Past-paper walk-through

Double-Slit Interference and Diffraction Gratings ▪ 14.8

eXercise

Questions in this set

- 2025 Q4
- 2022 Q1

Reading the mark scheme

- **B1** a mark that stands on its own – the point is either made or not.
- **M1** a *method* mark: the right approach, even if the number is wrong.
- **A1** an *answer* mark, and it usually needs its M mark first.
- **C1** a working mark on the way to the answer.
- // separates answers the examiner accepts equally.
- **ecf** = error carried forward: a later part is marked on your own earlier answer.
- **owtte** = "or words to that effect" – the wording need not match.

Question 4

2025 ▪ Q4

Two narrow slits are a distance d apart. A screen is a distance L from the midpoint of the slits, where $L \gg d$. When a laser emits monochromatic light toward the slits, a pattern of narrow bright and dark bands is observed on the screen. The centers of bright bands A and B are indicated. Three additional bright bands, including the central bright band, are observed on the screen between bands A and B, as shown. [Figure: Two vertical slits separated by distance d on the left, labeled "Slits." A vertical "Screen" line is a distance L to the right of the slits' midpoint (marked with a horizontal double-arrow labeled L). On the screen, from top to bottom, four dots are marked: "Bright Band A" (topmost), then two unlabeled dots, then "Central Bright Band" (aligned with the midpoint of the slits via a horizontal dashed line), then one more unlabeled dot, then "Bright Band B" (bottommost). This places three additional bright bands, including the central bright band, between Bands A and B.]

Question 4

Note: Figure not drawn to scale.

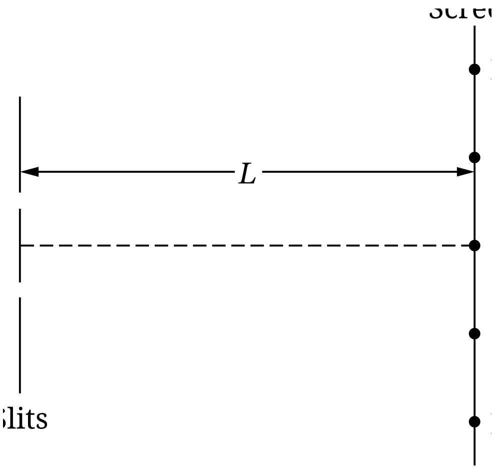
A student claims that the distance between the center of Band A and the center of the central bright band is smaller when using a laser that emits violet light than when using a laser that emits red light.

(a) Indicate whether the student's claim is correct or incorrect. Without manipulating equations, **justify** your answer by referencing the difference in path length traveled by the light from each slit to the center of Band A.

(b) Derive an expression for the distance between the centers of bands A and B when light of frequency f is emitted toward the slits. Express your answer in terms of d, L, f, and physical constants, as appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference information.

(c) Indicate whether the expression you derived in part B is or is not consistent with your answer from part A. Briefly **justify** your answer.

Question 4



Solution 4

(a) Mark scheme

- The claim is correct (full credit is also given for any indication consistent with the justification provided, even if the initial indication is wrong). Justification: violet light has a shorter wavelength than red light (equivalently, a greater frequency than red light). A shorter wavelength leads to a shorter path-length difference for violet light compared to red light at a given point on the screen, which corresponds to a shorter distance between the center of Band A and the center of the central bright band. Full credit requires: (1) indicating the claim is correct (or consistent with the justification given); (2) a correct comparison that violet light has a shorter wavelength (or greater frequency) than red light; (3) explicitly

Solution 4

connecting a shorter wavelength to a shorter path-length difference and hence a shorter distance between Band A and the central band.

