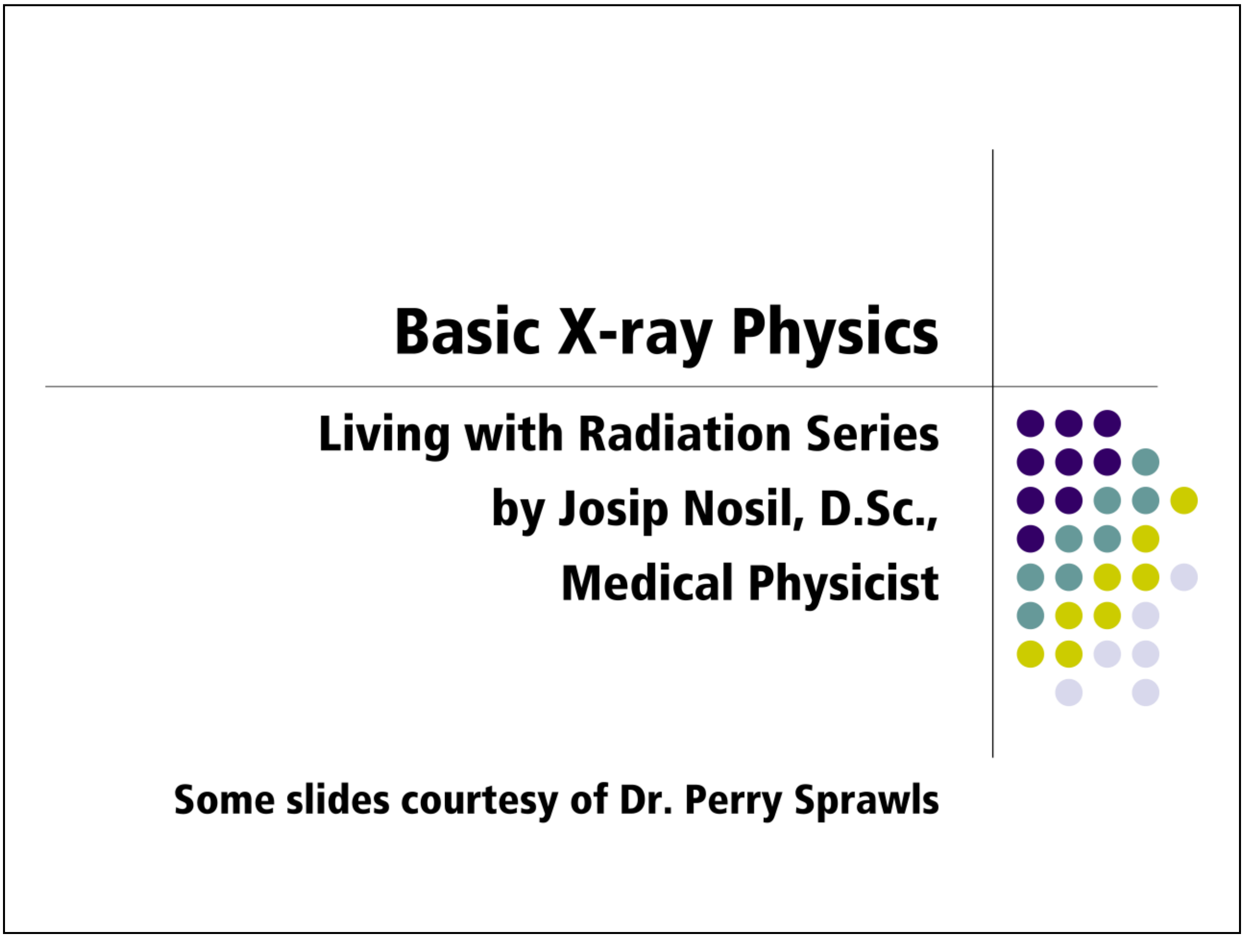

Basic X-ray Physics

Living with Radiation Series

by Josip Nosil, D.Sc.,
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Some slides courtesy of Dr. Perry Sprawls

Basic X-Ray Physics is the first in the series of training CDs designed for staff that use or are exposed to x-ray radiation in their daily work. It is important to learn first how radiation interacts with material, before biological theories can be developed.

For some this presentation will act as a review, for many these will be new material. There is a lack of such training in professional education. Also, x-ray applications, radiation biology, radiation protection and radiation limits have changed as we learn more about risk factors involved.

This course consists of slides, notes and narration. The narration covers the material that is mostly on the slides. They can be heard by selecting the loudspeaker icon when each slide is displayed.

The notes explain principles in more detail or deal with associated material.

Our present knowledge, as expressed in this lecture, is by no means complete, but it is sufficient to act as a guide. An understanding of x-ray radiation interactions, and its ramifications is mandatory for physicians and others who use x-rays, either directly or indirectly, in their practice.

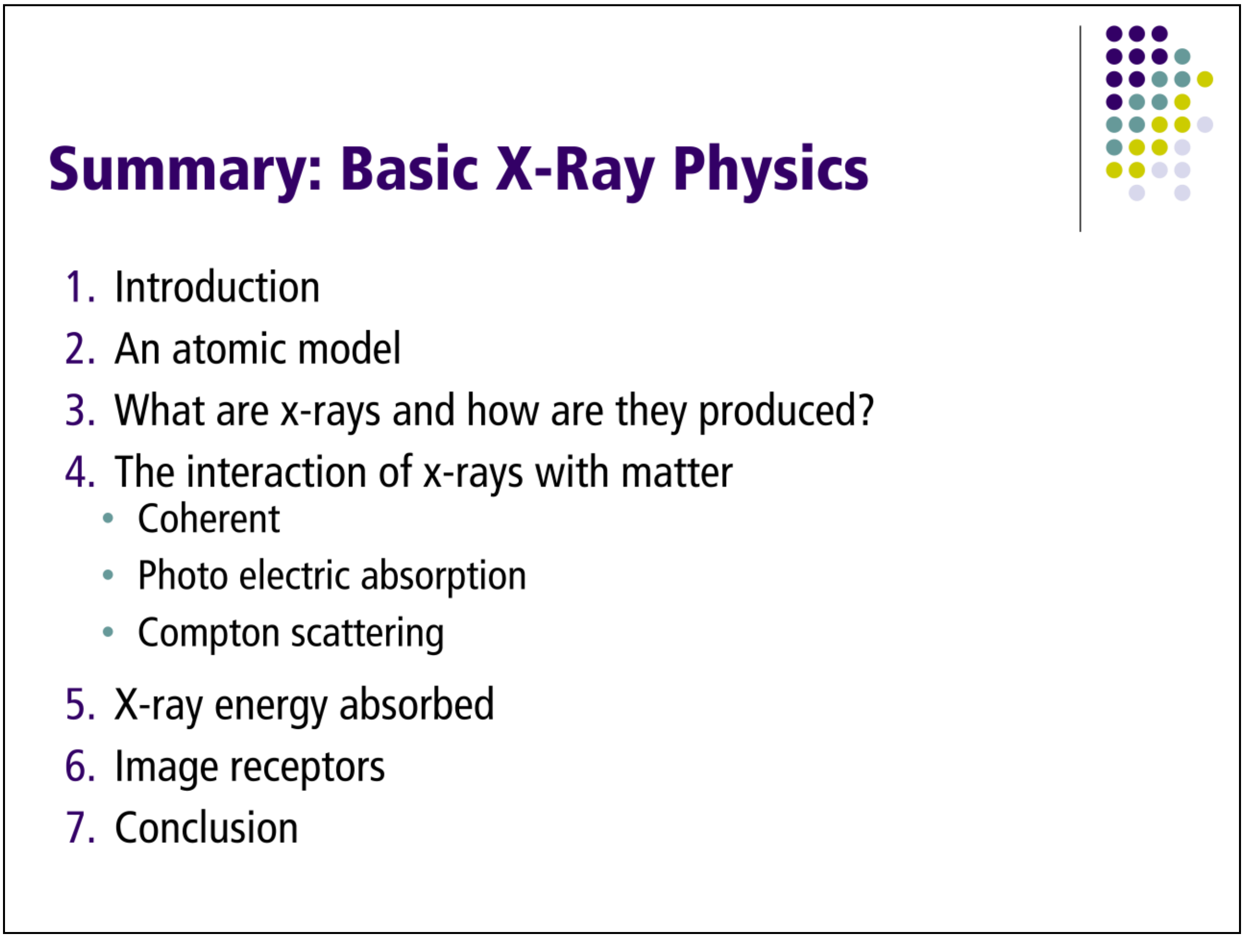
Basic X-ray Physics

- Why do we use x-rays to examine internal structure and functioning of the body?
- What are x-rays, anyway, and how do they work?

The uses of radiation in medicine and dentistry are unlike the other uses of radiation discussed in other presentations. This is because it involves the irradiation of human beings other than the operator. The reasons may be therapeutic (as in radiation oncology) or diagnostic (as in medical or dental imaging).

The benefit comes from the x-rays producing an image that is useful in the diagnosis of the medical or dental condition under study. It goes without saying that an unreadable image means that the patient has been exposed to radiation with no benefit. Thus it is important that the exposure be controlled within relatively narrow limits. In fluoroscopy, not only must the exposure rate be kept to the minimum that will produce a useful image, but also ensure that all steps in the imaging chain must be functioning optimally.

X-rays travel outward from the focal spot of the x-ray tube (like light from a light bulb), and they can be blocked out to cast a shadow. Just as light is scattered in all directions from an object it strikes, so are x-rays. But unlike light, x-rays are not stopped at the first surface they encounter. They penetrate materials to a degree depending upon how they are generated and upon the nature of the material. Bone shows up in a radiographic image because it absorbs more x-rays than does soft tissue. Lead and steel absorb x-rays even more effectively and are used as protective barriers to x-rays. This is why we can use x-ray to examine human body.



Summary: Basic X-Ray Physics

1. Introduction
2. An atomic model
3. What are x-rays and how are they produced?
4. The interaction of x-rays with matter
   - Coherent
   - Photo electric absorption
   - Compton scattering
5. X-ray energy absorbed
6. Image receptors
7. Conclusion

The course is roughly divided into these seven general sections.

1. Introduction
2. An atomic model
3. What are x-rays and how are they produced?
4. The interaction of x-rays with matter
   - Coherent
   - Photo electric absorption
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7. Conclusion

Introduction

Ionizing radiation Bermuda is widely used in

- Medicine,
- Research,
- Education, and
- Industry

The use of radiation in Bermuda comes under the mandate of the Ministry of Health, it is a requirement that all users of such radiations have evidence that they have received training in the principles of radiation safety as it applies to themselves, their staff, their patients, and others.

Ionizing radiation is widely used in medicine, research, education and industry.

There is a lack in the knowledge base of basic radiation physics and how it applies to risks.

The use of radiation in Bermuda now comes under the mandate of the Ministry of Health, it is a requirement that all users of such radiations have evidence that they have received training in the principles of radiation safety as it applies to themselves, their staff their patients, and others.

Also various professional societies have formally adopted a policy to encourage the teaching of radiation protection during their training programs.

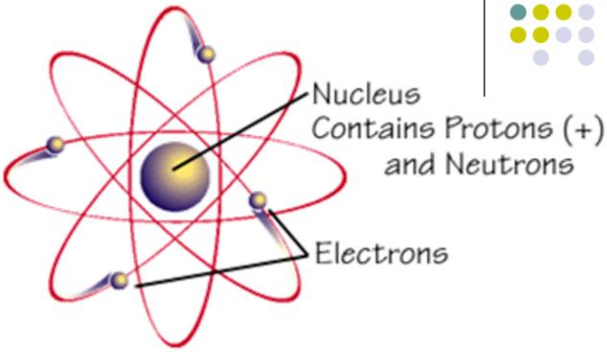
Opening

- Why is ‘physics’ a part of this series of lectures?
- Why is it important that we know about physics of radiation?
- How will this knowledge help us and our patients?

This basic physics lecture examines what happens at the atomic level when x-rays impinge upon matter. We se that atoms are ionized by the removal of one or more orbital electrons, with the result that ‘ion pairs' (consisting of a negatively-charged electron and a positively charged atom) are produced.

What is physics?

Model of An Atom



1. **Nucleus:** nucleus taking place of the sun in the center of the atom, and it is positive in charge.
2. **Electrons**: electrons are negative in charge and are whirling around nucleus in orbits.
3. **Atom**: atoms are neutral in charge, ant it consists of nucleus and electrons.
4. **Orbits**: orbits are defined by energy levels and distances form the nucleus.

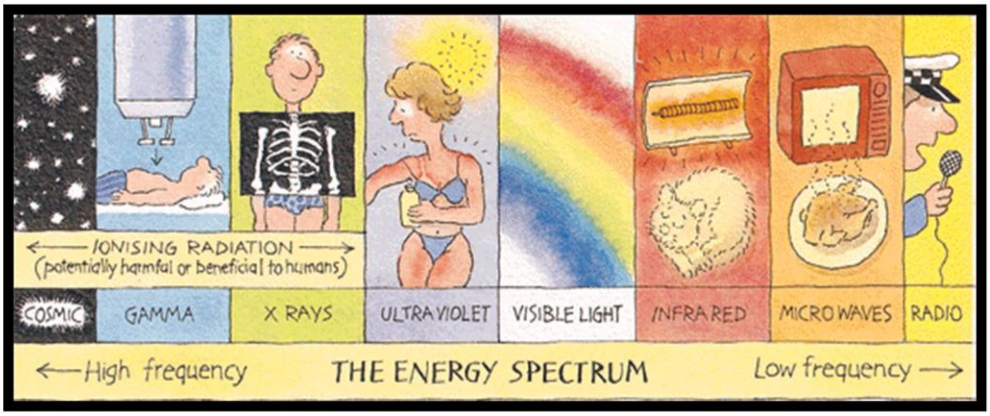
Since x-rays are produced at the atomic level, we start with discussing a model of the atom which will help us understand x-rays. Most of the mass of the atom is concentrated in the nucleus, which has a net positive charge equal to the number of protons it contains. In the neutral atom, an equal number of negatively-charged electrons (much less massive) are in orbits about the nucleus. It is the interaction of high energy electrons with the atom which gives rise to the production of electromagnetic radiation, including x-rays.

We see the atom as a kind of miniature solar system, with the nucleus taking the place of the sun, and electrons whirling around it in orbits similar to those of the planets. As in the solar system, by far the most of the atomic mass is concentrated in the nucleus. The similarity ends there, however, with the differences being:

The size of the solar system is measured in billions of kilometers, while atoms are measured in billionths of kilometers.

