Image characteristics

Exercise 1

A and B are two ideal images characterized respectively by a spatial frequency spectrum with of k_{xAmax}= k_{yAmax} 5 lp/mm and k_{xBmax} = k_{yBmax}=10 lp/mm (lp=line pair).

1) What does this mean in terms of image resolution? (1 point)
2) Let's suppose we use a digital detector with 40x40 cm FOV and 2048x2048 pixel grid. How is the final image resolution affected? (3 points)
3) What does it change when we use an 20x20 cm FOV? (2 points)

1) Image resolution B > Image resolution A

2) $d_x=d_y$=0.2 mm is the actual pixel size

The minimum pixel size (or pixel pitch) required to achieve a certain spatial resolution can be calculated as

$d_x=d_y= 1/(2*k_{xmax})$, that means 0.1 mm for A and 0.05 mm for B

In both cases the final image resolution will be limited by the detector size, i.e. 0.2 mm, and it will be reduced to $0.2=1/2*k_{max} \rightarrow k_{max}$ 1/0.4=2.5 lp

3) $d_x=d_y$=0.1 mm that means the ideal resolution of A won't be degraded while B will be reduced to 5 lp/mm

Exercise 2

Given the following image where the gray box represents the imaged object and the white area the background (no interactions). Compute

1) Contrast (1 points)
2) SNR (2 points)
3) CNR (2 points)

1	**0**	**3**	**2**
1	**42**	**43**	**1**
2	**41**	**40**	**1**
0	**4**	**2**	**2**

4 pixels for the object
12 pixels for the background

Mean(object)=(42+43+41+40)/4=41.50
Mean(background)= (4+4+5+6)/12=1.58
Std(object)=sqrt((0.5^2+1.5^2+0.5^2+1.5^2)/(4-1))=1.29
Std(background)=sqrt((2*1.58^2+4*0.58^2+4*0.42^2+1.42^2+2.42^2)/(12-1))= 1.16

1)contrast=(41.5-1.58)/1.58=25.27
2)SNR= Mean(object)/ Std(background)=41.5/1.16=35.78
3)CNR= Mean(object)- Mean(background)/ Std(object)=(41.5-1.58)/1.29=30.95

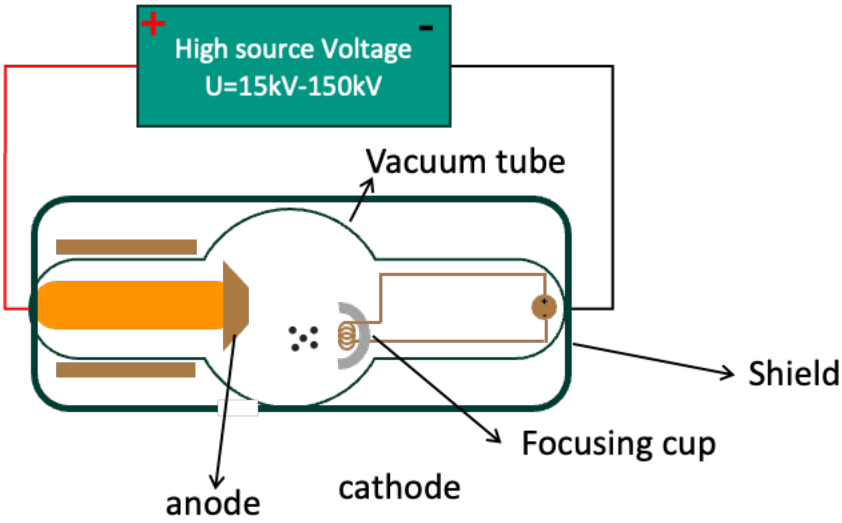
X-ray production

Exercise 3

1) Sketch and label the most important components of the X-ray tube and describe each component (5 points)

2) What do we mean with “anode angle”? How does it affect the X-ray beam production and image quality? (4 points)
3) How can the X-ray intensity spectrum can be modified? (4 points)

1)



The x-ray tube consists of

- Vacuum tube with 2 electrodes (15kV-150kV potential):
    - a negative charged electrode (cathode) that acts as electrons source.
        - The cathode consists of tungsten 1 or 2 spiral wires, heated up (~2200°C) by an electric current (up to 10 A).
        - Electrons are released through thermionic effect.
        - Electrons are accelerated and focused towards the anode by means of a focusing cup
        - The kinetic energy of the electrons depends on the source voltage