Solution 4

(b) Mark scheme

- Derive the expression for the distance between the centers of bands A and B in terms of d, L, f. Starting from the double-slit/interference condition d*(y_max/L) is approximately m*lambda (equivalent to d*sin(theta) = m*lambda, or the path difference Delta D = m*lambda with sin(theta) approximately y_max/L or tan(theta) approximately y_max/L for small angles): substitute lambda = c/f to get d*(y_max/L) = m*(c/f), so y_max = m*c*L/(f*d). Relating y_max to the orders corresponding to bands A and B (per the figure's band numbering, with the central band at m=0 and the relevant band at m=2): Delta y = 2*(y_max,2 - y_max,0) = 2*[(2)*c*L/(f*d)] = 4*c*L/(f*d). Full credit requires: (1) a multistep derivation starting from d*(y_max/L) = m*lambda or an equivalent

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listed/relevant equation; (2) substituting c/f for lambda; (3) the correct final expression relating y_max (or the band spacing) to the orders of bands A and B, e.g. Delta y = 4*c*L/(f*d). A correct isolated final expression alone earns the last two points.

Solution 4

(c) Mark scheme

- The expression derived in part B is consistent with the answer given in part A. Justification: since Delta y = 4*c*L/(f*d), the band spacing Delta y is inversely proportional to frequency f (equivalently, directly proportional to wavelength lambda). Violet light has a greater frequency (shorter wavelength) than red light, so per this expression it produces a smaller Delta y – a shorter distance between the bands – which matches the part A conclusion that violet light corresponds to a shorter distance between Band A and the central band. Full credit requires: (1) correctly stating that the part B expression is (or is not, if the student's part A/B are themselves inconsistent) consistent with part A; (2) a justification citing the

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correct functional dependence of the band spacing on frequency or wavelength that supports that consistency claim.

Question 1

2022 ▪ Q1

Students are investigating electromagnetic wave phenomena in transparent media. They use a string to support a stationary thin, rectangular block of mass m_b, volume V_b, and density ρ_b. The block has two narrow slits in its center and is submerged in a glass tank containing water with density ρ_w, as shown above.

[Diagram: A rectangular glass tank of water, viewed from the side. A string hangs from the top of the tank down to a thin rectangular block suspended in the water; the block has two narrow slits in its center. A laser is aimed horizontally at the block from outside the left wall of the tank. A screen is shown near the bottom right, inside the tank.]

(a)(i) On the dot below, which represents the block, draw and label the forces that are exerted on the block. Each force must be represented by a distinct arrow starting on, and pointing away from, the dot.

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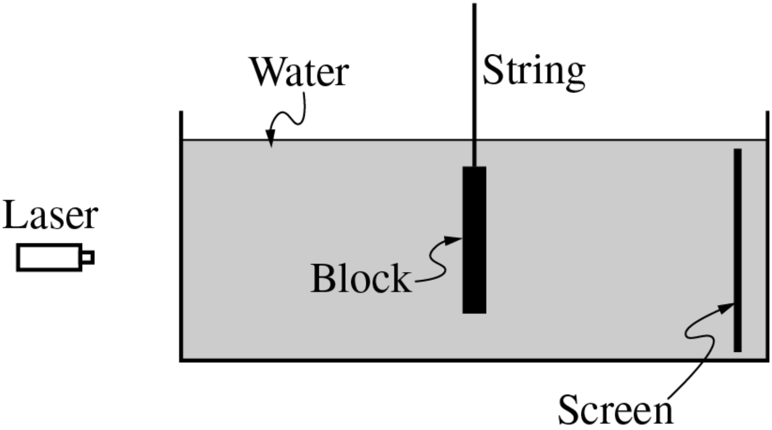
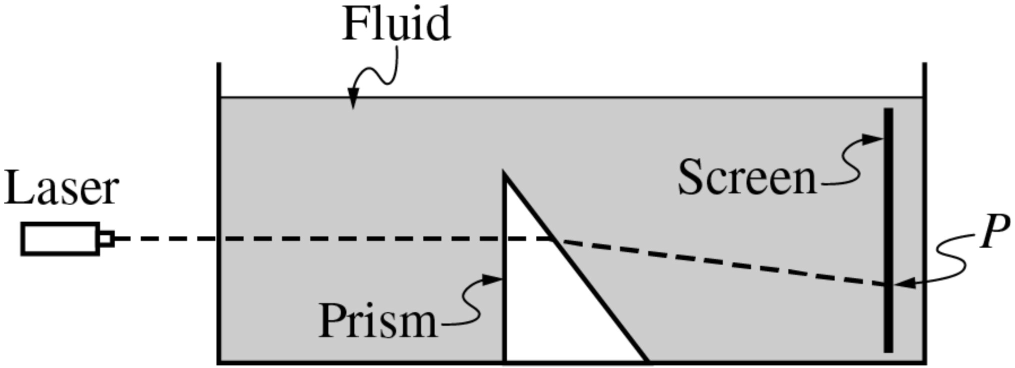
[A single dot is shown, representing the block, for the student to draw force vectors on.]
(a)(ii) Derive an expression for the force exerted on the block by the string in terms of the given quantities and physical constants, as appropriate.