In the solar system the planets are all different and take different orbits around the sun: in the atom the orbital electrons are all the same, and some share orbits.

The Electromagnetic Energy Spectrum

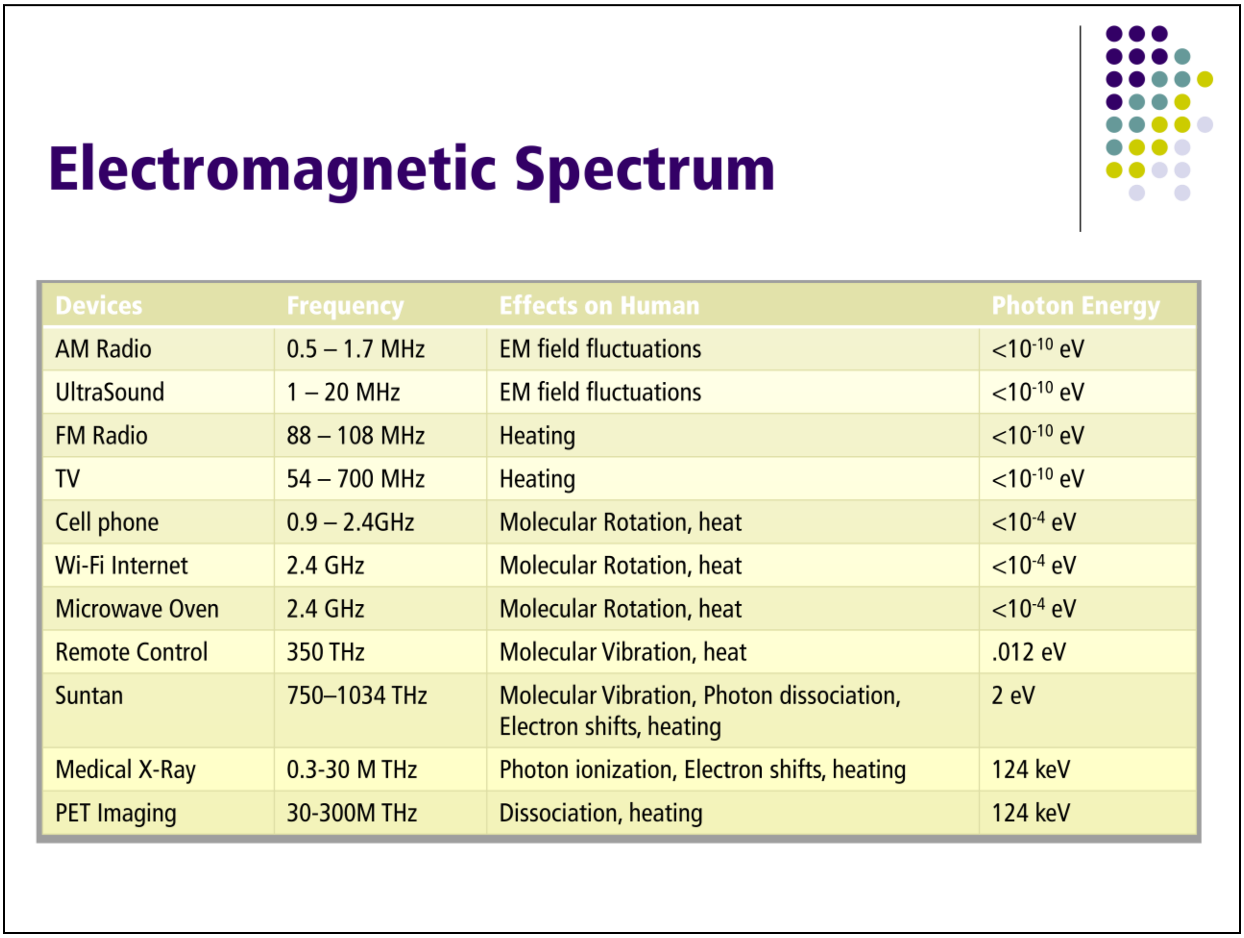


- Radiation is energy travelling through the space.
- It delivers light, heat, suntans, and x-ray images.
- To much of it is not a good thing.

Electromagnetic radiation of one kind or another, encompasses every aspect of our daily life. We listen to radio and TV, we cook with microwaves, we warm ourselves with heat (infrared) and we see be visible light. The only difference between these forms of radiation is the frequency which characterized them, and which determines how they interact with matter. At higher frequencies than those of visible light are ultraviolet radiation, x-rays , gamma rays and the radiation from the cosmos. It is with the production and use of x-rays that we are concerned here.

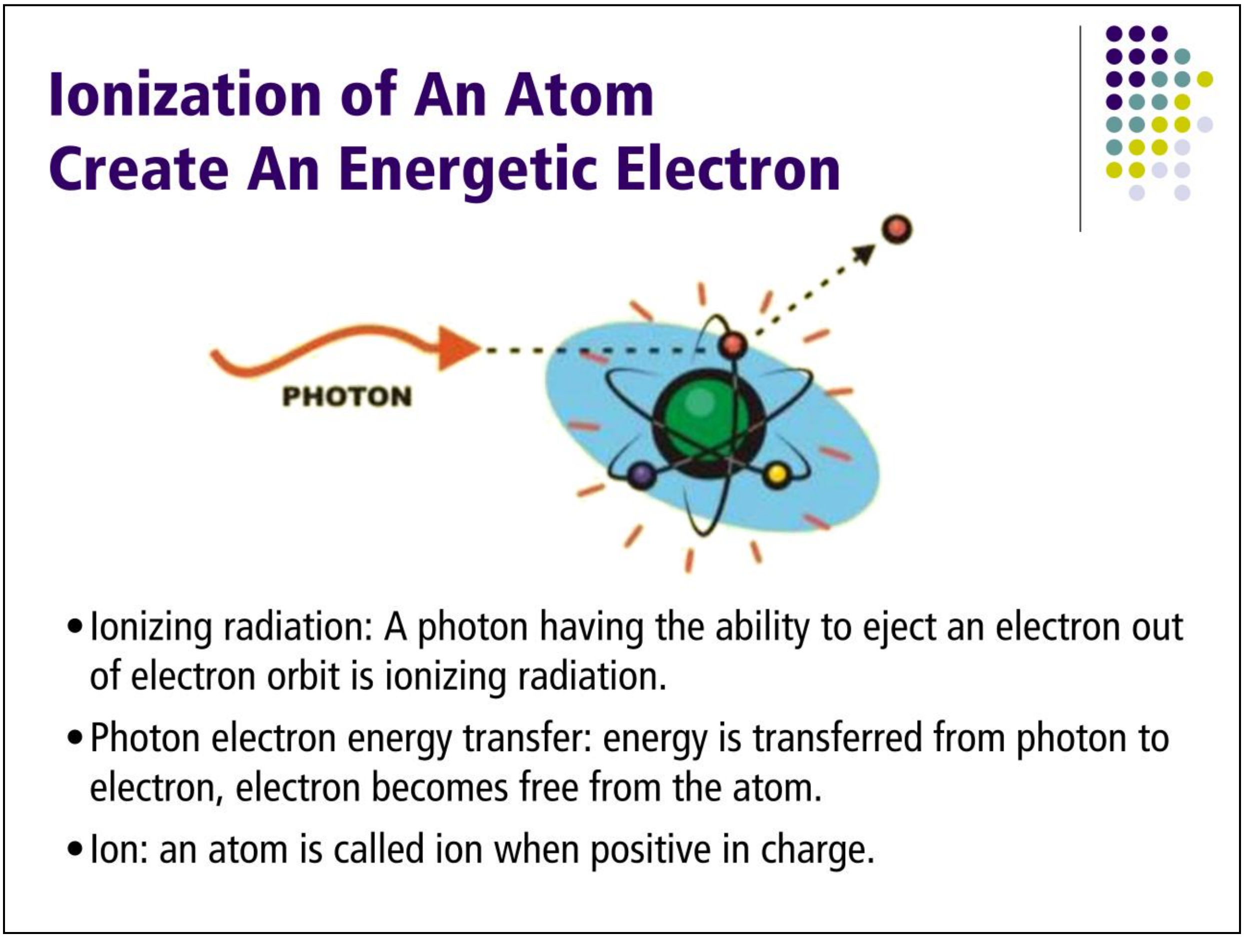
There is a difference between non-ionizing electromagnetic fields, optical radiation and ionising radiation. Describe the electromagnetic spectrum - visible/invisible-detect directly/indirectly.

Radio waves, microwaves, infra red, visible light, ultra violet, X-rays, gamma rays. X-ray generators. Ionisation. Radioactivity/radioactive decay. Atoms, elements, isotopes. Particle radiation -alpha, beta, neutrons. Half-life radioactivity disappears naturally). Natural radioactivity.



Electromagnetic Spectrum

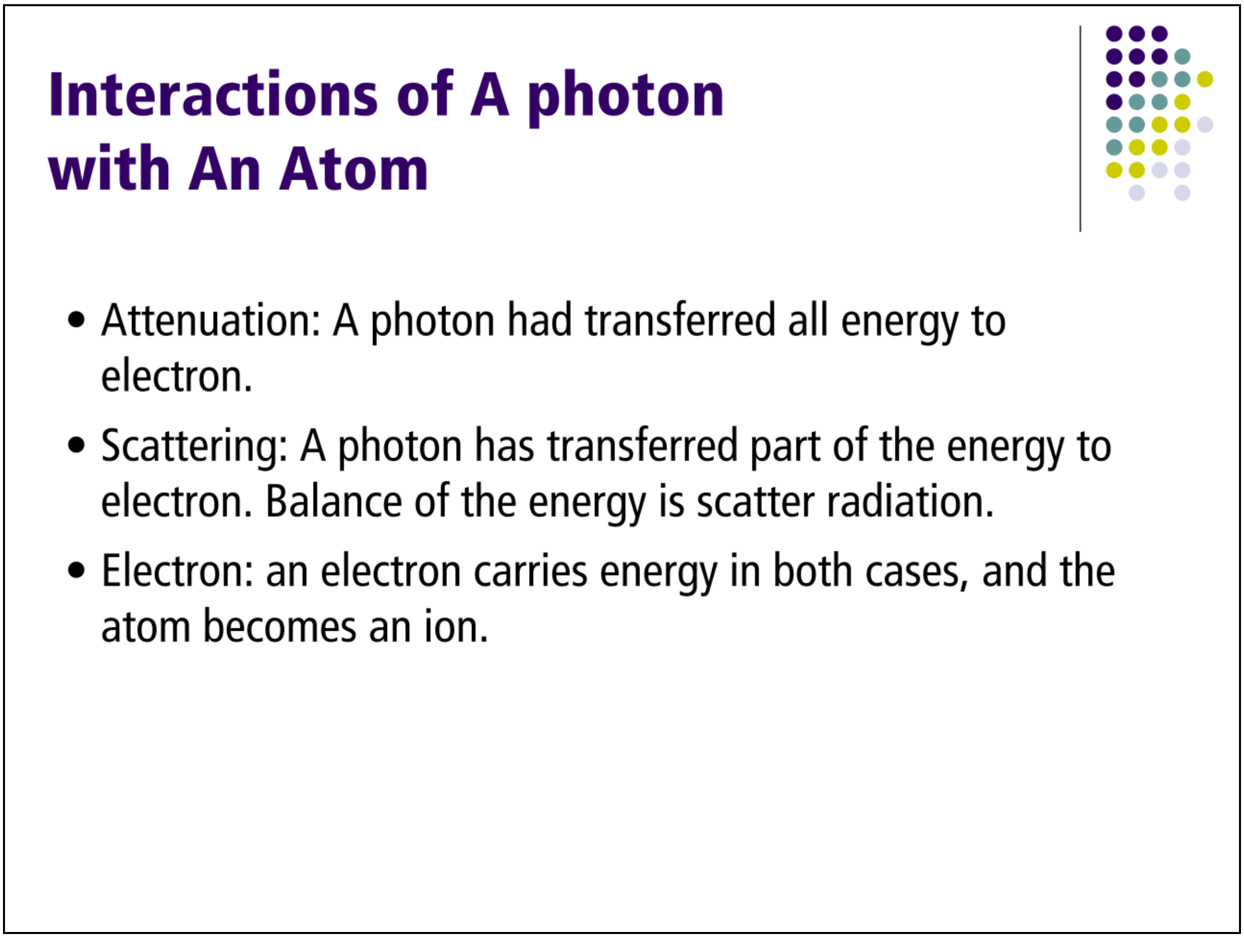
Devices	Frequency	Effects on Human	Photon Energy
AM Radio	0.5 – 1.7 MHz	EM field fluctuations	$<10^{-10}$ eV
UltraSound	1 – 20 MHz	EM field fluctuations	$<10^{-10}$ eV
FM Radio	88 – 108 MHz	Heating	$<10^{-10}$ eV
TV	54 – 700 MHz	Heating	$<10^{-10}$ eV
Cell phone	0.9 – 2.4GHz	Molecular Rotation, heat	$<10^{-4}$ eV
Wi-Fi Internet	2.4 GHz	Molecular Rotation, heat	$<10^{-4}$ eV
Microwave Oven	2.4 GHz	Molecular Rotation, heat	$<10^{-4}$ eV
Remote Control	350 THz	Molecular Vibration, heat	.012 eV
Suntan	750–1034 THz	Molecular Vibration, Photon dissociation, Electron shifts, heating	2 eV
Medical X-Ray	0.3-30 M THz	Photon ionization, Electron shifts, heating	124 keV
PET Imaging	30-300M THz	Dissociation, heating	124 keV



Ionization of An Atom Create An Energetic Electron

- Ionizing radiation: A photon having the ability to eject an electron out of electron orbit is ionizing radiation.
- Photon electron energy transfer: energy is transferred from photon to electron, electron becomes free from the atom.
- Ion: an atom is called ion when positive in charge.

