speed of light)
  - Frequency (measured in Hz)
  - Wavelength (measured in Angstroms)

Wave Equation: Velocity= frequency x wavelength

Planck's Quantum Theory

- X-Rays exist at the speed of light or not at all
  - 299,792,458 meters/second
  - 186,000 miles/second
  - Velocity is always the constant, we vary frequency and wavelength when we choose technique.

Photon

- An x-Ray photon is a quantum of electromagnetic energy.
- Velocity of all electromagnetic radiation is the speed of light
- Illustrated as traveling in a sinusoidal form

Types of X Radiation

- Diffraction (less than 10 kEv)
- Grenz (10-20 kEv) dermatology
- Superficial (50-100 kEv) therapy of tissues
- Diagnostic (30-15- kEv) imaging
- Orthovoltage (200-300 kEv)therapy
- Supervoltage (300-1000 kEv) therapy
- Megavoltage (>1000 kEv) industry

Wave Particle Duality

- Photons interact with matter most easily when the matter is approximately the same size as the photon wavelength.
- Similar in energy.
- Examples: microwaves and food, visible light and eye, radiowaves and antennas.

Energy

- Energy of a photon is directly proportional to its frequency.
- Higher energy, higher frequency
- We choose energy by setting kVp

Attenuation

- The reduction in intensity that results from:
  - Scattering: change in direction and loss of energy
  - Absorption: total transfer of energy

- Radiolucent: allows transmission of radiation without an interaction.
  - Air
- Radiopaque: absorb x-rays
  - Barium
  - Bone

- Images are the result of radiopaque and radiolucencies demonstrated that represent structures.
- Atomic number and mass density of structures determines whether or not an interaction will occur.
- Atomic number and mass density also determine what type of interaction will occur.

X-RAY PRODUCTION

- X-Ray photons are man made
- This is the only thing that distinguishes them from gamma rays

- X-Rays are produced thru the interactions that occur when the electrons from the space charge strike the anode at half the speed of light.
- The incident electrons are accelerated from zero to this speed in a 2cm distance.
- This occurs because of the potential difference

- The incident electrons convert their kinetic energy into x-ray photons and heat.
- 99% become heat
- 1% becomes x-ray photons

- So……x-ray tubes are very inefficient
- Heat becomes a limiting factor in making exposures
- This is one of the reasons we have two focal spots

Making of a Photon

- When the incident electrons strike the target two types of interactions produce x-ray photons.
  - Bremsstrahlung (braking) radiation
  - Characteristic radiation

BREMSSTRAHLUNG

- Incident electron strikes the tungsten target and is attracted to the nuclear force field of an atom. (+/- attraction)
- The incident electron slows down near the nucleus and changes direction.
- The energy lost when it slows down becomes an x-ray photon.

Law of Conservation of Energy

- The energy of the photon is equal to the energy entering the atom minus the energy exiting the atom.

Bremsstrahlung Production

- Random
- Photon energy can range from the maximum kVp to zero.
- We do know that most will fall at about 1/3 the maximum kVp.

SPECTRUM

- Bremsstrahlung creates a CONTINUOUS SPECTRUM.

  Photon energy starts at zero and goes to the maximum kVp

  Techniques set below 69 kVp will only have bremsstrahlung production

Characteristic Radiation

- It is called “characteristic” because production is dependent on the binding energy of the shells
- Each element has its own atomic number (# of protons) and therefore will have a different binding energy

Shell Binding Energy

- To understand this interaction you must understand the binding energy of the shells.
- The closer to the nucleus, the higher the binding energy of the shell

Shell Binding Energy

- This is the result of the positive attraction of the protons in the nucleus
- Therefore, K will have the highest energy, then L, then M and so forth

The Interaction

- In this case, the incident electron interacts with an electron by removing it from the atom (ionization).
- When it ionizes the target atom it creates a hole.

The Interaction

- The “hole” makes the atom unstable and in an effort to stabilize itself an electron from another shell jumps down to fill the hole.

- The energy the electron must give up to jump into the hole becomes the x-ray photon.

The Interaction

- The vacancy created by the "jumper" gets filled by another shell and lower level characteristic radiation continues to be produced.

The Energy Level

- The energy of the photon is predictable.
  - The energy will be the difference in the binding energy of the two shells involved.

Cascading

- The filling of the holes from adjacent shells can result in “cascading”
- If the hole is filled by a loosely bound outer shell electron we get useful radiation.

Outer Shell

- The electron transfers to shells other than K have energies too low to be significant. Will result in heat production also.

Photons

- Most photons are produced by Bremsstrahlung
- Characteristic photons are not produced until KeV is above 70 because the binding energy of the K shell in tungsten is 69.4

Spectrum

- Because we know the exact energy level at which this happens we have a discrete spectrum.

- Each individual element would have its own discrete spectrum.

Molybdenum

- In mammography, we use Mo as the target material because of its low K shell binding energy.
- K shell binding energy is 18 KeV.
- Works well with soft tissue which has a lower atomic number.

Changing the Spectrum

- In Bremsstrahlung we can change the spectrum by changing:

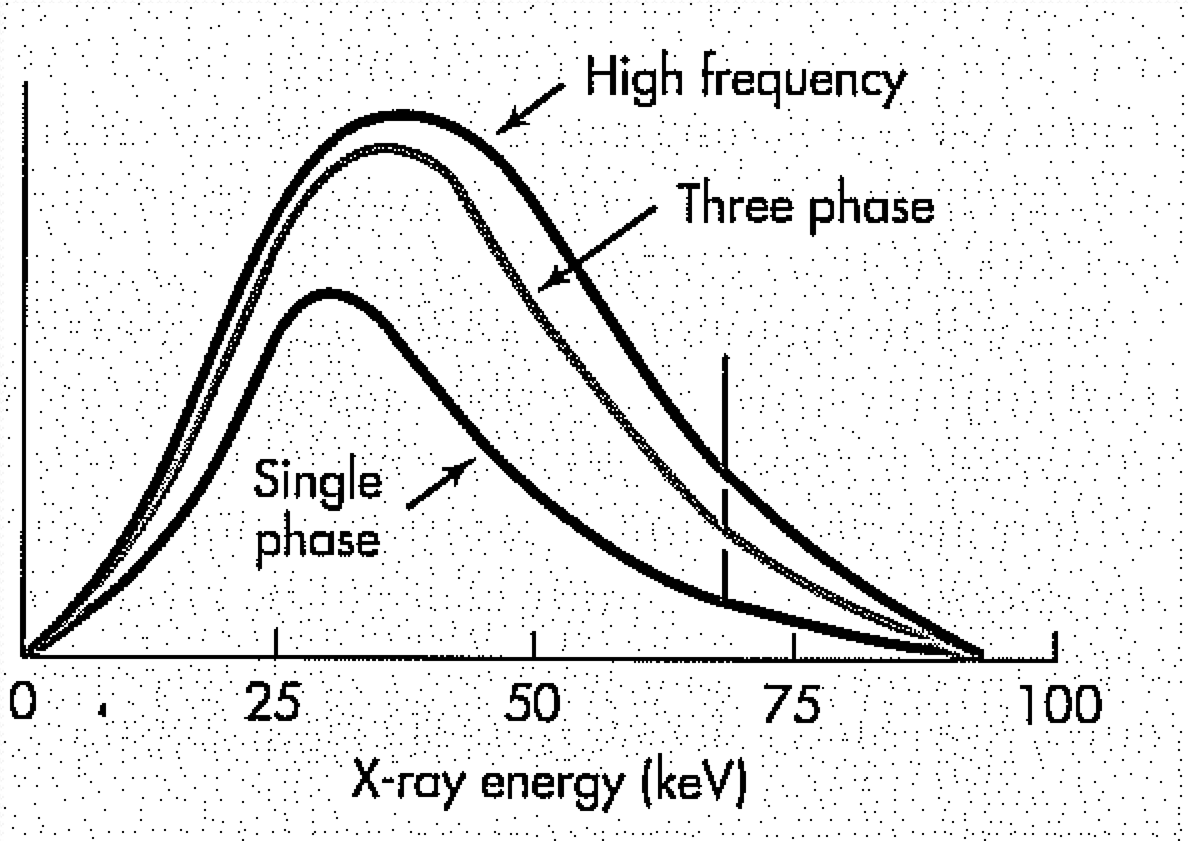
  - The kVp (energy)
  - The mAs (quantity of photons)

Changing the Spectrum

- In Characteristic we can change the spectrum by changing:
  - The target material (each element has a different K shell binding energy)
  - The mAs (quantity of photons)

The Spectrum

- The x-ray spectrum is a combination of both the discrete and continuous spectrum.



