Light and waves

Subtopic 3.1: Wave behaviour of light

This uses the concept of waves developed in the Stage 1, Subtopics 5.1: Wave model and 5.3 Light.

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| Oscillating charges produce electromagnetic waves of the same frequency as the oscillation; electromagnetic waves cause charges to oscillate at the frequency of the wave.   * Use the frequency of oscillation of the electrons in the transmitting and receiving antennae to explain the transmission and reception of electromagnetic signals.   Electromagnetic waves are transverse waves made up of mutually perpendicular, oscillating electric and magnetic fields.   * Relate the orientation of the receiving antenna to the plane of polarisation of electromagnetic waves.   The speed of a wave, its frequency, and its wavelength are related through the formula .   * Solve problems using . |
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| Most light sources emit waves that radiate in all directions away from the source.  Monochromatic light is light composed of a single frequency.  Coherent waves maintain a constant phase relationship with each other.   * Describe what is meant by two wave sources being in phase or out of phase. * Explain why light from an incandescent source is neither coherent nor monochromatic. |
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| When two or more electromagnetic waves overlap, the resultant electric and magnetic fields at a point can be determined using the principle of superposition.  When the waves at a point are in phase, ‘constructive interference’ occurs.  When the waves at a point are out of phase, ‘destructive interference’ occurs.   * Use the principle of superposition to describe and represent constructive and destructive interference. |
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| For two monochromatic sources in phase, the waves at a point some distance away in a vacuum:   * constructively interfere when the path difference from the sources to the point is * destructively interfere when the path difference from the sources to the point is   where m is an integer and  is the wavelength.   * Use the principle of superposition to determine points of maximum or minimum amplitude resulting from the interference of light from two wave sources of the same frequency. * Use constructive and destructive interference to explain the maximum and minimum amplitudes. |
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| Young’s double-slit experiment can be used to demonstrate the wave behaviour of light.  The formulae  and  can be used to analyse the interference pattern, where d is the distance between the slits,  is the angular position of the maximum,  is the distance between adjacent minima or maxima on the screen, and L is the slit-to-screen distance.   * Describe how two-slit interference is produced in the laboratory using a coherent light source or using a single slit between a light source and the double slit. |
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| * Describe how diffraction of the light by the slits in a two-slit interference apparatus allows the light to overlap and hence interfere. * Sketch a graph of the intensity distribution for two-slit interference of monochromatic light. (Consider only cases where the slit separation is much greater than the width of the slits.) * Explain the bright fringes of a two-slit interference pattern using constructive interference, and the dark fringes using destructive interference. * Solve problems involving the use of  and . * Determine the wavelength of monochromatic light from measurements of the two-slit interference pattern. |
| The interference pattern produced by light passing through a transmission diffraction grating demonstrates the wave behaviour of light.  Transmission diffraction gratings can be used to analyse the spectra of various light sources.  The formula  can be used to analyse the interference pattern.   * Describe how diffraction by the very thin slits in a grating allows the light from the slits to overlap and hence interfere to produce significant intensity maxima at large angles. * Derive  for the intensity maxima in the pattern produced by a transmission diffraction grating, where d is the distance between the slits in the grating and is the angular position of the  maximum (m specifies the order of the maximum). * Solve problems involving the use of . * Sketch a graph of the intensity distribution of the maxima produced by a grating, for monochromatic light. |
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| * Determine, from the distance between the slits in the grating, the maximum number of orders possible for a given grating and wavelength. * Describe how a grating can be used to measure the wavelength of light from a monochromatic source. * Describe and explain the white-light pattern produced by a grating. * Identify the properties of a grating that make it useful in spectroscopy. |

Subtopic 3.2: Wave–particle duality (except X-rays)

This uses the concepts of energy developed in Stage 1, Subtopic 4.1: Energy and Stage 2, Subtopic 2.2: Motion of charged particles in electric fields; momentum developed in Stage 1, Subtopic 4.2: Momentum; and waves developed in Stage 1, Subtopics 5.1: Wave model and 5.3: Light.

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| In interacting with matter, light behaves like particles (called ‘photons’), with energy given by  and momentum given by  where h is Planck’s constant, f is the frequency of the light, and  is its wavelength.   * Solve problems using  and |
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| Electrons may be emitted from a metal surface when light of sufficiently high frequency is incident on the metal surface. This process is called the ‘photoelectric effect’.  If monochromatic light is used the intensity of the incident light affects the number, but not the energy, of emitted electrons.  The minimum frequency,  at which electrons are emitted varies with the type of material and is called the ‘threshold frequency’.  The work function, W, of a surface is the minimum energy required to remove an electron from it.  The work function is related to the threshold frequency by   * Describe an experimental method for investigating the relationship between the maximum kinetic energy of the emitted electrons, calculated from the measured stopping voltage using  and the frequency of the light incident on a metal surface. * Describe how Einstein used the concept of photons and the conservation of energy to explain the experimental observations of the photoelectric effect. * Deduce the formula  where  is the maximum kinetic energy of the emitted electrons. * Plot experimental values of maximum kinetic energy vs frequency, and relate the slope and axes intercepts to the formula: * Solve problems that require the use of |
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| Particles exhibit wave behaviour with a wavelength (called the ‘de Broglie wavelength’) that depends on the momentum of the particle. The de Broglie wavelength is given by the formula  where h is Planck’s constant and p is the momentum of the particles.  The wave behaviour of particles can be demonstrated using Young’s double-slit experiment and the Davisson–Germer experiment. |
| * Solve problems involving the use of the formula  for electrons and other particles. * Describe two-slit interference pattern produced by electrons in double-slit experiments. * Describe the Davisson–Germer experiment, in which the diffraction of electrons by the surface layers of a crystal lattice was observed. * Compare the de Broglie wavelength of electrons with the wavelength required to produce the observations of the Davisson–Germer experiment and in two-slit interference experiments. |