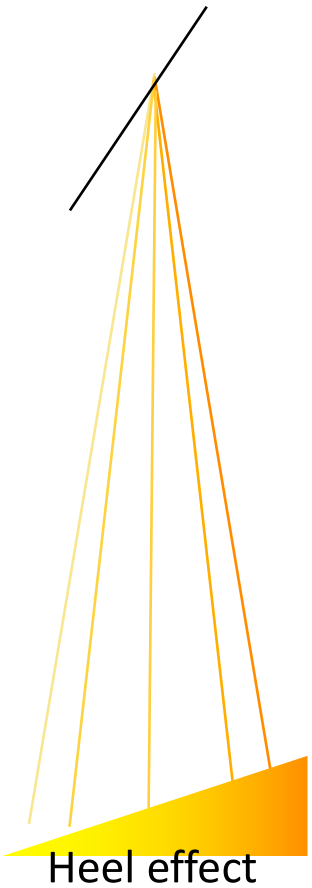
$$eU = \frac{1}{2} m_e v^2$$

    - a positive charged electrode (anode) that acts as target and it’s where X-rays are produced. The anode is a high Z material that:
        - must have a very high melting temperature;
        - determines the energy spectrum of produced X-ray (higher atomic number → higher average energy and characteristic radiation);
        - is set on a rotating (10000 rpm) beveled plate to preserve the from always hitting the same spot;
        - the anode rotates
    - A lead shield prevents from irradiating in undesired directions.

2) The **anode angle** is the angle between the target surface of the anode and the vertical. The anode angle ranges between 10°-20° and a large anode angle means:

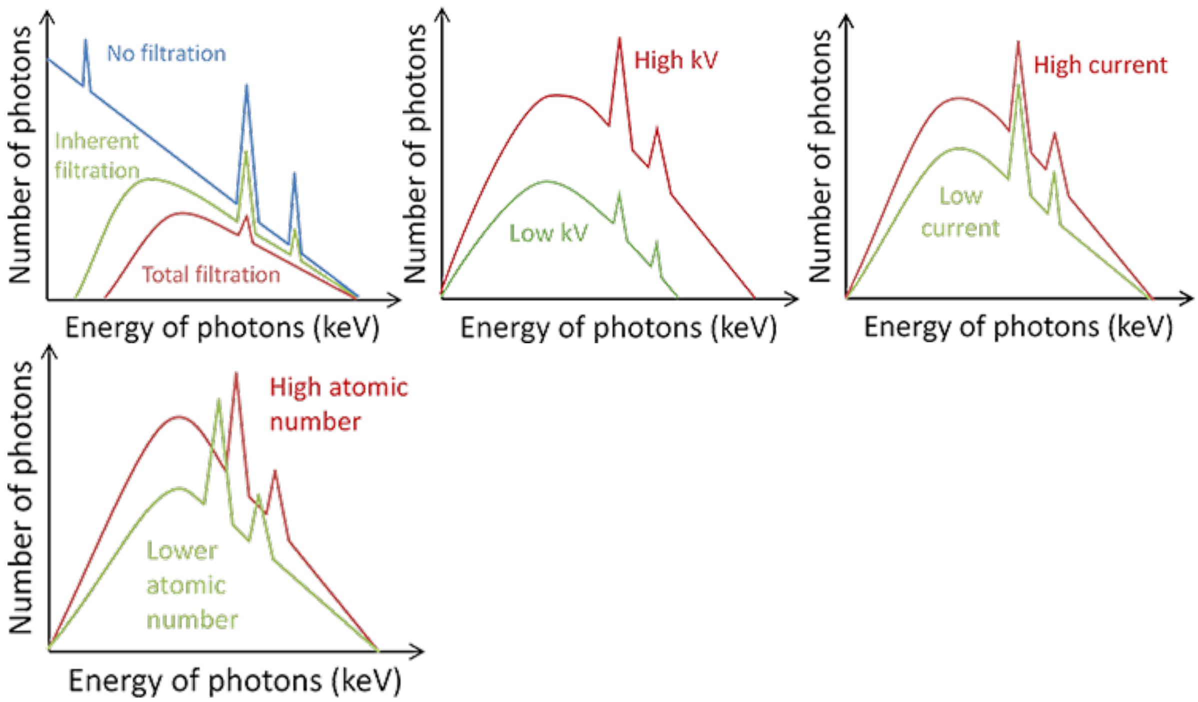
- Large focal area, this allows to distribute the heat on a larger surface and permits higher cathode's currents
- Larger FOV
- Larger effective spots that, as countereffect, causes image blur (penumbra area) and so poor image quality

The anode angle also causes the heel effect. This is because x-rays are produced deep in the target material and they must travel through the material before they can proceed to the target. By looking



at the figure we can see that photon produced closer to the cathode have to travel less material and have more energy.
The final result is that **the field intensity** towards the cathode is more than that towards the anode.

