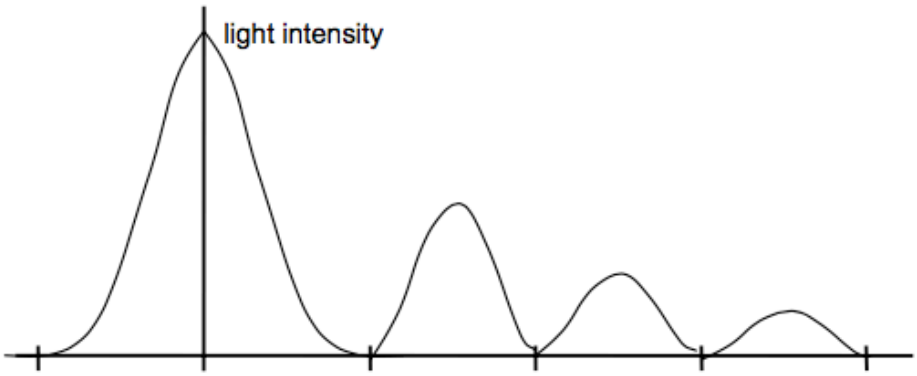
1)

(a)	3 subsidiary maxima in correct positions ✓ intensity decreasing ✓  	**2**
(b)	a single wavelength ✓ constant phase relationship/difference ✓	**2**
(c)	maxima further apart/central maximum wider/subsidiary maximum wider/maxima are wider ✓	**1**
(d)	wider/increased separation ✓ lower intensity ✓	**2**
(e)	distinct fringes shown with subsidiary maxima ✓ indication that colours are present within each subsidiary maxima ✓ blue/violet on the inner edge **or** red outer for at least one subsidiary maximum ✓ (middle of) central maximum white ✓	**3**
	Total	**10**

2)

(a)	(i)	**diffraction** ✓	**9**
	(ii)	**any 4 points from** **interference** (fringes formed) ✓ where light from the two slits overlaps (or superposes) ✓ bright (or red) fringes are formed where light (from the two slits) reinforces (or interfere constructively/crest meets crest) ✓ dark fringes are formed where light (from the two slits) cancels (or interferes destructively/trough meets crest) ✓ the light (from the two slits) is coherent ✓ *either* reinforcement occurs where light waves are in phase (or path difference = whole number of wavelengths) ✓ *or* cancellation occurs where light waves are out of phase of 180° (in anti-phase) (or path difference = whole number + 0.5 wavelengths) ✓ (not 'out of phase')	
	(iii)	($w = \frac{\lambda D}{s}$) gives $\lambda = \frac{ws}{D}$ ✓ w (= 3.6/**4**) = 0.9(0) mm ✓ (failure to /4 is max 2) λ ($= \frac{ws}{D}$) $= \frac{0.90\times(10^{-3})\times0.56\times(10^{-3})}{0.80}$ ✓ $= 6.3 \times 10^{-7}$ m ✓	
(b)		central (bright) fringe would be white ✓ side fringes are (continuous) spectra ✓ (dark) fringes would be closer together (because λ_{red} > average λ_{white}) ✓ the bright fringes would be blue on the side nearest the centre (or red on the side away from the centre) ✓ bright fringes merge away from centre ✓ bright fringes wider (or dark fringes narrower) ✓	**max 3**
		Total	**12**

3)

(a)	λ correct ✓ d correct ✓ arrow or line needed, both ends extending beyond central black line	**2**
(b)	angle θ gets smaller ✓ because path difference gets smaller/***d* constant**, (λ smaller) so sin θ smaller ✓ max 1 for correct explanation for λ increasing	**3**
(c)	boxes 1,5,6 ✓✓ two correct 1 mark 4 ticks max 1 5 or 6 ticks gets 0	**2**
(d) (i)	3.3×10^{-6} m ✓ (1/300 = 3.33×10^{-3} **mm**, 3300 **nm**) DNA 1 sf here DNA 1/300 000 as answer accept 3 1/3 x 10^{-6}, 3.33 x 10^{-6} recurring, etc	**1**
(d) (ii)	(sin θ =) $\frac{540 \text{ to } 560 \times (10^{-9})}{((d)(i))}$ ✓ correct wavelength used and seen (**545 to 548 x 10^{-9}**) **and** 9.4 to 9.6 (°) ✓ ecf (d) (i), for correct wavelength only (545 to 548 × 10^{-9})	**2**
	Total	**10**

