InkPhysics

ANSWER BOOK

The nature of light

Turning points · Year 13

AQA 3.12.2.1, 3.12.2.2, 3.12.2.3 · OCR A 4.4.3(f)

18 questions · 52 marks

NAVY EDITION

SECTION A · Warm-up

A1 No diffraction of light had been observed, and shadows seemed perfectly sharp, consistent with particles in straight lines (1); and Newton's enormous scientific authority made his theory the default (1). [2]

A2 Light spreading from the two slits overlaps on the screen. Where the two sets of waves arrive in step they reinforce, giving a bright fringe (1); where they arrive out of step they cancel, giving darkness (1). [2]

A3 ε_0, the permittivity of free space, relates to the electric field strength due to a charged object in free space (1); μ_0, the permeability of free space, relates to the magnetic flux density due to a current-carrying wire (1). [2]

A4 Reflection (1) and refraction (1): both theories accounted for these, disagreeing only over the speed of light in the denser medium. [2]

A5 Oscillating electric and magnetic fields at right angles to each other and to the direction of travel (1); the wave is self-propagating and needs no medium (1). [2]

SECTION B · Standard

B1 [3]
$c = 1/\sqrt{(\mu_0\varepsilon_0)}$ (1)
$c = 3.00 \times 10^8$ m s^{-1} (1)
Equal to the measured speed of light, implying light is an electromagnetic wave (1)

B2 [3]
Adjacent nodes are half a wavelength apart, so $\lambda = 3.3$ m (1)
$c = f\lambda = 3.0 \times 10^8$ m s^{-1} (1)
Radio waves travel at the speed of light, confirming Maxwell's prediction (1)

B3 [4]
First blocking: the wheel advances half a tooth, 1/1440 of a turn, during the round trip (1)
$t = 1/(1440 \times 12.6) = 5.51 \times 10^{-5}$ s (1)
$c = 2d/t = 2 \times 8630/(5.51 \times 10^{-5})$ (1)
$c = 3.1 \times 10^8$ m s^{-1} (1)

B4 The dark fringes are places where light from one slit plus light from the other produces darkness (1). Streams of particles can only ever add together, giving more light (1); only waves arriving out of step can cancel, so the fringes demand a wave description (1). [3]

B5 A dark fringe (1): with a path difference of a whole number plus half a wavelength the waves arrive in antiphase, crest meeting trough, and cancel (1). [2]

B6 Rearranging, $\varepsilon_0 = 1/(\mu_0 c^2)$ (1) $= 1/(4\pi \times 10^{-7} \times (3.00 \times 10^{8})^2)$ (1) $= 8.84 \times 10^{-12}$ F m^{-1} (1). [3]

SECTION C · Stretch

C1 Newton's corpuscular theory required light to travel faster in the denser medium to explain refraction towards the normal (1); Huygens' wave theory required it to travel slower (1). Light proved slower in water, so the wave theory's prediction was confirmed and the corpuscular account failed (1). [3]

C2 Hertz generated previously unknown waves from purely electrical sparks (1), showed they reflect, refract and form stationary waves like light (1), and measured their speed as c. This confirmed Maxwell's electromagnetic theory directly (1), established that light belongs to a wider electromagnetic family, and opened the spectrum beyond the visible, radio first (1). [4]

C3 Newton's reputation stood behind the corpuscular theory, and one experiment was not enough to overturn a century of consensus (1); acceptance came only as interference and diffraction evidence accumulated and the speed-in-water test went the wave theory's way (1). [2]

C4 Round-trip time $t = 2d/c = 2 \times 9500/(3.0 \times 10^{8}) = 6.3 \times 10^{-5}$ s (1). At the first blocking the wheel advances half a tooth spacing, 1/1200 of a turn, in this time (1). Rotation rate needed $= (1/1200)/(6.3 \times 10^{-5}) = 13$ rev s^{-1} (1). This is below the motor's 15 rev s^{-1}, so the first blocking is just observable (1). [4]

C5 At the first blocking rate the wheel advances half a tooth spacing during the light's round trip, so the returning light lands on a tooth and the view is dark (1). At twice that rate the wheel advances a whole spacing in the same time (1), so the returning light passes through the next gap and the view brightens again (1). [3]

C6 The wavelength of light is extremely small, of order 10^{-7} m (1), so its bending at everyday obstacles and edges is far too slight to notice and shadows look sharp (1). Sharp shadows are exactly what streams of particles travelling in straight lines predict, so the observations seemed to confirm the corpuscular theory (1). [3]

C7 Light passes through a gap between the teeth of a rotating wheel, travels to a distant mirror several kilometres away and returns along the same path (1). The rotation rate is increased until the returning light is first blocked, when the wheel has advanced half a tooth spacing during the round trip (1). For N teeth rotating at f revolutions per second, the round-trip time is $t = 1/(2Nf)$ (1), and $c = 2d/t$ with d the measured distance to the mirror (1). Significance: the first accurate terrestrial measurement of c, making the speed of light a repeatable, checkable quantity, later compared against Maxwell's prediction (1). [5]