

Measuring wavelength • Required Practical 2 — solutions

Matching worked solutions and teaching prompts | 36 marks

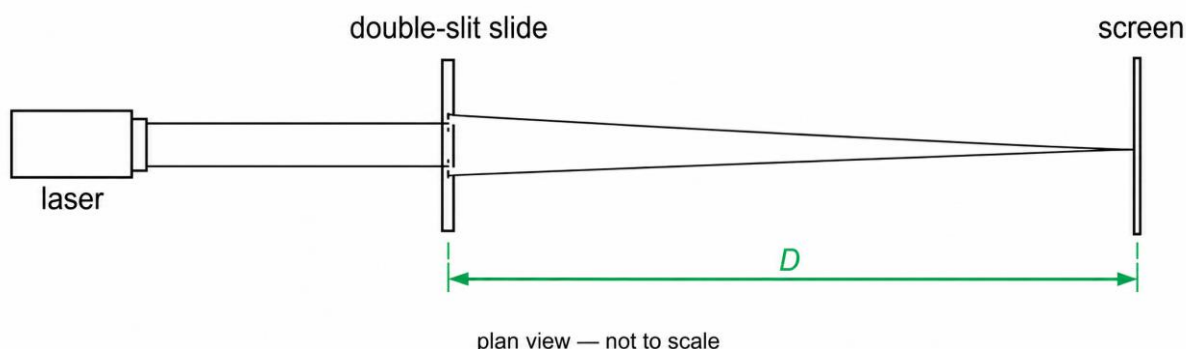
AQA AS Physics 7407 • First-year A Level 7408

Specification points covered

AQA AS 7407 / first-year A Level 7408: 3.3.2.1 — coherence, path difference, Young's slits and fringe spacing; Required Practical 2: interference with double slits and a diffraction grating. 3.3.2.2 — plane transmission grating at normal incidence; $d \sin \theta = n\lambda$ and its application. Supporting: 3.3.1.1 — $c = f\lambda$; 3.1.2 — absolute, percentage and combined uncertainties.

A wavelength check for a laser module

An optics team checks a replacement green laser module for a scanning instrument. It measures wavelength using double slits and a diffraction grating. The double-slit camera can record only a limited width. The module may be approved only if its whole wavelength uncertainty interval lies within 525–540 nm, inclusive.



Use $w = \lambda D/s$ for the small-angle double-slit arrangement and $d \sin \theta = n\lambda$ for a grating at normal incidence. D is the perpendicular slit/grating-to-screen distance. Use exact trigonometry for grating angles. $1 \text{ nm} = 10^{-9} \text{ m}$. Use worst-case uncertainties throughout. All diagrams are schematic; do not measure them.

1. Prepare the wavelength test [2 marks]

The same laser illuminates both narrow, parallel slits. Later the slide is replaced by a transmission grating with 400 lines per mm.

(a) State the two conditions that define coherent waves. [1 mark]

Same frequency and a constant phase difference. Both conditions required. [1] Coherent does not necessarily mean in phase or equal amplitude.

(b) Calculate the separation d of adjacent grating lines in metres. [1 mark]

$400 \text{ lines mm}^{-1} = 4.00 \times 10^5 \text{ lines m}^{-1}$, so $d = 1/(4.00 \times 10^5) = 2.50 \times 10^{-6} \text{ m}$. [1] The line density is not the slit spacing; use its reciprocal in consistent units.

Teaching prompt: Keep double-slit separation s distinct from grating spacing d . Coherence requires a fixed phase relationship, not necessarily zero phase difference.

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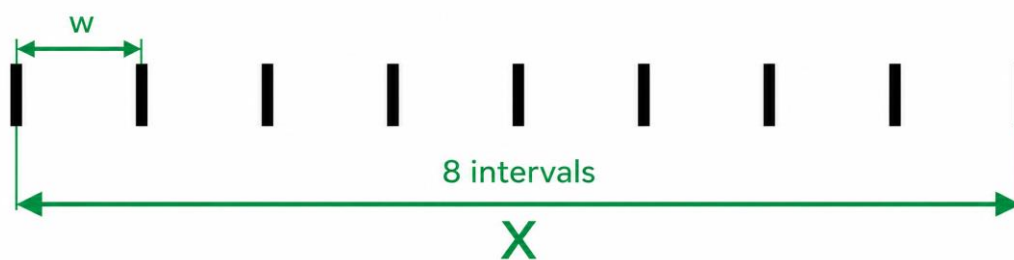
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2. Measure the double-slit fringes [7 marks]

