Exam Papers Practice

# 9.2 Single-Slit Diffraction

## Mark Schemes

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| Course | DP IB Physics |
| Section | 9. Wave Phenomena (HL only) |
| Topic | 9.2 Single-Slit Diffraction |
| Difficulty | Medium |

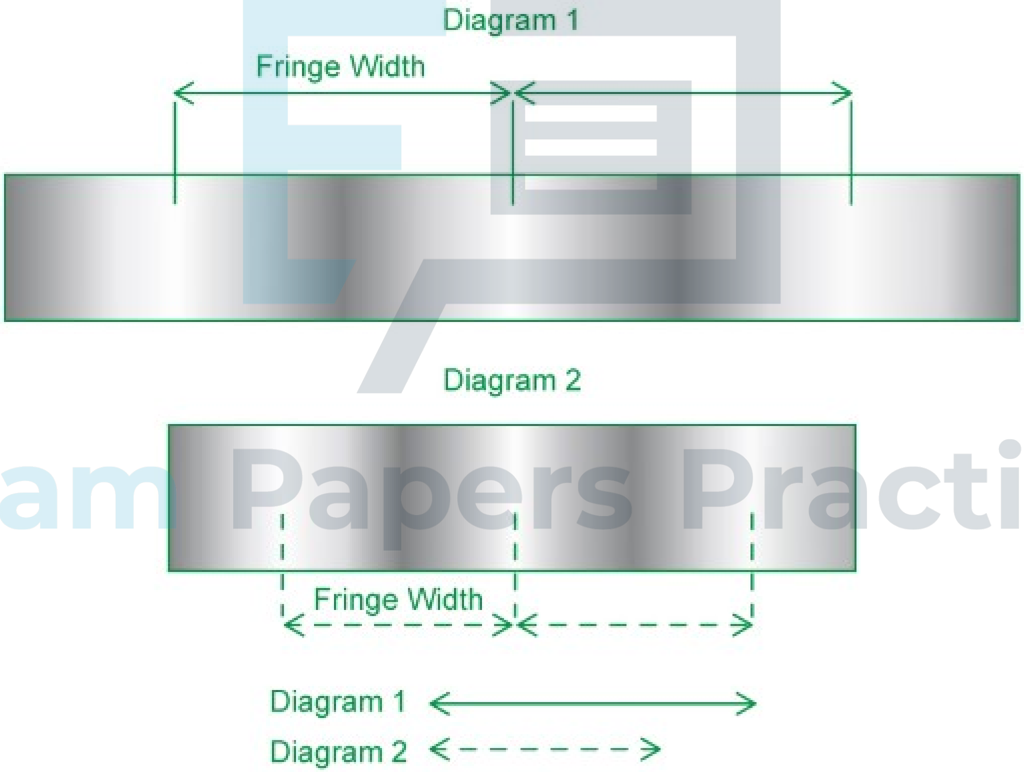


To be used by all students preparing for DP IB Physics HL
Students of other boards may also find this useful

1

The correct answer is **C** because:

- The interference pattern is affected by both the slit width $b$ and the wavelength of light $\lambda$
- Diagram 1 has a larger fringe spacing:
  - In other words, the distance between the centre of the bright fringes is larger than in diagram 2
  - The larger fringe spacing means that the angle of diffraction $\theta$ of light is also larger




- So, since $\theta = \frac{\lambda}{b}$, then:
  - For $\theta_1$ to be larger than $\theta_2$, $\frac{\lambda_1}{b_1}$ must be larger than $\frac{\lambda_2}{b_2}$
  - So, the correct answer is C: $\frac{\lambda_1}{b_1} > \frac{\lambda_2}{b_2}$

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| **A** and **B** are incorrect as | both wavelength and slit width need to be considered in the expression |
| **D** is incorrect as | $\frac{\lambda_1}{b_1} > \frac{\lambda_2}{b_2}$ and not $\frac{\lambda_1}{b_1} < \frac{\lambda_2}{b_2}$ because<br>• $\lambda_1$ will be longer than $\lambda_2$<br>• $b_1$ will be narrower than $b_2$ |

Remember that when dividing fractions, if the denominator is bigger then the fraction itself will be smaller.