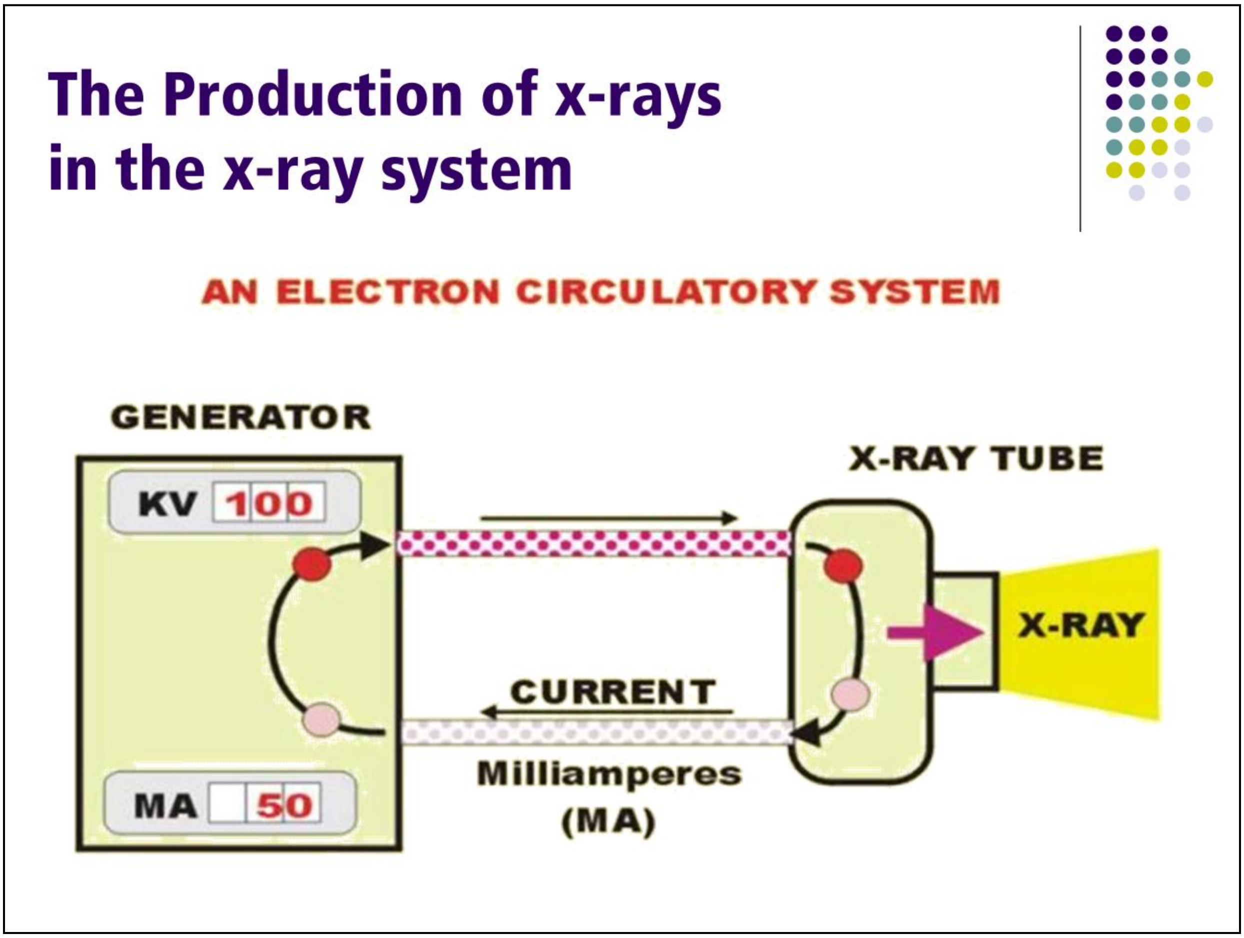
Electromagnetic radiation of frequencies higher than ultraviolet are referred to as ‘ionizing radiations’ because their photons are capable, in interacting with atoms, of removing one or more orbital electrons from the atom, thus converting the atom into a positively-charged ‘ion’. In this ‘ionization process’ energy is transferred from the photon to the electron and to the atom.



Interactions of A photon with An Atom

- Attenuation: A photon had transferred all energy to electron.
- Scattering: A photon has transferred part of the energy to electron. Balance of the energy is scatter radiation.
- Electron: an electron carries energy in both cases, and the atom becomes an ion.

The interaction of an x- or gamma-ray photon with an atom can result in a number of events. All of the photon energy can be absorbed directly by the atom, or some of it can be absorbed and some scattered. In both of these cases, the atom receives some energy from the photon, and becomes ionized. In a third type of interaction, the photon is scattered without loss of energy, and with no transfer of energy to the atom (coherent scattering). These types of interaction will be discussed later.



The Production of x-rays in the x-ray system

AN ELECTRON CIRCULATORY SYSTEM

The x-rays are produced as follows. Alternating electric current is raised in voltage from the standard 120/220 volts to 30 - 150 thousand volts in a transformer. The alternating voltage is rectified in the high voltage generator and then applied across an evacuated x-ray tube. In the x-ray tube, electrons from a heated filament are accelerated across from the negative to the positive electrode (SLIDE). The voltage difference between the two electrodes is set by the controls of the generator, and can be anywhere from 30,000 to 150,000 volts (30 to 150 kilovolts). The positive electrode upon which the high speed electrons impinge is usually made of tungsten (Z=74), which has a very melting point. As the electrons are stopped by the atoms of tungsten, about 99% of their energy is turned into heat (hence the high melting point!) and the rest becomes x-rays, which are given off in all directions (SLIDE). The x-ray tube is contained in a lead-lined enclosure, which absorbs all the x-rays except those which are directed at the patient (SLIDE). The crossectional area of the useful beam, which is matched to the size of the detector, is set by adjustable absorbing plates.

The Production of x-rays in the x-ray system

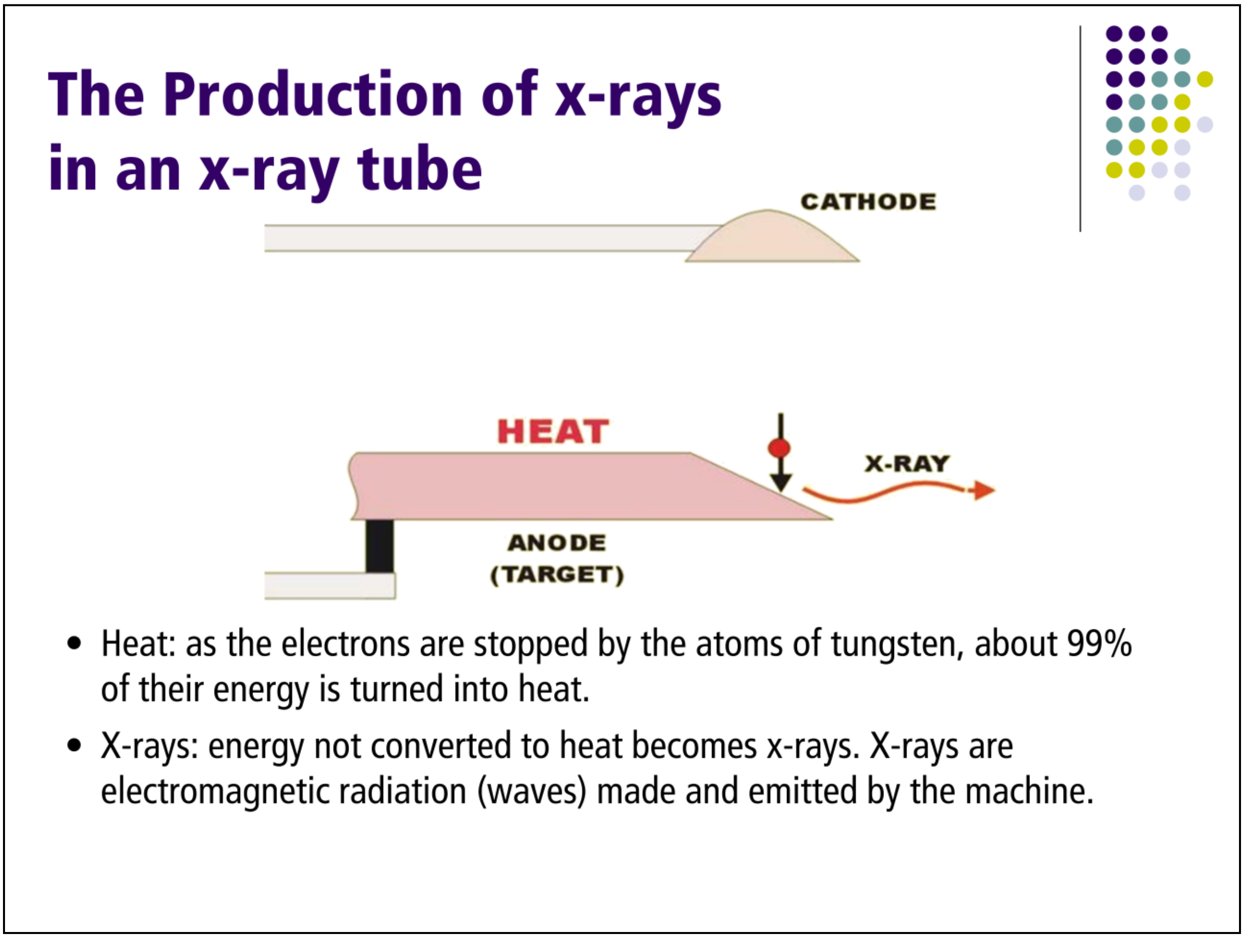
- Transformer:
  the alternating electric current is raised in voltage from the standard 120 volts to 100 kV.
- Generator:
  the alternating voltage is rectified in the high voltage generator.
- X-ray tube:
  electrons are accelerated across from the negative to the positive electrode to produce heat and x-rays.
- Cooling system:
  is required to take heat out of the x-ray tube.

X-rays are produced from an electrical power supply in the following manner.

In a voltage transformer,the alternating electric current is raised in voltage from the standard 120 volts to about 100 kV. This alternating voltage is transformed into a direct voltage in a high voltage rectifier. Depending upon the type of generator, this voltage may be pulsed or constant.

The direct voltage is applied across the X-ray tube which has a negative and a positive electrode.: Electrons are repelled by the negative and attracted by the positive electrode. When they impinge upon the positive electrode (the anode or target) heat, light and and x-rays are produced. The target is usually made of tungsten.

A cooling system is connected to the target to remove heat from the x-ray tube.



The Production of x-rays in an x-ray tube

- Heat: as the electrons are stopped by the atoms of tungsten, about 99% of their energy is turned into heat.
- X-rays: energy not converted to heat becomes x-rays. X-rays are electromagnetic radiation (waves) made and emitted by the machine.

As the electrons are stopped by the atoms of tungsten, about 99% of their energy is turned into heat, which must be removed.

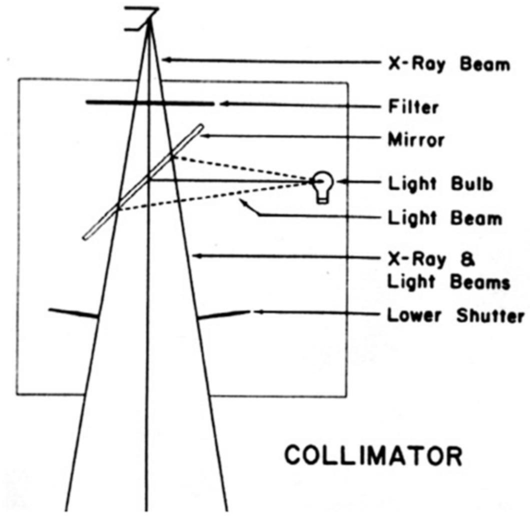
The electron energy not converted to heat is transformed into x-rays. X-rays are penetrating electromagnetic radiation. The penetrating power depends upon the maximum voltage applied across the x-ray tube.

The Production of heat in an x-ray tube

- Anode:
  heated anode emits red visible light due to the high temperature.
- Cooling system:
  water or the air-cooling system is often used to cool down the tube.

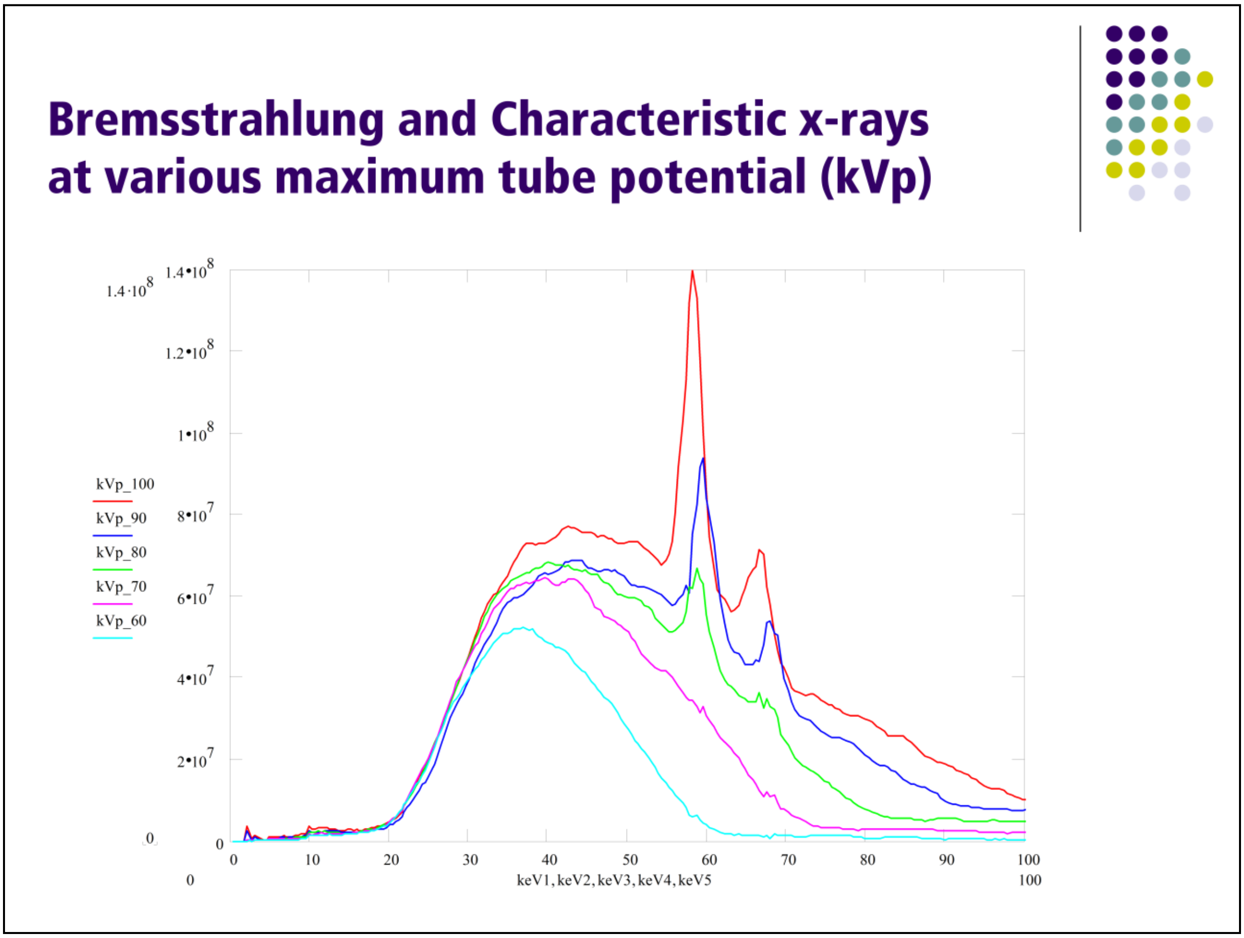
This picture shows how the rotating anode of an x-ray tube heats up and glows under the electron bombardment. This heat must be removed, or the anode will be destroyed. This is achieved by water or air cooling.