The marks show the centres of nine consecutive bright fringes. The measured span X between the first and last centres is 27.2 mm. The slit separation s is 0.250 mm and the screen distance D is 1.60 m.



bright-fringe centres — not to scale

(a) Use the diagram to determine the number of fringe spacings in X , then calculate the fringe spacing w . [1 mark]

Nine centres span eight intervals, so $w = 27.2/8 = 3.40$ mm. Both count and result correct. [1]
Dividing by nine counts bright fringes rather than the gaps between their centres.

(b) Determine the wavelength of the laser light in nm. [2 marks]

$\lambda = ws/D = (3.40 \times 10^{-3} \times 0.250 \times 10^{-3})/1.60$. Correct rearrangement/substitution with consistent units. [1] $\lambda = 5.3125 \times 10^{-7}$ m = 531 nm to 3 significant figures. [1]

(c) Light leaves the two slits in phase. Explain, using path difference, why bright fringes and dark fringes occur. Assume the arriving waves have equal amplitudes. [2 marks]

At a bright fringe, path difference is an integer number of wavelengths, so the arriving waves are in phase and superpose constructively. [1] At a dark fringe, path difference is an odd number of half-wavelengths, so they arrive in antiphase and superpose destructively; equal amplitudes allow complete cancellation. [1] The dark region is not caused by light rays colliding and disappearing.

(d) A second test beam has 1.25 times the original frequency. With the same s and D , calculate its fringe spacing and explain the change. Light speed in air is unchanged. [2 marks]

From $c = f\lambda$, the wavelength is divided by 1.25 at fixed c ; w is proportional to λ for fixed s and D . [1]
New $w = 3.40/1.25 = 2.72$ mm. [1] Greater frequency means shorter wavelength and closer fringes, not a greater light speed.

Teaching prompt: Count centre-to-centre intervals. Use both millimetre-to-metre conversions in $\lambda = ws/D$, and keep frequency, wavelength and speed separate.



3. Work within the camera window [7 marks]

The camera gives the first and last centre positions as (11.0 ± 0.2) mm and (38.2 ± 0.2) mm. Treat these endpoint uncertainties as separate worst-case contributions. The percentage uncertainty in s is 1.0%, and $D = (1.60 \pm 0.01)$ m.

(a) Calculate the absolute and percentage uncertainty in $X = 27.2$ mm. [2 marks]

$\Delta X = 0.2 + 0.2 = 0.4$ mm. [1] Percentage uncertainty = $(0.4/27.2) \times 100 = 1.47\% \approx 1.5\%$. [1]
Subtraction of position readings requires addition of their absolute uncertainties in this worst-case approach.

(b) Use $\lambda = ws/D$ to calculate the percentage uncertainty in the wavelength from Question 2. The interval count is exact. [2 marks]

The percentage uncertainty in $w = X/8$ is the same as in X , 1.47%. Add percentage uncertainties for the product/quotient: $\Delta\lambda/\lambda (\%) = 1.47 + 1.0 + (0.01/1.60) \times 100$. [1] = 3.10% $\approx 3.1\%$. [1] Do not divide 1.47% by eight again; the absolute uncertainty in w , not its percentage uncertainty, is divided by eight.

(c) The usable camera window is 30.0 mm wide and may be shifted sideways to frame the chosen fringes. The team proposes increasing D to 2.40 m, with the same light and slits. Calculate the new w and the greatest whole number of consecutive fringe spacings that fits. If ΔX stays at 0.4 mm, does measuring that maximum span reduce the percentage uncertainty in X compared with the original test? Support your conclusion numerically. [3 marks]

