A Level Physics Online

# OCR B Physics – H557

## Module 4: Understanding Processes

| You should be able to demonstrate and show your understanding of: | Progress and understanding: | | | |
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| | 1 | 2 | 3 | 4 |
| **4.1 Waves and Quantum Behaviour** | | | | |
| Amplitude: Maximum displacement from the equilibrium position (can be positive or negative) | | | | |
| Wavelength: Distance between any two points on the same part of consecutive wave cycles | | | | |
| Period: Time a point takes to return to the same position in the cycle, moving in the same direction, T=1/f | | | | |
| Phase: Describes the stage in a wave cycle e.g. at the top of a wave | | | | |
| In phase: When two points are at the same stage in a wave cycle | | | | |
| Antiphase: When two waves do exactly opposite things at the same moment | | | | |
| Out of phase: When waves are neither exactly in phase or in antiphase | | | | |
| Phase Difference: In phase there is no phase difference. In antiphase there is a phase difference of π radians | | | | |
| Phasor Arrows: Displacement from equilibrium can be shown by an arrow below or above the equilibrium position. In a time equal to the period of the wave, a phasor rotates 2π radians | | | | |
| Superposition: When two or more waves meet, their displacements add together at every point (resultant displacement = sum of individual displacements) | | | | |
| Graphs of Waves:<br><br>Displacement-displacement graph: Shows a snapshot of a wave at a certain time<br>Displacement-time graph: Shows how the displacement of a point along a wave changes over time | | | | |

<table>
<tr><th rowspan="2">You should be able to demonstrate and show your understanding of:</th><th colspan="4">Progress and understanding:</th></tr>
<tr><th>1</th><th>2</th><th>3</th><th>4</th></tr>
<tr><td><u>Oscilloscopes:</u> Show how the p.d. across a component or supply varies with time.<br><u>Time Base –</u> The horizontal value. Each square on the oscilloscope is 1cm wide. Time base sets the time value for each 1cm division. Sometimes labelled as time/div. Units are seconds per centimetre<br><u>Y-sensitivity -</u> The value of voltage that is assigned to each vertical division. Units are volts per centimetre<br>-To find the period, find the time base, then measure the distance in cm between two successive peaks or troughs. Then multiply the time base by the distance in cm.<br>-A wave with a period in ns on an oscilloscope with time base in seconds won't be detected as the wave is moving too fast</td><td></td><td></td><td></td><td></td></tr>
<tr><td>An interference pattern is produced when waves superpose. Constructive superposition occurs when waves meet in phase. Destructive occurs when waves meet in antiphase</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Path difference: When waves travel from one point to another by two or more routes, the difference in distance is the path difference. This introduces a time delay, which is the difference in time for the waves to arrive at the destination. This in turn causes the phase of the waves to differ when the waves meet (causing interference effects).<br><br>In phase – Path difference is nλ (constructive interference, superposition maximum)<br>Antiphase – Path difference is 1.5nλ (destructive interference, superposition minimum)</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Fundamentals and Harmonics:<br><br>-The first harmonic is the fundamental, it gives the pitch of a wave. If two waves have the same fundamental, they have the same pitch. If there is a difference in the sound, this is due to other frequencies/harmonics present.
<table>
<tr><td>Harmonic:</td><td>String/Two Open Ends:</td><td>1 Open, 1 Closed End:</td></tr>
<tr><td>First</td><td>0.5λ</td><td>0.25λ</td></tr>
<tr><td>Second</td><td>λ</td><td>0.75λ</td></tr>
<tr><td>Third</td><td>1.5λ</td><td>1.25λ</td></tr>
</table></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Standing Waves: Formed when two progressive waves of the same frequency are travelling in opposite directions (e.g. on a string). When a string is plucked;<br><br>1) Waves move along the string in opposite directions<br>2) Waves reflect at the ends of the string<br>3) They superpose as they pass each other</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Nodes are positions on a standing wave of zero amplitude, the waves meet in antiphase. Adjacent nodes are 0.5λ apart</td><td></td><td></td><td></td><td></td></tr>
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| Antinodes are positions on a standing wave of maximum amplitude, the waves meet in phase | | | | |
| In an air column with two open ends, there is an antinode at each end. In an air column with one open, one closed end, there is a node at the closed end and an antinode at the open end. (see table above) | | | | |
| Finding the Speed of Sound in Air:<br><br>1) Use a resonance tube, a hollow tube with one end immersed in water<br>2) A tuning fork of known frequency is held over the top of the tube<br>3) $l_1$ is found, the shortest length of the tube that increases the amplitude of the sound (the fundamental)<br>4) $l_1 = \frac{\lambda}{4} - k$ (k is the end correction, see below) because $\frac{\lambda}{4}$ is the length of the fundamental (in the table above)<br>5) $l_2$ is roughly equal to $3l_1$ as it is the second harmonic<br>6) $l_2 = \frac{3\lambda}{4} - k \approx 3l_1$ (this is a reasonable approximation as k is small)<br>7) Find λ by solving these two equations simultaneously (note: k cancels)<br>8) Using v = fλ, find v, the speed of sound in air, where f is the frequency of the tuning fork<br>-The end correction, k, is needed as the antinode at the opening is formed a little over the top of the pipe/tube | | | | |
| Stable superposition patterns occur when the position of maxima and minima don't change over time, <u>when phase difference is constant.</u> | | | | |
| Coherence: When two waves have constant phase difference and the same frequency. (Two waves can either be in phase of out of phase, as long as they stay that way) | | | | |
| Refraction: Waves change speed when they move from one medium to another. They also change direction. Light interacts with electrons in a medium. This causes the speed of light in air to be lower than in a vacuum. More interactions with electrons results in a slower speed of light through that medium. | | | | |
| Refractive Index, n: Ratio of speed of light in a medium to the speed of light in another $n = \frac{c_{first\ medium}}{c_{second\ medium}} = \frac{\sin(i)}{\sin(r)}$ (Snell's Law)<br><br>-Angle between light ray entering and the normal to the boundary is the angle of incidence, i<br>-Angle between light ray exiting and the normal to the boundary is the angle of refraction, r<br>-The absolute refractive index is when the first medium is a vacuum (this is the refractive index given in questions) | | | | |
| -Refractive index varies with wavelength, it causes dispersion (into the spectrum). If waves enter a material with a lower refractive index, sin(i) < sin(r). | | | | |

