Radio Physics

Lecture(5& 6)

Definition of Contrast and Physical Determinants of Contrast

- contrast can be defined as the fractional difference in some measurable quantity in two regions of an image.
- Usually when we say "contrast", we mean image contrast, which is the fractional difference in optical density or brightness between two adjacent regions in an image. In conventional radiography, image contrast depends on two other types of "contrast" called (a) radiographic contrast and (b) detector contrast. Radiographic contrast (sometimes called subject contrast) refers to the difference in the number of x-ray or gamma ray photons emerging from adjacent regions of the object being scanned, which depends on differences in atomic number, physical density, electron density, thickness, as well as the energy spectrum of the x-ray beam emitted by the source.
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- Detector contrast refers to the ability of the detector to convert differences in photon fluency across the x-ray beam into differences in optical density (film), image brightness (image intensifiers), signal amplitude (electronic detectors), or some other physical, optical, or electronic signal used to represent the image in the imaging system. The detector contrast depends on the:
- chemical composition of the detector material
- its thickness
- atomic number,
- electron density,
- as well as the physical process by which the detector converts the radiation signal into an optical, photographic, or electronic signal.
- The x-ray spectrum used to image the object.

The detector may increase or decrease the radiographic contrast; that is, the detector may produce photographic or electronic signals that have a larger or smaller fractional difference between adjacent areas of the image in comparison to the difference found in the radiographic signal.

The photon attenuation of each material depends on:

- its elemental composition
- the energy of the beam.

This effect is assessed using its linear attenuation coefficient (µ), which gives the fraction of photons absorbed by a unit thickness of the material.

- $I_x = I_o \exp(-\mu_{\ m} x)$
- $I_x = {}^{number\ of\ photons}/_{area\ leaving\ the\ tissue}$
- $I_o = {}^{number\ of\ photons}/_{area\ entering\ the\ tissue}$
- X= material thickness

$\mu_m(E) = \dfrac{\mu(E)}{\rho} =$ mass attenuation coefficient as a function of the photon energy E, then

- The first component mass attenuation coefficient depends explicitly on ***energy***(E) and implicitly on the ***atomic number*** of the material and its ***electron density***.
- The second component is the mass density of the material. The greater the density, the larger the attenuation afforded by that material, as seen in the product .
- The third component represents the thickness of the material. Again, the thicker the material the more attenuation that material provides to the x-ray beam.

- According to the above equation
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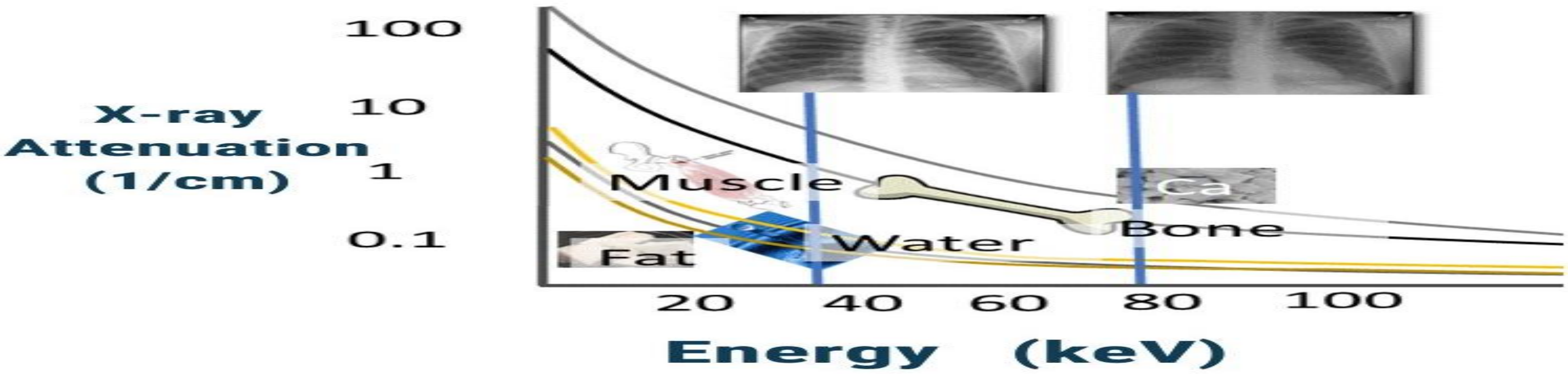
Radiographic Contrast of Biological Tissues