2

The correct answer is **C** because:

- Consider the equation for the angle of diffraction of the first minimum, $\theta = \frac{\lambda}{b}$
  - Where $\lambda$ is the wavelength of the light and $b$ is the width of the single slit
- The wavelength of blue light is shorter than the wavelength of red light
  - In the equation, when $\lambda$ is smaller and $b$ is constant then $\theta$ is also smaller
  - So statement I is false
- The smaller the slit width $b$ then the bigger the diffraction angle $\theta$ when $\lambda$ is constant
  - So statement II is true
- So, the correct answer is **C**

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| **A**, **B** and **D** are incorrect as | only II. is correct. Red light creates a diffraction pattern with a bigger angle of diffraction, $\theta$ than blue light. |

It is important to memorise how the diffraction pattern changes with changes in wavelength, slit width and distance from slit to screen.

3

The correct answer is **B** because:

- A 10-slit diffraction grating is the grating with the most slits, so it will have the most number of subsidiary maxima between the highest intensity maxima, /in the interference pattern
    - There are 8 equally spaced subsidiary maxima between the highest intensity maxima
    - The subsidiary maxima decrease in intensity from the highest intensity maxima to halfway along to the next highest intensity maxima
    - The intensity of the first subsidiary maxima are 1/15 th of the intensity of the highest intensity maxima and 1/3 rd of the width
- Single slit interference has:
    - A central maximum with the highest intensity, /
    - Equally spaced subsidiary maxima, successively smaller in intensity and half the width of the central maximum
- Double slit interference has:
    - Equally spaced maxima
    - All maxima are of equal intensity, /
- Five-slit interference has:
    - The highest intensity maxima, all have the same intensity, /
    - There are three equally spaced subsidiary maxima between the highest intensity maxima
    - The central subsidiary maxima has a slightly smaller intensity than the subsidiary maxima on either side
    - The intensity of the first subsidiary maxima are 1/10th of the highest intensity maxima and 2/3 rd of the width

It is important to remember the features of the intensity pattern of light when diffracted through a single slit, different sized diffraction gratings, and a double slit. Being able to describe the intensity patterns in terms of maxima and subsidiary maxima can help with structured questions too.

4

The correct answer is **C** because:

- When the slit width is increased:
  - The central peak intensity is increased, so there is a higher central peak on the graph
  - Fringe spacing between subsequent maxima is reduced
- So, the correct answer is **C**

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| **A** is incorrect as | the fringe spacing has been increased and not reduced |
| **B** is incorrect as | • The central peak intensity is not increased, the new pattern is not drawn higher than the original pattern<br>• The new spacing between subsequent maxima has been increased and not reduced |
| **D** is incorrect as | the central peak intensity is not increased, the new pattern is not drawn higher than the original pattern |

Remember that slit width affects the **maximum intensity** of the central fringe on an intensity pattern. If the slit width increases, the maximum intensity **increases**, because more light is incident through the slit. You should also remember, if the slit width increases, the fringe spacing decreases, such that each bright fringe is closer together. This makes sense: if the slit width increases to infinity (i.e., there is no more slit!) then diffraction reduces to zero: the intensity observed will simply be a central area of brightness which fades away on both sides of the maximum.