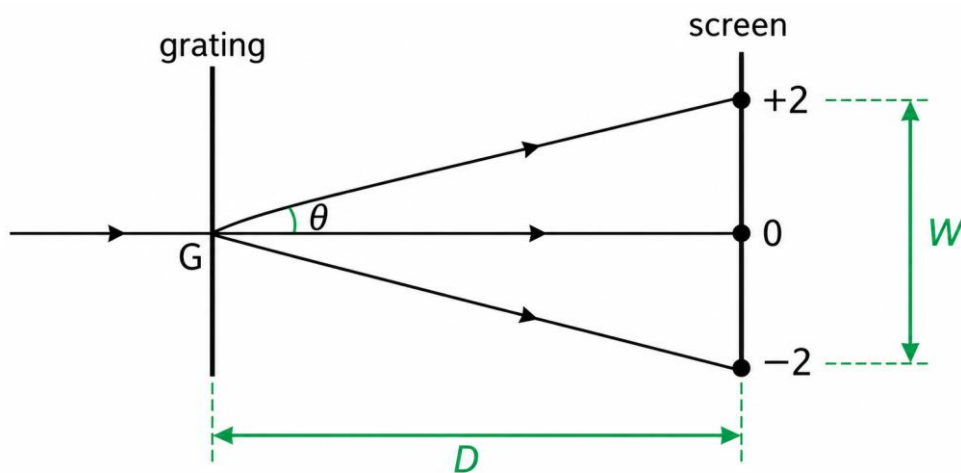
w scales with D : new $w = 3.40 \times 2.40/1.60 = 5.10$ mm. [1] $30.0/5.10 = 5.88$, so at most five complete intervals fit, spanning $X = 25.5$ mm. [1] Percentage uncertainty in $X = (0.4/25.5) \times 100 = 1.57\%$, larger than the original 1.47%; it is not reduced. [1] Six intervals need 30.6 mm and do not fit. This comparison concerns X only: the percentage uncertainty in D would decrease if its absolute uncertainty stayed fixed.

Teaching prompt: A greater screen distance spreads fringes out, but the detector width can limit the total usable span. Assess the stated uncertainty contribution rather than asserting that a bigger pattern is always better.



4. Cross-check with the diffraction grating [6 marks]

The 400 lines per mm grating is illuminated at normal incidence. A separate, larger screen is parallel to it at $D = 0.800$ m. The separation W of the two second-order spots is 0.752 m. Only orders 0 and ± 2 are drawn.



only orders 0 and ± 2 shown — not to scale

(a) Calculate the diffraction angle θ of either second-order beam relative to the central beam. [2 marks]

Distance from the central spot to either second-order spot is $y = W/2 = 0.376$ m, so $\tan \theta = 0.376/0.800$. [1] $\theta = 25.17^\circ \approx 25.2^\circ$. [1] W is the separation of both second-order spots, not the distance from the centre to one spot.

(b) Use the grating equation to determine the wavelength in nm. [2 marks]

For $n = 2$, $\lambda = d \sin \theta/2 = (2.50 \times 10^{-6} \times \sin 25.1735^\circ)/2$. [1] $\lambda = 5.3170 \times 10^{-7}$ m = 532 nm to 3 significant figures. [1] Use $\sin \theta$ in the grating equation, not $\tan \theta$. Accept a consistent result from the candidate's angle.

(c) A spreadsheet replaces $\sin \theta$ by $\tan \theta$ in the grating equation. Calculate the wavelength it would report and explain why this is unsuitable for the test. [2 marks]

It would give $\lambda = d \tan \theta/2 = (2.50 \times 10^{-6} \times 0.470)/2 = 5.875 \times 10^{-7}$ m = 588 nm. [1] At about 25° , $\tan \theta$ is not a sufficiently close approximation to $\sin \theta$: it overestimates λ by about 10.5% and would misclassify this module. [1] The small-angle double-slit approximation cannot simply be transferred to these grating angles.

Teaching prompt: Use geometry to obtain θ , then the correct grating relation to obtain λ . The orders are equally spaced in $\sin \theta$, not generally in angle or position on a flat screen.



5. Write the practical methods [7 marks]

Parts (a) and (b) scaffold a six-mark-style response. Describe repeatable methods for measuring this laser's wavelength. The camera reads calibrated screen positions; no spectrometer is used.

