Unit 2 Quanta and Waves Learning Outcomes

2.1 Quanta

Introduction to Quantum Theory

Challenges to classical theory

1. Describe the challenges to classical theory that led to the development of quantum theory

Blackbody radiation

2. Describe a model of a black body
3. State that the continuous spectrum of radiation emitted by a black body is called blackbody radiation
4. Describe how the distribution of blackbody radiation varies with wavelength and temperature
5. Describe the classical model of a harmonic oscillator and its limitations
6. Explain the meaning of the ultra-violet catastrophe
7. State the assumptions made in Plank's theory of blackbody radiation
8. State the relationship between the oscillator energy, quantum number, frequency and Plank's constant
9. State a value for Plank's constant
10. Carry out calculations using the relationship between oscillator energy, quantum number, frequency and Planck's constant

Photoelectric effect

11. Describe how the experimental observations made when radiation of different frequencies is incident on a metal surface supports the particle model of light
12. State that electromagnetic radiation is emitted and absorbed in small packets or photons
13. State the relationship between the energy and frequency of a photon
14. Carry out calculations using the relationship between energy, frequency of photons and Plank's constant

Bohr model of the atom

15. Describe qualitatively the planetary model of the atom and its limitations
16. Describe the origins of the line spectra observed when a low pressure gas undergoes electric discharge
17. State the relationship between the wavelength, Rydberg constant and an integer that can be used to predict the wavelengths in the lines in the emission spectra of hydrogen
18. Carry out calculations involving this relationship
19. Describe qualitatively the Bohr model of the atom
20. State that the quantisation of angular momentum is given by: $mvr = \frac{nh}{2\pi}$
21. Carry out calculations using the relationship above
22. Draw a diagram which represents qualitatively the energy levels of a hydrogen atom

Wave–particle duality

23. State that electrons can behave like waves
24. Describe evidence which shows that electrons and electromagnetic radiation exhibit wave–particle duality
25. State that the wave and particle models are related by the expression: $\lambda = h/p$ where p is the associated momentum
26. Carry out calculations using the relationship above

Quantum mechanics

27. State that quantum mechanics provides methods to determine probabilities
28. Describe how the double slit experiment with photons and electrons supports the quantum mechanical view that wave and particle properties cannot be measured at the same time

Uncertainty principle

29. State that a more far-reaching model of atomic and nuclear structure interprets waves in terms of probabilities
30. State that Heisenberg's uncertainty principle means that you cannot measure position and momentum at the same time. If the position is known, the momentum cannot be determined accurately and vice versa
31. State that the uncertainty in position, uncertainty in the component of momentum in the x-direction and Plank's constant are related by the expression: $\Delta x \Delta p_x \geq \frac{h}{4\pi}$
32. State that position and momentum and energy and time are pairs of quantities that are indeterminate

33. State that the uncertainty in energy, uncertainty in time and Plank's constant are related by the expression:
    $$\Delta E \Delta t \ \geq \frac{h}{4\pi}$$
34. Carry out calculations using the two relationships shown above
35. State that the units of the pairs of quantities (energy and time and position and momentum) are Js
36. Describe the limitations of the quantum well model of potential energy and show how quantum tunneling can be used to explain some physically observed phenomena
37. Describe three examples of quantum tunneling

Particles from Space

Cosmic rays

1. State the definition of cosmic rays
2. Describe the origin and composition of cosmic rays
3. Describe the energy range of cosmic rays in comparison to a particle accelerator
4. Describe the interaction of cosmic rays with particles in the Earth's atmosphere, their detection and their role in Cherenkov radiation
5. State that the sun contains three main regions

The solar wind and the magnetosphere

6. Describe the structure of the sun
7. State a definition of the solar wind
8. Describe the origins of the solar wind, its effect on comet tails and the impact of coronal holes
9. State a definition of a solar flare
10. Describe solar flares, the solar cycle and sunspots

The magnetosphere

11. State a definition of the magnetosphere
12. Describe the origin of the Earth's magnetic field
13. Describe the interaction of the solar wind with the Earth's magnetic field
14. Describe the Van Allen belts of radiation

Charged particles in a magnetic field

15. State the relationship $F = qvB$ for the magnitude of the force acting on a charge q moving with a speed v through a magnetic field B, where F, v and B are all at right angles to each other
16. Explain how the circular motion of a charged particle in a magnetic field arises
17. State the relationship $r = \frac{mv}{qB}$ for a particle of charge q and mass m moving with velocity v through a magnetic field B in a circle of radius r
18. Carry out calculations on the motion of charged particles moving with non-relativistic velocities in uniform magnetic fields using the relationships above
19. State that if a charged particle's velocity vector is not perpendicular to the field, then its velocity can be resolved into two orthogonal components
20. Explain how the orthogonal components of velocity of a charged particle moving at an angle through a magnetic field gives rise to helical motion
21. Describe how charged particles which penetrate the Earth's upper atmosphere give rise to the aurorae