The Collimation of x-rays in an x-ray tube



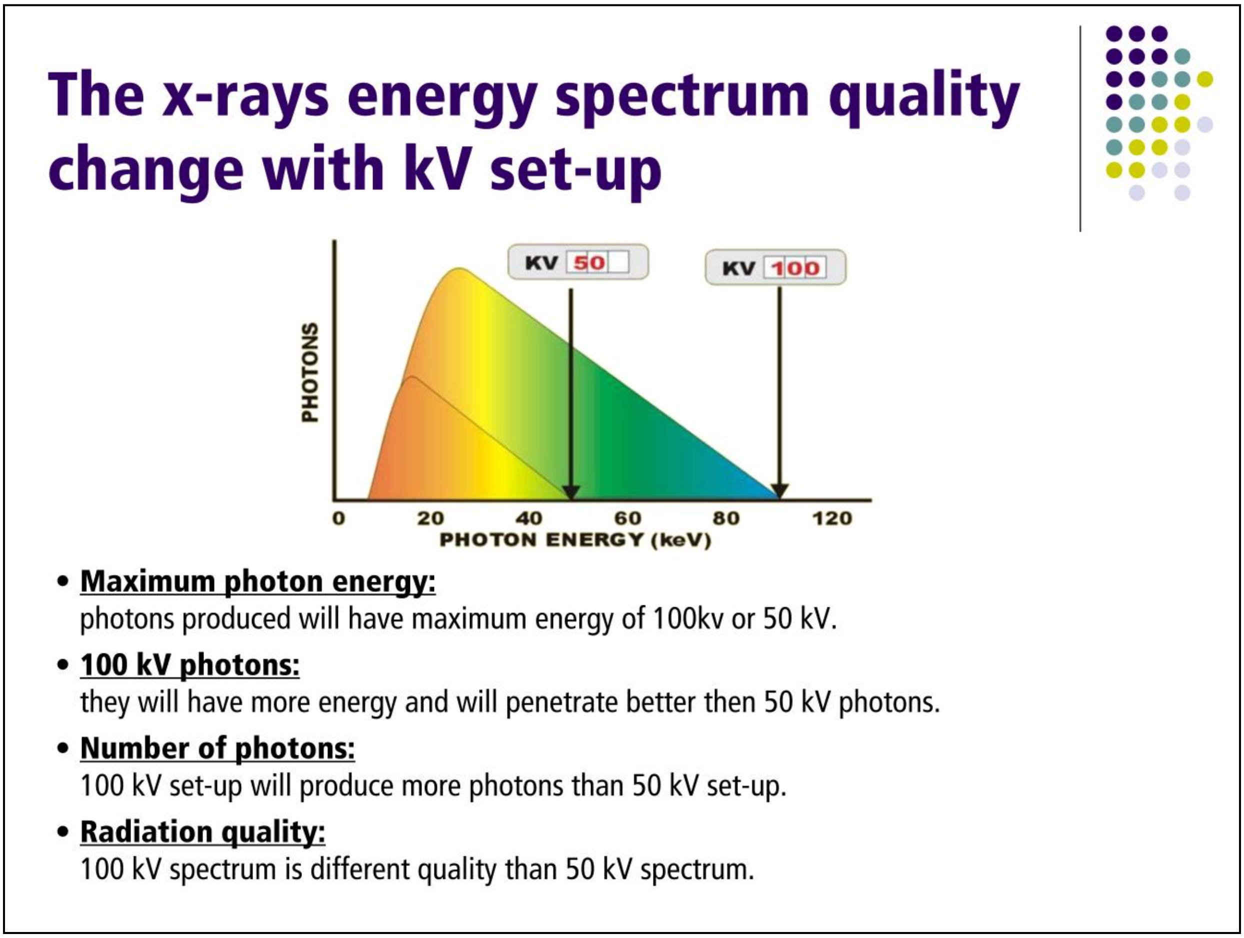
- **X-rays:**
  traveling in all directions, but collimated to exit.
- **Collimator:**
  placed below the cathode to select the needed beam of the x-rays.
- **Patient:**
  positioned below the tube.
- **Lead shield:**
  surrounds the x-ray tube.

The x-rays emitted from a bombarded anode are emitted in all directions.Most are absorbed in the anode itself, while others are absorbed in the lead shield surrounding the tube. The 'useful beam' emerges through a aperture in this shield which directs it to the patient. The dimensions of the beam as it reaches the patient is determined by the settings of a 'collimator' (a set of mutually- opposing lead plates) which absorbs the unwanted radiation. A projected light beam simulates the x-ray beam to facilitate alignment to the desired area of the patient.



Bremsstrahlung and Characteristic x-rays at various maximum tube potential (kVp)

The graphical presentation of Spectra is a display of the number of x-rays for each kVp. Red spectra is produced by higher voltage than green spectra.



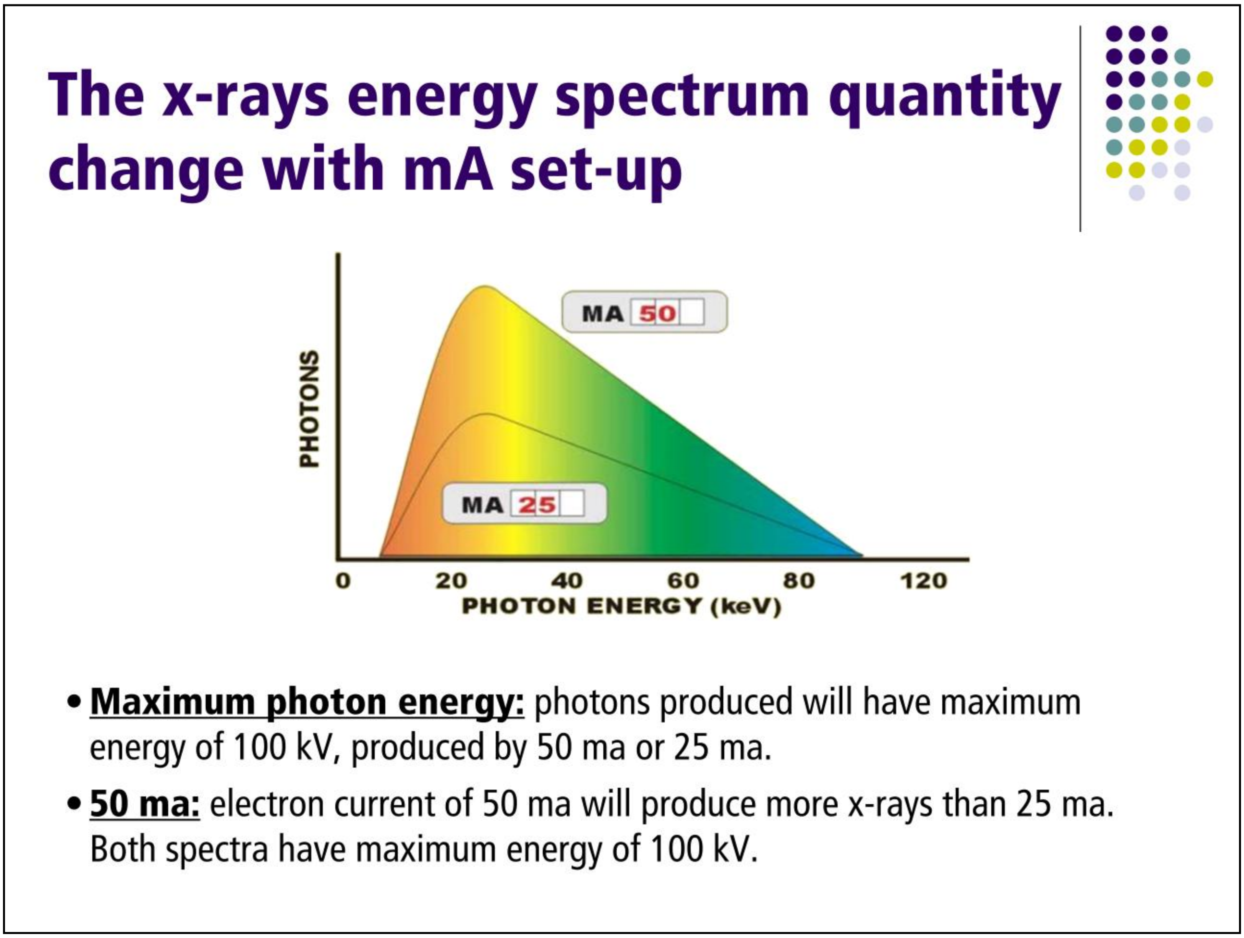
The x-rays energy spectrum quality change with kV set-up

- **Maximum photon energy:**
  photons produced will have maximum energy of 100kv or 50 kV.
- **100 kV photons:**
  they will have more energy and will penetrate better then 50 kV photons.
- **Number of photons:**
  100 kV set-up will produce more photons than 50 kV set-up.
- **Radiation quality:**
  100 kV spectrum is different quality than 50 kV spectrum.

The x-rays photons emitted from an x-ray tube cover a spectrum of energies, the maximum of which is determined by the voltage applied across the x-ray tube. Photons at the low energy end of the spectrum are absorbed by within the x-ray tube, and are not part of the useful beam. The shape of the spectrum depends upon the degree of rectification of the voltage applied across the x-ray tube.

The effective penetration (or radiation quality) of an x-rays beam depends upon the applied voltage because the greater the voltage, the more high energy photons there will be in the beam. This penetration is also dependent upon absorbers purposely placed in the beam between the tube and the patient.

As seen in the illustration, the spectrum produced at 100 kVp has more high energy photons (and more photons) than one produced at 50 kVp.



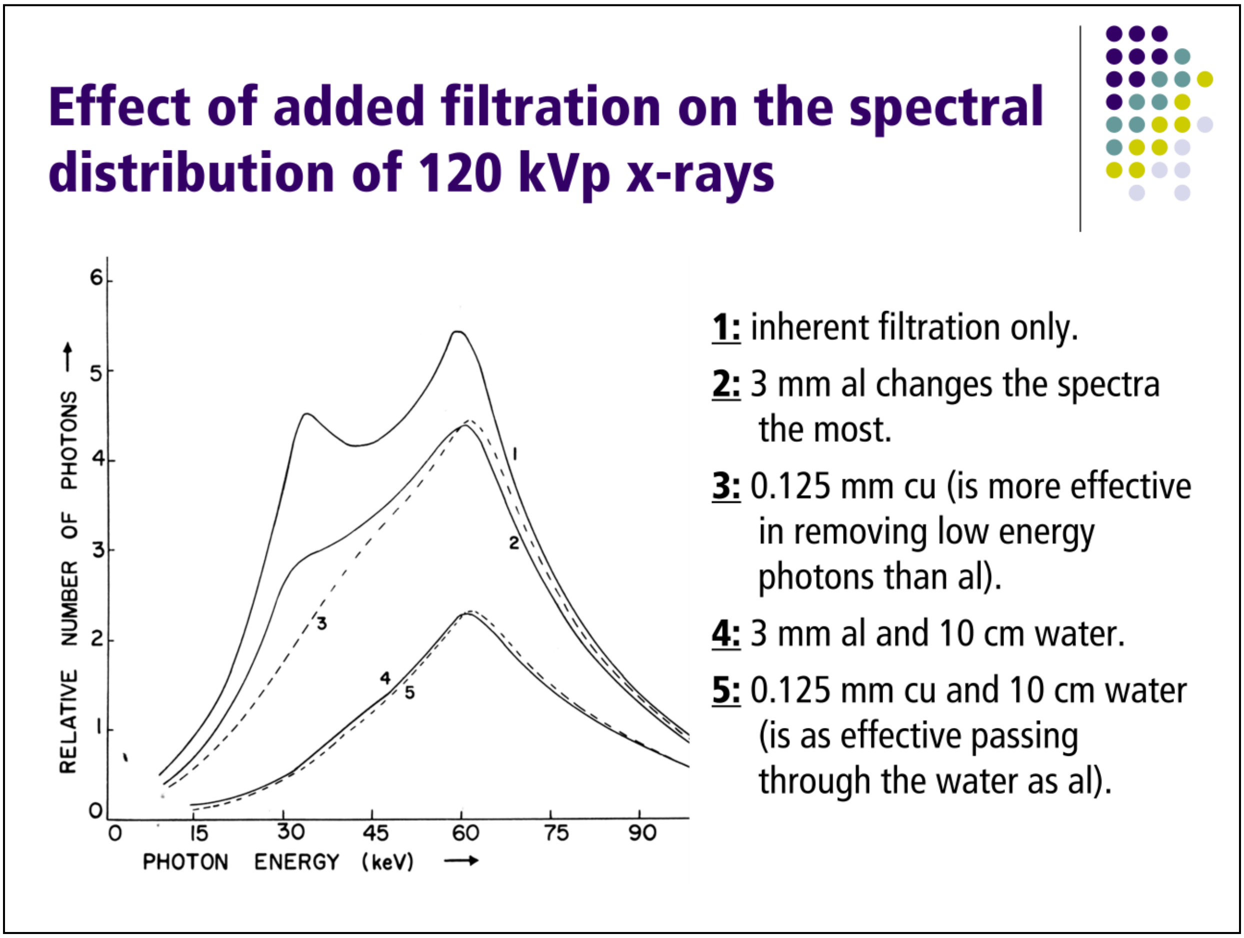
The x-rays energy spectrum quantity change with mA set-up

- **<u>Maximum photon energy:</u>** photons produced will have maximum energy of 100 kV, produced by 50 ma or 25 ma.
- **<u>50 ma:</u>** electron current of 50 ma will produce more x-rays than 25 ma. Both spectra have maximum energy of 100 kV.

We now consider the effect on the x-rays energy spectrum with milliampere (tube current) setting.