5

The correct answer is **C** because:

- For the first minima, the angle of diffraction, $\theta = \frac{wavelength\ of\ light}{slit\ width} = \frac{\lambda}{b}$
- Use the graph to find the diffraction angle from the central maximum to the first minima = $1 \times 10^{-2}$ rad
- Convert the slit width from mm to m: $2 \times 10^{-3}$ m

- Rearrange the equation for the angle of diffraction to find the wavelength, $\lambda = \theta \times b$
  - $\lambda = (1 \times 10^{-2}) \times (2 \times 10^{-3}) = 2 \times 10^{-5}$ m $= 20 \times 10^{-6}$ m $= 20$ μm
- So, the correct answer is **C**

6

The correct answer is **C** because:

- The maximum amount of constructive interference occurs at the central maxima
  - So the central maxima is all white
- When white light diffracts through a single slit:
  - longer wavelengths (red light) have a larger angle of diffraction
  - shorter wavelengths (violet light) have a smaller angle of diffraction
- So violet light appears closer to the central maximum and red light further away
- This gives option **C**

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| **A** is incorrect as | the central maximum is white and not coloured |
| **B** is incorrect as | this shows the positions of violet and red light the wrong way around. Red light should be diffracted the most and violet light the least |
| **D** is incorrect as | the central maximum is white and the outer fringes coloured, this is the opposite to what is shown in this diagram |

This question is not tricky but requires you to look carefully at each diagram to identify the correct interference pattern.

7

The correct answer is **A** because:

- Decreasing the wavelength of the light will decrease the width of the central maximum peak

- According to the equation for the angle of diffraction of the first minima, $\theta = \frac{\lambda}{b}$ for wavelength $\lambda$ and slit width $b$
  - When $\lambda$ is smaller for constant $b$ then $\theta$ will also be smaller
  - $\theta$ is proportional to $\lambda$
- Red light has a longer wavelength than blue light, so changing the colour will decrease the wavelength of the light

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| **B** is incorrect as | increasing the wavelength of the light will increase the width of the central maximum and not decrease it |
| **C** is incorrect as | making the slit width narrower will<br>• decrease the intensity of the central maximum<br>• increase the fringe spacing |
| **D** is incorrect as | moving the screen further away will increase and not decrease the width of the central maximum |

You should memorise the properties that affect the width of the central maxima.

8



The correct answer is **D** because:

- Let the width of the central maxima be given by $w$
  - So half the central maximum width = $\frac{1}{2}w$
- Using trigonometry:
  - $\tan\theta = \frac{opposite}{adjacent}$
- Using the small-angle approximation for the angle of diffraction, $\tan\theta \approx \theta$ for very small $\theta$
  - Therefore, $\tan\theta \approx \theta = \frac{opposite}{adjacent} = \frac{\frac{1}{2}w}{D}$
  - Rearranging this gives: $\theta D = \frac{1}{2}w$

- Therefore, the width of the central maximum $w = 2\theta D$
- The angle of diffraction for the first minimum, $\theta = \frac{\lambda}{b}$
- Substituting $\theta$ into the expression for the central maximum gives:
  - $2\theta D = w$
  - $2 \times \frac{\lambda}{b} \times D = w$
  - So, the width of the central maximum $w = \frac{2\lambda D}{b}$