- The difference in this spectrum has to do with voltage ripple.
- Single phase has 100% ripple
- Three phase has 12% ripple
- High frequency has less than 1%
- Lower the % of ripple, more efficient the generator

5 Basic Mechanisms By Which X-Rays Interact

- Classical Scatter
- Comptons
- Photoelectric
- Pair Production
- Photodisintegration

Classical Scattering

- Low energy photons (energies below 10 kEv)
- Also called Thompson or Coherent scattering

Classical Scattering

- The incident photon interacts with a target atom and causes it to be excited. The target releases this excess energy as a secondary or scattered photon with wavelength and energy equal to the incident photon.

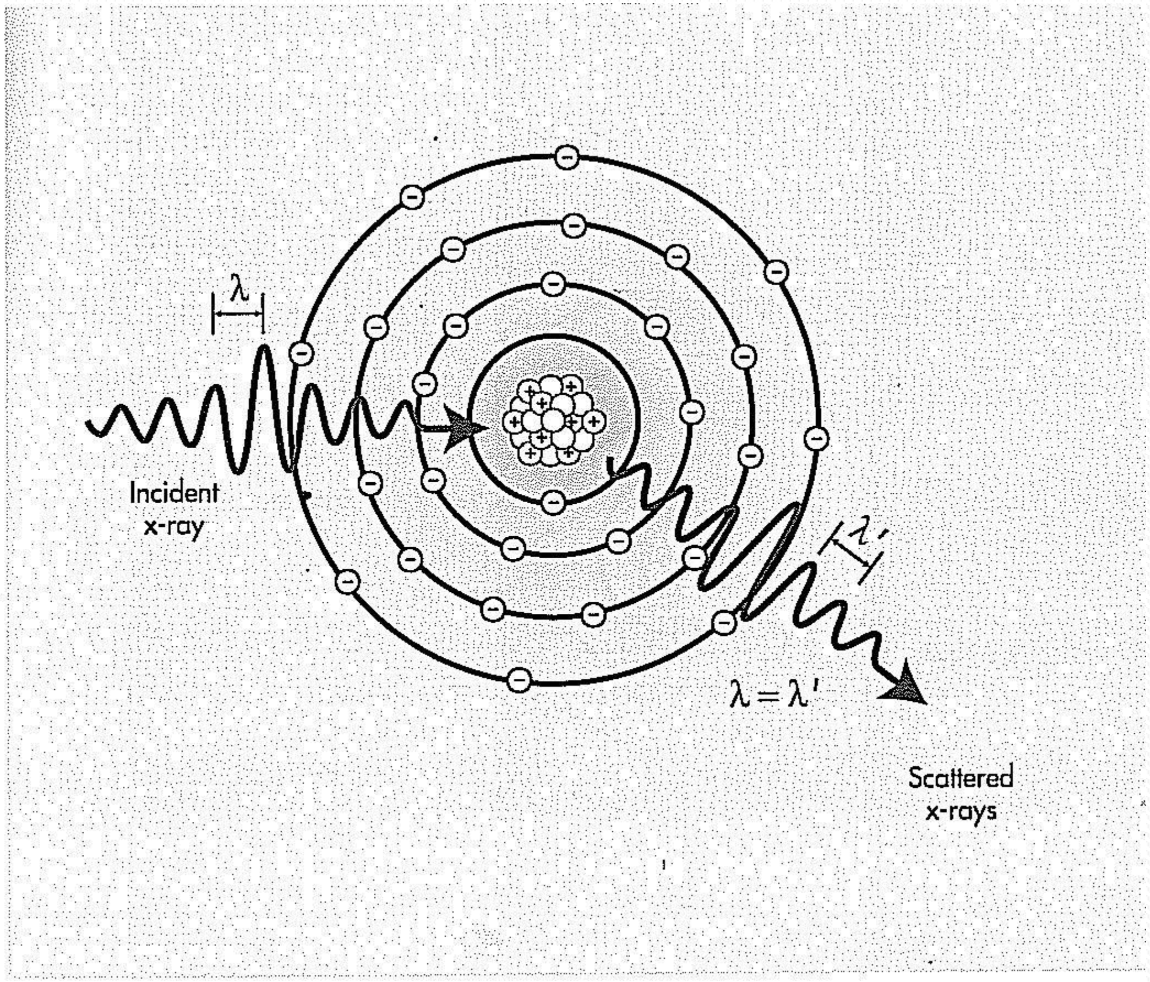


FIGURE 12-1 Classical scattering is an interaction between low-energy x-rays and atoms. The x-ray loses no energy but changes direction slightly. The wavelength of the incident x-ray is equal to the wavelength of the scattered x-ray.

SO…………..

- The direction of the secondary photon is different from the incident photon but the energy and the wavelength remain the same.

NET RESULT

- Change in direction without change in energy
- No transfer of electrons and no ionization
- Can be a cause of film fog

COMPTON EFFECT

- 30 to 150 kEv range
- Moderate energy x-rays interact with outer shell electrons by ejecting an outer shell electron and ionizing the atom.
- Photon continues in an altered direction with decreased energy.

COMPTON EFFECT

- Energy Lost = binding energy of ejected electron + electron kinetic energy

- The ejected electron is called the Compton electron and will eventually drop into a hole previously created by an ionizing event.

COMPTON EFFECT

- The photon itself is deflected and the greater the angle of deflection, the more energy is transferred to the secondary electron.
- Even at 180 degrees it still retains about two thirds of its original energy
- Photons can be scattered back in original direction are called backscatter radiation.