More contrast between bone and soft tissue than within soft tissue

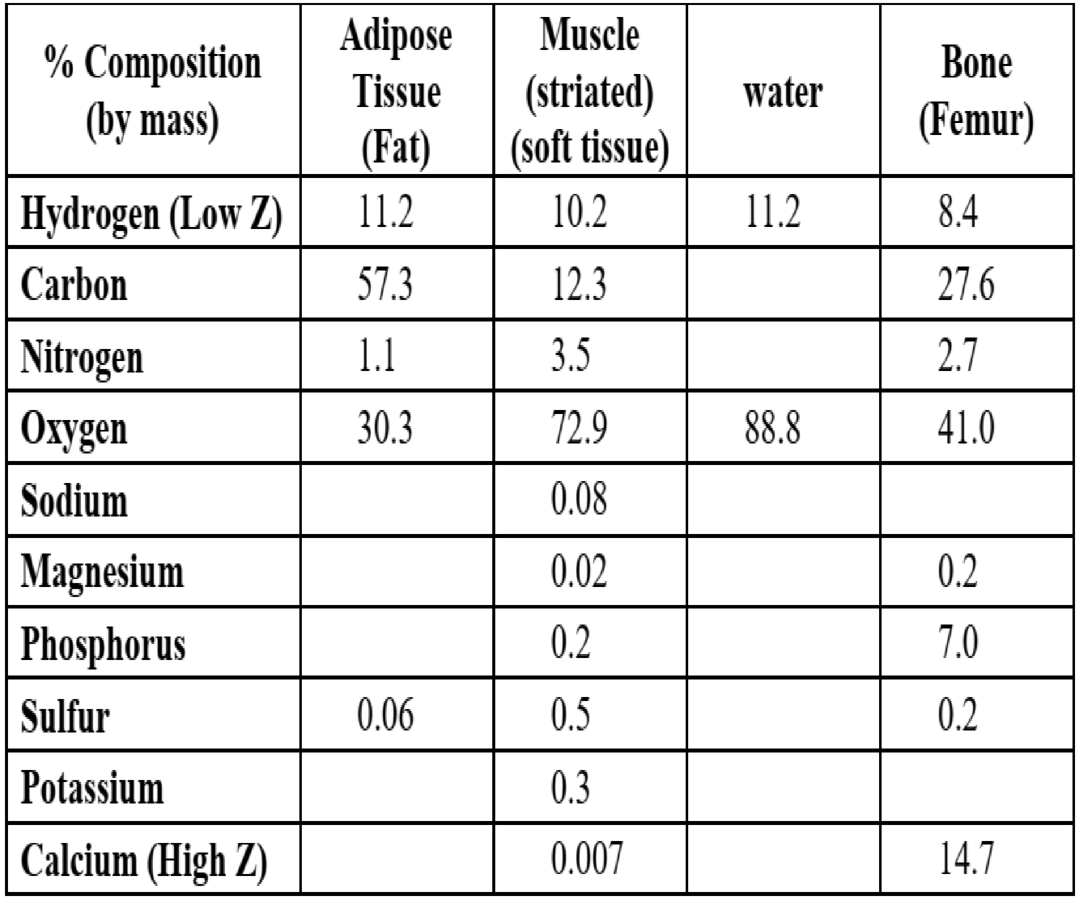


At lower energies the contrast between bone and soft tissue is even greater.

