Radiation Physics

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Lecture 6: production of X-Ray

(Quality and Quantity of X-Ray)

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1-Quality and Quantity of X-Ray

1.1 Quality of X-Ray

- The term quality describes the penetrating power of the radiation.
- Altering the penetrating power of the x-ray beam affects its absorption and transmission through the anatomic tissue being radiographed.

1.2 Quantity of X-Ray

The intensity is a measure of quantity of radiation. The term exposure is often used in radiology.

- The term quantity refers the number of X-ray photons in the beam.

Factors Affecting Quality and Quantity

A number of factors that affect the X-ray production efficiency, quality, quantity may be considered.

1-Tube Voltage (kVp)

- The applied voltage affects both the quality and intensity of the X-rays.

Two factors contribute to this increase:

First the electrons have more energy to lose when they hit the target.

Second, as shown in Table 1, the efficiency of conversion of electrons into X-rays rather than into heat also increases with tube kilovoltage.

Table 1: Efficiency of converting electron energy into x rays as a function of tube Kilovoltage

Tube Kilovoltage (kV)	Heat (%)	X-rays (%)
60	99.5	0.5
200	99	1.0
4000	60	40

2-Tube Current (mA)

This determines the number of electrons striking the anode. But only the quantity of X-rays is affected.

3-Time of Exposure

Determines the length of X-ray production. The total quantity of X-rays is directly proportional to the product of the tube current and exposure time (mAs).
Only the quantity of X-rays is affected.

4-Waveform of Applied Voltage

Most effective at high energy and also quantity

5-Filtration

The effect on both the quantity and quality of the X-ray beam, by reducing the overall output but also reducing the proportion of low energy photons.

6-Target Material (Z)

The atomic number of the target material affects the intensity of the X-rays. The atomic number of the target material also determines the energy (quality) of characteristic X-rays.

Table 2: Electron Shell Binding Energies (keV)

Shell	*Molybdenum* ($Z = 42$)	*Tungsten* ($Z = 74$)
K	20	69
L	2.9, 2.6, 2.5[a]	12, 11, 10
M	0.50, 0.41, 0.39, 0.23, 0.22	2.8, 2.6, 2.3, 1.9, 1.8

Effect of kVp (Kilovolt Peak)

- The amount of radiation produced increases as the square of the kilo voltage,

i.e. Radiation exposure (E) ∝ (kVp)^2

- Thus, increase in kVp increases the quality, quantity and efficiency of X-ray production.
- The position of any characteristic lines will not change (see figure).

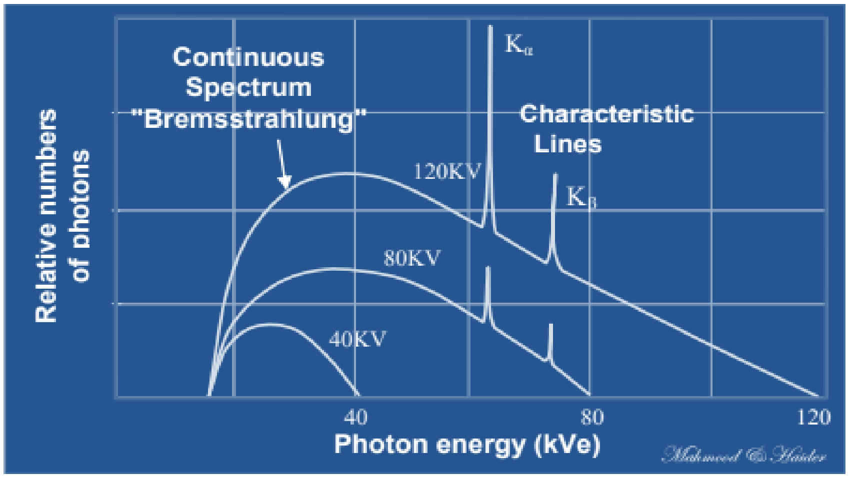


Figure 1: Effect of tube kilovoltage on X-ray spectra

in other words, if were doubled, the x-ray intensity would increase by a factor of four.

$$\frac{I_1}{I_2} = \left(\frac{kVp_1}{kVp_2}\right)^2$$

Where I_1 and I_2 are the X-ray intensities at kVp_1 and kVp_2, respectively.