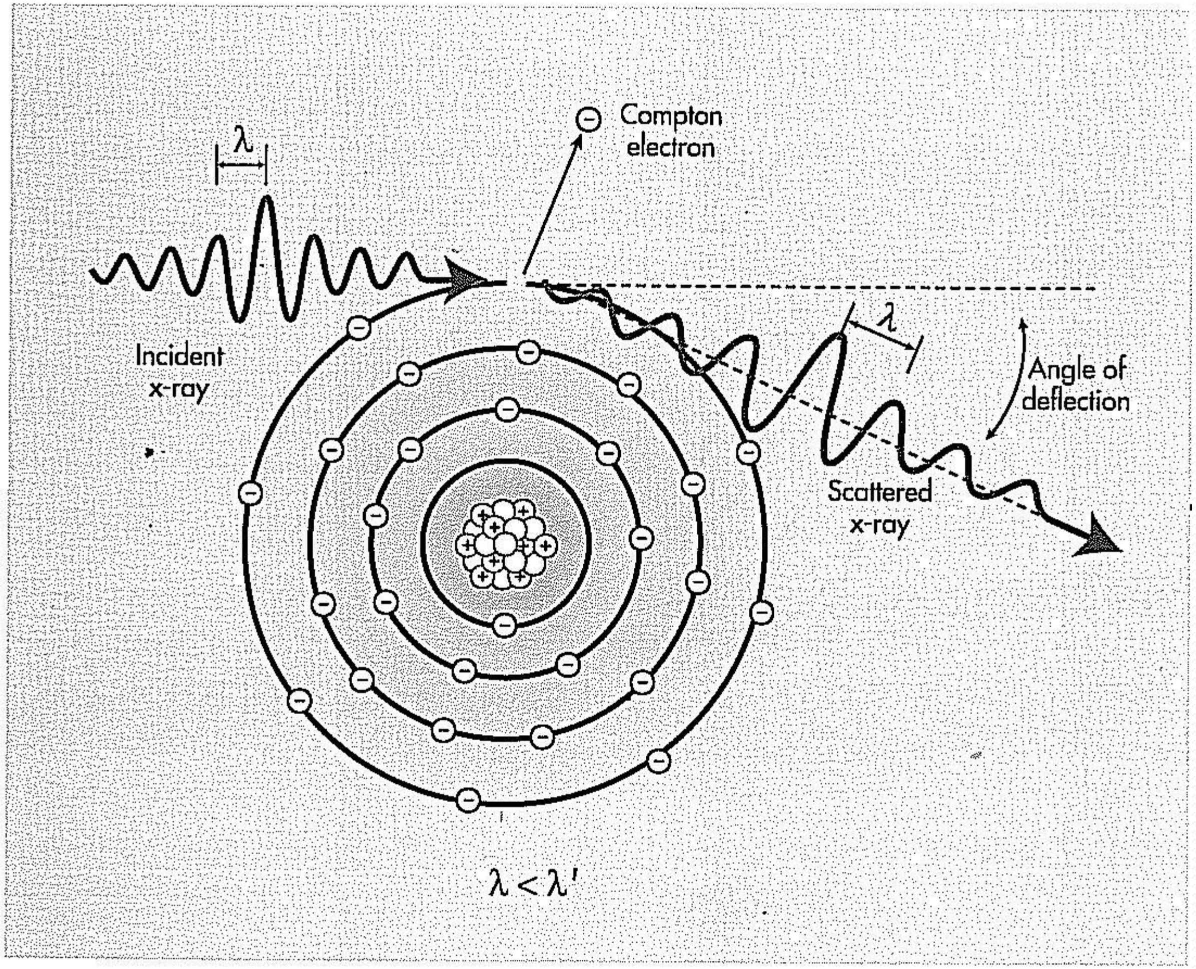


FIGURE 12-2 The Compton effect occurs between moderate-energy x-rays and outer-shell electrons. It results in ionization of the target atom, change in x-ray direction, and reduction of x-ray energy. The wavelength of the scattered x-ray is greater than that of the incident x-ray.

Contrast

- RESPONSIBLE FOR GRAYS
- NOT USEFUL INFORMATION BECAUSE PHOTON HAS CHANGED DIRECTION!!!!!

PHOTOELECTRIC EFFECT

- Photon Absorption Interaction
- Energy Levels of 30 to 150 kEv
- The X-ray photon is not scattered but it is absorbed

PHOTOELECTRIC EFFECT

- Photon interacts with an inner shell electron and is completely absorbed.
- Ejected electron is the photoelectron
- Secondary radiation is produced when the hole created by the ionizing event is filled with an outer shell electron (just like characteristic. Secondary radiation of no diagnostic value.

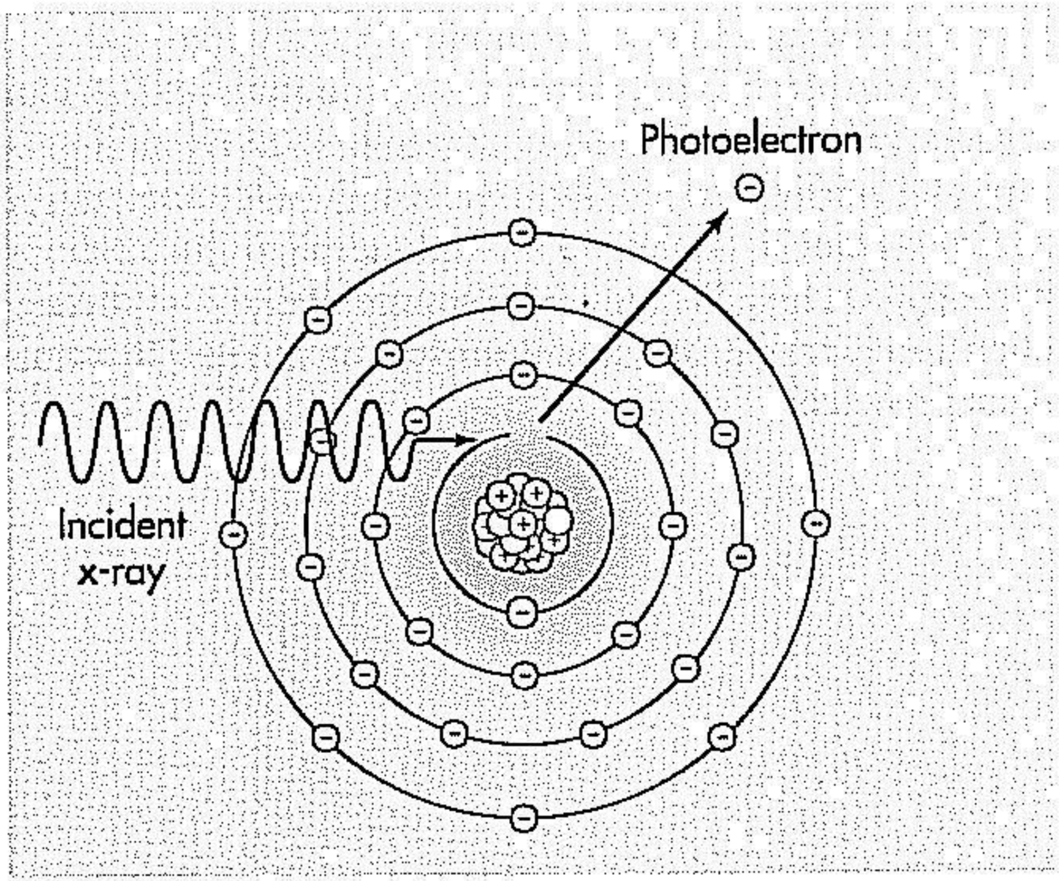


FIGURE 12-4 The photoelectric effect occurs when an incident x-ray is totally absorbed during the ionization of an inner-shell electron. The incident photon disappears and the K-shell electron, now called a *photoelectron*, is ejected from the atom.

PHOTOELECTRIC EFFECT

- A PHOTOELECTRIC INTERACTION CANNOT OCCUR UNLESS THE INCIDENT PHOTON HAS EQUAL OR GREATER THAN ENERGY THAN THE ELECTRON BINDING ENERGY!!!!!!!!!!!!!!!!!

CONTRAST

- Creates the “white” on films.
- Photoelectric happens in atoms of higher atomic numbers and great mass density.
- Dependent on the body part being imaged.

SO.....

- The probability that an x-ray photon will under go photoelectric is dependent on the energy of the photon and the binding energy of the absorber or target atom.

PAIR PRODUCTION

- Photon energy above 1.02 mEv
- Interacts with nuclear force field
- Incident photon totally absorbed
- Production of positron and electron from nucleus.