Question 1

Question 1



Question 1



Question 1

2022 ▪ Q1

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(b) A monochromatic laser beam is incident perpendicular to the wall of the tank. The beam passes through the slits in the block. An interference pattern is formed on the screen inside the tank. The water is then replaced with a clear fluid with a greater index of refraction than that of water. In a coherent, paragraph-length response,

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describe how the greater index of refraction of the new fluid affects the interference pattern. Explain your reasoning in terms of speed, frequency, and wavelength of the light.

Question 1

2022 ▪ Q1

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(c) [Diagram: The same tank, now containing a fluid instead of water, with a triangular prism placed in it in place of the block. A laser enters from the left, perpendicular to the tank wall, and its path is shown as a dotted line traveling through

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the fluid to the prism; after passing through the prism the beam is refracted and travels (dotted line) to a screen on the right, striking it at a labeled point P.]
The block is replaced by a triangular prism, as shown above. The path of the beam is indicated by the dotted line, and the beam reaches the screen at point P. The fluid is then removed from the tank, and the prism is surrounded by air. Predict whether the beam will reach the side of the tank above point P, at point P, or below point P when the prism is surrounded by air. Support your answer using physics principles.

Solution 1

(a)(i)

Mark scheme

- Free-body diagram on the dot representing the block, with exactly three labeled force arrows starting at the dot: $F_{buoyant}$ (upward, from the surrounding fluid), $F_{tension}$ (upward, from the string), and $F_{gravity}$ (downward, weight of the block). Full credit requires all three forces correctly drawn and labeled with no extraneous forces (e.g. no friction, no normal force).

Solution 1

(a)(ii) Mark scheme

- Apply Newton's second law to the submerged block, which is in equilibrium (zero net force), consistent with the part (a)(i) diagram: $\Sigma F = ma = 0 \Rightarrow F_T + F_B - F_g = 0 \Rightarrow F_T = F_g - F_B$ (1 point: correct application of Newton's laws consistent with the diagram, indicating zero net force). Substitute the buoyant force $F_B = \rho_w V_b g$ (weight of displaced fluid) and gravitational force $F_g = m_b g$: $F_T = m_b g - \rho_w V_b g$ (1 point: correct substitution of the buoyant force into a solution consistent with the previous equation). A correct final answer with no supporting work earns both points.

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(b) Mark scheme

- Paragraph-length response earning 5 points for addressing each of the following in a coherent argument: (1) the speed of light in the new fluid is less than in water because the new fluid has a greater index of refraction ($v = c/n$, so larger n gives smaller v); (2) the frequency of the light does not change when it enters a new medium; (3) since $v = f\lambda$ and f is constant while v decreases, the wavelength λ must decrease; (4) using the double-slit relation $m\lambda = d\sin\theta$, a smaller wavelength gives a smaller angular separation between bright fringes for the same slit spacing d, so the fringe separation decreases; (5) an overall logical, relevant, and internally consistent argument that follows the paragraph-response guidelines. Model response: "The speed of light in the new fluid is less than the speed of

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light in water because the fluid has a greater index of refraction. This means that the wavelength of the light in the beam will be smaller because the frequency does not change. Since the wavelength is smaller, the angular separation of the bright fringes will decrease, as described by the equation $m\lambda = d \sin\theta$."

Solution 1

(c)

Mark scheme

- (1 point) Explicitly indicate that the amount of refraction at the fluid-prism interface depends on the ratio (or, acceptably, the difference) of the indices of refraction of the two materials. (1 point) Correctly relate a larger angle of refraction to the beam hitting the screen below point P. Model response: "The beam refracts more when the air is present because the difference between the indices of refraction between the prism and the surrounding medium is greater. So, the beam hits the screen below point P."