Topic 25 Quantum physics

Summary

Energy of a photon

- A photon is a quantum (or packet) of energy of electromagnetic radiation having energy equal to the product of the Planck constant and the frequency of the radiation, $E = hf$.

Photoelectric emission of electrons

- Electrons may be emitted from metal surfaces if the metal is illuminated by electromagnetic radiation. This phenomenon is called photoelectric emission.
- Photoelectric emission cannot be explained by the wave theory of light. It is necessary to use the quantum theory, in which electromagnetic radiation is thought of as consisting of packets of energy called photons.
- The work function energy φ of a metal is the minimum energy needed to free an electron from the surface of the metal.
- The Einstein photoelectric equation is: $hf = \phi = \frac{1}{2} m_e V_{max}^2$
- The threshold frequency f_0 is given by:
  $hf_0 = \varphi$

Wave−particle duality

- Moving particles show wave-like properties.
- The de Broglie wavelength is given by $\lambda = h/p$, where p is the momentum of the particle and h is the Planck constant.

Energy levels in atoms and line spectra

- Electrons in isolated atoms can have only certain energies. These energies may be represented in an energy level diagram.
- Electrons in a given energy level may absorb energy and make a transition to a higher energy level.
- Excited electrons may return to a lower level with the emission of a photon. The frequency f of the emitted radiation is given by $E_2 - E_1 = hf$, where E_2 and E_1 are the energies of the upper and lower levels and h is the Planck constant; the wavelength λ is given by $\lambda = c/f$, where c is the speed of light.
- When an electron absorbs energy from white light and moves to a higher energy level, a line absorption spectrum is produced.

Band theory

- Current is due to a movement of negative charge carriers (electrons) in the conduction band and to a movement of positive charge carriers (holes) in the valence band.
- The forbidden band in insulators is very wide. In intrinsic semiconductors it is approximately 1 eV in width.
- In metals, the valence band and the conduction band overlap.
- Lattice vibrations increase in amplitude as temperature rises.
- In intrinsic semiconductors, effects due to increased numbers of charge carriers outweigh effects due to increased lattice vibrations.
- In metals, the number of charge carriers does not increase significantly and increased lattice vibrations cause an increase in resistance with temperature rise.

Production and use of X-rays

- Remote sensing enables investigations to be made where there is no contact with the object under investigation.
- X-rays are produced when high-speed electrons are stopped by a metal target.
- An X-ray image is a 'shadow' of structures in which the X-ray beam is attenuated.
- The attenuation in the intensity of an X-ray beam is given by:

  $I = I_0 \, e^{-\mu x}$
- Computed tomography (CT scanning) enables an image of a section through the body to be obtained by combining many X-ray images, each one taken from a different angle.

Definitions and formulae

- A photon is a packet of energy/quantum of energy when the energy is in the form of electromagnetic radiation.
- $E = hf$ for photons
- Photoelectric emission is the release of electrons from the surface of a metal when electromagnetic radiation is incident on its surface.
- Photoelectric emission:
- occurs instantaneously (there is no delay between illumination and emission)
- takes place only if the frequency of the incident radiation is above a certain minimum value called the threshold frequency f_0
- does not depend on the intensity of the radiation
- for a given frequency the rate of emission of photoelectrons is proportional to the intensity of the radiation.
- $hf = \Phi + \frac{1}{2}mv_{\text{max}}^2$ (Einstein's photoelectric equation)
- Φ is the work function energy and is the minimum energy required for an electron to escape from the surface of a metal.
- $\Phi = hf_0$
- $\lambda = h/p$, where λ is the de Broglie wavelength of a particle
- $hf = E_1 - E_2$ for emission and absorption line spectra
- Intensity of X-rays is power per unit area.
- Hardness of X-rays is related to the penetration of the X-ray beam.
- Attenuation of X-rays follows $I = I_0 e^{-\mu x}$ where μ is the linear absorption coefficient.