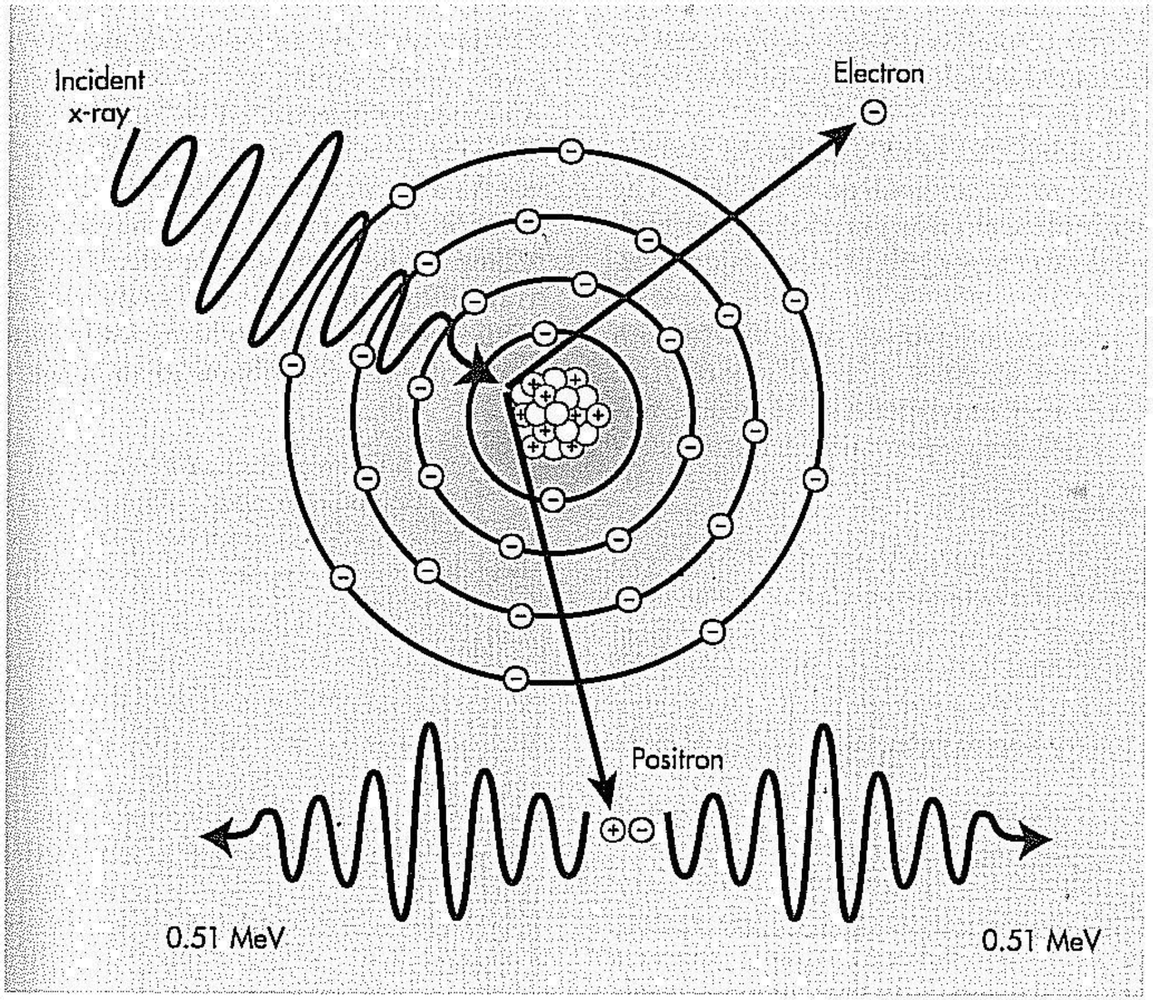


FIGURE 12-8 Pair production occurs with x-rays that have energies greater than 1.02 MeV. The x-ray interacts with the nuclear force field and two electrons that have opposite electrostatic charges are created.

PHOTODISINTEGRATION

- Incident photon above 10 mEv
- Interacts with nucleus of an atom
- Incident photon totally absorbed
- Nuclear fragment released

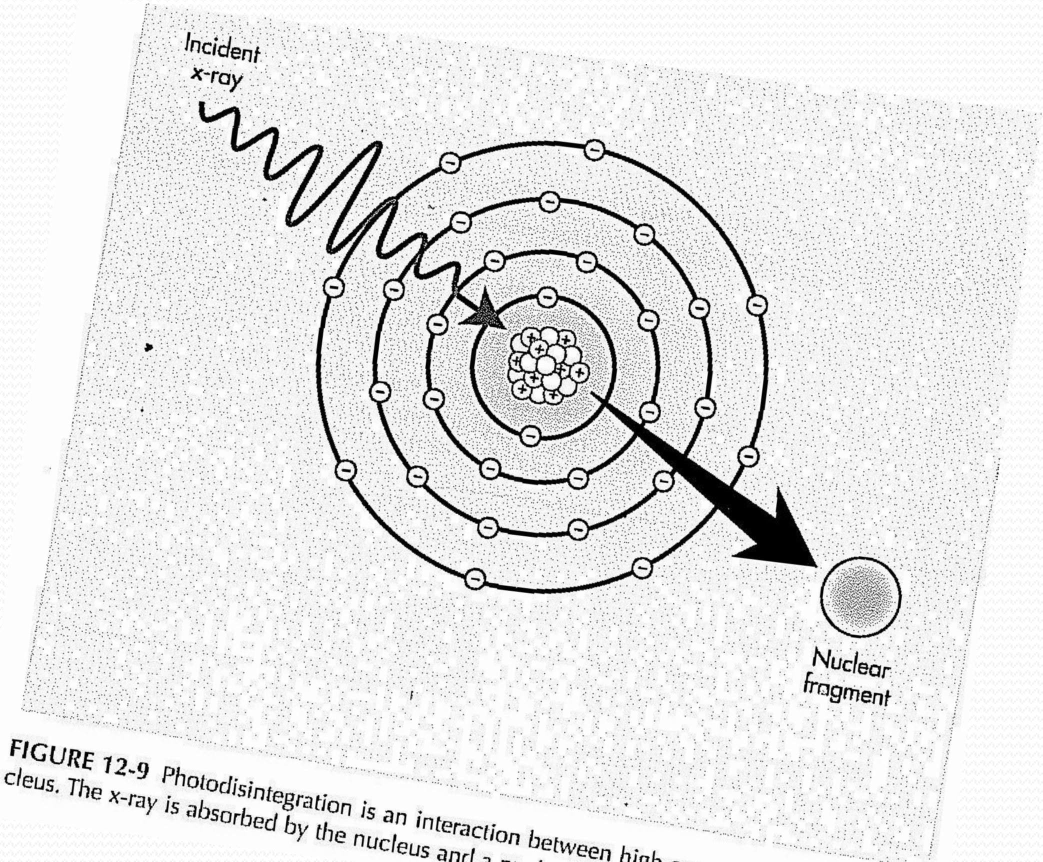


FIGURE 12-9 Photodisintegration is an interaction between high-energy x-rays and the nucleus. The x-ray is absorbed by the nucleus and a nuclear fragment is emitted.

Differential Absorption

- X-Ray image is the result of the difference between the x-rays absorbed photoelectrically and those not absorbed.

Compton's

- Most x-rays interact by Compton effect
- *For most radiographs, less than 5% of the incident x-rays reach the film and less than half of these interact with the film to form the image.
- Image is the result of approximately 1% of the x-rays emitted from the machine.

kVp

- KVP is the controller of differential absorption.
- Differential absorption increases as the kVp is lowered but this would also increase patient dose when mAs was adjusted for density.

COMPTON

- Compton scatter is independent of the atomic number of the absorbing material.
- The probability of compton scatter increases as x-ray energy (kVp) increases.

HOWEVER!

- As x-ray energy (kVp) is increased, the chance of an interaction decreases and more x-rays pass thru the patient without interaction and a lower output (mAs) is required.