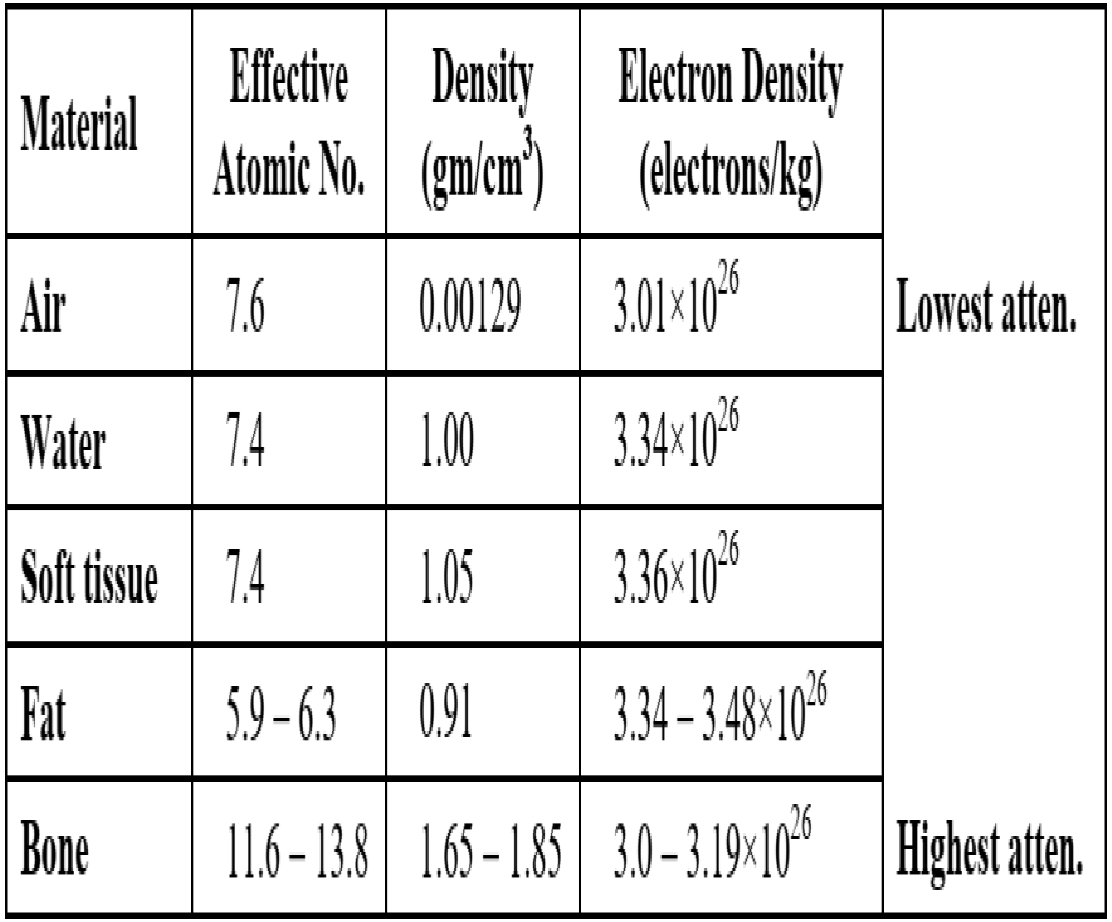
- One of the principal determinants of contrast in a radiograph of the human body is, of course, the types of tissue found in the body region being imaged. The radiation attenuation properties of each tissue type in turn are determined by its elemental and chemical composition

- For purposes of our discussion, we can consider the body being composed of three different tissues:
- Fat
- soft tissue (Lean)
- Bone
- Air found in the lungs (and in the gastrointestinal tract)
- contrast agents that possibly will be introduced into the body

The chemical composition of the three major tissue types are given in the following Table



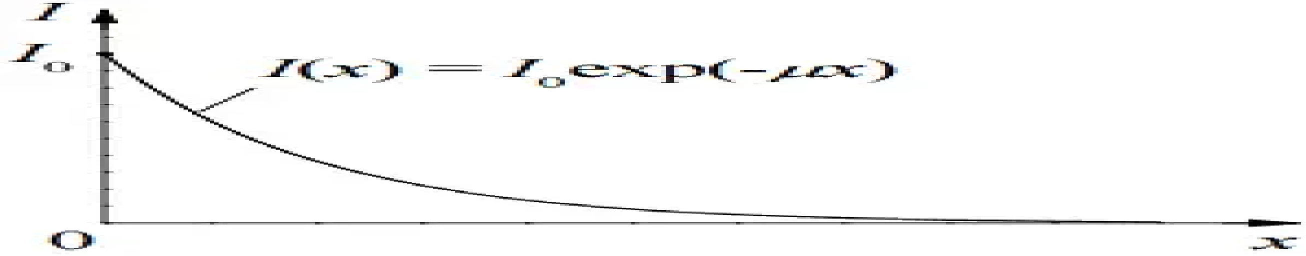
% Composition (by mass)	Adipose Tissue (Fat)	Muscle (striated) (soft tissue)	water	Bone (Femur)
Hydrogen (Low Z)	11.2	10.2	11.2	8.4
Carbon	57.3	12.3		27.6
Nitrogen	1.1	3.5		2.7
Oxygen	30.3	72.9	88.8	41.0
Sodium		0.08		
Magnesium		0.02		0.2
Phosphorus		0.2		7.0
Sulfur	0.06	0.5		0.2
Potassium		0.3		
Calcium (High Z)		0.007		14.7



