Chapter 1

Basic physics – Questions

S. Ilyas

1. Which of the following statements regarding protons are correct?
   a. They have a negative charge
   b. They are equal to the number of electrons in a non-ionized atom
   c. They are equal to the atomic number in a non-ionized atom
   d. They have no mass
   e. They increase in number relative to neutrons, following electron capture

2. The binding energy of electrons:
   a. Is the energy expended in moving an electron from an inner to an outer shell
   b. Is higher for an L-shell electron than an M-shell electron
   c. Is influenced by the number of neutrons within an atom
   d. Determines Bremsstrahlung photon energy
   e. Determines the energy of the photoelectron produced following photoelectric absorption

3. Which of the following are correct regarding electromagnetic radiation?
   a. Gamma rays are a form of electromagnetic radiation
   b. The particles have a mass equivalent to that of neutrons
   c. In a vacuum, the velocity of the particles differs depending on their individual properties
   d. It results in a sinusoidal graph when magnetic field strength is plotted against time
   e. The frequency is the interval between two successive crests

4. Regarding electromagnetic beam radiation:
   a. Energy fluence is the number of photons per unit area of a beam
   b. Beam intensity is the total amount of energy per unit area travelling per unit time
   c. Wavelength is inversely proportional to frequency
   d. Frequency is inversely proportional to photon energy (keV)
   e. Photon energy is inversely proportional to wavelength

5. Concerning electromagnetic rays:
   a. They travel parallel to each other in a straight line
   b. Beam intensity is proportional to the square of the amplitude
   c. The area of the beam is proportional to the square of the distance as it travels away from a point source

d. Beam intensity is proportional to the square of the distance as it travels away from a point source
e. The inverse square law is useful for estimating the intensity of a beam once it has passed through a copper filter

6. Which of the following statements are correct regarding an X-ray tube?
   a. The tube current (mA) is increased by increasing the filament voltage
   b. An increase in the tube voltage (kV) leads to a proportional increase in tube current (mA)
   c. Electrons are generated by heating the anode, which is usually made from tungsten
   d. The kinetic energy of electrons (keV) in the X-ray tube is dependent on the tube voltage (kV)
   e. The collision of electrons with a tungsten target mainly results in the production of X-ray radiation

7. Which of the following are true regarding the production of X-ray photons when using a tungsten target?
   a. The majority of X-rays emitted are a result of characteristic radiation
   b. The kinetic energy of electrons (keV) interacting with the target is equal to the kV between the anode and cathode of the X-ray tube
   c. Filament electrons with 90 keV can dislodge K-shell electrons in the target
   d. The energy of K_α radiation is greater than K_β radiation
   e. L-shell radiation makes up 25% of characteristic radiation emitted from the tube

8. Concerning characteristic radiation:
   a. It results in photons with a fixed energy, for a given material
   b. It mainly involves filament electrons dislodging L-shell electrons
   c. Photon energy is directly proportional to the tube voltage
   d. The rate of production of characteristic radiation is directly proportional to the filament voltage
   e. Atomic number influences photon energy of K-radiation

9. Concerning Bremsstrahlung radiation:
   a. It results mainly from filament electrons colliding with the nucleus
   b. It can result in photons that are equivalent in energy to the tube voltage
   c. It results in X-ray photons of the same energy, which are dependent on the target material
   d. An increase in atomic number of the target material results in an increase in the energy of photons
   e. A reduction in atomic number results in reduced photon production

10. Which of the following are true with regard to X-ray photon production?
    a. The area of a continuous spectrum graph represents the total output of all X-ray photons emitted as a result of characteristic radiation
    b. Increasing the tube voltage (kV) results in the continuous spectrum shifting to the right and the line spectrum increasing in height

c. One-quarter of the photons from Bremsstrahlung radiation that reach the patient are less than 20 keV
d. Increasing the filament voltage causes Bremsstrahlung and characteristic radiation graphs to increase in height
e. Reducing the filament voltage has no effect on the maximum photon energy produced by characteristic or Bremsstrahlung radiation

