Exam Papers Practice

9.3 Interference

Mark Schemes

Course	DP IB Physics
Section	9. Wave Phenomena (HL only)
Topic	9.3 Interference
Difficulty	Medium

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

1

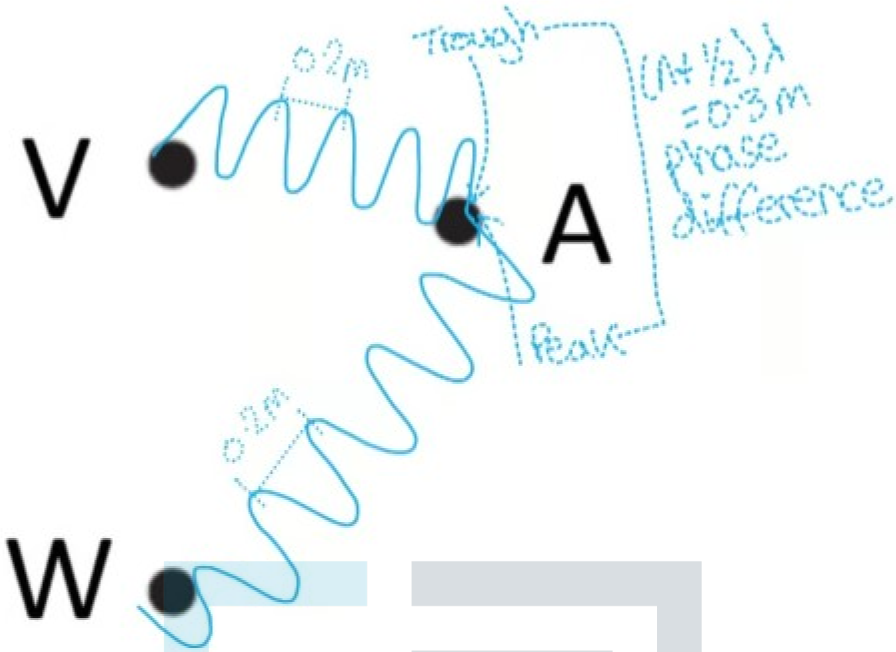
The correct answer is **C** because:

- For destructive interference path difference = $(n + \frac{1}{2})\lambda$ = 0.3 m
  - Where *n* is the number of the maxima away from the central order of *n* = 0
  - This means the path difference has to be a multiple of half wavelengths
- Now consider the wavelength at different values of *n*
  - A is not equidistant between V and W, so it is not the central maxima of the interference pattern, so we know $n \neq 0$
- For the first order maxima at *n* = 1
  - $(1 + \frac{1}{2})\lambda = 0.3$
  - $\frac{3}{2}\lambda = 0.3$
  - $3\lambda = 0.6$
  - λ = 0.2 m
- Hence, the answer is **C**: λ = 0.20 m

A is incorrect as	this is when *n* = 0, but A is not near the central maximum
B is incorrect as	this is the path difference given in the question and not the wavelength of the wave. It would also be λ for *n* = 1 if constructive interference ($n\lambda$ = path difference) took place, not destructive
D is incorrect as	this would be λ for *n* = 2, but the question asks for the maximum possible wavelength i.e. the smallest value of *n* that gives one of the possible values

It is important you remember the path difference equations for both constructive and destructive interference and can spot when you need to use them.

The diagram below shows a possible destructive interference pattern of waves coming from V and W.

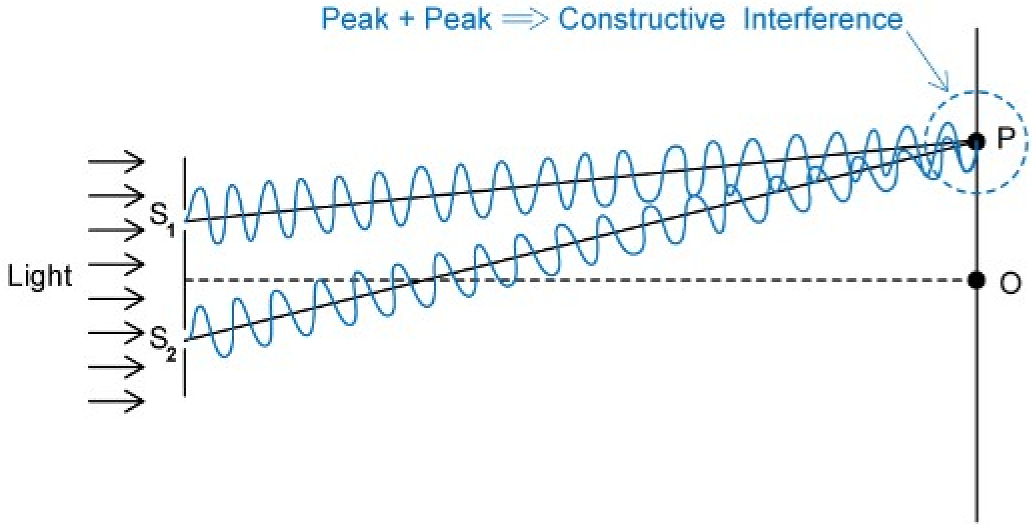


2

The correct answer is **C** because:

- P is the next bright fringe, so it is the next point of constructive interference on the screen from O
- Constructive interference at P means that $S_2P - S_1P = n\lambda$
- As P is the next point of constructive interference then P is the first order maximum, so $n = 1$
  - Therefore, $S_2P - S_1P = \lambda$
- Recall the wave equation:
  - $c = f\lambda$
- Rearrange for λ gives:
  - $\lambda = \dfrac{c}{f}$
- Therefore:
  - $S_2P - S_1P = \dfrac{c}{f}$

This question requires you to remember the conditions for constructive interference. This is when two **crests** or two **troughs** that meet at the same point and their amplitudes add accordingly.



3

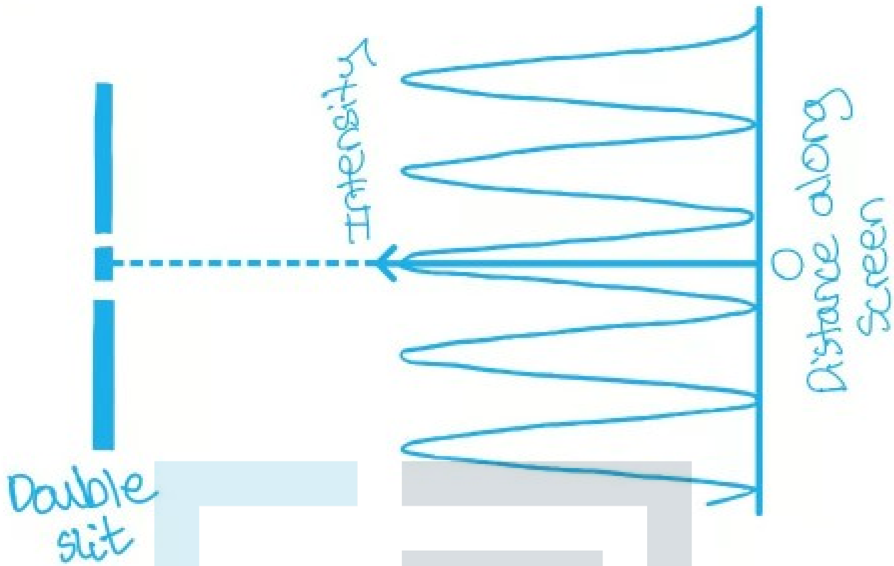
The correct answer is **A** because:

- The maximum intensity of the light will be present at the central maxima O
- The intensity of the light on the screen will oscillate from zero intensity where there are dark fringes, to high intensity where there are bright fringes
- All the fringes will have an **equal** intensity in a double slit interference pattern

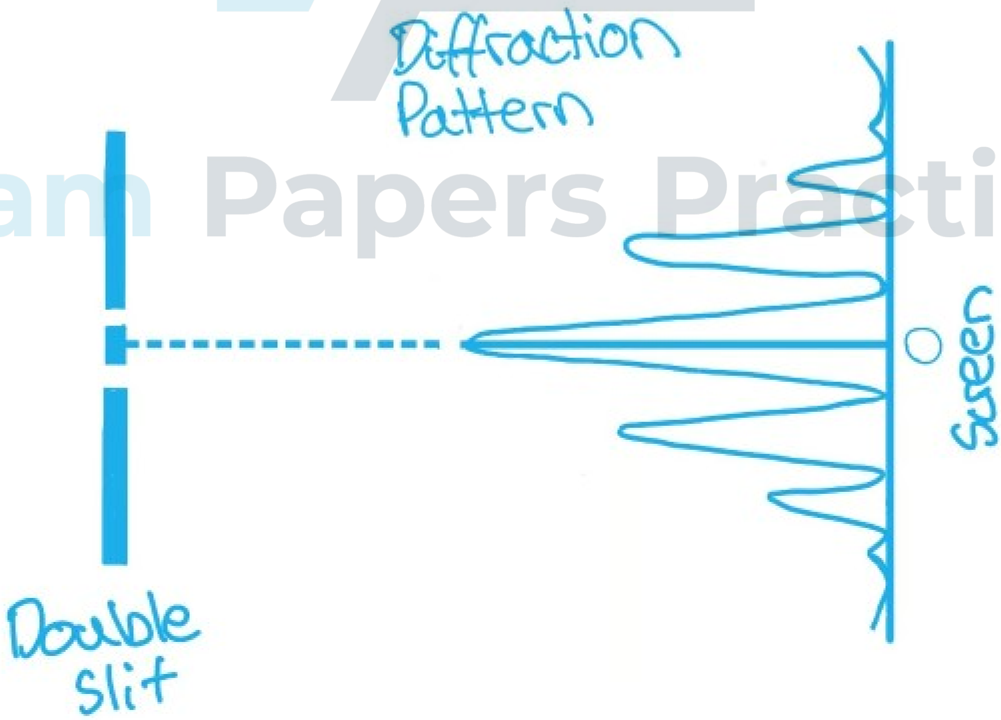
B is incorrect as	this is the intensity, distance graph for a single slit interference pattern
C is incorrect as	O is the central maximum so should have the maximum intensity and not an intensity of zero
D is incorrect as	the intensity pattern should have a sinusoidal shape and not wide fringes of zero intensity

It is important to know and recognise the difference between the intensity, distance graph of a double slit diffraction pattern and the diffraction pattern that will be observed on the screen.