Material	Effective Atomic No.	Density (gm/cm^3)	Electron Density (electrons/kg)	
Air	7.6	0.00129	3.01×10^{26}	Lowest atten.
Water	7.4	1.00	3.34×10^{26}	
Soft tissue	7.4	1.05	3.36×10^{26}	
Fat	5.9 – 6.3	0.91	$3.34 - 3.48 \times 10^{26}$	
Bone	11.6 – 13.8	1.65 – 1.85	$3.0 - 3.19 \times 10^{26}$	Highest atten.

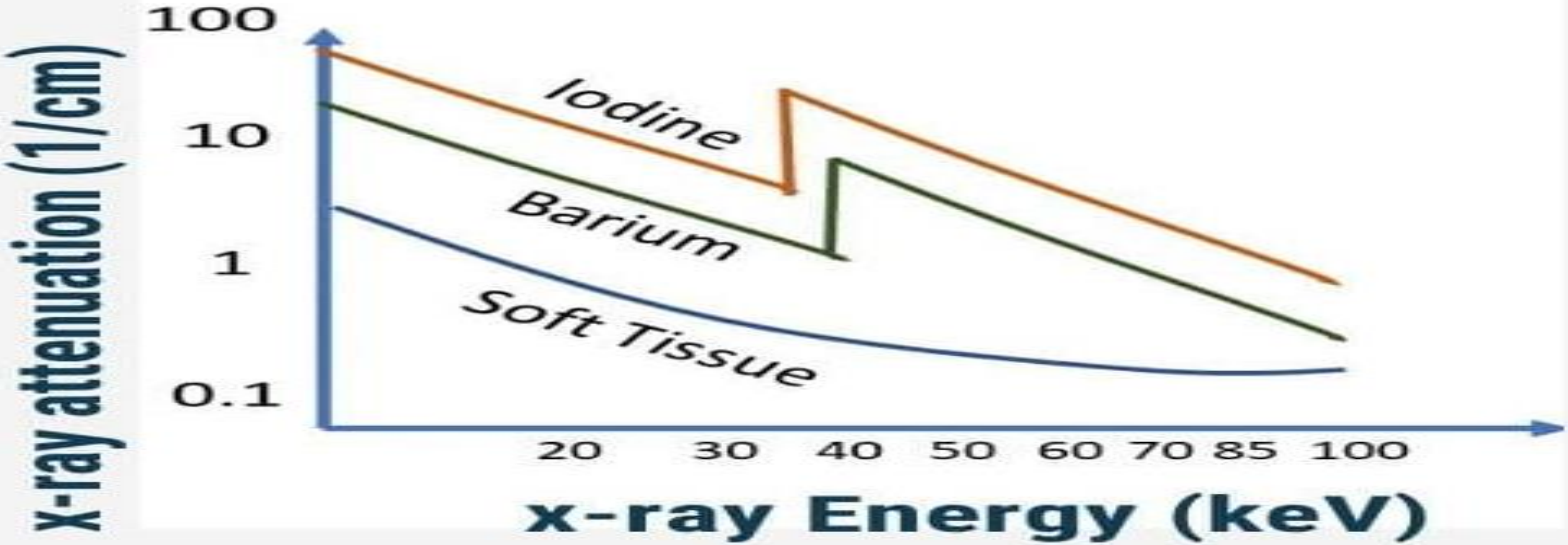
Soft Tissue

- Attenuation of x-rays is a function of energy and the materials that the x-ray beam is passing through.
- This plot is a useful schematic if you know the averag energy of the x-ray beam you can estimate the contrast between different materials.
- soft tissue including liver tissue, collagen, ligaments, blood, cerebrospinal fluid, and so on. However, the chemical composition of these tissues is dominated by elements with low atomic numbers. Therefore, we will assume that they are radio-graphically equivalent to water and have an effective atomic number of 7.4 and an electron density of 3.34×10^{26} electrons per gram.
- Water-equivalent tissues have several important radiologic properties that contribute to their contrast.



fat

- Due to the presence of low atomic number elements, fat has a lower physical density and lower effective atomic number, and therefore a lower photoelectric attenuation coefficient, than either soft tissue or bone. For this reason, fat has a lower attenuation coefficient than other materials in the body (except air) at low energies where the photoelectric interactions are the dominant effect.
- However, at higher energies, fat has a somewhat higher Compton mass attenuation coefficient than other tissues found in the body.
- linear attenuation coefficient approximately 6 times greater than that of soft tissue or fat. This difference decreases at higher energies where the Compton Effect becomes more dominant. However, even at higher energies, the higher density of bone still allows it to have excellent contrast with respect to both soft tissue and fat.