<u>Maximum photon energy:</u> Photons produced will have a maximum energy of determined by the kilovoltage, regardless of the mA setting. An electron current of 50 mA will produce more x-ray photons than will 25 mA, but the maximum photon energy will be the same. The x-rays energy spectrum quantity change with mA set-up. <u>Radiation Quantity at</u> 50 mA spectrum has different quantity than 25 mA spectrum.

<u>50 mA:</u> Electron current of 50 mA will produce more x-rays than 25 mA. Both spectra have maximum energy of 100 kV.



Effect of added filtration on the spectral distribution of 120 kVp x-rays

1: inherent filtration only.

2: 3 mm al changes the spectra the most.

3: 0.125 mm cu (is more effective in removing low energy photons than al).

4: 3 mm al and 10 cm water.

5: 0.125 mm cu and 10 cm water (is as effective passing through the water as al).

Radiation Quantity: *We now consider the effect of added filtration on the spectral distribution of 120 kVp x-rays. We now examine the effect on the transmitted spectrum of absorbers in an x-ray beam generated at a kilovoltage of 120 kVp.*

In 1. is the spectrum with only the inherent filtration. (i.e.. The anode and tube wall)..

In 2. is shown the effect of 3 mm of Al inserted into the beam between the tube and the patient.

In 3. It is seen that 0.125 mm Cu is more effective in removing low energy photons than Al.

In 4. Is shown the spectrum transmitted through 3 mm Al and 10 cm water.

In 5. Is shown the transmitted spectrum after passing through 0.125 mm Cu and 10 cm water

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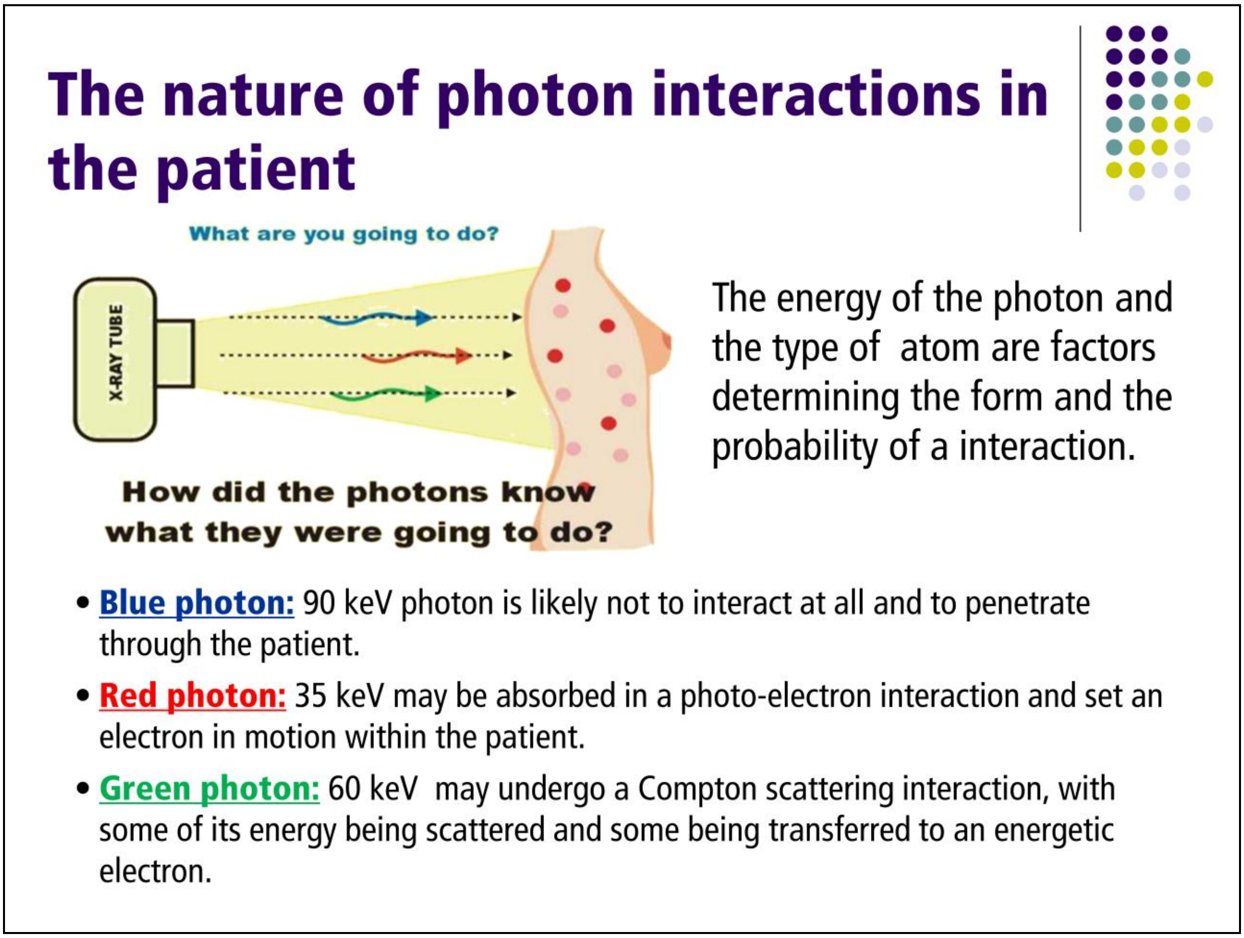
It is apparent that the penetrability (quality) of the beam can be altered by the insertion of absorbers.



The nature of photon interactions in the patient

What are you going to do?

How did the photons know what they were going to do?

The energy of the photon and the type of atom are factors determining the form and the probability of a interaction.

- **Blue photon:** 90 keV photon is likely not to interact at all and to penetrate through the patient.
- **Red photon:** 35 keV may be absorbed in a photo-electron interaction and set an electron in motion within the patient.
- **Green photon:** 60 keV may undergo a Compton scattering interaction, with some of its energy being scattered and some being transferred to an energetic electron.

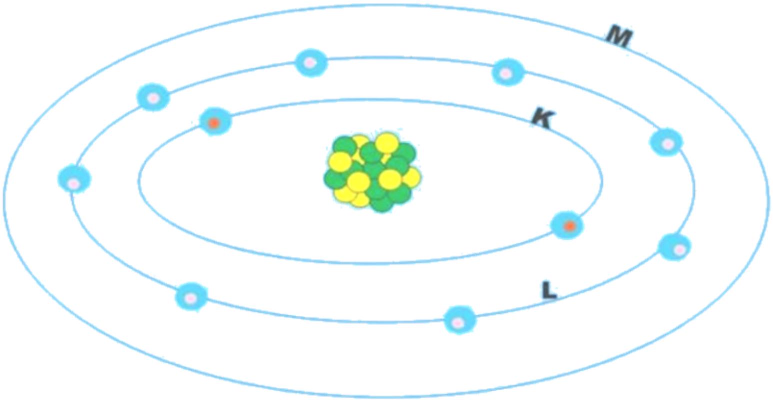
As the diagnostic x-ray beam passes through the patient, it can interact with the atoms of the patient in a number of possible ways. An individual x-ray photon in the beam will interact in a manner determined by its energy and by the atom with which it interacts. In interacting with matter a photon can exhibit both particle-like and wave-like characteristics. A photon's particle energy and its wavelength are connected by the equation:

Wavelength l = 1.24 x 10-6 meters / E (in eV)

Thus a 100 keV photon is associated with a wavelength of 1.24 x 10-11 meters (= 0.0124 nanometers, which is of the same order of magnitude as the dimensions of an atom).

The interaction of an energetic x-ray photon with an absorber is governed by the laws of physics, and is probabilistic in nature. That is, the interaction of a specific photon cannot be predicted with certainty, but the probability of a particular type of interaction is determined by the energy of the photon and the atom with which it interacts. These will now be discussed.

Simple atomic model describes possible electron energy orbits



Electron orbits:

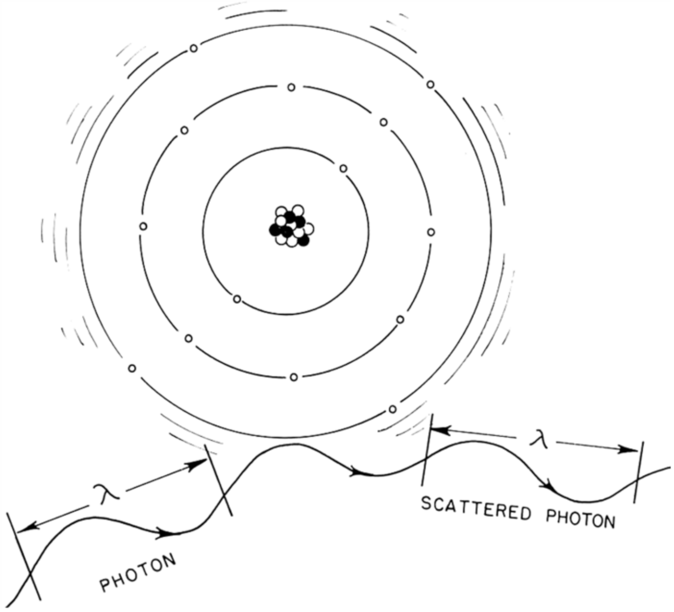
negative electrons fit orbits following a fixed set of rules. There are 2 electrons in K orbit, and 8 electrons in the L orbit.

We now look into our atomic model more closely. The number of + protons Z in the nucleus determines the element to which the atom belongs, and how it will react chemically. In a neutral atom, there is an equal number of – electrons in the space surrounding the nucleus. The electrons are much smaller and have less mass than the protons, but their electric charge is equal to that of the protons, but negative rather than positive.

The laws of quantum mechanics determine how the electrons are arranged in their orbits around the nucleus. In the innermost, or K shell, there cannot be more that 2 electrons. In the next, or L shell, there can be 8 electrons, arranged in 2 sub-shells. As the atomic number Z increases and the number of electrons becomes greater, so the spaces in the M shell are filled, and so on. Generally, in radiology we are only concerned with the inner shells, because the elements making up the human body are of low atomic number Z (eg. Oxygen Z=8, carbon Z=6, hydrogen Z=1, etc)

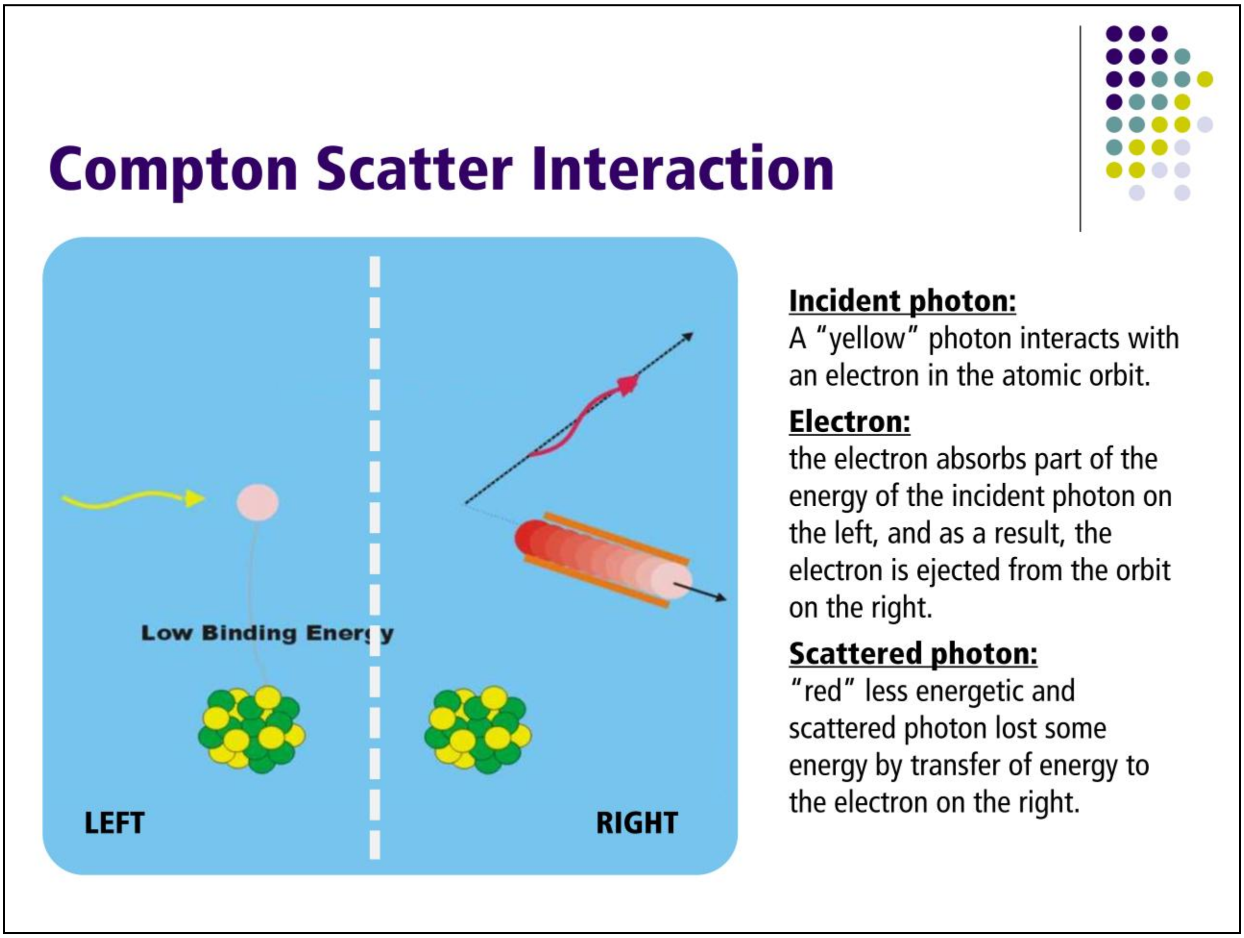
The electrons in each shell are bound to the nucleus by an attractive force which must be overcome in order to remove the electron from its orbit. In a particular atom this binding energy becomes weaker the farther out the shell is. Also, the binding force of an electron in an orbit depends upon the element, since the greater the number of protons in the nucleus, the stronger the attractive force upon the electron. These binding energies have a great effect upon photon-electron interactions.

Classical or coherent scattering of x-rays by an atom



- **<u>Classical:</u>** this type of scattering is completely explained by classical non-corpuscular theory.
- **<u>Incident x-ray:</u>** completely transfers all of its energy to the atom, which is thereby set into vibration.
- **<u>Atom:</u>** reemits "scattered" electromagnetic radiation of equal energy with the incident radiation.