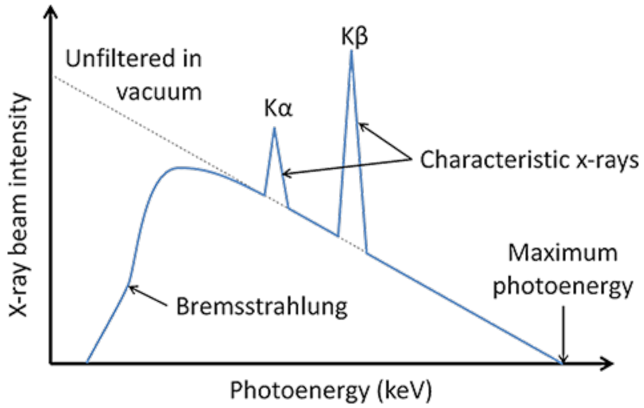
3)



Exercise 4

Sketch and explain the X-ray tube energy spectrum,
1) at the exit of the X-ray tube before any filtering takes place (2 points)
2) after the filter but before the X-rays have reached the patient (2 points)
3) Explain what the maximum energy value represents, and which energy is assumed to be the beam energy (2 points)

1 and 2



3 The maximum photoenergy is determined by the tube potential U and is equal to $e \cdot U$. We assume the average energy spectrum ad the beam energy

Exercise 5

2.1 Figure 2.43 shows the intensity of X-rays produced from a source as a function of their energy. With respect to the reference graph shown on the left, one plot corresponds to a decrease in tube current, and the other to a decrease in the accelerating voltage (kVp). Explain which plot corresponds to a decrease in which parameter.

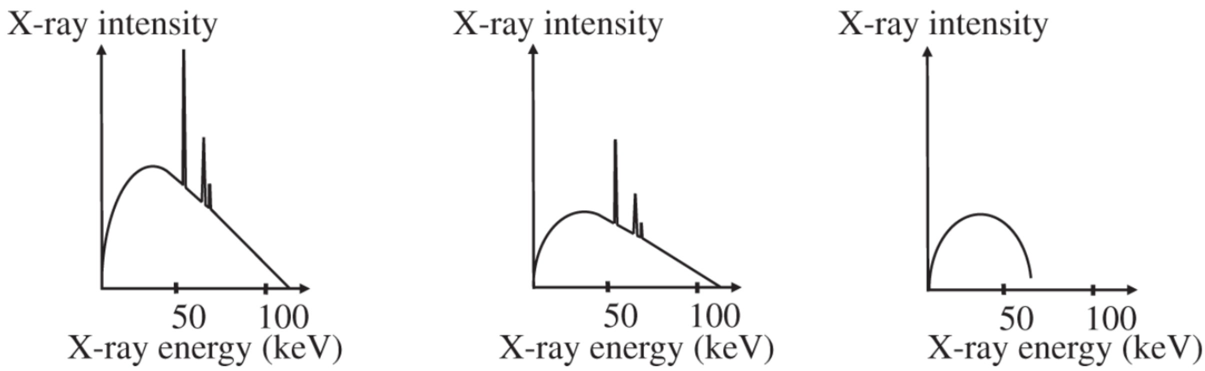


Figure 2.43 Illustration for Exercise 2.1.

The graph in the middle represents a reduction of the current in the cathode.
The graph on the right represents a reduction of the accelerating voltage.

Exercise 6

What is the effect of the kV and mA s of an X-ray tube on

(a) the patient dose (2 points)
(b) the image quality? (4 points)

(a) in both case by increasing energy or current we increase the dose to the patient because we generate more photons

(b)

Increasing Energy
- reduce contrast
- Increases Compton scatter
- Reduces quantum noise

Increasing current improve contrast
- Increases Compton scatter
- Reduces quantum noise

X-ray tissue interactions

Exercise 7

1) Explain which X-ray tissue interactions could occur at imaging energy range level (4 points)
2) Sketch the dependance of tissue interactions from energy (3 points)

1) There are two main X-ray tissue interactions occurring at the imaging energy level (30-100 keV):

- Compton scatter
- Photoelectric effect

Compton

1. X-ray photon hits free/ loosely bound outer shell electron
2. Electron absorbs some of the photon’s energy and is deflected
3. The photon, having lost some energy, is deflected and scattered. Because of the production of a scattered photon the Compton effect is considered a scattering process.