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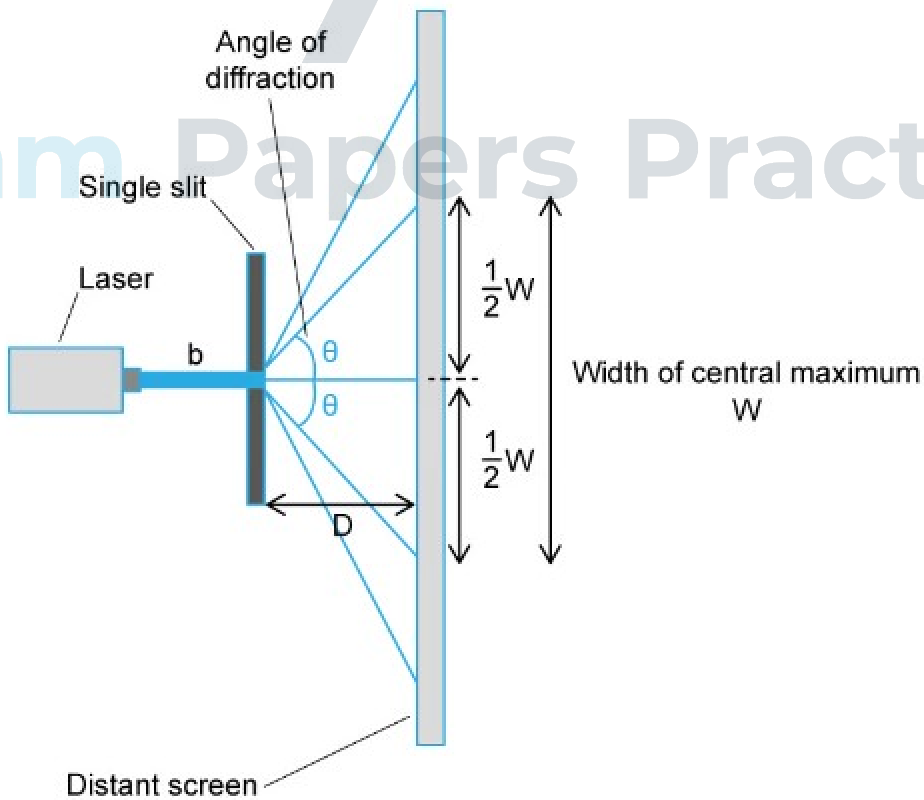
| **A**, **B** and **D** are incorrect as | they are the incorrect rearrangement and substitution of the angle of diffraction of the first minima and the trigonometry of this angle of diffraction |

This question requires very careful consideration of the geometry and equations involved in single slit diffraction and what this means for the width of the central maximum., Make sure you write down all the equations you know and draw a diagram to make it easier to understand what is happening.



9

The correct answer is **B** because:

- Reducing the single slit width will reduce the intensity, $I$ of the central maximum
- The angle of diffraction, $\theta$ to the first minima will increase, so the fringe spacing will be wider
  - This can be shown using the equation for the angle of diffraction for the first minima $\theta = \frac{\lambda}{b}$
  - $b$ is the slit width and $\lambda$ the wavelength, which remains the same
  - when $b$ is made smaller then $\theta$ is made bigger

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| **A**, **B** and **C** are incorrect as | the intensity, $I$ will decrease and the angle of diffraction, $\theta$ increase, and not any other combination of these options. |

You should confidently know how changing the slit width affects the angle of diffraction and the intensity of the central maxima on the screen.



10

The correct answer is **C** because:

- Using the equation for wave speed, frequency, and wavelength: $c = f\lambda$
  - So, $f = \frac{c}{\lambda}$
- When the frequency is doubled this means the wavelength is halved (as $c$ is the speed of light and is the same for any frequency of light)
  - So, $2f = \frac{c}{\frac{1}{2}\lambda}$

- Using the equation for the angle of diffraction to the first minima: $\theta = \frac{\lambda}{b}$
  - So the angle of diffraction, $Y = \frac{\lambda}{b}$
- When the slit width is halved, $b \rightarrow \frac{1}{2}b$
- Combining the change in slit width and wavelength $Y = \frac{\frac{1}{2}\lambda}{\frac{1}{2}b} = \frac{\lambda}{b}$
  - So, the new angle of diffraction of the first minimum = $Y$

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| **A** is incorrect as | $4Y$ is the value of the new angle of diffraction if the wavelength was double and not halved and the slit width was still halved |
| **B** is incorrect as | $\frac{1}{2}Y$ is the value of the new angle of diffraction if the frequency was doubled, so the wavelength was halved and the slit width remained the same |
| **D** is incorrect as | $\frac{1}{4}Y$ is the value of the new angle of diffraction if the frequency was quadrupled, so the wavelength was now $\frac{1}{4}\lambda$ |

Use what you know to carefully substitute the correct values into the equation for angular diffraction of the first minimum and obtain the correct new angle $Y$.