Here the (particle-like) photon interacts with one of the outer (loosely bound) atomic electrons. In considering these photon-electron interaction, we must remember that, in quantum theory, both of these entities have wave- and particle-like properties.In explaining classical (or coherent) scattering, we think of the photon as a wave which interacts with the whole atom, transferring all of its energy to the atom. Subsequently, the atom re-emits the energy in the form of a photon of equal energy to the absorbed photon, but with random direction. This phenomenon is most probable when the photon's energy is low, where the associated wavelength is of the same order of magnitude as the atom's dimensions.



Compton Scatter Interaction

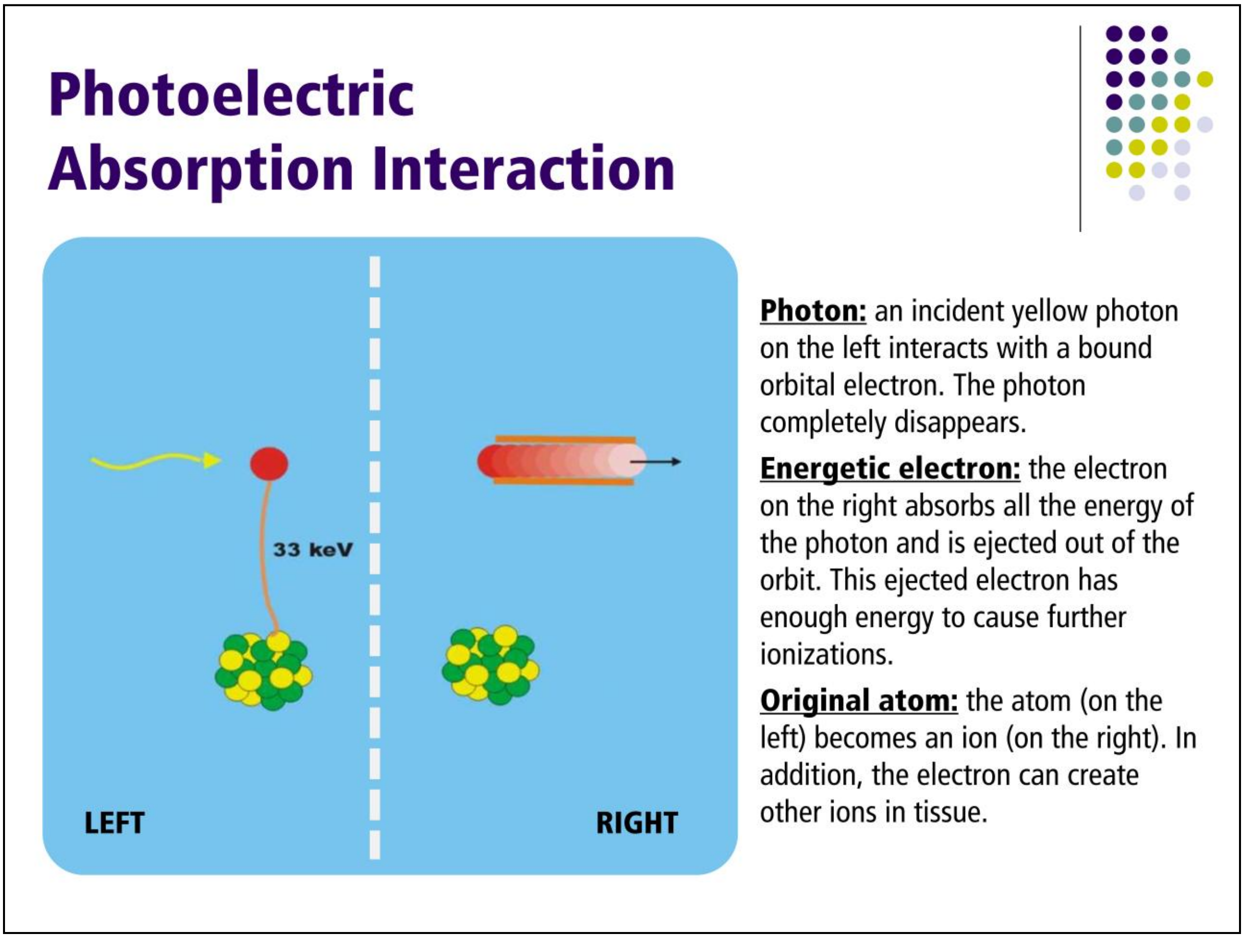
Incident photon:
A "yellow" photon interacts with an electron in the atomic orbit.

Electron:
the electron absorbs part of the energy of the incident photon on the left, and as a result, the electron is ejected from the orbit on the right.

Scattered photon:
"red" less energetic and scattered photon lost some energy by transfer of energy to the electron on the right.

In Compton (or incoherent scattering) the incoming photon interacts with an outer, loosely-bound, electron (that is, one with negligible binding energy). Part of the photon's energy is transferred to the electron as kinetic energy of motion. The rest of the photon's energy becomes a scattered photon of reduced energy. The directions taken by the ejected electron and the scattered photon are related in a quantum mechanical relation called the Klein-Nishina formula.The result of this type of interaction is an ionized atom, a scattered photon of reduced energy, and an energetic electron which can produce more ionizations along its track. This is the dominant process in the photon energy range between 200 keV and 2 MeV.

Some of its kinetic energy is transferred to the orbital electron, ejecting it from the atom, while the remainder of its energy is scattered as a photon of lower energy. The result of this Compton interaction is a scattered photon and an atom which is deficient in one electron (an ionized atom). In this way, the material of the absorber is said to absorb some of the photon's energy. The ejected electron can go on to produce more ion pairs by collision with other atoms. This phenomenon, generally speaking, involves x-ray photons of energies in excess of 50 keV, and so is relatively unimportant in diagnostic applications.



Photoelectric Absorption Interaction

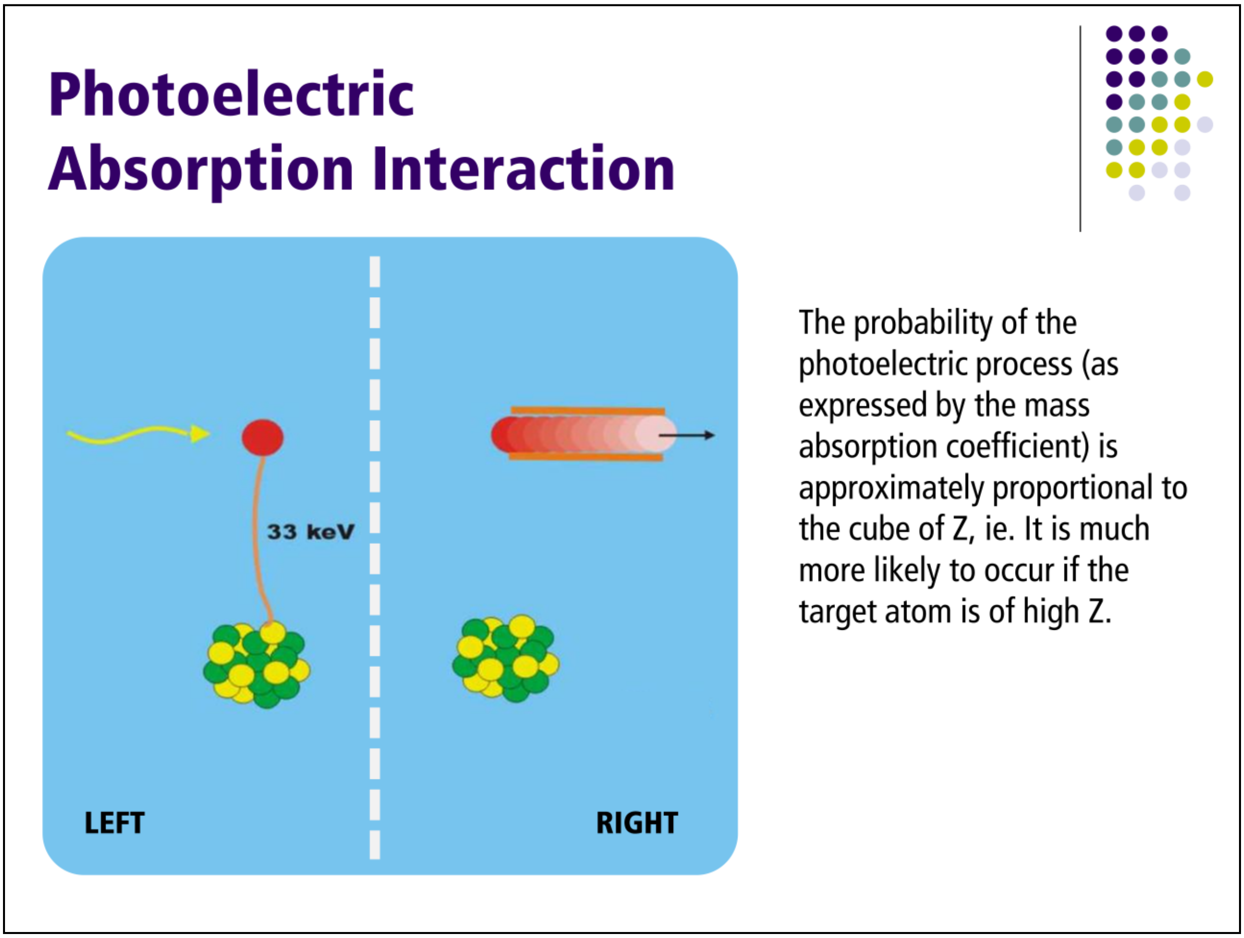
Photon: an incident yellow photon on the left interacts with a bound orbital electron. The photon completely disappears.

Energetic electron: the electron on the right absorbs all the energy of the photon and is ejected out of the orbit. This ejected electron has enough energy to cause further ionizations.

Original atom: the atom (on the left) becomes an ion (on the right). In addition, the electron can create other ions in tissue.

The photoelectric effect is the dominant one in the diagnostic range of x-ray energies. Here the incident x-ray photon interacts with an inner (K or L shell) electron, and transfers all of its energy to it. The photon disappears, and the electron emerges to produce further ionized atoms along its track. Since the absence of an electron in the inner orbit must be filled, an electron from an outer orbit moves in to replace it. The energy difference between the binding energies of the two orbits is emitted as an energetic photon whose energy is characteristic of the atom.

In the photoelectric process, the photon interacts with the atom as a whole, and the atom absorbs all of its energy. Some of the photon energy is used to overcome the binding energy of a K-, L - or M-electron to release it from its quantum orbit, while the remainder serves to give it kinetic energy of motion as it is ejected from the atom. It is this ejected high speed electron that brings about biological change as it loses energy through the ionization of other atoms and molecules. When the photoelectron is elected from an inner orbit, an outer electron falls into that orbit, giving off the difference in energy by the emission of a 'characteristic' photon This difference in energy is so small to be of little biological significance.

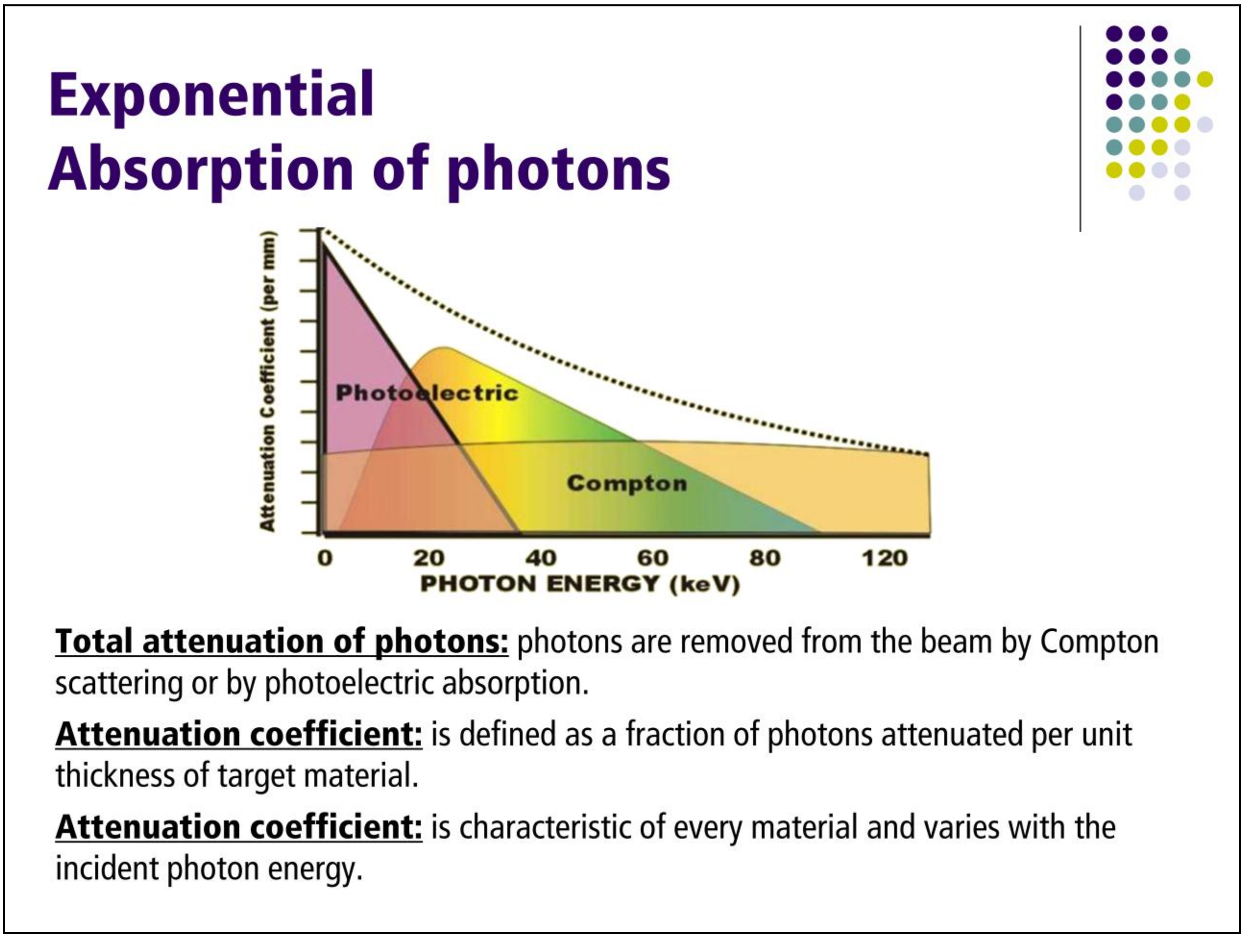


Photoelectric Absorption Interaction

The probability of the photoelectric process (as expressed by the mass absorption coefficient) is approximately proportional to the cube of Z, ie. It is much more likely to occur if the target atom is of high Z.