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| -Dispersion shows different wavelengths travel at different speeds as each wavelength is deviated by a different amount in the spectrum.<br>-Pyrex and glycerol have the same refractive index, one is immersed in the other. Pyrex appears invisible as light will not change direction when entering and leaving | | | | |
| Huygens' Wavelet Model: Every point on a wave front is a source of circular wavelets. Where wavelets meet in phase, a new wave front is formed (superposition). Where wavelets meet in antiphase, they cancel. This model can be used to explain refraction;<br><br>1) Huygens said waves slow down in glass to allow the waves behind to catch up<br>2) Wavelength is shorter in glass, and if the wave enters parallel to the normal, there is no change in direction<br>3) If a wave enters glass at an angle, wave fronts become kinked at the boundary due to the section in air travelling faster than in glass | | | | |
| Diffraction: When waves pass through a small gap or past the edge of an object they spread out. Diffraction occurs when the width of the gap is roughly equal to the wavelength of the passing waves. Diffraction does not alter wavelength, speed or frequency of the wave. Greater diffraction effects occur when wavelength is increased and gap width decreases | | | | |
| Young's Double Slit Experiment:<br><br>Path difference of light from the two slits is 1λ. The screen must be far away from the slits as the angles between fringes are very small, it allows light and dark fringes to be observed easier.<br>$sin\theta = \frac{\lambda}{d} \quad tan\theta = \frac{x}{L}$ $so\ for\ small\ \theta, sin\theta \approx tan\theta \ \therefore\ \lambda = \frac{xd}{L}$<br>Where d is the distance between the slits, x is the distance between central and $n^{th}$ fringe and L is the distance from the slits to the screen where the fringes form | | | | |
| Bright fringes occur when waves meet in phase, constructive superposition so 1λ path difference $n\lambda = d\sin(\theta_n)$<br><br>Dark fringes occur when waves meet in antiphase, destructive superposition so 1.5λ path difference $(1.5\lambda)n = d\sin(\theta_n)$ | | | | |