11. Concerning the interaction of X-ray photons with matter:
a. It is possible to predict the fraction of photons that will be absorbed or scattered, when passing through a given material
b. Attenuation is represented by the number of photons absorbed or scattered by matter
c. Scattered photons help form the primary image on the film
d. The half-value layer (HVL) of a material is the thickness needed to reduce the number of photons in a beam by half
e. The HVL is inversely proportional to the linear attenuation coefficient (LAC) of a material

12. Concerning factors affecting absorption and scatter of X-rays:
a. An increase in the density of a material results in an increase in the linear attenuation coefficient (LAC)
b. Increasing the atomic number of a material increases its half-value layer (HVL)
c. Reducing the tube voltage increases the LAC
d. Increasing the filament voltage reduces the HVL of a material
e. A narrow beam has a higher scatter-to-transmission ratio than a wide beam

13. Concerning an X-ray beam:
a. It reduces in equal quantities as it passes through material of equal thickness
b. No matter how thick the material, it is not possible to completely absorb the primary X-ray beam
c. Beam hardening results from a reduced number of photons being removed from the primary beam
d. For a heterogeneous beam, the half-value layer (HVL) increases as the beam passes through the material
e. Wearing lead gloves protects the operator's fingers from the X-ray beam

14. Which of the following are correct with regard to attenuation of X-ray photons?
a. The Compton effect refers to the interaction of X-ray photons with free electrons
b. Attenuation is the difference between the incident beam and the attenuated beam
c. Photoelectric absorption refers to the interaction of X-ray photons with loosely bound electrons
d. An increase in atomic number increases the linear attenuation coefficient (LAC)
e. Elastic scatter results in no loss of energy

15. Concerning Compton interaction, which of the following are correct?
a. It involves the collision of X-ray photons with any electron
b. The probability that Compton attenuation will occur decreases as photon energy is increased
c. Increasing the tube voltage results in a higher proportion of side scatter

d. The higher the scatter angle, the greater the penetration of the recoil electrons
e. An increase in the incident photon energy results in scatter photons with greater energy

16. Regarding the photoelectric effect:
a. It results in the production of Bremsstrahlung radiation
b. It results in the production of scattered photons, the energy of which is dependent on the initial photon energy (keV)
c. X-rays passing through barium cause greater scatter than those passing through human tissues
d. Ejection of a K-shell electron by an incident photon results in the production of an Auger electron
e. Auger electrons are produced as an indirect result of photoelectric radiation

17. Concerning factors influencing attenuation:
a. In material with a low atomic number, the photoelectric effect results in complete absorption
b. The energy of the incident photon must be greater than the binding energy of the electron in photoelectric absorption
c. An increase in the incident photon energy results in recoil electrons with lower penetration
d. Reducing the tube voltage (kV) results in less scatter reaching the film
e. The kinetic energy of the photoelectron ejected as a result of the photoelectric effect is not dependent on the atomic number of the material

18. Which of the following are true regarding the linear attenuation coefficient (LAC)?
a. The photoelectric LAC is directly proportional to photon energy
b. The total LAC is dependent on the physical density of the material
c. The Compton LAC is dependent on atomic number
d. The photoelectric LAC increases as the atomic number increases
e. The Compton LAC is dependent on the electron density

19. Concerning absorption edges:
a. K-edge binding energy is lower than L-edge binding energy
b. Between the K-shell and L-shell, the increase in photoelectric attenuation is proportional to the photon energy
c. For tungsten, the K-shell binding energy (Ek) is equal to 74 keV
d. There is a sudden increase in attenuation when photon energy reaches L-shell binding energy (EL)
e. When choosing a filter, it is important to make sure that the peak of the X-ray spectrum lies on the high-energy side of its absorption edge

20. Which of the following are true with regard to materials and attenuation?
a. Following the Compton effect, the wavelength change of the X-ray photon depends on the atomic number of the material
b. Photoelectric absorption is the predominating mode of interaction in modalities using high-energy photons

c. The Compton effect is the predominating mode of interaction in soft tissues
d. Photoelectric absorption is the predominating mode of interaction in air
e. The Compton effect is the predominating mode of interaction in contrast medium