The graph of intensity is shown here:



The image of the diffraction pattern on the screen is shown here:



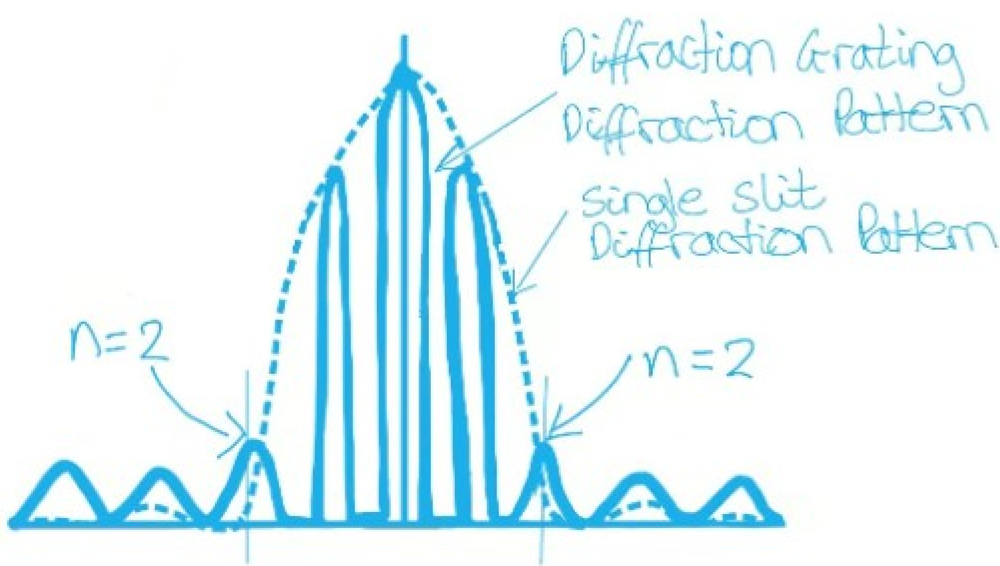
This is why the answer is graph **A** and **not** graph **D**.

4

The correct answer is **A** because:

- For the diffraction pattern
  - n = 2
  - for $n\lambda = d\sin\theta$
- For the single slit
  - The diffraction angle of the first minimum, $\theta = \frac{\lambda}{b}$
- For the angle of the first minimum of the single slit $\sin\theta \cong \theta$ due to small angle approximation
- Substitute θ into the diffraction grating equation for $\sin\theta$:
  - $n\lambda = d\frac{\lambda}{b}$
  - $\frac{n\lambda}{\lambda} = \frac{d}{b}$
- So, $nb = d$
  - When $n = 2$, $d = 2b$
- So the correct answer is **A**

Sketching an image, like the one below, of the two diffraction patterns in the correct places will help understand what this question is asking.

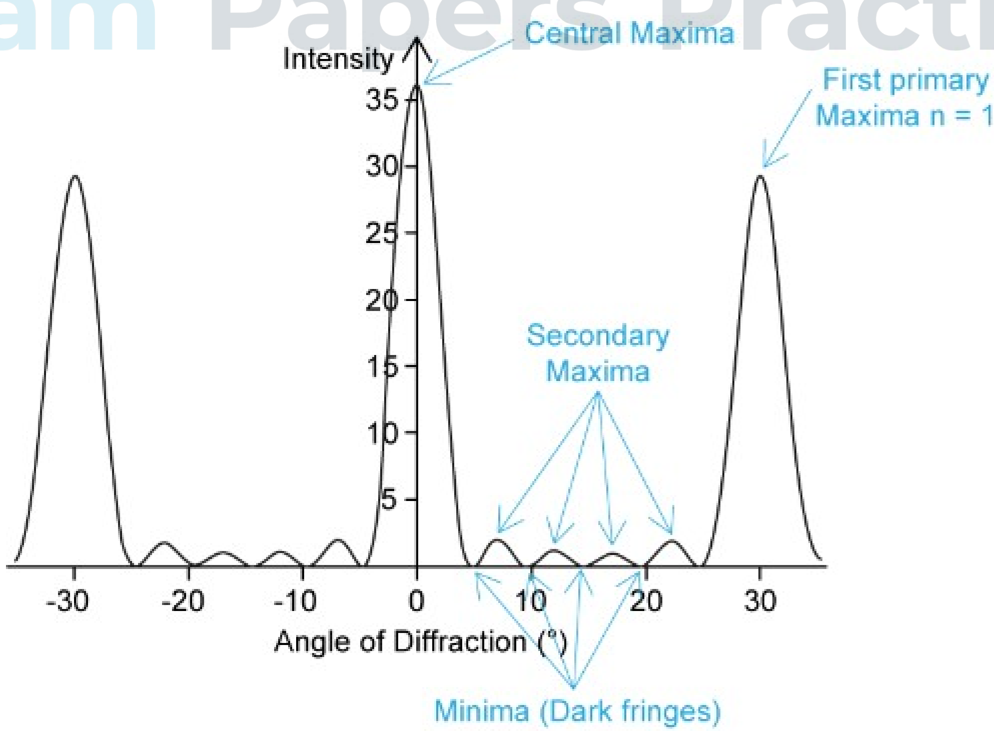


5

The correct answer is **B** because:

- The number of slits N is related to the number of secondary maxima between the primary maxima
  - Number of secondary maxima = $N - 2$
- There are 4 secondary maxima, so there must be 6 slits in the diffraction grating
  - This eliminates options **C** and **D**
- The relationship between slit separation, d and wavelength λ is given by the diffraction grating equation:
  - $n\lambda = d\sin\theta$
- The angle of the first maxima $n = 1$ is 30°
- So, the diffraction grating equation becomes:
  - $1 \times \lambda = d\sin(30)$
  - $\lambda = d\frac{1}{2}$
  - So, $d = 2\lambda$
- Therefore, option **B** is correct

Understanding and using the correct terminology for primary and secondary maxima and minima is key to understanding the graph for this question. Check your knowledge against the diagram below.



There are some key trigonometric values for you to remember in this topic:

- Sin(30) = $\frac{1}{2}$
- Sin(90) = 1

6

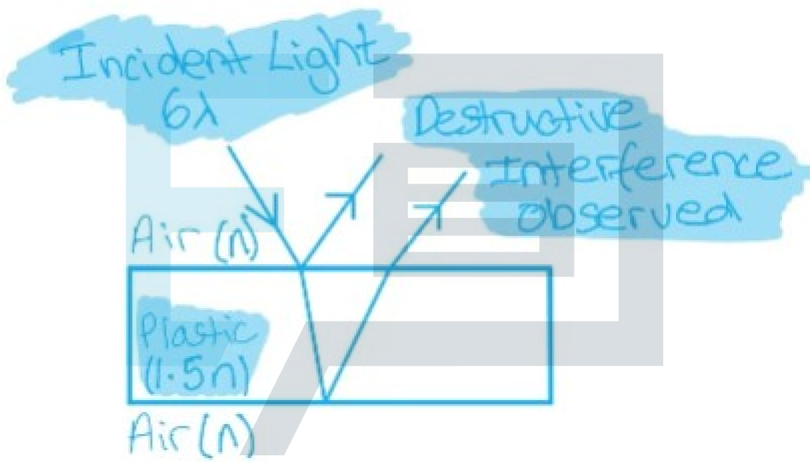
The correct answer is **D** because:

- The intensity is a minimum, so **destructive** interference is observed
- The equation for destructive interference in the thin film is: $2dn = m\lambda$
  - Where d is the thickness of the film, n is the refractive index of the film, m is an integer related to the number of wavelengths inside the film and λ is the wavelength of the light
- Substitute in the correct values for n and λ
  - $2d \times (1.5n) = m \times (6\lambda)$
  - $3dn = 6m\lambda$
- Rearrange to obtain an equation in terms of the thickness of the transparent plastic
  - $d = \frac{2m\lambda}{n}$
- Try different values of m until an answer option is obtained
  - When $m = 1$
    - $d = \frac{2 \times 1 \times \lambda}{n} = \frac{2\lambda}{n}$
  - When $m = 2$
    - $d = \frac{4\lambda}{n}$
  - When $m = 3$
    - $d = \frac{6\lambda}{n}$
- So the correct answer is **D**, when $m = 6$, as none of the other answer options are multiples of $\frac{2m\lambda}{n}$

There are two important aspects to consider when answering this question correctly.

- The first is that the intensity is a minimum so this must mean that there is destructive interference in the light coming from the two surfaces of the transparent plastic.
- The second is that it does not say that the thickness of the film is a minimum, so *m* does not have to equal one. The question asks for a possible thickness, so *m* could be any integer.

The diagram below shows the setup. It can be helpful to make a sketch like this for this question so you are clear with what is happening and how to formulate an answer best.