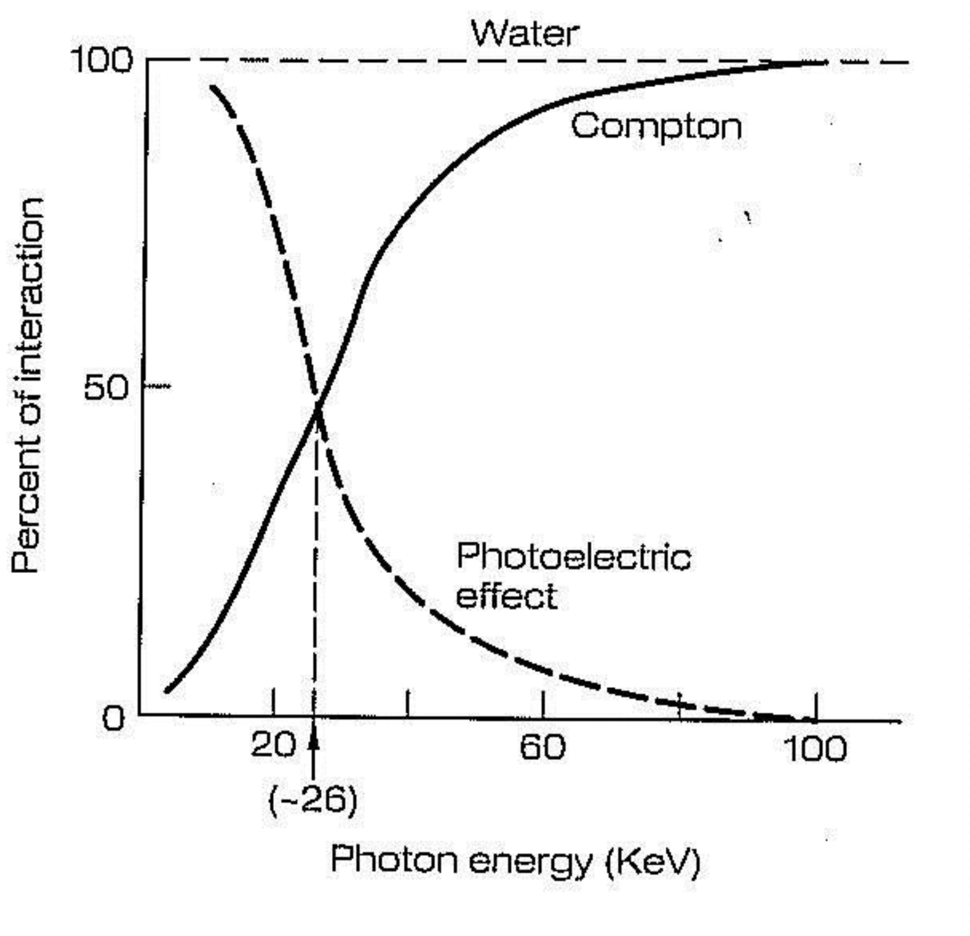
SOFT TISSUE

- To image small differences in soft tissue, one must use low kVp to get maximum differential absorption.
- This is the basis for mammography

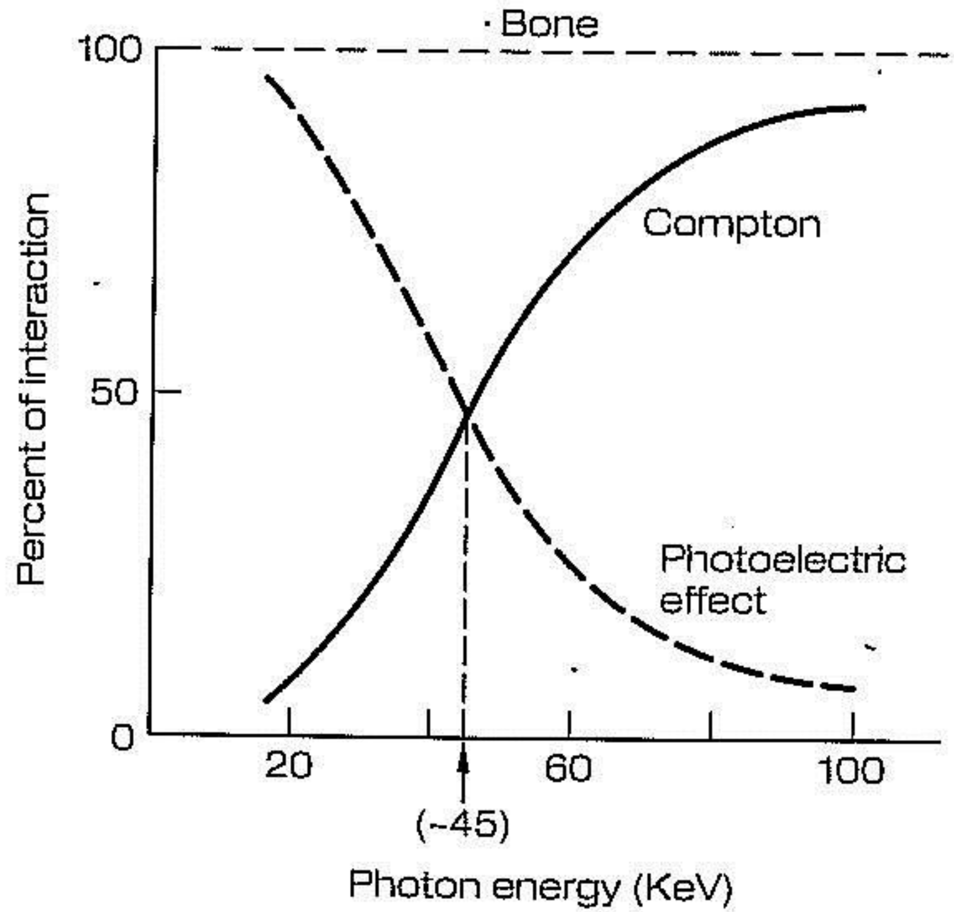
CROSSOVER POINT

- Because of the atomic number of tissue and other body parts, there is a point where one interaction dominates the other.

WATER


Water
100
50
0
Percent of interaction
Compton
Photoelectric effect
20
60
100
(~26)
Photon energy (KeV)

BONE



· Bone
100
50
0
Percent of interaction
Compton
Photoelectric
effect
20
60
100
(~45)
Photon energy (KeV)

CROSSOVER POINT

- The point at which Compton's becomes the prominent interaction
- In Water it is 26 kEv
- In Bone it is 45 kEv
- So whenever the average energy is above these levels the prominent interaction is Comptons.

When using high kVp

- When the energy level becomes high and the prominent interaction is compton scatter, we must often use grids to clean up the scatter and provide us with more contrast for a better image.

- High kVp must be used to penetrate dense objects.

Mass Density

- Quantity of matter per unit volume
- Higher the mass density, more chance of an interaction
- Basically tells us how tightly the atoms are packed together.