Example:
A lateral chest technique calls for 110 kVp, 20 mAs and results in an x-ray intensity of 32 mR. What will the intensity be if the kVp increased to 125 and the mAs remains fixed?

$$\frac{I_1}{I_2} = \left(\frac{kVp_1}{kVp_2}\right)^2$$

$$\frac{I}{32\,mR} = \left(\frac{125\,kVp}{110\,kVp}\right)^2$$

$$I = \left(\frac{125\,kVp}{110\,kVp}\right)^2 * (32\,mR)$$

$$= (1.4)^2 (32\,mR)$$

$$= 41.3\,mR$$

Effect of Amperage (mA and mAs)

- The number of electrons depends directly on the tube current (mA) used.

  greater the mA → high electrons that hit the target → high X-rays produced

- The tube current affects only the quantity or the amount of x-ray photons produced but not the quality of the X-rays.

i.e. the intensity is ∝ mA.

Increase of applied voltage is compensated by the reduction of tube current, which is required to maintain same exposure.

Change mA (kVp Constant	Change kVp (mA Constant

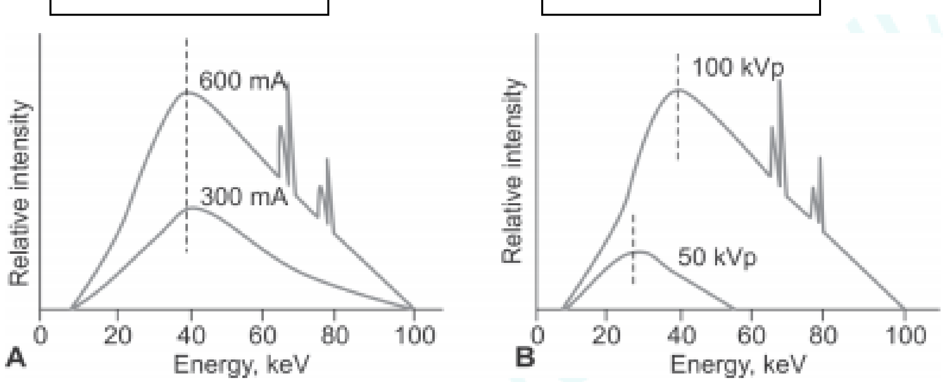


Figure 2: Relationship between kV, mA and energy.

To calculate the mAs, you multiply

Milliamperage (1/1000 of an amp) × time (in seconds)

mA × s

For example

mA=100, s = 0.25.5

mAs = 100 × 1.5 = 150

Example : Calculate the total number of electrons bombarding the target of an x-ray tube operated at 200 mA for 0.1 sec.