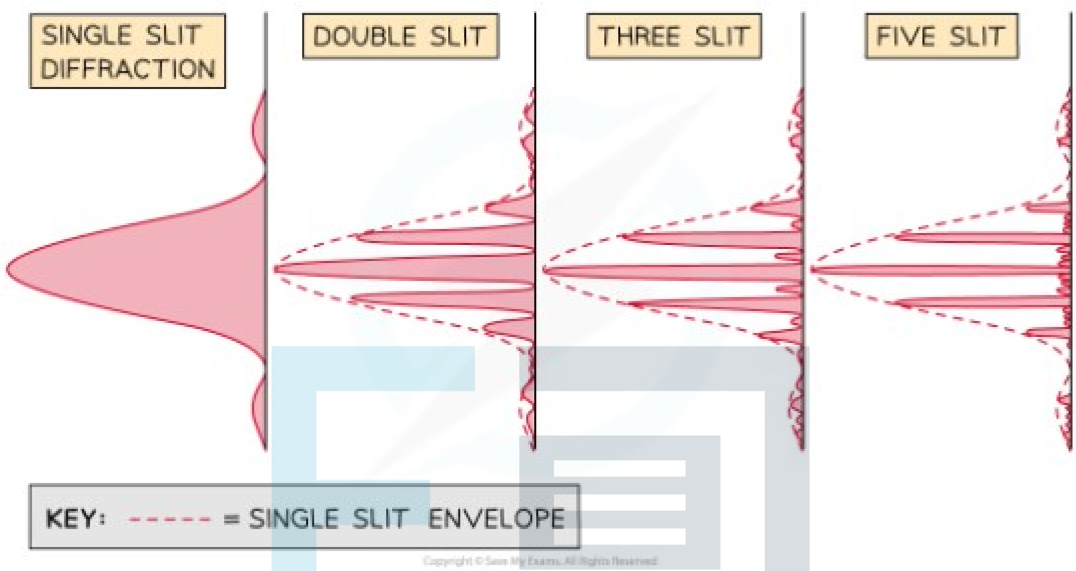


7

The correct answer is **B** because:

- p shows a pattern that is e**qually spaced** maxima of similar relative intensity and brightness
  - This is characteristic of a double slit diffraction pattern
- q shows a pattern that has one central maximum with the highest intensity. This fringe is much wider than the secondary maxima
  - This is characteristic of a single slit diffraction pattern
- r shows a pattern that consists of many equally spaced very thin maxima of equal intensity
  - This is characteristic of a diffraction grating
- Therefore, row **B** is correct

It is important to remember how a diffraction pattern changes depending on the number of slits. You can see clearly in the diagram below that as the number of slits increases, the width of the slit decreases and so does the width of the maxima fringes.



8

The correct answer is **C** because:

- When there is a phase change at a boundary between a **less** dense and a **more** dense material, the reflected wave undergoes a **phase** change
    - Part of the wave is also transmitted into the denser material of the thin film
- This is outlined in statement II so **C** is correct

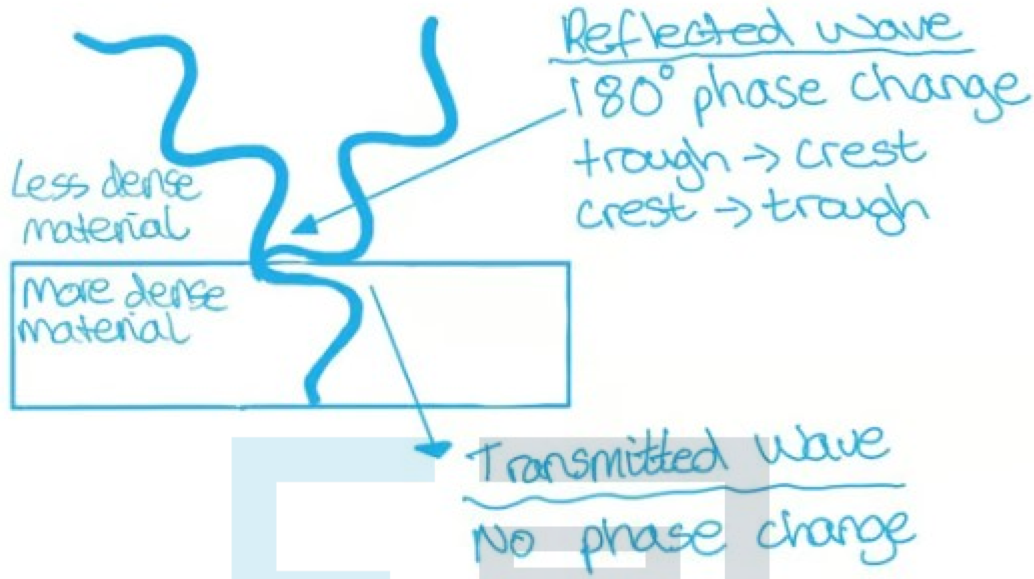
It is important to fully understand why the other statements are incorrect.

Statement I:

Statement I is incorrect because:

- A phase change occurs between a boundary when a light ray passes from a less dense material into a more dense material and not the other way around

You can see the phase change below at the boundary between the less dense and more dense material