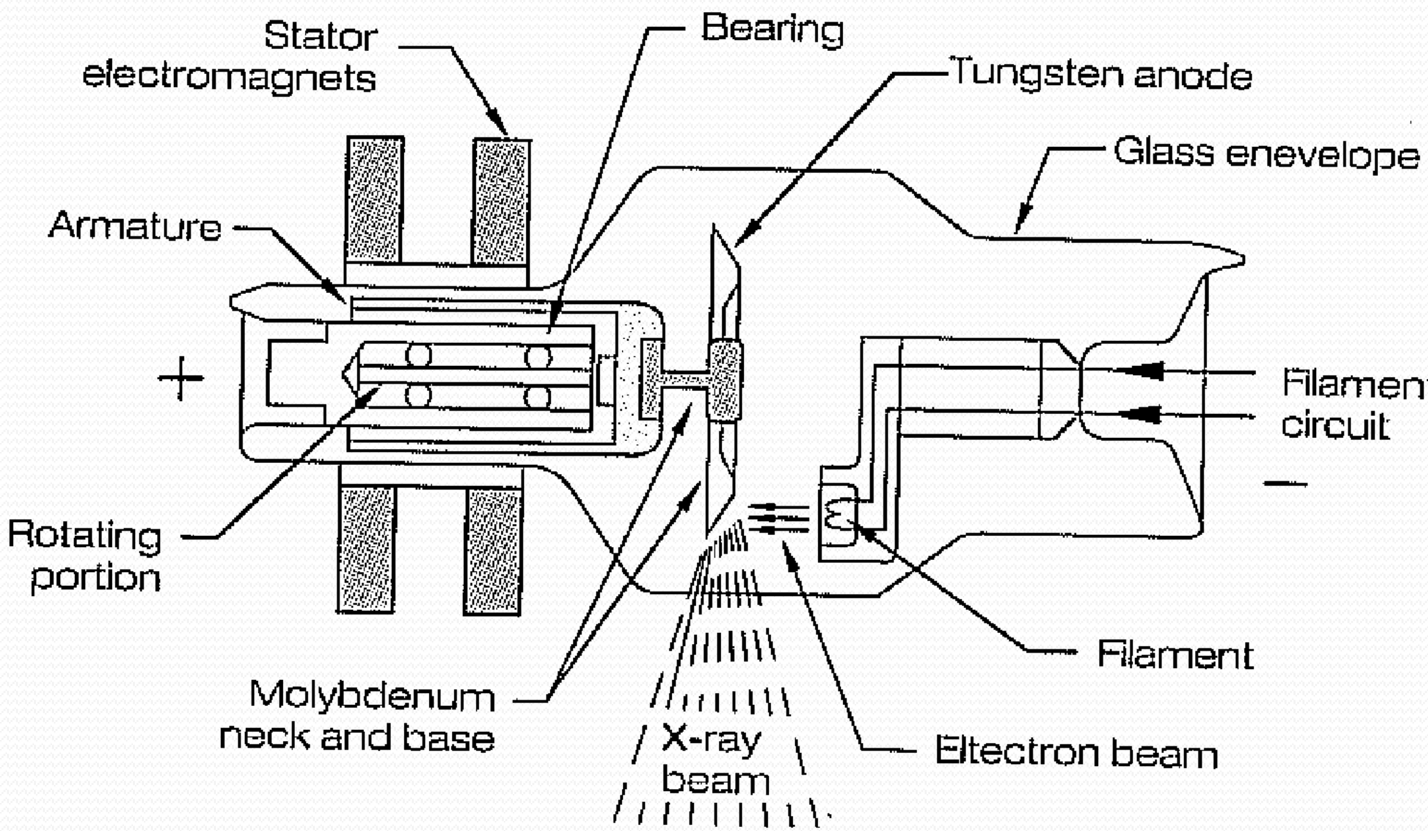
Mass Density

- The interaction between x-rays and tissue is proportional to the mass density of the tissue.
- When mass density is doubled, the chance for an interaction is doubled because there are 2x as many electrons to interact with.

Contrast

- Barium has an atomic number of 56
- Iodine has an atomic number of 53
- We must have energies above this number to penetrate and show the lumen.

The X-Ray Tube



Photon Production

- To Produce x-rays you must have the following:
  - Source of electrons
  - Appropriate target material
  - High voltage
  - Vaccuum

Source of Electrons

- Cathode: negative side of the x-ray tube.
- Function: to produce a cloud of electrons by the process of thermionic emission and focus the electron stream as it travels toward the anode.

Consists of:

- Focusing Cup
- Filament
- Filament circuit
- High Voltage Circuit

Filament

- Small coil of thin, thoriated (Thorium) Tungsten wire
- .1 to .2 mm thick

Tungsten

- Tungsten (W) is the material of choice because:
  - High atomic number
  - High melting point
  - Not easily vaporized

Dual Focal Spots

- In order to have dual focal spots you need:
  - 2 filaments
  - NOTE: Can use one filament for some machines such as a mamm machine.

Thermionic Emission

- Process by which electrons are “boiled” off
- Occurs when current is run thru a wire and the temperature reaches 2200 degrees Centigrade

Tube Failure

- Tungsten may vaporize and accumulate on the inside of the glass envelope
- Filaments break
- Bearings on rotor give out

Focusing Cup

- Device where filaments are mounted.
- Usually made of nickel
- Narrow the electron cloud as it is driven towards the anode.

Space Charge Effect

- Because like charges repel, eventually the negative charge becomes too strong to let any additional electrons be released by the filament.

- Now we have our source of electrons
- The Cathode has done its job!

ANODE

- Positive side of the tube
- Consists of:
  - Rotor
  - Stator
  - Anode

2 Types of Anodes

- Stationary – limited to low power functions such as dental units.
- Rotating – rhenium alloyed tungsten target area. Rotor/stator (induction motor) causes the anode to spin and give more area to dissipate heat.

Why Tungsten?

- High Atomic Number (w=74)
- High melting point (3410 degrees C)
- Good heat conductor

Mammography Tubes

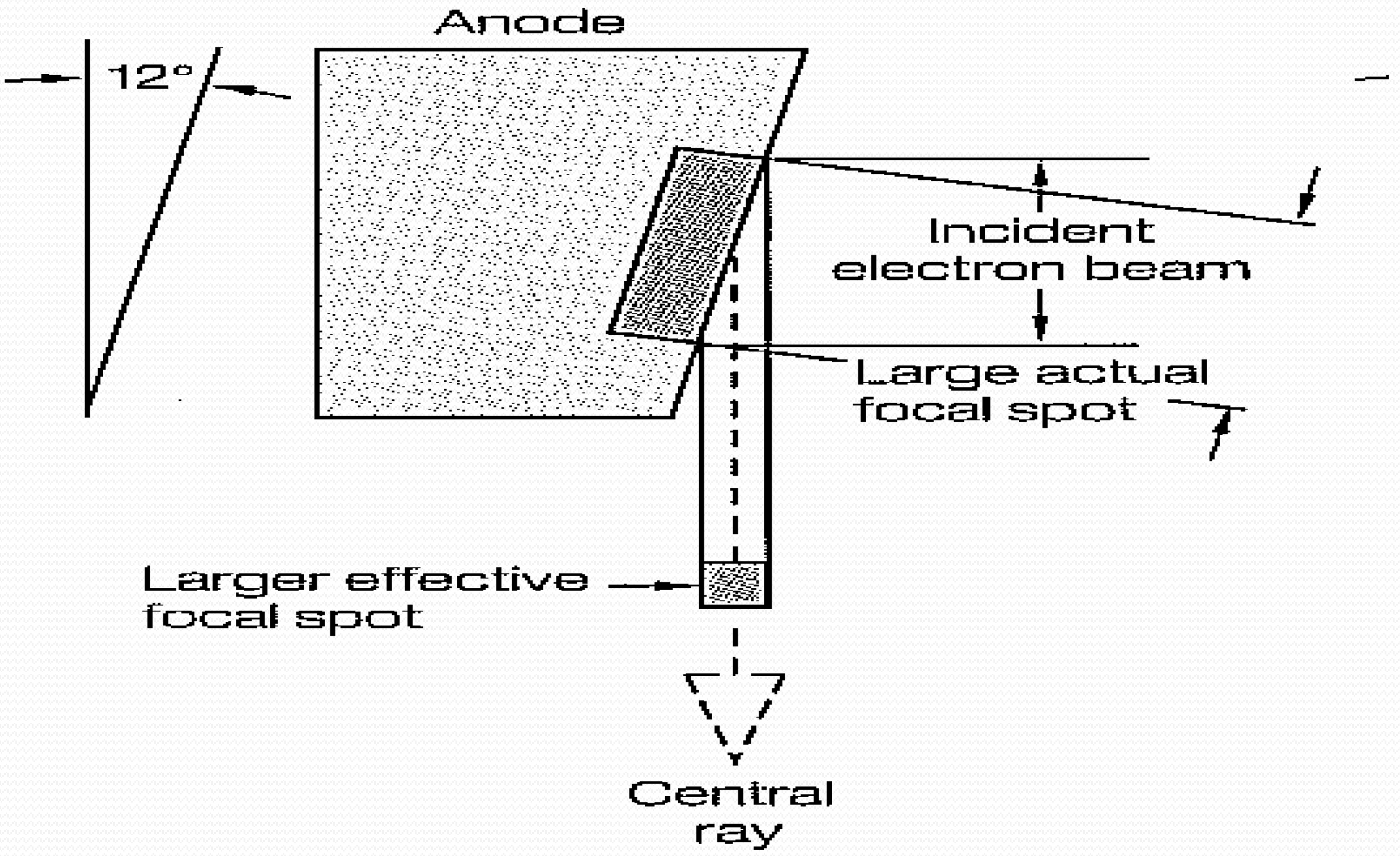
- We use Molybdenum (Mo=42)
- Emits more uniform range of lower energy photons

Rotating Anodes

- Target is also called the focal point, focal spot, focal track

- Rotating anode increases the target area up to 300x.