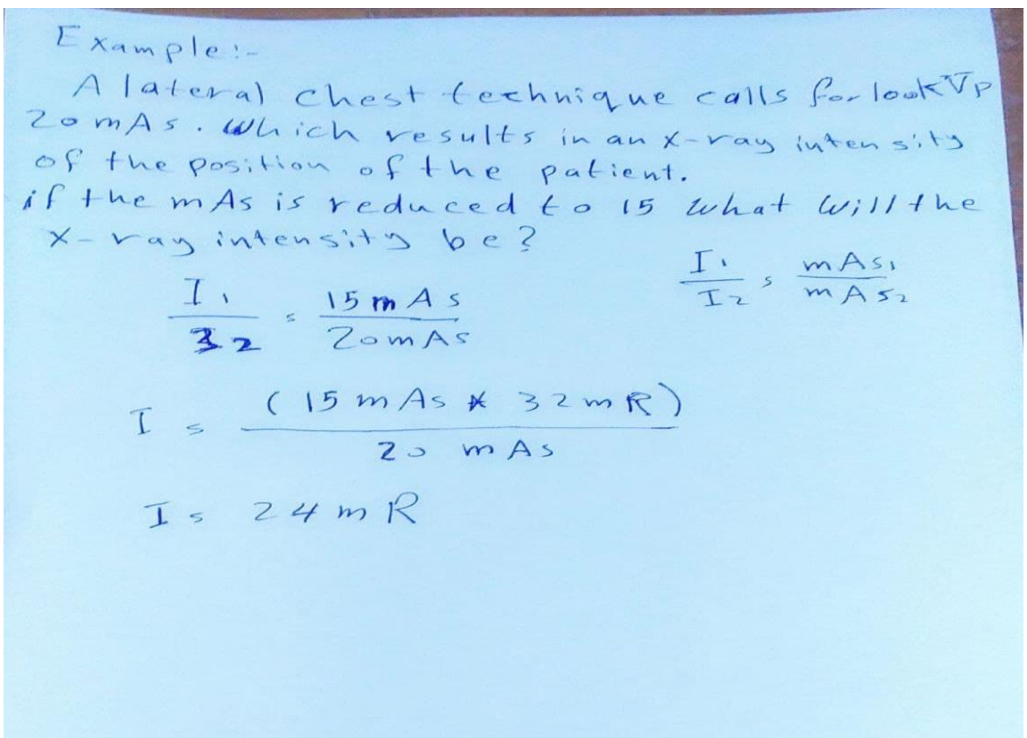
- The ampere, the unit of electrical current, equals 1 coulomb/sec.
- The product of current and time equals the total charge in coulombs.
- X-ray tube current is measured in milliamperes, where 1 mA = 10^{-3} amp.
- The charge of the electron is 1.6×10^{-19} coulombs, so

$$1\ mA \cdot s = \frac{(10^{-3} coulomb/sec)(sec)}{1.6 \times 10^{-19} coulomb/electron} = 6.25 \times 10^{15}\ \text{electrons}$$

No. of electron = (200 mA)(0.1 sec)(6.25×10^{15} electrons/mA.sec)
= 1.25×10^{17} electrons

When the mAs is doubled, the number of electrons striking the tube target is doubled, and therefore the number of x-rays emitted is doubled.

$$\frac{I_1}{I_2} = \frac{mAs_1}{mAs_2}$$


Example:-
A lateral chest technique calls for 100kVp 20mAs. Which results in an X-ray intensity of the position of the patient.
if the mAs is reduced to 15 what will the X-ray intensity be?

$$\frac{I_1}{I_2} = \frac{mAs_1}{mAs_2}$$

$$\frac{I_1}{32} = \frac{15\ mAs}{20\ mAs}$$

$$I = \frac{(15\ mAs * 32\ mR)}{20\ mAs}$$

$$I = 24\ mR$$

Effect of Added Filtration

- Filters are thin sheet of material (Al,Cu).
- The purpose of using filter is to reduce patient exposure at the skin level.
- Filters alter both the quality and quantity of X-rays by selectively removing the low energy photons in the spectrum.
- This reduces the photon number (quantity) and shifts the average energy to higher values by increasing the quality.

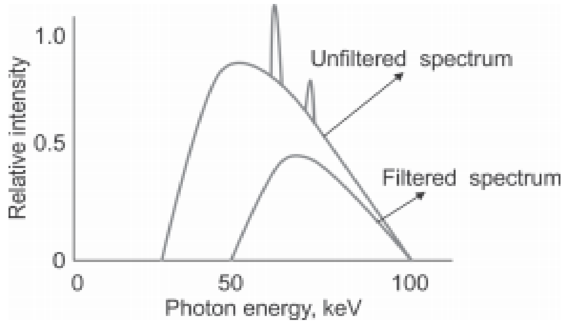


Figure 3: Effect of filter on X-ray spectra