3.3 Waves: 30-minute Pack

AQA 7408 · Calculator allowed · about 30 minutes

Total Marks

Name: _____ Date: ____ / ____ / _____

Answer ALL questions. Show all your working.

1 An optical fibre used in telecommunications has a core of refractive index 1.52, surrounded by cladding of refractive index 1.45. Use the Physics Equations Sheet.

(a) Calculate the critical angle for light travelling from the core towards the cladding, using $\sin(\theta_c) = n2/n1$. **(3)**

(b) The speed of light in a vacuum is $c = 3.00 \times 10^8$ m/s. Use $n = c/v$ to calculate the speed of light in the fibre core. **(2)**

(c) State the condition on the angle of incidence, at the core-cladding boundary, required for total internal reflection (and hence for the fibre to guide light along its length). **(2)**

(d) State one further condition, in terms of the refractive indices of the core and cladding, that must be satisfied for total internal reflection to be possible at all at this boundary. **(1)**

(e) Optical fibres used for long-distance telecommunications suffer from signal degradation. Discuss the physical causes of this degradation and explain how the design of the fibre and the transmitted signal can be adapted to reduce its effects. **(6)**

(Total for Question 1 is 14 marks)

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2 Two loudspeakers, A and B, are connected to the same signal generator so that they emit coherent sound waves of wavelength 0.680 m. A listener walks along a line parallel to the speakers and detects a series of loud and quiet points.

(a) State what is meant by two sources being coherent. **(1)**

(b) At a particular point, the path difference between the sound from speaker A and from speaker B is 2.04 m. Determine whether the listener hears a loud point (constructive interference) or a quiet point (destructive interference) at this position, showing your reasoning. **(3)**

(c) Explain why this experiment would not produce a stable interference pattern if speakers A and B were instead connected to two separate, independent signal generators of the same nominal frequency. **(2)**

(d) The wavelength of the sound is changed to 0.850 m by adjusting the frequency of the signal generator, with the speed of sound remaining 340 m/s. Use $v = f \times \lambda$ to calculate the new frequency of the signal generator. **(2)**

(Total for Question 2 is 8 marks)

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Mark scheme · 3.3 Waves: 30-minute Pack

Question 1

(a) correct substitution: $\sin(\theta_c) = 1.45/1.52$ **M1**

(a) = 0.954 (awrt), and takes inverse sine **M1**

(a) 72.5 degrees (awrt 72.4-72.6 degrees) **A1**

(a) Answer: 72.5 degrees

(b) correct rearrangement and substitution: $v = (3.00 \times 10^8)/1.52$ **M1**

(b) 1.97×10^8 m/s (awrt, cao) **A1**

(b) Answer: 1.97×10^8 m/s

(c) the angle of incidence must be greater than the critical angle (greater than 72.5 degrees, ft from (a)) **B1**

(c) this condition must be met at every reflection along the length of the fibre, so the light stays confined within the core oe **B1**

(c) Answer: The angle of incidence must exceed the critical angle (greater than 72.5 degrees) at every reflection along the fibre.

(d) the light must be travelling from a medium of higher refractive index (the core) into a medium of lower refractive index (the cladding) oe **B1**

(d) Answer: Light must travel from the higher refractive index medium (core) towards the lower refractive index medium (cladding).

(e) **L3** Coherent discussion of at least two distinct causes of degradation (e.g. absorption/attenuation and one form of dispersion), each with a clearly linked, valid method of reducing its effect. **5-6**

(e) **L2** Identifies at least one or two causes of degradation, with some explanation of solutions, though links between cause and solution may be incomplete. **3-4**

(e) **L1** Basic, general statements (e.g. 'the signal gets weaker') without detailed physical cause or a clearly linked improvement. **1-2**

(e) **L0** No creditable content. **0**

(e) Indicative content:

- Absorption: impurities in the fibre material absorb some of the light energy, causing attenuation (a gradual loss of signal amplitude/intensity) along the length of the fibre; using very pure glass reduces absorption.
- Modal dispersion: light rays entering the core at different angles travel different path lengths (and take different times) along the fibre, causing a pulse of light to broaden and, over long distances, overlap with neighbouring pulses; this is reduced by using a very narrow core (a single-mode/monomode fibre) so only one path is possible.
- Material (chromatic) dispersion: different wavelengths within a pulse travel at slightly different speeds in the fibre, because refractive index depends on wavelength, again causing pulse broadening; this is reduced by using a light source with a very narrow range of wavelengths (e.g. a laser rather than an LED).
- Regenerating (amplifying and reshaping) the signal at intervals along its length, using repeater stations, restores its strength and pulse shape before degradation makes the signal unreadable.

(e) Answer: Credit awarded via levels of response using the indicative content (absorption/attenuation, modal dispersion, material dispersion, and their corresponding solutions).

Question 2

(a) sources with the same frequency and a constant phase difference oe **B1**

(a) Answer: Sources of the same frequency with a constant phase difference.

(b) divides path difference by wavelength: 2.04/0.680 **M1**

(b) = 3.0, a whole number of wavelengths **A1**

(b) conclusion: constructive interference (a loud point), since the path difference is a whole number of wavelengths oe **A1**

(b) Answer: Loud point (constructive interference), since 2.04/0.680 = 3.0 exactly.

(c) the two sources would no longer be coherent, as independent generators cannot maintain a constant phase difference oe **B1**

(c) the positions of the loud and quiet points would therefore shift continuously/randomly over time, so no stable pattern would be observed oe **B1**

(c) Answer: The sources would not be coherent, since independent generators drift in phase relative to each other, so the loud and quiet points would shift constantly and no stable pattern would form.

(d) correct substitution: f = 340/0.850 **M1**

(d) 400 Hz (cao) **A1**

(d) Answer: 400 Hz

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