4)

(a)	showed that light was a **wave** (rather than a particle)/**wave** nature (of light) ✓	**1**
(b) (i)	single wavelength (or frequency) ✓	**1**
(b) (ii)	(waves/source(s) have) constant phase difference ✓	**1**
(b) (iii)	any sensible precaution, eg do not look into laser/do not point the laser at others/do not let (regular) reflections enter the eye/safety signs/suitable safety goggles ✓	**1**
(c)	(0.16/8) = 0.02(0) ✓ = $\frac{0.020 \times 0.30\ (\times 10^{-3})}{10.0}$ ✓ ecf from calculation of fringe spacing = 6.0×10^{-7} m ✓ (= 600 nm) ecf from calculation of fringe spacing	**3**
(d)	maxima closer together ✓ (quotes equation and states that) spacing is proportional to wavelength/ *D* and *s* are constant therefore as λ decreases so ω decreases ✓ **or** links smaller wavelength to smaller path difference ✓	**2**
	Total	**9**

5)

a	**max three from** central maximum shown ✓ two equally spaced first order maxima ✓ central and one first order labelled correctly ✓ central white maximum ✓ indication of spectra/colours in at least one first order beam ✓ at least one first order beam labelled with violet (indigo or blue) closest to the centre **or** red furthest ✓	**max 3**
b	**dark/black** lines **or** absorption spectrum **or** Fraunhofer lines ✓ (reveal the) composition (of the star's atmosphere) ✓ accept dark 'bands' accept atoms or elements in the star **or** the peak of intensity ✓ (is related to) the temperature ✓ **or** Doppler (blue or red) shift ✓ (speed of) rotation **or** speed of star (relative to Earth) ✓	**2**
c i	grating and screen shown with both labelled ✓ laser or laser beam labelled ✓	**2**
c ii	**The candidate's writing should be legible and the spelling, punctuation and grammar should be sufficiently accurate for the meaning to be clear.** The candidate's answer will be assessed holistically. The answer will be assigned to one of three levels according to the following criteria. **High Level (Good to excellent): 5 or 6 marks** The information conveyed by the answer is clearly organised, logical and coherent, using appropriate specialist vocabulary correctly. The form and style of writing is appropriate to answer the question. • correct use of $(n)\lambda = d \sin\theta$ • **and** measure appropriate angle (eg 'to first order beam' is the minimum required) • **and** method to measure angle (eg $\tan\theta = x/D$, spectrometer, accept protractor) • **and** at least **one** way of improving accuracy/reliability • for **full** marks: also explain how d is calculated, eg d = 1/ lines per mm ($\times 10^3$)	**max 6**

	Intermediate Level (Modest to adequate): 3 or 4 marks The information conveyed by the answer may be less well organised and not fully coherent. There is less use of specialist vocabulary, or specialist vocabulary may be used incorrectly. The form and style of writing is less appropriate. • use of $(n)\lambda = d \sin\theta$ • **and** measure appropriate angle (eg 'to first order beam' is the minimum required) • **and** method of measurement of θ (eg $\tan\theta = x/D$, spectrometer, accept protractor) **or** at least **one** way of improving accuracy/reliability **Low Level (Poor to limited): 1 or 2 marks** The information conveyed by the answer is poorly organised and may not be relevant or coherent. There is little correct use of specialist vocabulary. The form and style of writing may be only partly appropriate. • use of $(n)\lambda = d \sin\theta$ • **or** measure appropriate angle (eg 'to first order beam' is the minimum required) • **or** at least **one** way of improving accuracy/reliability **Incorrect, inappropriate of no response: 0 marks** No answer or answer refers to unrelated, incorrect or inappropriate physics. **The explanation expected in a competent answer should include** **Accuracy/reliability points** • measure between more than one order (eg 2 θ) • measure θ for different orders (for average λ **not average angle**) • check or repeat/repeat for different distances (D) • use of spectrometer • use large distance to screen (D) • protractor with 0.5 degree (or less) intervals • graphical method: **plot sin θ against n** (gradient $= \lambda/d$)	
	Total	**13**