Line Focus Principle



- Actual is the area that the electron beam strikes
- Incident beam is the path of the projectile electrons
- Effective focal spot is what leaves the glass envelope

Target Angles

- Any time the target angle is less than 45 degrees, the effective focal spot is smaller than the actual focal spot.
- Tubes can be angled 7 – 17 degrees
- Most tubes 12 – 15 degrees

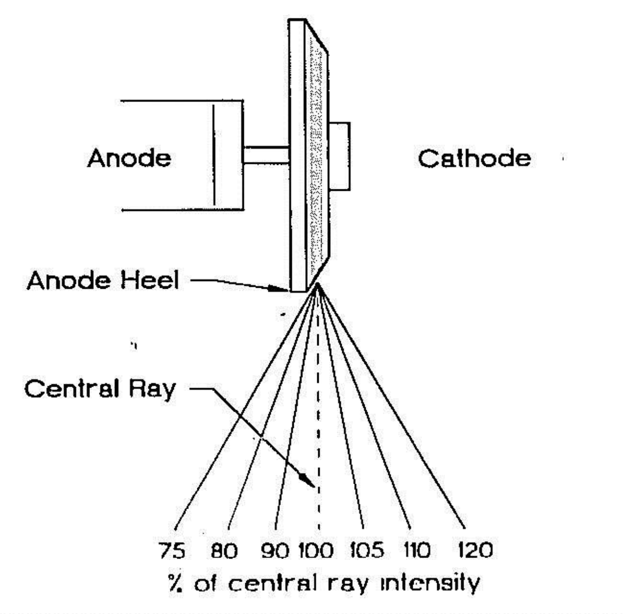
Focal Spots

- Diagnostic Tubes
  - Small Focal Spot .1
  - Large Focal Spot .3

This is the effective focal spot size

Anode Heel Effect

- Because of the geometry of an angled target the following is true:
  - Radiation intensity on the Cathode end of the tube has greater intensity
  - FAT - CAT



Anode
Cathode
Anode Heel
Central Ray
75 80 90 100 105 110 120
% of central ray intensity

Intensity Difference

- The intensity at the cathode end is approximately 125%
- The intensity at the anode end is approximately 75%

Induction Motor

- The Rotor/Stator assembly is an induction motor
- The stator is a series of bar magnets that energize in sequence
- The rotor aligns itself with the magnetic field created by the stator and rotates.

Rotor

- Rotor has speeds of:
  - 3400 rpm regular tube
  - 10,000 – 12,000 rpm high speed
  - Faster the speed, more heat is dissipated.

Rotor Construction

- Target area is on the face
  - Consists of tunsten with added rhenium
  - This is the area where projectile electrons will become x-ray photons.
  - Supported by copper, molybdenum, and graphite. They dissipate the heat produced by the interactions.

Glass Envelope

- All of this is encased in a glass envelope to create a vacuum
  - A vacuum takes out other particles and makes a clear path for the photons to be produced.

Metal Housing

- Metal housing provides physical support and protection for the tube
- Controls radiation leakage to a rate of 100 mr/hour at one meter.

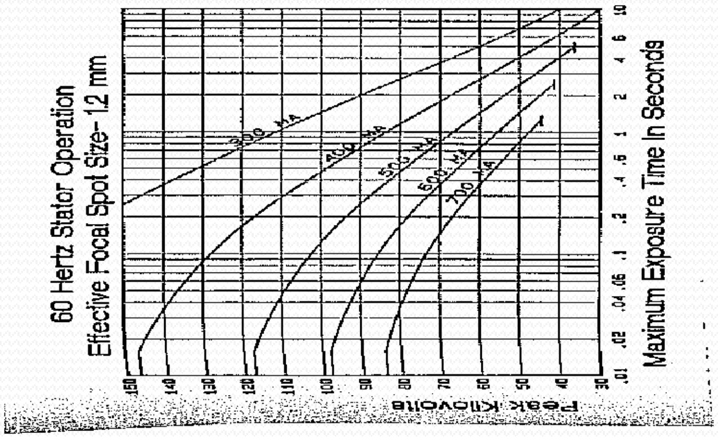
Insulation

- Oil between the glass envelope and tube housing serves as an insulator for the high voltage components.
- Also dissipates heat.
- Can have a fan or a recirculating system

Off Focus Radiation

- When x-ray photons are produced, they are produced isotropically (in all directions)
- Tube housing absorbs those not headed out the window

Tube Rating Charts



Tube Rating Charts

- Plot the maximum technical factors that can be used without overloading the tube.
- Plot mA, time, kVp
- If exposure falls below the line it is safe

Anode Cooling Charts

- Calculates the time necessary for the anode to cool enough for additional exposures to be made.
- To use this chart, you must know how to calculate heat units.

Calculating Heat Units

- Heat Units are measured in BTU's (British Thermal Units)
- HU=kVp x mA x time x cf
- Cf is different for each type of generator

Determining CF

- Single phase units = 1.0
- Three phase six pulse = 1.35
- Three phase 12 pulse = 1.41
- High Frequency = 1.45

Calculating Heat Units

- Calculate the number of heat units for each exposure and multiply times the number of exposures for total heat units.

X-Ray Circuit

- The X-Ray circuit has three transformers
  - Autotransformer
  - Step Up Transformer
  - Step Down Transformer

  - Transformers need alternating current to work

Autotransformer

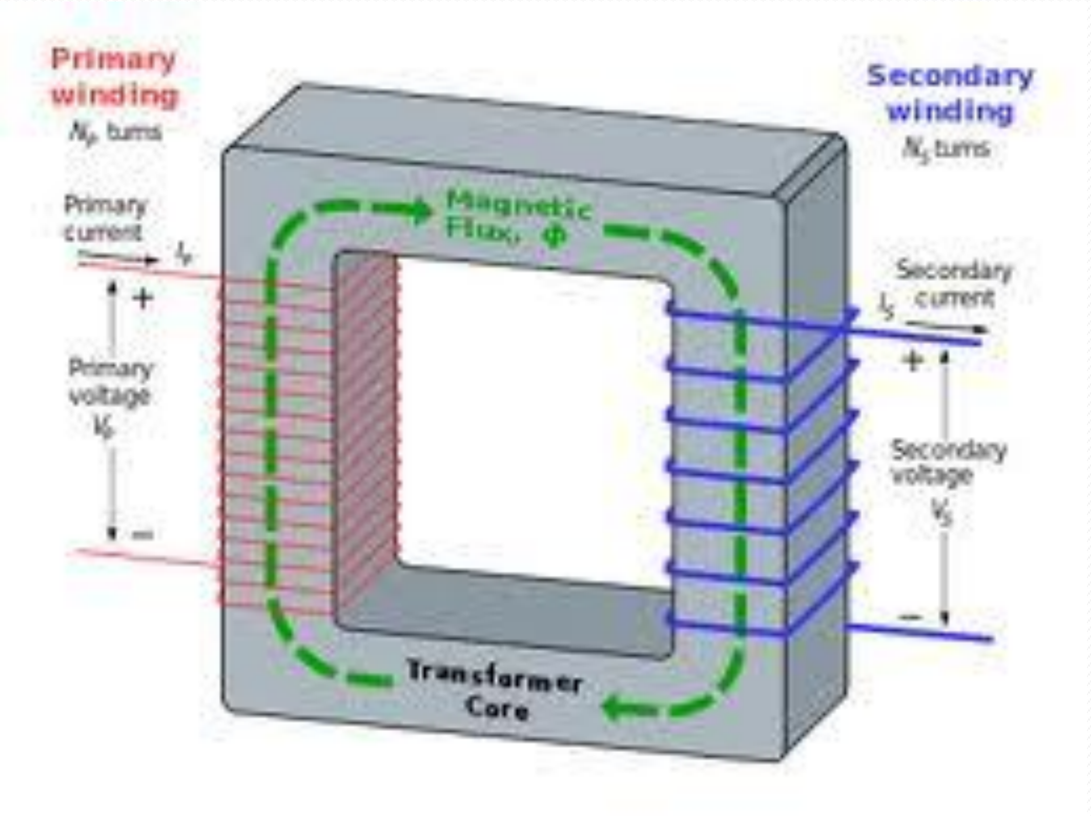
- Operates on the principle of “self” induction. Uses only one wire.
- kVp is chosen here