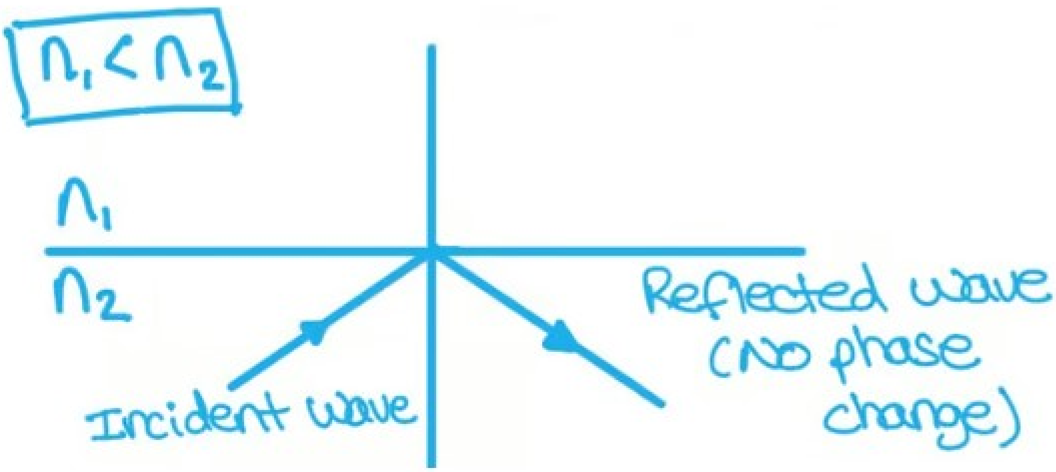


Statement II:

Statement II is incorrect because:

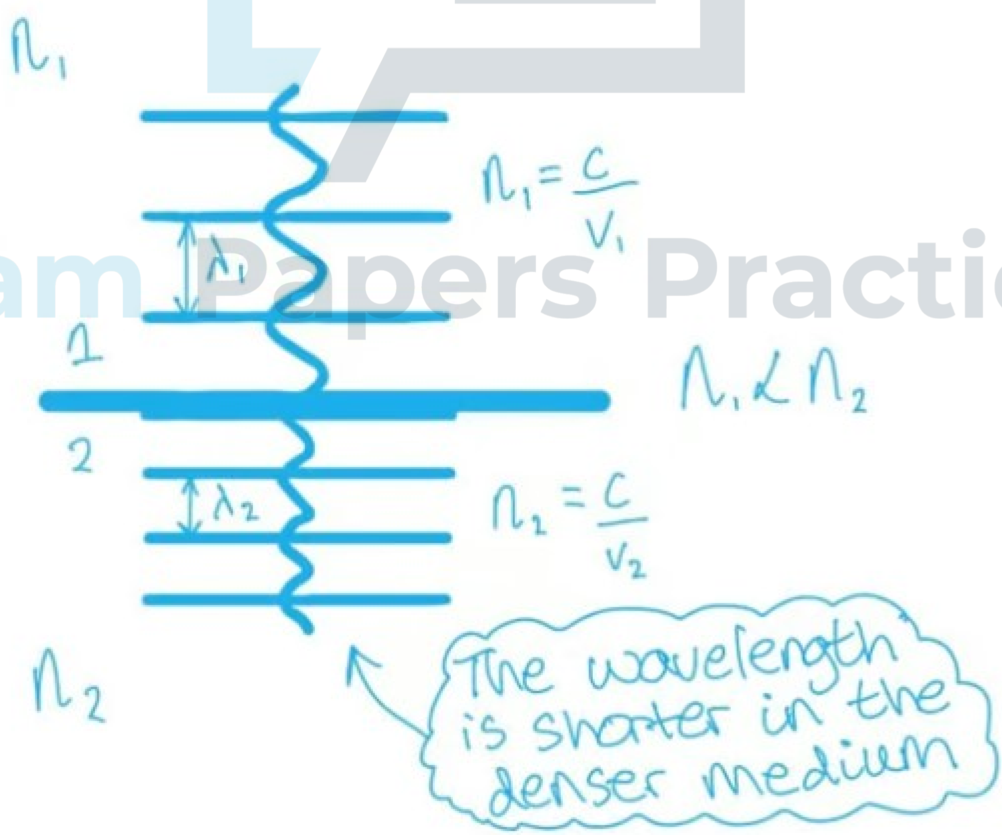
- The wavelength of a wave transmitted between materials changes depending on the refractive index and the density of the material
- The denser a material the slower the wave will travel and the shorter its wavelength becomes

You can see in the diagram that transmission and reflection both take place at a boundary between a less dense and a more dense material



Statement III:

You can see in the diagram below that when the density and the refractive index of the material increase then the wavelength of the wave and also the speed of the wave decrease.