6)

a		same wavelength/ frequency ✓ constant phase relationship ✓ allow 'constant phase difference' but not 'in phase'	2	
b	i	($\lambda = \frac{c}{f}$) $3.00\times10^{8} = 9.4\times(10^{9})\ \lambda$ OR $= \frac{3.00\times10^{8}}{9.4\times(10^{9})}$ ✓ $= 3.2\times10^{-2}$ $(3.19\times10^{-2}$ m) ✓	2	Use of speed of sound gets zero Allow 0.03
b	ii	3.2×10^{-2} ✓ (m) ecf from bi	1	Don't allow '1 wavelength', 1λ, etc Do not accept: zero, 2π, 360°
c		maximum (at position shown) ✓ constructive interference / reinforcement ✓ **ecf for 'minimum' or for reference to wrong maximum** (the waves meet) 'in step' / peak meets peak / trough meets trough / path difference is (n)λ / in phase ✓	3	allow constructive superposition. 'Addition' is not enough
d		$s = \frac{\lambda D}{w}$ $= \frac{0.0319\times0.42}{0.11}$ ✓ ecf 7bi = 0.12 (0.1218 m) ✓ = **any 2sf** number ✓	3	Don't allow use of Fig 5 as a scale diagram. Do not penalise *s* and *w* symbols wrong way round in working if answer is correct. Correct answer gains first two marks. Independent sf mark for **any** 2 sf number
e		a maximum ✓ (f × 2 results in) $\lambda/2$ ✓ path difference is an even number of multiples of the new wavelength (2n λ_{new}) ✓ allow 'path difference is $n\lambda$' / any even number of multiples of the new λ quoted e.g. 'path difference is now 2λ'	3	Candidates stating 'minimum' can get second mark only
		total	14	

7)

(a)	(i)	= 590 × 10^{-9} m ✓ (using *d* sin θ = *nλ* gives) sin θ = $\frac{n\lambda}{d}$ or = $\frac{2\times590\times(10^{-9})}{1.67\times10^{-6}}$ ✓ = **0.707** or 7.07 × 10^{8} if nm used ✓ θ = 45.0° ✓ (accept 45°)	**7**
	(ii)	(sin θ ≤ 1) gives $\frac{n\lambda}{d} \leq 1$ or $n \leq \frac{d}{\lambda}$ or = $\frac{1.67\times10^{-6}}{590\times10^{-9}}$ ✓ = 2.83 ✓ so 3rd order or higher order is not possible ✓ alternative solution: (substituting) ***n* = 3** (into *d* sin θ = *nλ* gives) ✓ sin θ (= $\frac{n\lambda}{d}$ = $\frac{3\times590\times10^{-9}}{1.67\times10^{-6}}$) = 1.06 ✓ gives 'error'/which is not possible ✓	
(b)		(using *d* sin θ = *nλ* gives) 2 *λ* = 1.67 × 10^{-6} × sin 42.1 ✓ *λ* (= 0.5 × 1.67 × 10^{-6} × sin 42.1) = 5.6(0) × 10^{-7} m (or 560 nm) ✓	**2**
		Total	**9**

8)