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| Maxima and Minima: The order of maxima shows the number of wavelengths path difference between the light from each slit and the screen.<br><br>Zeroth order has a maximum when path difference is 0<br>First order has a maximum when path difference is 1λ<br>Second order has a maximum when path difference is 2λ<br>If the path difference for the first fringe is 0.5λ, second fringe is 1.5λ etc, then the fringe at that point is a dark fringe (a minimum)<br>$Maximum\ number\ of\ orders\ of\ maxima = \frac{d}{\lambda}$ | | | | |
| Diffraction Gratings:<br><br>Differences from Two Slits:<br>-Brightness of image on screen increases as more light gets through.<br>-Sharper fringe pattern produced<br>-Spreads white light into its component colours, spectra, as each wavelength will produce a maximum at a different angle<br>Increasing the Number of Slits:<br>-Larger path difference (bigger separation of maxima and minima)<br>-Increases brightness of constructive regions (bright fringes)<br>-Decreases brightness of destructive regions (dark fringes)<br><br>-Putting slits closer together gives a larger separation of maxima and minima<br>$line\ separation = \frac{1}{number\ of\ lines\ per\ metre}$ | | | | |
| Single Slit Diffraction: At an angle θ, the phase difference across the whole slit is λ. This means all phasors are slightly out of phase, producing a zero resultant. Each end of the slit acts as an independent source of light, travelling to the same spot on the screen. For a single slit, the central maximum is larger and other maxima are much smaller.<br><br>Phasors-<br>1) Wave passes through slit, modelled as rotating phasor arrows<br>2) When the phasors are all in the same direction, a maximum is produced<br>3) When in antiphase, a minimum is produced | | | | |
| Diffraction of White vs Monochromatic Light: White has different wavelengths so bright fringes appear at different points. Monochromatic has one wavelength, the same pattern is produced but bright fringes occur at particular points (one per order, as opposed to multiple per order for white light) | | | | |
| The value of $\sin\theta_n$:<br><br>-Red light has a larger value of sinθ as it has a larger wavelength<br>-Blue light has a smaller value of sinθ as it has a smaller wavelength<br>-$\sin\theta \leq 1$<br>-The greatest order maxima occurs when $\sin\theta = 1$ | | | | |

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| Photon: A quanta of light<br><br>-Bright Fringe: High probability of a photon arriving there<br>-Dark Fringe: Low probability of a photon arriving there | | | | |
| E=hv | | | | |
| Electronvolt: Energy transferred when one electron moves through a potential difference of one volt. They are used when joules are too big. $1eV=1.6x10^{-19}J$ | | | | |
| E=VQ=hc/λ | | | | |
| Frequency and Intensity:<br><br>-The energy of photons is related to frequency<br>-The number of photons is related to intensity<br>-Higher intensity means more photoelectrons are liberated (see below)<br>-Intensity: The amount of energy transferred per metre squared per second | | | | |
| Photoelectric Effect and Photoelectrons: The set up is two zinc plates set parallel in a vacuum chamber connected to a cell. A photon source is directed at one of the zinc plates. As the intensity of the source increases, more photoelectrons drift from the negative to the positive plate. As the intensity increases, the kinetic energy is not changed but more photoelectrons are liberated. For both low and high intensity, the time of emission is the same. If the frequency of the photon source is increased, the kinetic energy of the photoelectrons increases but the number released stays the same | | | | |
| Threshold Frequency, $f_o$: The minimum frequency needed to eject photoelectrons from a given surface. It varies with different materials. If the frequency of light incident on the surface is below the threshold frequency, no photoelectrons are emitted. Above the threshold frequency, increasing the frequency increases the maximum kinetic energy of the photoelectrons emitted | | | | |
| Work Function, ϕ: The minimum energy required to eject photoelectrons from a given SURFACE. The kinetic energy of the photoelectrons must be described as a maximum kinetic energy, not exact, as we cannot be sure whether the emitted photoelectrons came from the surface or below it<br><br>$E_k = E_{photon} - \phi \text{ and so } E_k = hf - hf_o$<br>-The work function is the energy that goes into releasing the photoelectron from the surface | | | | |
| Electrons and Spectra:<br><br>Electrons gain or lose energy by changing energy levels. A photon is released when an electron falls from a higher E level to a lower one. The difference in the energy levels is the energy of the photon released. Recall E=hf and c=λv so these can be combined to get E=hc/λ for the energy of a photon | | | | |

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| LEDs: Constructed from a semiconductor, it is a type of diode. It only allows current to flow in one direction. A photon is emitted when an electron crosses from one side of the diode to the other as it falls to a lower energy level. The striking potential is the p.d. across the LED when it just begins to glow. The energy change between levels at this point is given by the striking potential multiplied by the charge on an electron (E=qV). | | | | |
| Wave – Particle Duality: Quantum objects (e.g. photons) explore all possible paths. An example of a wave-like effect is interference. An example of a particle-like effect is how images build up point by point | | | | |
| Young's Double Slit Experiment in terms of Photons: Photons are emitted from the source. They take every possible path simultaneously. They arrive at the detector at a certain time | | | | |
| Electron Interference: A thin layer of atoms acts as a diffraction grating. The interference pattern of electrons passing through is a series of concentric circles (wave-like behaviour). If they exhibited particle-like behaviour, a central bright region with no concentric circles would be observed. These effects are only seen with layers of atoms as an electron has a much smaller wavelength than a photon of equivalent energy. So for diffraction effects to be seen, the gap they need to pass through must be much smaller | | | | |
| deBroglie Wavelength: Wavelength of an electron $$\lambda = \frac{h}{p} = \frac{h}{mv}$$ | | | | |