The probability of the photoelectric process (as expressed by the mass absorption coefficient) is approximately proportional to the cube of Z, ie. it is much more likely to occur if the target atom is of high Z. It is also more likely if the photon energy is just greater than the binding energy of the electron.

The attractive force between the positive nucleus and a negative orbital electron depends upon the Z of the nucleus (more protons to attract the electron) and the orbit of the electron (the farther out, the weaker the attractive force). Thus it requires more energy to remove a K electron from a high Z atom than from a low Z one, and more energy to remove a K electron than an L electron from the same atom. These 'binding energies' are important when we examine the interaction between an atom and a bombarding photon.



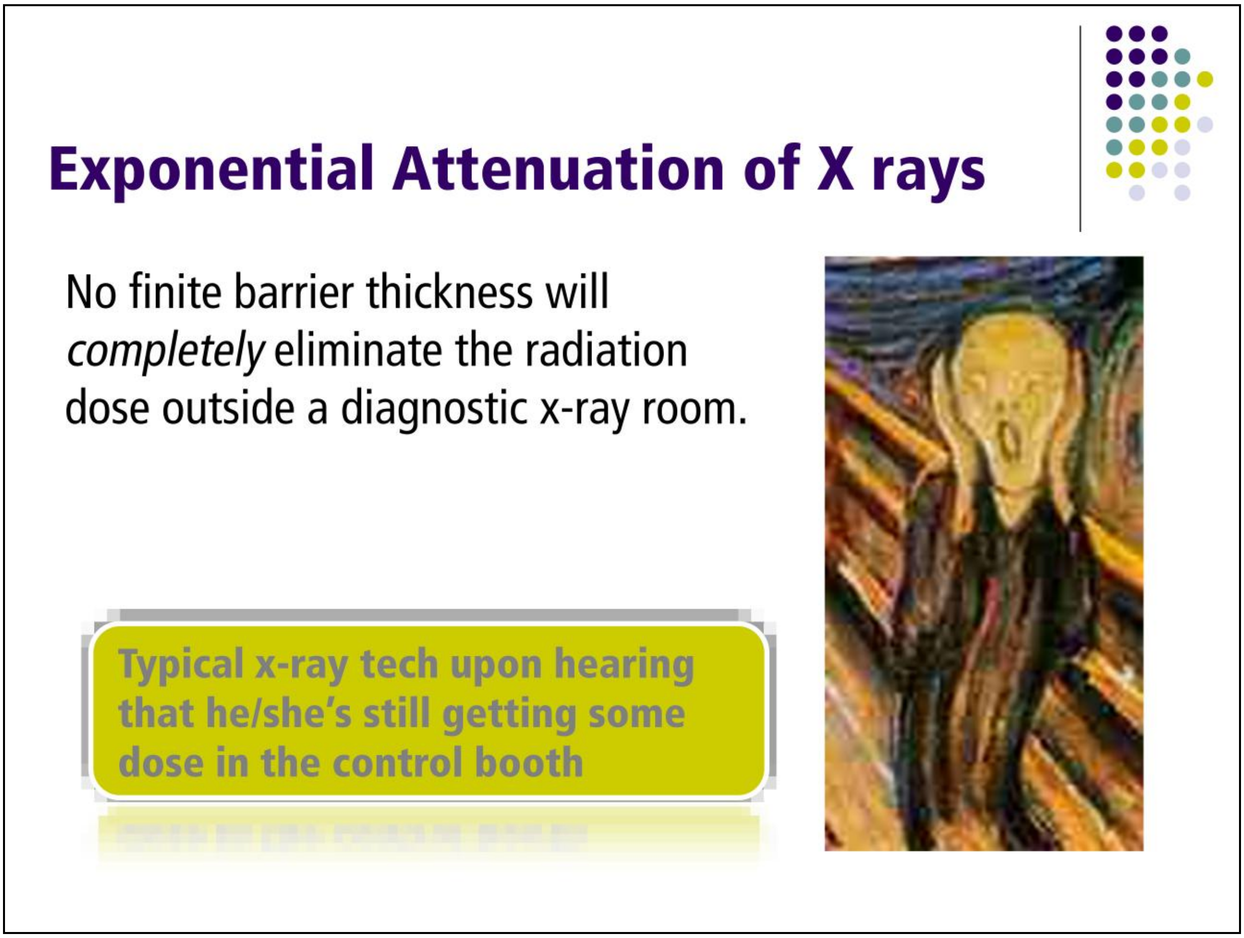
Exponential Absorption of photons

Total attenuation of photons: photons are removed from the beam by Compton scattering or by photoelectric absorption.

Attenuation coefficient: is defined as a fraction of photons attenuated per unit thickness of target material.

Attenuation coefficient: is characteristic of every material and varies with the incident photon energy.

As the x-ray beam passes through an absorber (eg. the human body) its intensity is attenuated as photons are removed from it. As we have seen, these are removed by the photoelectric effect, the Compton effect or classical scattering. The probability of each of these processes depends upon the energy of the photon and the type of atom in the absorber. This probability is expressed as the attenuation coefficient, which is the fraction of the incident photons removed per unit thickness of the absorber.



Exponential Attenuation of X rays

No finite barrier thickness will *completely* eliminate the radiation dose outside a diagnostic x-ray room.

Typical x-ray tech upon hearing that he/she's still getting some dose in the control booth

Since this attenuation process is probabilistic in nature, it is exponential and so, in theory, some photons will penetrate any thickness of an absorber That is, no absorber will absorb all of the incident photons, but a sufficient thickness will reduce the number to a negligible amount.

Radiation units

New Dose unit

Sievert, 1 Sv = 1000 mSv = J/kg

Old Dose unit

Roentgen = 10 mSv

Effective Dose

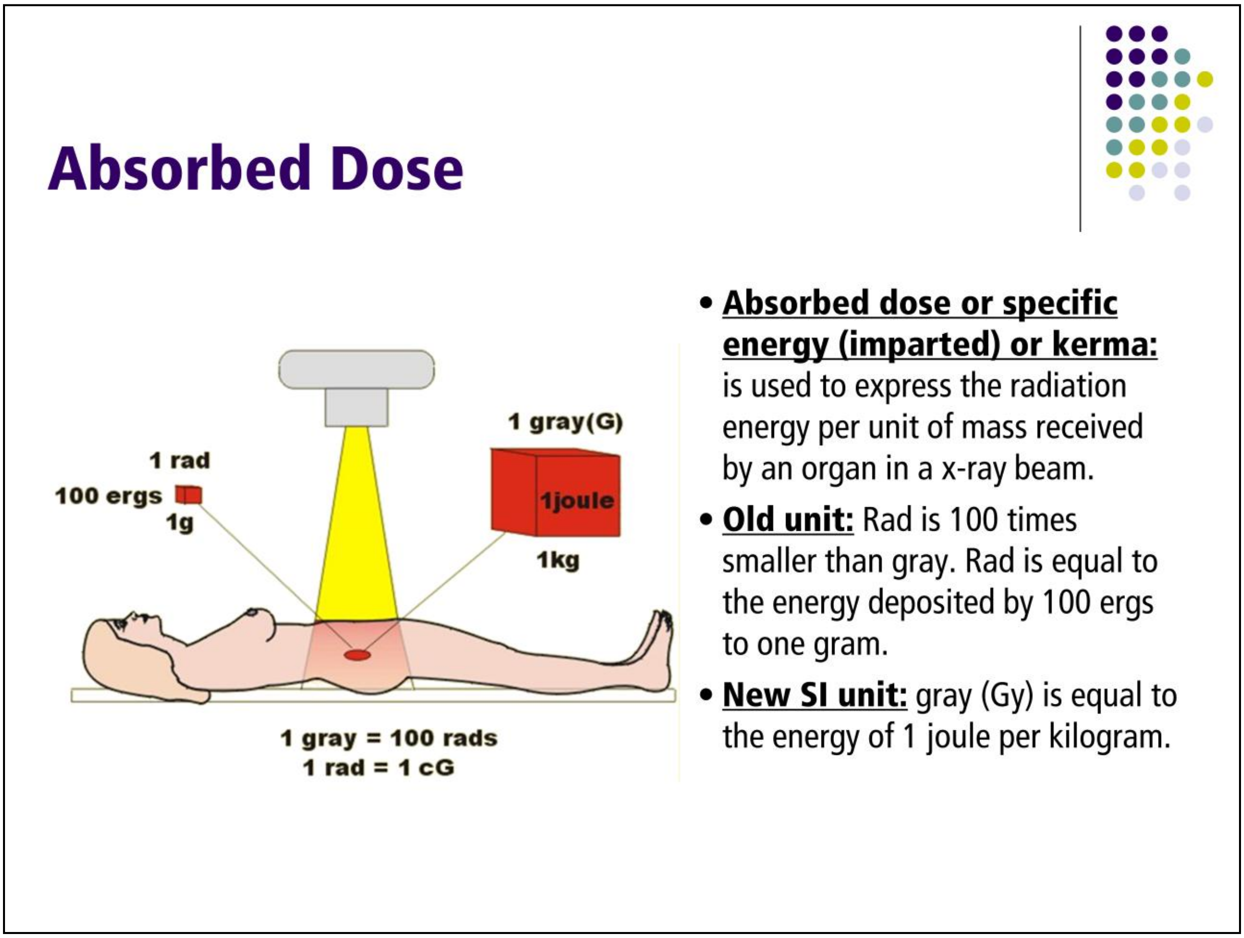
- gives a measurement of the dose to the whole body if one or a few organs are irradiated
- measured in Sv
- equal to dose to organ(s) x its weighting factor

Dose Limits (other than for medical purposes)

	Radiation Workers	**Public**
Body	20 mSv/year	1 mSv/year
Eye	150 mSv/year	15 mSv/year
Skin	500 mSv/year	50 mSv/year
Hand/Feet	500 mSv/year	-

IRCP 60 (1990)

Typical Radiographer Dose: < 1 mSv/year



Absorbed Dose

- **Absorbed dose or specific energy (imparted) or kerma:** is used to express the radiation energy per unit of mass received by an organ in a x-ray beam.
- **Old unit:** Rad is 100 times smaller than gray. Rad is equal to the energy deposited by 100 ergs to one gram.
- **New SI unit:** gray (Gy) is equal to the energy of 1 joule per kilogram.

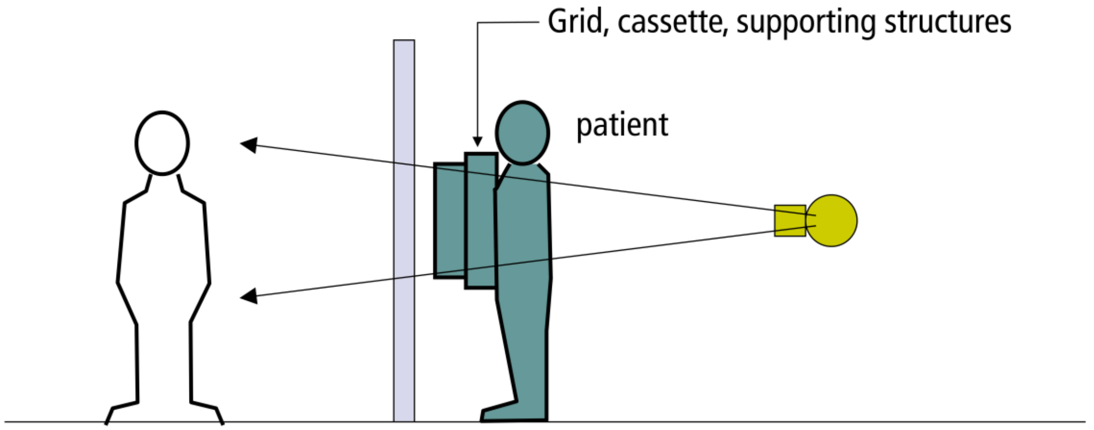
When radiation is absorbed, energy is transferred to the absorber. If the absorber is biological (ie the human body) this energy can bring about a biological effect.

The energy absorbed is expressed in Joules, and the unit of absorber energy is the Gray (Gy) which is defined as 1 Joule/ kilogram of absorber. The old unit, the rad, is 1/100th of this of 100 ergs/gram. (The erg is a smaller unit of energy).

The amount of energy absorber can be determined in a number of ways – by direct measurement or by calculating from measurements of air ionization.

The biological effect is expressed in units of Sieverts (Sv), which can be derived directly from the energy absorbed in Grays. It is this unit that is used to express safe levels of radiation.

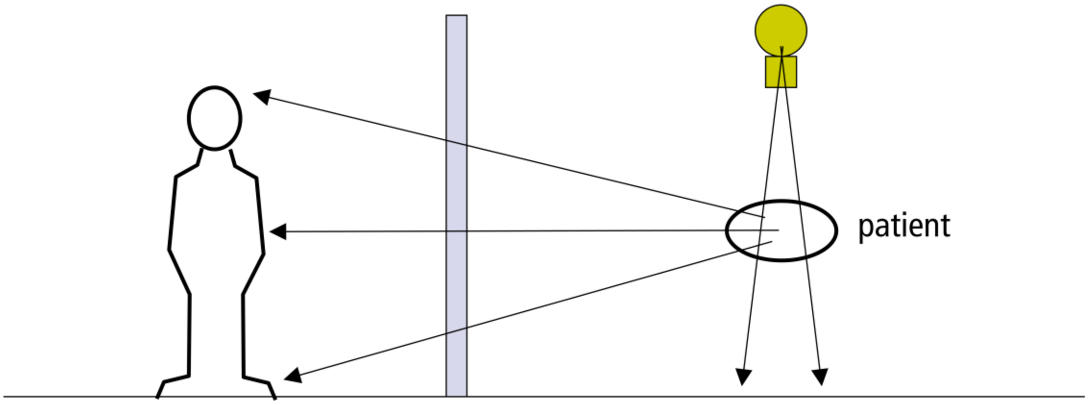
Primary Radiation: A Realistic Model



Primary radiation is significantly attenuated before reaching barrier

The collimated beam of primary radiation passes through the patient, the grid, the cassette and the supporting structures and is finally attenuated by the back-up barrier. This attenuates it to the point where it poses no significant hazard to personnel.