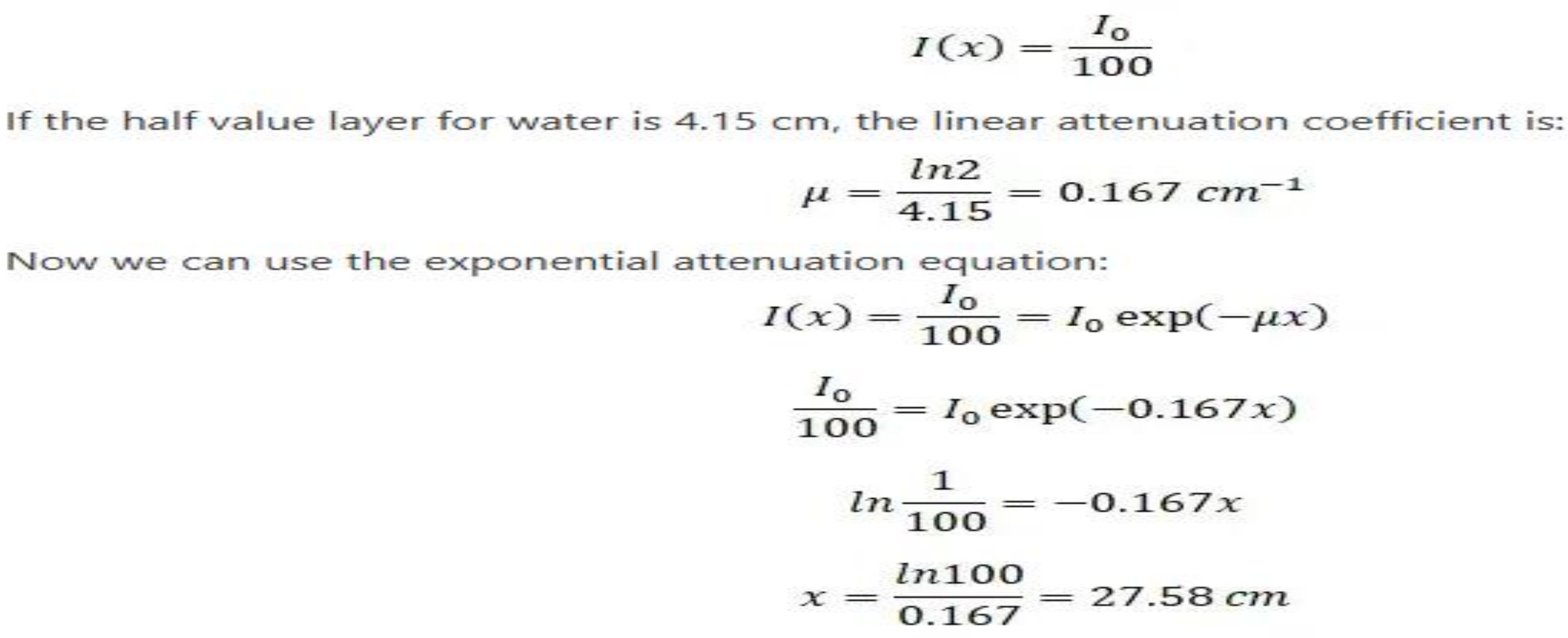

100
10
1
0.1
X-ray attenuation (1/cm)
Iodine
Barium
Soft Tissue
20
30
40
50
60
70
85
100
x-ray Energy (keV)

Bone

- The mineral component of bone gives it excellent contrast properties for x-ray photons in the diagnostic range. This is due to two properties. First, its physical density is 60% to 80% higher than soft tissue. This increases the linear attenuation coefficient of bone by a proportionate fraction over that of soft tissue. Second, its effective atomic number (about 11.6) is significantly higher than that of soft tissue (about 7.4). Since the photoelectric mass attenuation coefficient varies with the cube of the atomic number, the photoelectric mass attenuation coefficient for bone is about [11.6/7.4]3 = 3.85 times that of soft tissue. The combined effect of its greater physical density and its larger effective atomic number gives bone a photoelectric