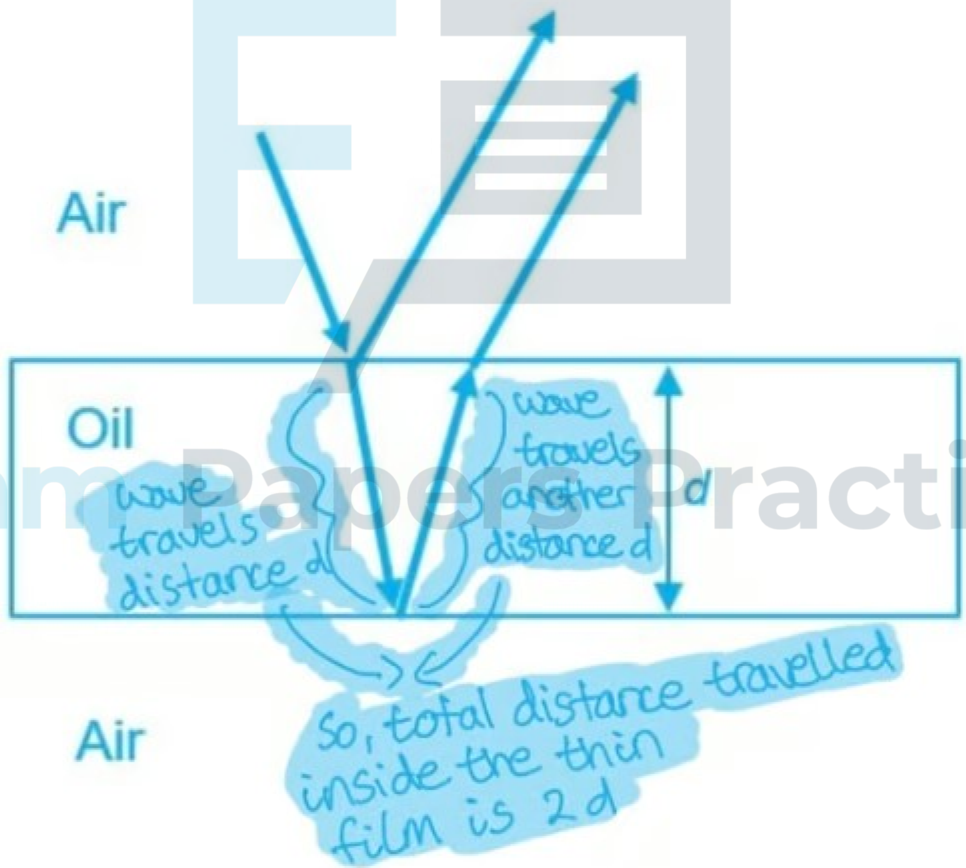


Statement IV

Statement IV is incorrect because:

- Light travels the same distance within a thin film whether it undergoes constructive or destructive interference

You can see from the diagram below that the light enters from one surface of the thin film, passes through the thin film of thickness *d* is reflected off the other surface travelling a further distance of *d* to the original surface. So the total distance travelled whether the light interferes constructively or destructively is 2*d*.



9

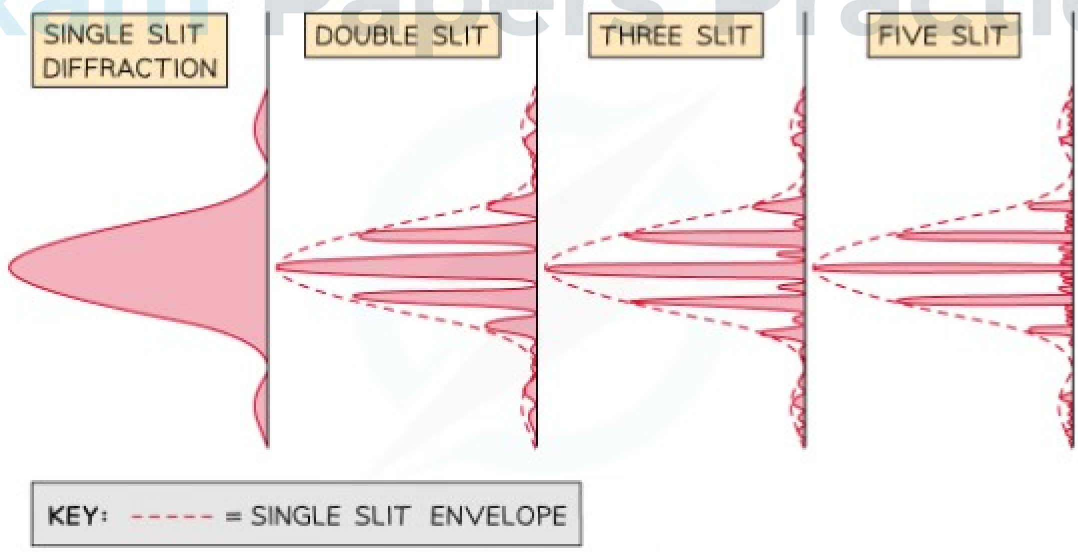
The correct answer is **C** because:

- The width of the primary maxima, and other subsidiary maxima, increases with a decrease in the number of slits in the diffraction grating:
- When the number of slits is < 20, there are now secondary maxima visible between the primary maxima
- So, statements II and III are correct

It is important to know from memory exactly how an intensity graph will change as the number of slits in the diffraction grating changes.

- As the number of slits increases:
  - Between the maxima, secondary maxima appear
  - The intensity of the central and other larger maxima increases
  - The central maxima and subsequent bright fringes become narrower

The diagram below shows the relative intensity for a single slit, a double slit, a three slit grating and a five slit grating.