(a) Describe a double-slit method. Include the arrangement, the measurements used to find w and the calculation, and a way to improve the reliability of the result. [3 marks]

Secure the laser and illuminate both narrow slits, with known centre-to-centre separation s ; place the screen parallel to the slit plane, measuring perpendicular D from the slits to the screen. [1]
Measure the span X across several consecutive bright-fringe centres, count the intervals N , then use $w = X/N$ and $\lambda = ws/D$. [1] Repeat the span/centre readings and average, or repeat at several D and check consistent λ ; use the largest clear span that fits the calibrated camera window. [1] Keep illumination, slit slide and alignment unchanged while comparing repeats; do not claim that repetitions remove a calibration error.

(b) Describe a diffraction-grating method using a flat screen. Include alignment, the measurements and equations, and a check that improves confidence in the result. [3 marks]

Set the laser beam normal to the grating, use known line density to obtain d , and place the screen parallel to the grating at measured perpendicular D . [1] Identify the central maximum and a known order n ; measure its offset y from the centre, find θ from $\tan \theta = y/D$, then calculate $\lambda = d \sin \theta/n$. [1]
Measure the corresponding spots on both sides and/or other visible orders, repeat readings and compare/average consistent λ values; use symmetric spot separation divided by two when appropriate. [1] A known central maximum and correct order number are essential; do not assume grating spots have equal linear spacing.

(c) State one specific laser precaution for this arrangement. Do not give a general laboratory clothing rule. [1 mark]

Secure the laser below eye level and terminate the beam on a non-reflective screen/beam stop. [1]
Accept another specific valid precaution, such as avoiding direct viewing of the beam and specular reflections or removing reflective items from the beam path. "Wear goggles" alone is not a sufficient laser-specific precaution.

Teaching prompt: Methods need operational detail: where a length starts and ends, how fringe/order numbers are identified and how measurements become wavelength. Normal incidence is required by the stated grating equation.



6. Check screen limits and approve the module [7 marks]

For this final section use $\lambda = 532 \text{ nm}$ and $d = 2.50 \times 10^{-6} \text{ m}$, regardless of your earlier answers. Assume a grating order exists when $n\lambda/d \leq 1$, and ignore brightness limits. The grating measurement has a stated worst-case wavelength uncertainty of 1.5%; you do not need to propagate angular uncertainties.

(a) Calculate the highest possible diffraction order. State the total number of maxima, including both sides and the central maximum, if the screen size is unlimited. [2 marks]

$n \leq d/\lambda = (2.50 \times 10^{-6})/(532 \times 10^{-9}) = 4.70$, so the greatest integer order is 4. [1] Total number = $2 \times 4 + 1 = 9$ maxima. [1] Do not round 4.70 up to five or omit the central maximum.

(b) The actual screen extends 0.500 m on each side of its central maximum and is 0.800 m from the grating. Determine how many maxima fall on this screen. Justify your count with a calculation. [2 marks]

At the edge, $\theta = \tan^{-1}(0.500/0.800) = 32.0^\circ$, giving $n \leq d \sin \theta / \lambda = 2.49$, so only orders 0, ± 1 and ± 2 fit. [1] Hence five maxima fall on the screen. [1] Equivalent check: second-order $y = 0.376 \text{ m}$ fits, third-order $y = 0.664 \text{ m}$ does not; higher orders are farther out.

(c) Calculate the uncertainty interval for the 532 nm grating result. Apply the rule that the whole interval must lie within 525–540 nm, inclusive, to decide whether the team can approve the module from this result. [2 marks]

Absolute uncertainty = $0.015 \times 532 = 7.98 \text{ nm}$, so the interval is 524.02–539.98 nm, or about 524–540 nm. [1] Do not approve from this result: its lower end is below 525 nm. [1] The central estimate lies in the allowed band, but that alone does not meet the stated acceptance rule; the result does not prove that the module itself is outside the band.

(d) The double-slit result has an uncertainty interval of about 515–548 nm. Does it agree with the grating result within the stated uncertainties? Explain why this is a different judgement from approving the module. [1 mark]

Yes: the wavelength uncertainty intervals overlap, so the two measurements are consistent within their stated uncertainties. However, this does not establish that the whole interval lies in the required 525–540 nm acceptance band. Both points required. [1] Agreement between methods is not the same as meeting the instrument's tolerance.

Teaching prompt: Distinguish order number from number of spots, possible orders from spots that reach a finite screen, and agreement between measurements from compliance with an acceptance range.