21. Regarding secondary electrons:
a. Positrons are negatively charged electrons that result from radioactive decay
b. Beta particles can ionize atoms
c. The collision of two positrons results in two gamma photons, each with 511 keV
d. The range of the secondary electron is inversely proportional to the material density
e. Secondary electrons result in biological damage of tissues

22. Which of the following are true with regard to filtration?
a. The aim of filtration is to make the beam intensity more uniform by removing the very high-energy rays
b. The tube housing acts as a valuable filter
c. The predominant attenuation process in a filter should be photoelectric absorption
d. At 80 kV, the half-value layer (HVL) of a beam with 2.5 mm Al filtration is typically measured as 2–3 mm Al
e. The thickness of copper required to reduce the intensity of an X-ray beam by a factor of 2 is greater than the required thickness of aluminium needed to have the same effect

23. Concerning the effects of filtration:
a. It increases the intensity of the beam
b. It increases the half-value layer (HVL) of the beam
c. It reduces the peak photon energy
d. It reduces the effective photon energy
e. It increases skin exit/entry dose ratio

24. Decreasing the tube voltage (kV) results in which of the following?
a. It reduces the number of electrons colliding with the target
b. It reduces the photon fluence
c. It reduces the beam intensity
d. It results in the increase of the half-value layer (HVL) for a given material
e. The rate of photoelectric attenuation increases more than the rate of Compton attenuation

25. Which of the following increase X-ray beam intensity at a given point from a source?
a. Increasing the filter thickness
b. Increasing the tube current
c. Increasing the distance
d. Increasing the tube voltage
e. Reducing the atomic number of the target material

26. Regarding the atom, which of the following are true?
a. The mass number is equal to the number of nucleons
b. Positrons are found within the nucleus

c. The inner shell influences the chemical properties of an atom
d. The outermost shell with electrons is known as the valence shell
e. Radioactivity is dependent on the nucleus

27. Which of the following are correct with regard to X-ray production?
a. Increasing the tube voltage increases the heat production at the target
b. Reducing the actual focal spot reduces the heat load on the target
c. Increasing the target angle increases the target heat rating for a given effective spot size
d. Increasing the target angle increases the effective focal spot
e. A rotating anode can take a higher heat load than a stationary anode

28. The nucleons in an atom:
a. Reduce following beta-positive (β^+) decay
b. Are equal to the atomic number
c. Are equal to the difference between mass number and the number of protons
d. May have a negative charge
e. Affect the binding energy of electrons

29. Regarding photons:
a. X-ray photons are produced following K-electron capture
b. Collision of a positron with a negative beta particle results in the production of gamma photons
c. X-ray photons are produced following photoelectric absorption
d. They can be scattered only sideways or backwards following Compton attenuation
e. They have a mass

30. Regarding radioactivity:
a. Decay of radionuclides with a neutron excess produces a daughter nucleus with a higher atomic number
b. The rate of decay can be increased by heating the radionuclide
c. Isomers have the same half-life
d. Decay of radionuclides with a neutron deficit produces a daughter nucleus with a lower atomic number
e. Positron annihilation results in energy being converted to mass

Chapter 1

Basic physics – Answers

1. a. **False**. Protons have a positive charge. Electrons have a negative charge.
   b. **True**.
   c. **True**. Protons (atomic number (Z)) + neutrons ($A - Z$) = mass number (A)).
   d. **False**. Both protons and neutrons have a mass. Electrons have a negligible mass.
   e. **False**. Following electron capture the nucleus may increase its number of neutrons relative to protons by capturing an electron from the K-shell ($p + e \rightarrow n$)

2. a. **False**. Binding energy is the energy expended in completely removing the electron from the atom, against a positive force of the nucleus.
   b. **True**. The nucleus exerts a stronger pull on the inner electrons than the outer electrons.
   c. **False**. Neutrons have a charge of zero and hence do not affect the binding energy of electrons.
   d. **False**. Bremsstrahlung radiation is produced from filament electrons that penetrate the K-shell and approach the nucleus. Characteristic radiation is formed when an electron shifts from an outer to an inner shell, releasing a photon with energy equal to the difference in the binding energy of the two shells.
   e. **True**. In photoelectric absorption, when a photon collides with an electron from an inner shell, it ejects the electron, which is then termed a photoelectron.
   Kinetic energy of photoelectron (E_k for K-shell) = photon energy – binding energy.