a	**The candidate's writing should be legible and the spelling, punctuation and grammar should be sufficiently accurate for the meaning to be clear.** The candidate's answer will be assessed holistically. The answer will be assigned to one of three levels according to the following criteria. **High Level (Good to excellent): 5 or 6 marks** The information conveyed by the answer is clearly organised, logical and coherent, using appropriate specialist vocabulary correctly. The form and style of writing is appropriate to answer the question. The candidate provides a comprehensive and coherent description which includes; fringe spacing/separation *w* **and** distance *D* measured with one **instrument named**, uses $\lambda = \frac{ws}{D}$ to obtain value for λ, measures distance between several maxima and includes a valid point about safety. **Intermediate Level (Modest to adequate): 3 or 4 marks** The information conveyed by the answer may be less well organised and not fully coherent. There is less use of specialist vocabulary, or specialist vocabulary may be used incorrectly. The form and style of writing is less appropriate. The candidate provides an adequate explanation that lacks some of the essential points. The candidate is expected to include; *w* **or** 'fringes' measured **or** uses $\lambda = \frac{ws}{D}$ to obtain value for λ. They include one accuracy point **or** a valid point about safety. **Low Level (Poor to limited): 1 or 2 marks** The information conveyed by the answer is poorly organised and may not be relevant or coherent. There is little correct use of specialist vocabulary. The form and style of writing may be only partly appropriate. The candidate provides a limited explanation with no more than one or two valid points. **Incorrect, inappropriate of no response: 0 marks** No answer or answer refers to unrelated, incorrect or inappropriate physics.	**max 6**

	The explanation expected in a competent answer should include a coherent selection of the following points. **Measurements** • suitable measuring instrument for *w* • suitable measuring instrument for *D* **Finding the wavelength** • uses $\lambda = \frac{ws}{D}$ to obtain value for λ • explains graphical approach **Accuracy** • several fringe spaces measured • centres of fringes used • five or more fringes/four fringe spaces measured • large value of *D* • *D* greater than or equal to 2 m • dark room • repeat measurements • **vernier** calliper for *w* (not 'calliper', not micrometer) • graphical method varying *D* and measuring *w* • other valid accuracy point **Safety** • avoid shining laser at (or near) a person • **laser** safety goggles • avoid reflections • warning sign or light	
b	(light from both sources has) constant phase **relationship/difference** ✓✓ 'in phase' or 'same wavelength' or 'same frequency' is **one mark**	**2**
c	single slit **then** double slits to the right ✓ single slit and double slits **labelled** ✓	**2**

<table>
<tr><td>d</td><td>
<table>
<tr><th>if candidate refers to white light Young's fringes with white light;</th><th>or
if candidate refers to the laser;</th></tr>
<tr><td>contain (different) colours or central white fringe</td><td>monochromatic/one colour</td></tr>
<tr><td>less intense</td><td>more intense</td></tr>
<tr><td>maxima wider/minima narrower or max or min closer together for white light compared to a red laser</td><td>maxima narrower/minima wider or max or min further apart for a red laser</td></tr>
<tr><td>fringes/lines/bands etc compared to 'dots'</td><td>'dots' for laser compared to 'bands' etc</td></tr>
</table>
from each row, one only max 2 ✓
</td><td>2</td></tr>
<tr><td>e</td><td>cancellation/waves cancel/destructive interference/destructive superposition ✓

(light from one slit meets light from the other) in antiphase (180 out of phase) or a path difference of ((n+) ½)λ ✓</td><td>2</td></tr>
<tr><td></td><td>Total</td><td>14</td></tr>
</table>

9)

a		One of: (spectral) analysis of light from stars (analyse) composition of stars Chemical analysis Measuring red shift \ rotation of stars ✓ Insufficient answers: 'observe spectra', 'spectroscopy', 'view absorption \emission spectrum', 'compare spectra', 'look at light from stars'.	1		Allow : measuring wavelength or frequency from a named source of light. Allow any other legitimate application that specifies the source of light. E.g. absorbtion\emission spectra in stars, 'observe spectra of materials'
b	i	first order beam first order spectrum first order image ✓	1		Allow 'n=1' , '1' 'one', 1st
b	ii	The light at A will appear white (and at B there will be a spectrum) OR greater intensity at A ✓	1		
c		(d = 1/ (lines per mm x 10^3) = 6.757 x 10^{-7} (m) OR 6.757 x 10^{-4} (mm) ✓	3		Some working required for full marks. Correct