The amount of Compton scatter increases with:

- Increasing mass density
- Increasing electron density of the material
- X-ray beam energy

Photoelectric effect

1. An x-ray photon interacts with a bound electron from the inner shell.
2. All of the energy of the photon is transferred to the electron.
3. The electron then has enough energy to be freed as a photoelectron and leaves a ‘hole’ in the shell.
4. The hole is filled by electrons from outer shells. As these electrons move from a lower energy outer shell to a higher energy inner shell, the electrons release the energy at a characteristic energy (i.e. characteristic radiation).

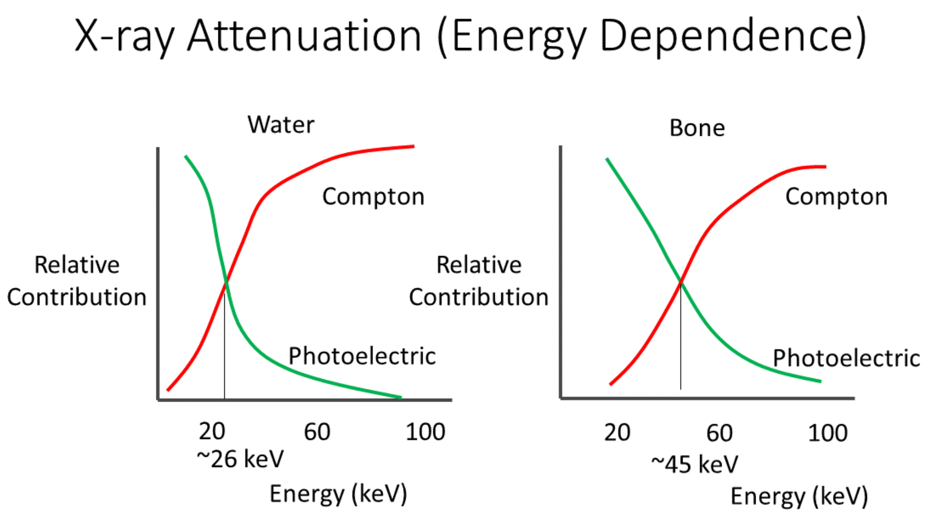
The probability of photoelectric interactions is proportional to the following factors

$\rho Z^3 / E^3$

ρ = mass density

Z = atomic number

E = photon energy



Computed tomography

We want to perform CT of the thorax covering a scan length 38.4 cm in the cranio-caudal direction with a beam collimation to the detector array of 0.60 mm (slice thickness).
The 360◦ rotation time is 0.33 s. Calculate the scan time with the following settings (5 points).

1) single raw detector with pitch=1
2) single raw detector with pitch=1.5
3) 64-raw scanner with pitch=1

4) 32-raw detector with pitch=1.5
5) What does it change, in terms of scan time if we choose 180° z-reconstruction instead of 360° z-reconstruction

First, we remind that the pitch is defined as table distance (d) travelled in one 360° gantry rotation, divided by beam collimation (slice thickness, s).

$$p = \frac{d}{s}$$

1) If p=1 and s=0.60 mm d=0.6 mm in one rotation that takes 0.33 s. To cover 38.4 cm we need 384mm/0.6 mm= 640 rotations
   So, the scan time is 640*0.33s=211.2 s or about 3 minutes and 31 seconds

2) If p=1.5 and s=0.60 mm d=0.9 mm in one rotation that takes 0.33 s. To cover 38.4 cm we need 384mm/0.9 mm= 427 rotations (it would be 426.7 but we always have to round up to the maximum integer)
   So, the scan time is 427*0.33s=140.91 s or about 2 minutes and 21 seconds

3) In case we have 64 raw detectors and p=1, according to what found in 1), to cover 38.4 cm we need (384mm/0.6 mm)/64= 10 rotations
   So, the scan time is 10*0.33s=3.3 s

4) In case we have 32 raw detectors and p=1.5, according to what found in 2), to cover 38.4 cm we need (384mm/0.9 mm)/32= 14 rotations
   So, the scan time is 14*0.33s=4.62 s

5) Nothing changes for the scan time because the tube has always to complete a full revolution to cover the distance