3. a. **True**. Electromagnetic radiation is named according to how it is produced, e.g. X-rays (X-ray tube), gamma rays (radioactive nuclei).
   b. **False**. The different types of electromagnetic radiation differ in their properties and are made up of photons, which do not have a mass or electric charge.
   c. **False**. All forms of electromagnetic radiation travel with the velocity of light in a vacuum.
   d. **True**. Electromagnetic radiation produces a sinusoidal graph when electric or magnetic field strength is plotted against time or distance, travelling with velocity (C). The peak field strength is called the amplitude (A).
   e. **False**. Frequency (f) is the number of crests passing a point in a second. The interval between successive crests is called the period.

4. a. **False**. Photon fluence is the number of photons through a cross-section of the beam (i.e. per unit area). Adding the particle energies gives the total amount of energy per unit area and is called energy fluence.

b. **True**.
c. **True**. Wavelength is the distance between crests, when field strength is plotted against distance. Frequency multiplied by wavelength equals velocity ($\lambda \times f = V$)
d. **False**. Frequency is proportional to photon energy; the content of proportionality is called Planck's constant.
e. **True**.

5. a. **False**. Electromagnetic rays originate from a point source and diverge out, travelling in a straight line, unless attenuated.
b. **True**.
c. **True**. The inverse square law states that the intensity of radiation emitted from a point source will reduce in intensity, proportional to the square of the distance from that point, i.e. the area covered by the beam increases as the rays are diverging from a point; however, the number of photons remains the same and hence their intensity reduces.
d. **False**.
e. **False**. Important points to remember regarding the inverse square law are:
   i. Radiation comes from a point source.
   ii. There is no absorption or scatter of radiation between source and point of measurement.

6. a. **True**. The filament is heated by passing an electrical current through it, known as the tube current, which subsequently emits electrons.
b. **False**. The tube voltage affects the kinetic energy of each electron (keV), not the tube current, i.e. number of electrons.
c. **False**. Electrons are released by heating the cathode filament.
d. **True**.
e. **False**. The collision of electrons with tungsten results mainly in the production of heat, due to interaction with outer electrons.

7. a. **False**. Approximately 80% of X-rays emitted by a tube are Bremsstrahlung radiation.
b. **True**.
c. **True**. The kinetic energy of filament electrons needs to exceed the binding energy of K-shell electrons (70 keV for tungsten).
d. **False**. For tungsten: K_α radiation = K-shell binding energy (70 keV) – L-shell binding energy (12 keV) = 58 keV. K_β radiation = K-shell binding energy (70 keV) – M-shell binding energy (2 keV) = 68 keV.
e. **False**. As the binding energy of L-shell electrons is equal to 12 keV, the photon energy produced when an electron from an outer shell occupies the gap is too small to leave the tube (i.e. less than 10 keV).

8. a. **True**. Characteristic radiation results in the end production of photons that have the same energy, constituting a line spectrum, i.e. the difference in binding energies between the two shells, which is constant for a given material.
b. **False**. It mainly involves filament electrons dislodging K-shell electrons.

c. **False**. The tube voltage and filament voltage increase the rate of production of photons, but do not influence the photon energy, which is dependent on the atomic number of the target material.
d. **True**.
e. **True**. An increase in atomic number results in an increase in the binding energy of electrons and hence K-radiation.