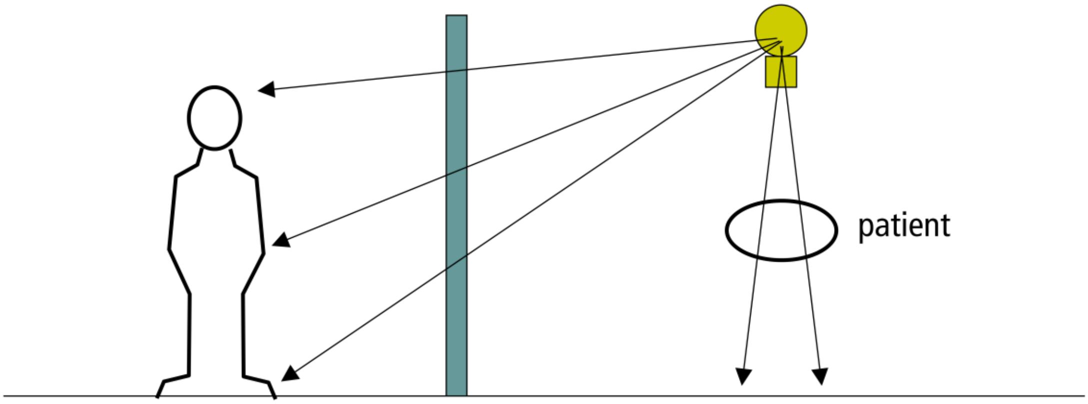
Scatter Radiation



Radiation scattered from the primary beam can be emitted in all directions, and so absorbing barriers must be placed appropriately. Generally, this radiation is less penetrating and less intense than the primary beam.

Leakage Radiation

Radiation originating from x-ray tube focal spot but not emanating from the tube portal



Even though the x-ray tube enclosure is designed to absorb x-rays, some will always penetrate it. This is just as penetrating as the primary beam, but very much less intense. It must be considered when protective barriers are designed.

Image receptors / Production

- Images are captured in an image receptor, typically a x-ray film or recently, digital storage devices
- x-ray film – sensitive to light, not very sensitive to x-rays
- need a means of converting x-rays to light with a relative high efficiency
    - x-ray intensifying screens

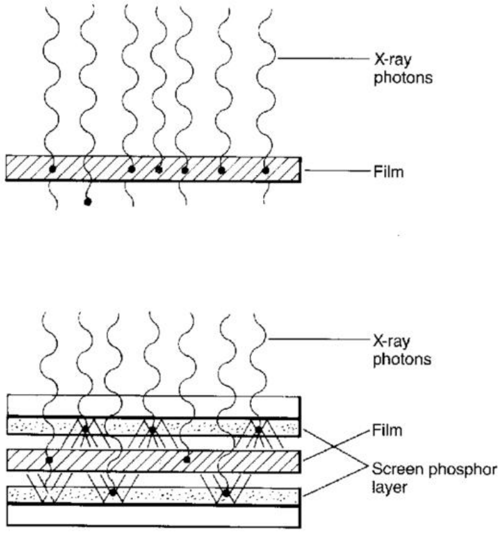
Over the last few years, as manufacturers and researchers around the world have taken digital x-ray detectors out of the lab and into clinical trials, it’s become clear that digital x-ray imaging will indeed revolutionize diagnostic radiology.

In fact, many observers have hailed it as the most significant breakthrough in x-ray imaging in the last 25 years, referring to it as "the New Modality."

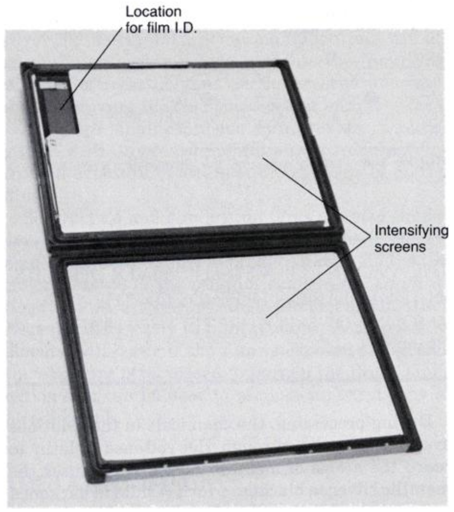
No matter how large or small your facility may be, it’s time to start giving serious consideration to how digital detection will impact your department – and which technology will meet your needs most thoroughly and cost-efficiently.

This tutorial introduces the key concepts around Digital X-ray technology and analyzes its impact and potential benefits.

Image receptors / Production



X-ray film / screen combination



X-ray cassette use to keep film light tight and in close contact with the screens

From four components to one

To understand the potential significance of digital detectors, consider what happens to the x-rays collected by even a state-of-the-art conventional x-ray device, such as a radiography & fluoroscopy system equipped with a digital box: The x-ray signal is transmitted from the tube, through the patient, and into an image intensifier. Next, the signal is processed through image-intensifier and camera optics before being sent on to a video camera and through digitization. Finally, the remaining signal is sent on for display and hard-copy generation.

Note that at each stage in this process, the x-ray signal is degraded to some extent, even if the individual components are optimized for the application. As a result, typically less than 40% of the original image information is available for use in image production.

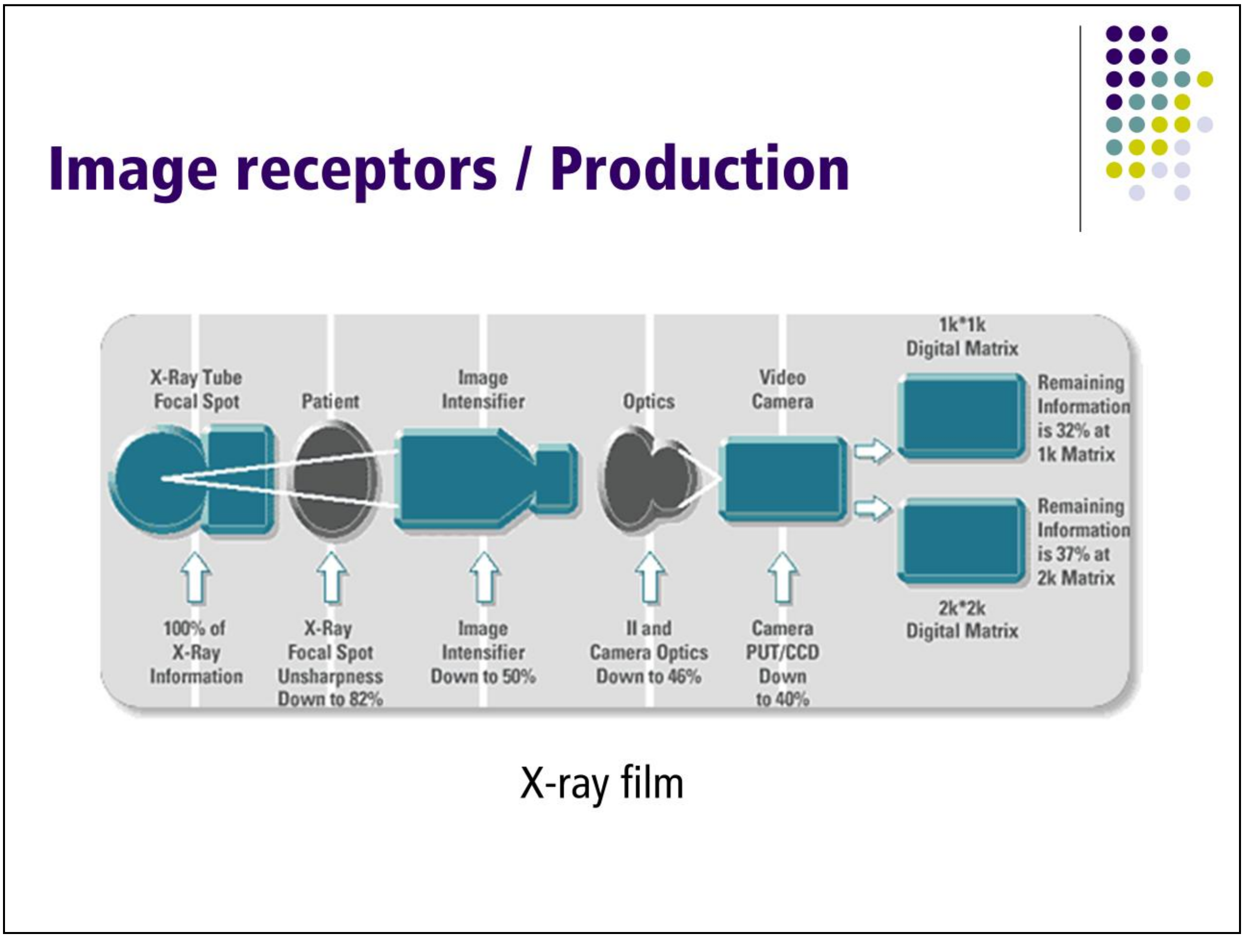


Image receptors / Production

X-ray film

From four components to one

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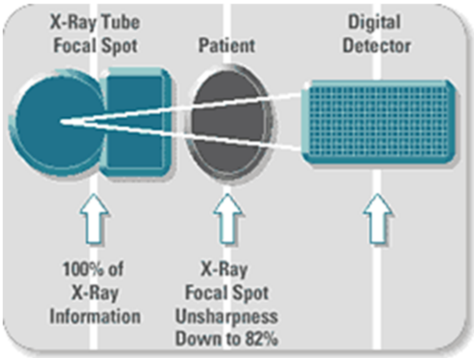
Note that at each stage in this process, the x-ray signal is degraded to some extent, even if the individual components are optimized for the application. As a result, typically less than 40% of the original image information is available for use in image production.

Now consider what happens when we add a digital detector to the equation: It replaces everything but the x-ray tube and patient (Fig. 1b)! Because of its high Detective Quantum Efficiency (DQE), it has the potential to capture over 80% of the original image information. And it equips the user with a wide range of post-processing tools to further improve that signal – including many that can be applied automatically.

Image receptors / Production

In a conventional, digitized R&F imaging chain, the signal degradation that occurs with each component consumes more than 60% of the original x-ray signal.



X-ray film / Digital Detector

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Bottom-line benefits

Fig. 3: Potential Impact on Department costs

Over time, departments using Digital-detector technology stand to realize substantial financial rewards.

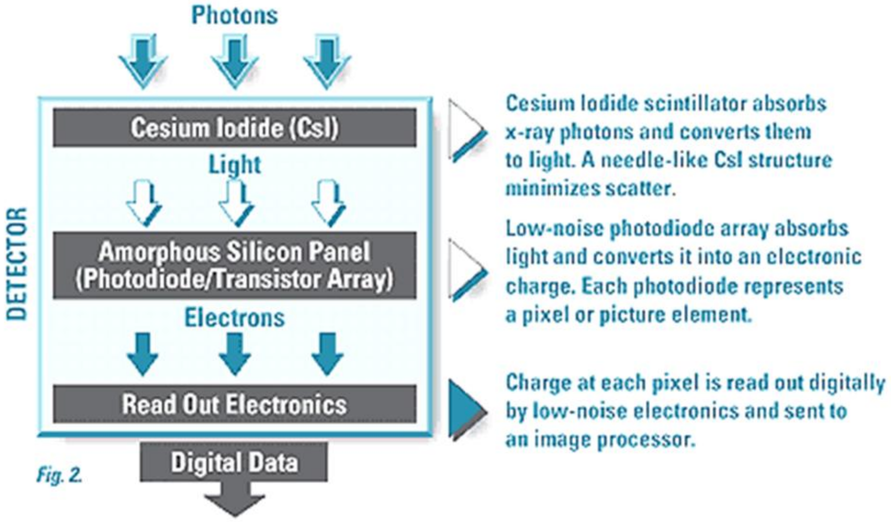
We can now predict with certainty the financial ramifications of the Digital X-ray technology. It already seems clear that users will reap substantial bottom-line rewards as digital technology takes hold, for reasons such as these (Fig. 3):

•Operating costs should decrease because of dwindling requirements for film, processing equipment, chemicals, and archiving space – not to mention the labor now required for managing these activities.

•Thanks to the inherent speed of digital exams, increased patient throughput should drive up revenues for facilities with adequate patient volume – or, alternatively, allow reductions in the number of rooms and their associated costs.

•Properly engineered digital detectors may pave the way for a broad range of future advanced applications, such as Computer Aided Detection and teleradiology, to permit cost-cutting consolidation of resources.

Image receptors / Production



Cesium Iodide scintillator absorbs x-ray photons and converts them to light. A needle-like CsI structure minimizes scatter.

Low-noise photodiode array absorbs light and converts it into an electronic charge. Each photodiode represents a pixel or picture element.

Charge at each pixel is read out digitally by low-noise electronics and sent to an image processor.

X-ray film / Digital Detector

The measure of the combined effect of detector noise and contrast performance, Detective Quantum Efficiency (DQE) is widely recognized in the scientific imaging community as the most accurate gauge of image quality – a gauge that incorporates most traditional image-quality measures, including signal-to-noise ratios and spatial frequency. And GE digital detectors deliver higher DQE than state-of-the-art film/screen, computed radiography and current flat-panel Selenium-based digital imaging systems, especially at the low-to-mid spatial frequencies where most clinically relevant information resides.

The reason? A combination of the right materials and the right design, which work together to optimize all the components of DQE – including Cesium Iodide's very high x-ray absorption and very low-noise panel electronics to capitalize on all available x-ray signal.

In addition, GE has chosen a single-piece, flat-panel design. Although this design required intensive R&D and manufacturing efforts that only a company with the resources of GE can contribute, it is worth it; this single-piece design eliminates the potential for misregistration or stitching artifacts that could plague alternative approaches (see next section: Alternative Digital X-ray technologies). The result is increased object detectability for virtually any clinical application.

Closing Questions - Quiz

- ✓ Why there is closing ‘radiation protection quiz’ a part of this series of lectures?
- ✓ Why is it important that we have certification process in Bermuda?
- ✓ How will this process help us and our patients?

Please send answers to the questions below to the Bermuda MOH if you wish to be included on the list of certified radiation users:

Why are radiographs like photographic negatives, while fluoroscopic images are like positives?

What sets the limits in the obtaining of x-ray images?

Why do lungs and bones show up so distinctly, and soft tissues and fat don't?

Conclusion:
X-Ray Physics Basics

1. Introduction
2. An atomic model
3. What are x-rays and how are they produced?
4. The interaction of x-rays with matter
   - Coherent
   - Photo electric absorption
   - Compton scattering
5. Determination of the energy absorbed form an x-ray beam (radiation dose)
6. Image receptors (old and new)
7. Conclusion