		($n\lambda = d \sin\theta$) = 6.757 x 10^{-7} x sin 51.0 ✓ ecf **only** for : • incorrect power of ten in otherwise correct calculation of d • use of d =1480, 1.48, 14.8 (etc) • from incorrect order in 6bii = 5.25 x 10^{-7} (m) ✓ ecf **only** for : • incorrect power of ten in otherwise correct d • from incorrect order in 6bii			answer only gets 2 Power of 10 error in d gets max 2. For use of d in mm, answer = 5.25 x 10^{-4} gets max 2 n =2 gets max 2 unless ecf from 6bii use of d=1480 yields wavelength of 1150m
d		n = d (sin90) / λ OR n = 6.757 x 10^{-7} / 5.25 x 10^{-7} ✓ ecf both numbers from 6c = 1.29 so no more beams observed ✓ or answer consistent with their working **OR** 2 = d (sinΘ) / λ OR sinΘ = 2 x 5.25 x 10^{-7} / 6.757 x 10^{-7} ✓ ecf both numbers from 6c sinΘ = 1.55 (so not possible to calculate angle) so no more beams ✓	2		Accept 1.28, 1.3 Second line gets both marks Conclusion consistent with working
		OR $\sin^{-1}$(2 x (their λ / their d)) ✓ (not possible to calculate) so no more beams ✓ ecf			

10)

7a	Uniform width peaks ✓ (accurate to within ± one division) A collection of peaks of constant amplitude or amplitude decreasing away from central peak ✓	Peaks need to be rounded ie not triangular The minima do not need to be exactly zero. Pattern must look symmetrical by eye Condone errors towards the edge of the pattern Double width centre peak total mark = 0	2
7bi	Constant/fixed/same phase relationship/difference (and same frequency/wavelength) ✓	In phase is not enough for the mark	1
bii	Single slit acts as a point/single source diffracting/spreading light to both slits ✓ OR The path lengths between the single slit and the double slits are constant/the same/fixed ✓		1
biii	Superposition of waves from two slits ✓ Diffraction (patterns) from both slits overlap (and interfere constructively) ✓(this mark may come from a diagram) Constructive interference / reinforcement (at bright fringe) peaks meet peaks / troughs meet troughs ✓(any reference to antinode will lose this mark) Waves from each slit meet in phase OR path difference = $n\lambda$ ✓	phrase 'constructive superposition' = 2 marks	4max3

ci	$D = \frac{ws}{\lambda} = \frac{0.004 \times 5.0\ 10^{-5}}{405 \times 10^{-9}}$ ✓ **do not penalise any incorrect powers of ten for this mark** = 0.5 (m) ✓ (0.4938 m)	Numbers can be substituted into the equation using any form Note 0.50 m is wrong because of a rounding error. Full marks available for answer only	2
cii	fringes further apart or fringe/pattern has a greater width/is wider ✓	Ignore any incorrect reasoning Changes to green is not enough for mark	1

11)

a		single frequency (or wavelength or photon energy) ✓	1	not single colour accept 'very narrow band of frequencies'
b		subsidiary maxima (centre of) peaks further away from centre ✓ subsidiary maxima peaks further away from centre **AND** central maximum twice width of subsidiaries **AND** symmetrical ✓	2	For second mark: One square tolerance horizontally. One whole subsid max seen on either side. Central higher than subsid and subsid same height +/- 2 squares. Minima on the x axis +/- 1 square. Must see 1 whole subsidiary for second mark
c		ONE FROM: • don't shine towards a person • avoid (accidental) reflections • wear laser safety goggles • 'laser on' warning light outside room • Stand behind laser • other sensible suggestion ✓ • eye / skin damage could occur ✓	2	allow green goggles for red laser, 'high intensity goggles', etc. not 'goggles', 'sunglasses'
d		3 from 4 ✓✓✓ • central white (fringe) • each/every/all subsidiary maxima are composed of a spectrum (clearly stated or implied) • each/every/all subsidiary maxima are composed of a spectrum (clearly stated or implied) **AND** (subsidiary maxima) have violet (allow blue) nearest central maximum **OR** red furthest from center • Fringe spacing less / maxima are wider / dark fringes are smaller (or not present)	3	allow 'white in middle' For second mark do not allow 'there are colours' or 'there is a spectrum' on their own Allow 'rainbow pattern' instead of spectrum but not 'a rainbow' If they get the first, the second and third are easier to award Allow full credit for annotated sketch