9. a. **False**. Bremsstrahlung radiation mainly results from filament electrons penetrating the K-shell and being deflected by the nucleus, resulting in a loss of some of its energy in the form of a single photon.
b. **True**. Rarely, an electron can collide with the nucleus, which completely stops it, resulting in a photon with the same energy as the applied tube voltage.
c. **False**. This is true for characteristic radiation. However, Bremsstrahlung radiation produces photons with varying energies, resulting in a continuous spectrum.
d. **False**. Increasing the atomic number of the target material results in an increase in the number of photons, but does not affect the photon energy, which is dependent on the energy of the electrons (keV).
e. **True**.

10. a. **False**. The area of a continuous spectrum graph represents the total output of X-ray photons emitted as a result of Bremsstrahlung radiation, not characteristic radiation.
b. **True**. Increasing the tube voltage increases the frequency of photon production as a result of characteristic radiation; however, it does not influence photon energy, which is dependent on the target material. Photons produced by Bremsstrahlung radiation increase in both their frequency and energy (keV).
c. **False**. Photons with an energy of less than 20 keV are absorbed by the glass tube and do not reach the patient.
d. **True**. Increasing the filament voltage increases the number of electrons colliding with the target material causing an increase in the number of photons produced by both characteristic and Bremsstrahlung radiation.
e. **True**. Filament voltage does not influence photon energy in either characteristic or Bremsstrahlung radiation.

11. a. **False**. X-ray absorption and scatter are stochastic processes.
b. **True**. Attenuation is the total number of photons that have been removed, as a result of scatter or absorption, from the primary beam after passing through the attenuated material.
c. **False**. The X-rays transmitted through the patient form the primary image, while the scattered X-rays obscure it.
d. **False**. The HVL is the thickness of a material that will reduce the intensity of a mono-energetic beam to half its value, not the number of photons.
e. **True**. The LAC is the probability that a photon interacts (absorbed or scattered) per unit length it travels in a specific material. Hence, the greater the LAC, the lower the HVL of the material.

12. a. **True**. An increase in density results in a higher probability that a photon will interact with an electron as it passes through the material.
    b. **False**. An increase in atomic number results in a higher probability that a photon will interact with an electron (photoelectric effect) as it passes through the material and hence reduces the HVL.
    c. **True**. A reduction in tube voltage results in reduced photon energy, which means it is more likely to get attenuated as it passes through the material.
    d. **False**. Filament voltage increases the number of photons but not photon energy.
    e. **False**. A narrow beam results in a smaller amount of scatter.

13. a. **False**. This is only true for a mono-energetic beam. X-ray beams consist of photons with varying energies (poly-energetic).
    b. **True**. This is known as the exponential law.
    c. **False**. Beam hardening results from the low-energy photons being attenuated proportionally more than the high-energy photons as the beam travels through a material.
    d. **True**. As a result of beam hardening the penetrating power of the beam increases, resulting in an increase in the HVL.
    e. **False**. Protective equipment does not provide protection against the primary beam, only the attenuated rays.

14. a. **True**. The Compton effect is the interaction of X-ray photons with loosely bound or free electrons.
    b. **True**.
    c. **False**. Photoelectric absorption is the interaction of X-ray photons with an inner shell or 'bound' electron.
    d. **True**. An increase in atomic number results in a higher probability that a photon will interact with an electron (photoelectric effect) as it passes through the material.
    e. **True**. This also known as coherent scatter and occurs when the photon does not have enough energy to overcome the binding energy of an electron shell and hence 'bounces' off without the loss of energy.

15. a. **False**. Compton interaction refers to the interaction of incident photons with free or loosely bound electrons only.
    b. **True**. Attenuation generally decreases with increasing photon energies. However, the rate of decrease is much higher for photoelectric than for Compton attenuation.
    c. **False**. Increasing the tube voltage results in increased photon energy (keV) that in turn causes less side scatter.
    d. **True**. The greater the scatter angle, the greater the energy and range of the recoil electrons.
    e. **True**.

16. a. **False**. The photoelectric effect involves an incident photon removing a bound electron from its shell, resulting in the hole created being filled by electrons from outer shells, causing the emission of characteristic radiation.
    b. **False**. Unlike the Compton effect, the energy of the incident photon is completely absorbed after colliding with the electron and the photon disappears, resulting in no scatter photons.