2.2 Waves

Simple harmonic motion

1. Describe examples of Simple Harmonic Motion (SHM)
2. State that in SHM, the unbalanced force is proportional to the displacement of the body and acts in the opposite direction
3. State and explain the equation $\frac{d^2y}{dt^2} = -w^2 y$
4. Show that $y = A\sin\omega t$ and $y = A\cos\omega t$ are solutions of the equation for SHM
5. Show that $v = \pm\varpi\sqrt{A^2 - y^2}$ for the relationship shown above
6. State that the period of a simple pendulum of mass m and length L is given by the expression $T = 2\pi\sqrt{\frac{g}{L}}$
7. Derive the expressions $E_k = \frac{1}{2}m\varpi^2\left(A^2 - y^2\right)$ and $E_p = \frac{1}{2}m\varpi^2 y^2$ for the kinetic and potential energies of a particle executing SHM
8. State that damping on an oscillatory system causes the amplitude of oscillation to decay

Travelling waves

9. State that in wave motion energy is transferred with no net mass transport
10. State that y = *A sin ωt* and *y = A cos ωt* is the simplest mathematical form of a wave
11. Explain that the relationship $y = A \sin 2\pi(ft - \frac{x}{\lambda})$ represents a travelling wave
12. Carry out calculations on travelling waves using the above relationship
13. State that the intensity of a wave is directly proportional to $(\text{amplitude})^2$
14. State that each particle oscillates at right angles to the direction of travel for a transverse wave
15. State that each particle vibrates along the direction of travel for a longitudinal wave
16. State that all waveforms can be described by the superposition of sine or cosine waves
17. Explain the meaning of phase difference
18. State that the phase difference between two points on a wave separated by a distance x is given by:
    $\phi = 2\pi\frac{x}{\lambda}$
19. Explain what is meant by a stationery wave
20. Define the terms 'node' and 'antinode'
21. The distance between successive 'nodes' and 'antinodes' is λ/2
22. State that 'nodes' occur at certain fixed values of x for which $\cos\frac{2\pi x}{\lambda} = 0$
23. State that 'antinodes' occur at certain fixed values of x for which $\cos\frac{2\pi x}{\lambda} = 1$

Interference

24. State in simple terms the condition for two light beams to be coherent
25. State the reasons why the conditions for coherence are usually more difficult to satisfy for light than for sound and microwaves
26. Define the term 'optical path difference' and relate it to phase difference
27. State that the optical path length = refractive index x geometric path lengt
28. State that for constructive interference, the optical path difference = mλ, where m is an integer
29. State that for destructive interference, the optical path difference = (m+1/2)λ, where m is an integer
30. State that the phase difference = $\frac{2\pi}{\lambda}$ x optical path difference
31. State that there is a phase change of λ on reflection at an interface when there is an increase in optical density and that there is no change in phase at an interface when there is a decrease in optical density

Division of amplitude

32. State what is meant by division of amplitude
33. Describe how interference by division of amplitude can be produced by thin films
34. Describe how division of amplitude allows an extended source to be used
35. Derive the expressions for maxima and minima in the fringes formed by reflection and transmission of monochromatic light or microwaves in a ‘thin film’
36. Carry out calculations using the above expressions
37. Derive the expression for the distance between the fringes which are formed by reflection of light at normal incidence from a ‘thin wedge’
38. Carry out calculations using the above expressions
39. Explain how lenses are made non-reflecting for a wavelength of light
40. Derive the expression $d = \frac{\lambda}{4n}$ for the thickness of a non-reflecting coating
41. Carry out calculations using the above expression
42. Explain why coated lenses have a coloured hue when viewed in reflected light
43. Explain the formation of coloured fringes in a thin film illuminated by white light

Division of wavefront

44. State what is meant by the principle of interference by division of wavefront
45. Explain why the principle of division of wavefront requires the use of a ‘point’ or ‘line’ source
46. Derive the expression $\Delta x = \frac{\lambda D}{d}$ for the fringe spacing in the Young’s slit experiment for $x << D$
47. Carry out calculations using the above expression

Polarisation

48. Explain the difference between polarised and unpolarised waves
49. State that only transverse waves can be polarised
50. State that light can be linearly polarised using a Polaroid filter
51. Explain how a combination of a ‘polariser’ and ‘analyser’ can prevent the transmission of light
52. State that light reflected from any electrical insulator may be polarised
53. Explain what is meant by the polarising angle i_p (brewster’s angle)
54. Derive the expression $n = \tan i_p$
55. Carry out calculations using the above expression
56. Explain how Polaroid sunglasses can remove glare