The changes that can be observed are summarised below:

- When there are 3 slits, 1 secondary maxima can be seen between the primary maxima
- When there are 5 slits, 3 secondary maxima can be seen between the primary maxima
    - Therefore, with N slits (when N > 2), there are **(N – 2) secondary maxima**
- Since the overall amount of light being let through is increased, the pattern increases in intensity by a factor of $N^2 I_0$
    - Where I_0 is the intensity of the central maximum by a single slit
- Once the number of slits increases to **N > 20**:
    - The primary maxima will become thinner and sharper (since slit width, $d \propto \frac{1}{N}$)
    - The (N – 2) secondary maxima will become unobservable

So, statement I is incorrect because:

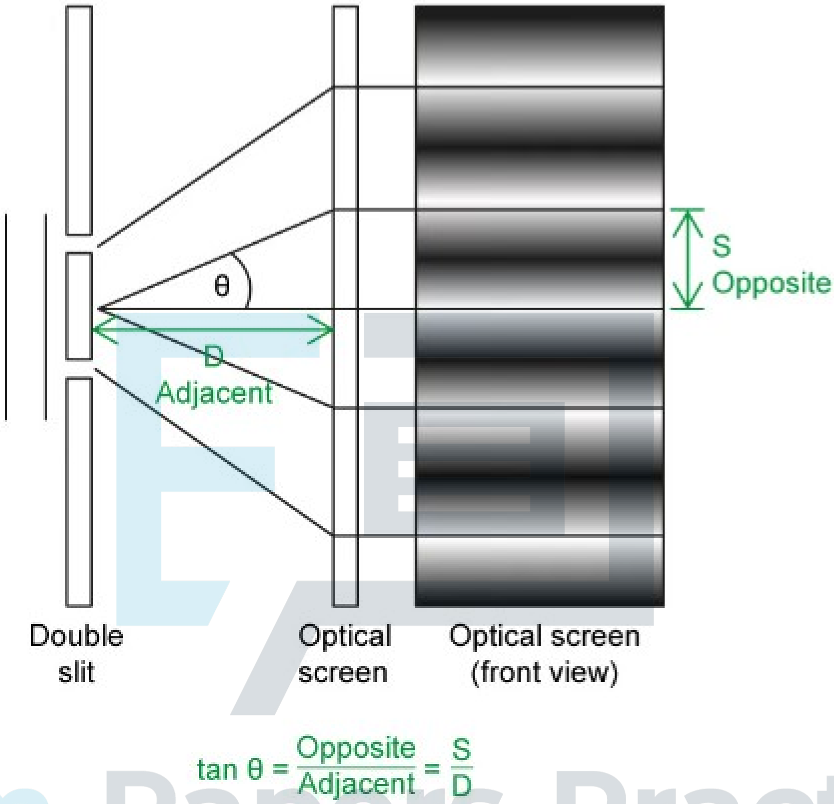
- The intensity of the primary maxima decreases with a decrease in the number of slits.
- There is less interference, as there are fewer slits for the light to diffract through

10

The correct answer is **D** because:

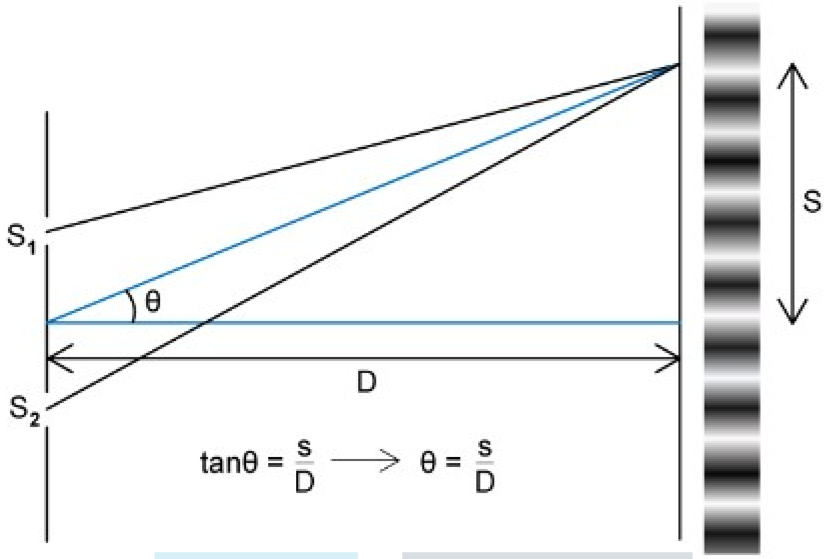
- The equation for the fringe spacing in a double-slit interference pattern:
    - $s = \frac{\lambda D}{d}$
    - Where s is the fringe spacing, λ is the wavelength of the light, D is the distance from the double slit to the screen and d is the slit separation
- Rearranging the equation for λ gives:
    - $\lambda = \frac{sd}{D}$

- Considering the trigonometry of the double-slit diffraction pattern we can see that 'tan' of the angle of diffraction θ is:
  - $\tan\theta = \frac{opposite}{adjacent} = \frac{s}{D}$



- Using the small-angle approximation for the double-slit diffraction pattern $\tan\theta \approx \theta$
- Substituting $\theta = \frac{s}{D}$ into the equation for λ gives:
  - $\lambda = \theta d$
- So, the correct answer is **D**

Reading this question carefully and considering the trigonometry involved in the angle of diffraction will enable you to find a suitable equation for $\sin\theta$. You must also remember the small-angle approximation of $\sin\theta \approx \theta$. You can see this in the diagram below.



Small angle approximation: $\tan\theta \approx \sin\theta \approx \theta$