Past-paper walk-through

Thin-Film Interference ▪ 14.9

eXercise

Questions in this set

- 2018 Q4

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

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[Diagram: a large boat viewed from above/side, labeled with an arrow pointing to steel bars stacked on its deck, labeled “Steel Bars”. A small cabin structure sits at the rear of the boat.]

A large boat like the one shown above has a mass M_b and can displace a maximum volume V_b. The boat is floating in a river with water of density ρ_{water} and is being loaded with steel beams each of density ρ_{steel} and volume V_{steel}. The boat owners want to be able to carry as many beams as possible.

(a) Derive an expression for the maximum number N of steel beams that can be loaded on the boat without exceeding the maximum displaced volume, in terms of the given quantities and physical constants, as appropriate.

(b) The captain realizes that oil is leaking from the boat, creating a thin film of oil on the water surface. In one area of the oil film the surface looks mostly green. Explain in

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detail how constructive interference contributes to the green appearance. Assume the index of refraction of the oil is greater than the index of refraction of the water.
(c) Later the boat is floating down the river with the water current, heading for a town. The river has a width of 60 m and a constant depth and flows at a speed of 5 km/hr. Partway to the town, the river narrows to a width of 30 m while its depth remains the same. Calculate the speed of the water in the narrow section.

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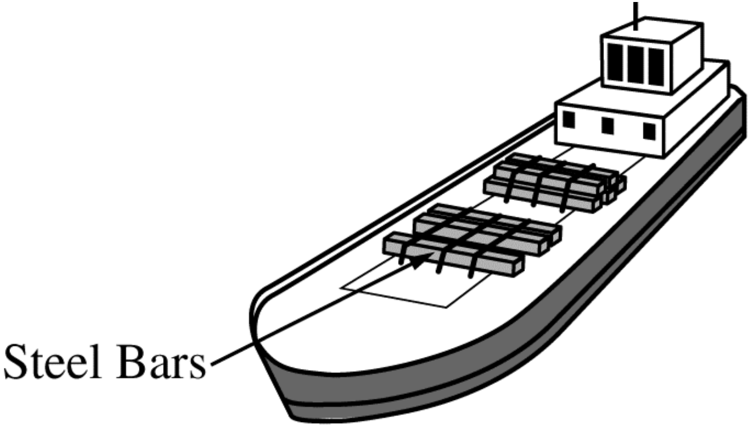

Solution 4

(a)

Mark scheme

- At maximum load, the boat floats with the maximum displaced volume V_b, so the buoyant force equals the total weight of the boat-plus-beams system: $F_b = W_{system}$. Weight of the system: $W_{system} = (M_b + N\rho_{steel}V_{steel})g$, where N is the number of steel beams. Buoyant force (Archimedes' principle): $F_b = \rho_{water} g V_b$. Setting these equal and solving for N: $(M_b + N\rho_{steel}V_{steel})g = \rho_{water} g V_b \Rightarrow N = \dfrac{\rho_{water}V_b - M_b}{\rho_{steel}V_{steel}}$.

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(b) Mark scheme

- The green appearance results from constructive interference between the light wave reflected at the air-oil interface and the light wave reflected at the oil-water interface — interference between these two reflected waves. Because the oil has a higher refractive index than air, the wave reflecting off the air-oil interface undergoes a 180° phase shift on reflection, while the reflection at the oil-water interface (oil index greater than water index, as given) does not gain that same extra shift — so there is a net relative phase shift arising from one of the two reflections. The wavelength of the light inside the oil film is shorter than in air/vacuum ($\lambda_{oil} = \lambda_{air}/n_{oil}$), which sets the phase accumulated as the wave travels through the film. There is also a path-length difference between the two

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reflected rays, equal to twice the oil film's thickness (the extra distance traveled by the ray that penetrates to the oil-water interface and reflects back). When the combined phase difference — from the path-length difference through the oil (using the wavelength in oil) together with the reflection phase shift — corresponds to constructive interference specifically for green wavelengths, the reflected light appears green.

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(c)

Mark scheme

- By conservation of mass for an incompressible fluid (the continuity equation), $A_{wide}v_{wide} = A_{narrow}v_{narrow}$, where cross-sectional area $=$ width $\times$ depth; since the depth is the same in both sections it cancels, leaving width in place of area: $(60\text{ m})(\text{depth})(5\text{ km/hr}) = (30\text{ m})(\text{depth})(v_{narrow})$. Solving: $v_{narrow} = \dfrac{(60\text{ m})(5\text{ km/hr})}{30\text{ m}} = 10\text{ km/hr}$.