Solved problem

- How much water schielding do you require, if you want to reduce the intensity of a 100 keV **monoenergetic** X-ray beam (**narrow beam**) to **1%** of its incident intensity? The half value layer for 100 keV X-rays in water is 4.15 cm and the linear attenuation coefficient for 100 keV X-rays in water is 0.167 cm^{-1}.



$$I(x) = \frac{I_o}{100}$$

If the half value layer for water is 4.15 cm, the linear attenuation coefficient is:

$$\mu = \frac{ln2}{4.15} = 0.167\ cm^{-1}$$

Now we can use the exponential attenuation equation:

$$I(x) = \frac{I_o}{100} = I_o \exp(-\mu x)$$

$$\frac{I_o}{100} = I_o \exp(-0.167x)$$

$$ln\frac{1}{100} = -0.167x$$

$$x = \frac{ln100}{0.167} = 27.58\ cm$$

Luminescence

- Luminescence is "cold light", light from other sources of energy, which can take place at normal and lower temperatures.
- In Latin ‘Lumen’ means ‘light’. The materials exhibiting this phenomenon are known as ‘Luminescent materials’ or ‘Phosphors’ meaning ‘light bearer’ in Greek.
- In luminescence, some energy source kicks an electron of an atom out of its "ground" (lowest energy) state into an "excited" (higher-energy) state; then the electron gives back the energy in the form of light in the visible region, so that it can fall back to its "ground" state. We can observe the luminescence phenomenon
- in glow-worms, •fireflies, •and in certain sea bacteria •and deep-sea animals.

- Luminescence can be classified on the basis of duration of emission, $\tau_c$in to two parts:
- The following points represents the difference between them:

1- Fluorescence where $\tau_c < 10^{-8}s$ (Temperature independent process).

2- Phosphorescence where $\tau_{c>10^{-8}s}$ (Temperature dependent process).

The Phosphorescence phenomenon can be further divided into two parts:

(a) short period $\tau_c < 10^{-4}s$ and long period $\tau_c > 10^{-4}s$ is called Thermo luminescence (TL)

- Solids exhibiting property of luminescence are usually referred to as Phosphors. The Fluorescence emission is seen to be spontaneous as 'τ_c' $< 10^{-4}s$) and long-period ('τ_c' $> 10^{-4}s$) Phosphorescence. Thus fluorescence emission is seen to be taking place simultaneously with absorption of radiation and stopping immediately as radiation ceases.
- Fluorescence is essentially independent of temperature, whereas decay of phosphorescence exhibits strong temperature dependence.

- X-ray luminescence is an optical phenomenon in which chemical compounds known as scintillators can emit short-wavelength light upon the excitation of X-ray photons. Since X-rays exhibit well-recognized advantages of deep penetration toward tissues and a minimal auto fluorescence background in biological samples, X-ray luminescence has been increasingly becoming a promising optical tool for tackling the challenges in the fields of imaging, biosensing, and theragnostics. In recent years, the emergence of nanocrystal scintillators have further expanded the application scenarios of X-ray luminescence, such as high-resolution X-ray imaging, autofluorescence-free detection of biomarkers, and noninvasive phototherapy in deep tissues. Meanwhile, X-ray luminescence holds great promise in breaking the depth dependency of deep-seated lesion treatment and achieving synergistic radiotherapy with phototherapy.

- X-ray luminescence, also known as X-ray fluorescence, is a phenomenon in which a material emits secondary X-rays when it is exposed to primary X-rays. When high-energy X-rays are directed at a material, they can interact with the atoms in the material, causing the atoms to become excited. As the excited atoms return to their ground state, they release secondary X-rays with characteristic energies that are unique to the elements present in the material. This property is used in X-ray fluorescence spectroscopy to identify and analyze the elemental composition of various substances. It has applications in fields such as materials analysis, archaeology, and environmental science

- X ray phosphorescence, also known as X-ray afterglow, refers to the phenomenon where certain materials emit light (phosphorescence) after being exposed to X-rays. This emission of light occurs as a delayed response to the initial X-ray exposure. The emitted light is typically of lower energy than the X-rays and can persist for a varying amount of time, depending on the specific material and conditions. This phenomenon has been studied and utilized in various applications, including imaging. Some materials, such as certain phosphors, are designed to emit visible light after exposure to X-rays, making them useful in X-ray imaging and radiation therapy