Step Up Transformer

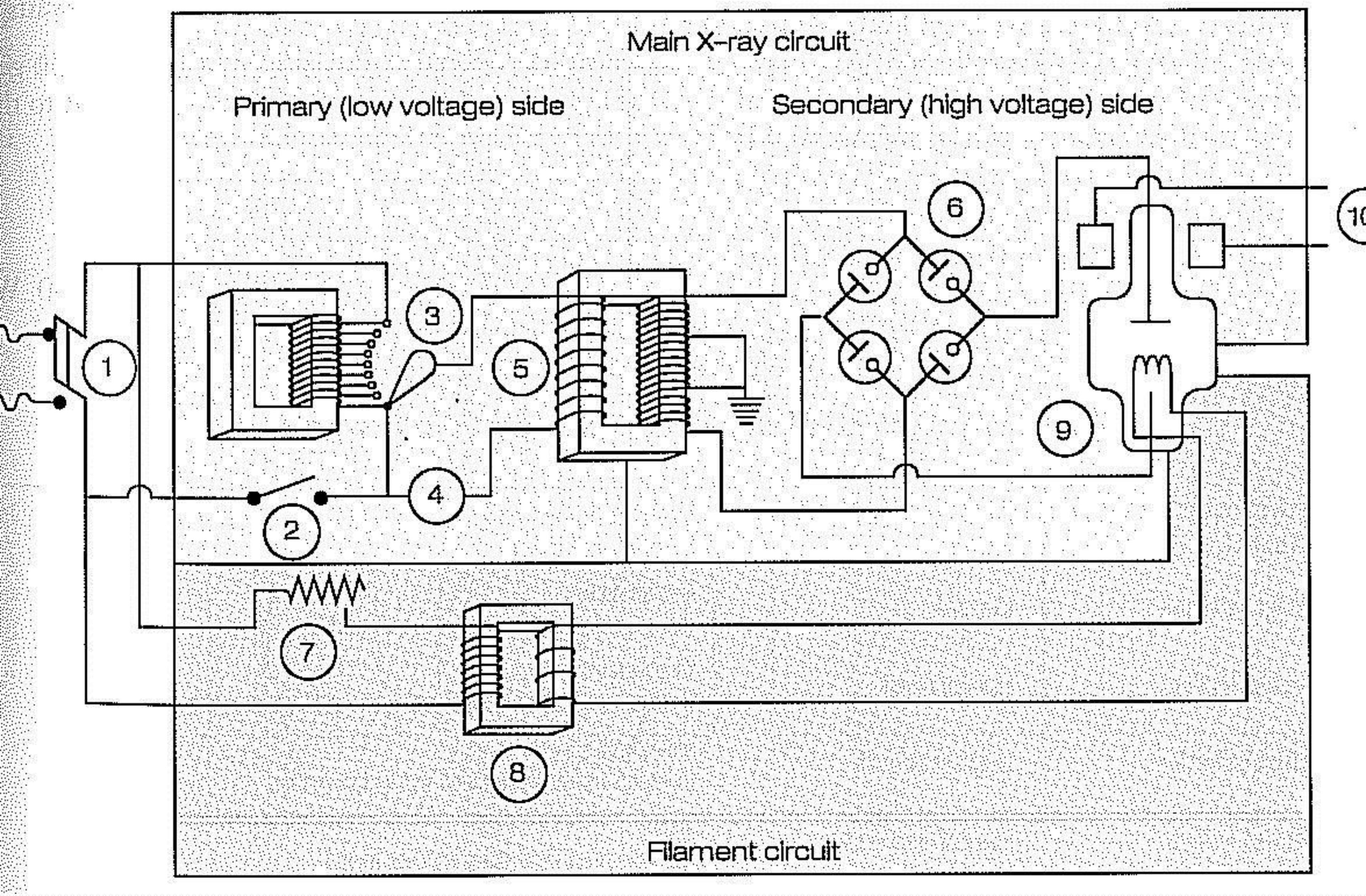
- Takes volts and converts to kilovolts (1000 volts)
- Two wires, primary side less than the secondary side

Step Down Transformer

- Steps down the voltage and current so it can be used for the filament to boil off electrons
- Primary has more turns than the secondary



Primary winding
N_P turns
Primary current
I_P
+
Primary voltage
V_P
−
Magnetic Flux, Φ
Secondary winding
N_S turns
Secondary current
I_S
+
Secondary voltage
V_S
−
Transformer Core

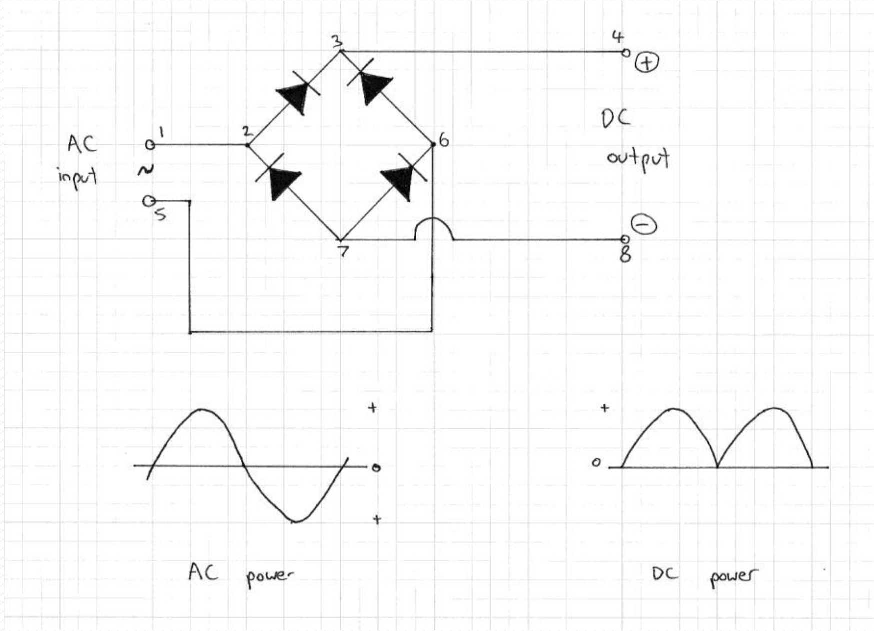

Main X-ray circuit
Primary (low voltage) side
Secondary (high voltage) side
1
2
3
4
5
6
7
8
9
Filament circuit

Rectification

- We needed alternating current to make the transformers work but the voltage ripple causes inefficiency in the output of the tube so we need to convert ac to dc
- This is done by the use of rectifiers

Rectifiers

- Devices that only allow the flow of electrons in one direction.
- Turns – half +



- Each phase needs four rectifiers
- Three phase equipment needs 12 rectifiers
- End result is much more efficient output of the tube.
- Your technique will vary from single phase to three phase. It sounds like we are delivering much more radiation with single phase but it is just that single phase is less efficient.

Questions?