1 Describe a laboratory experiment to investigate how the fundamental frequency of a stretched string depends on the tension in the string.

The stretched string has a mass per unit length of 1.5×10^{-3} kg m^{-1}.

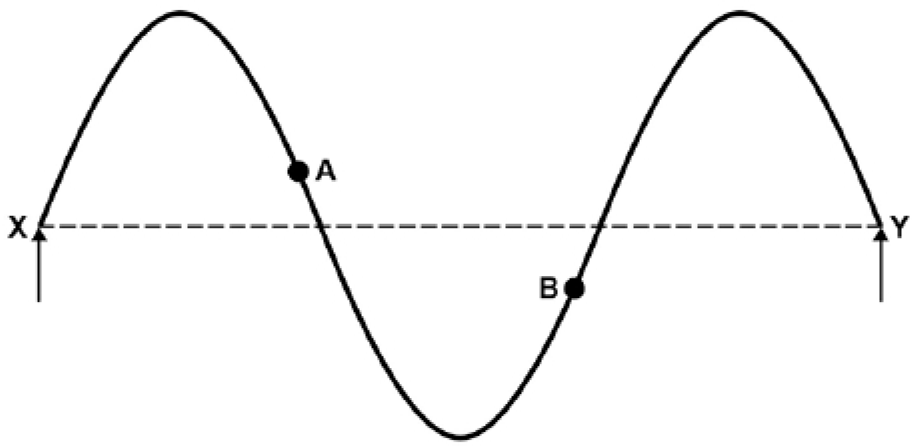
Your detailed method should include:

- a labelled diagram of the experiment arrangement
- suitable estimates of any quantities involved in the experiment
- how you would use the data to demonstrate the relationship between fundamental frequency and tension.

The quality of your written communication will be assessed in your answer.

(Total 6 marks)

2 The diagram below shows one position of a guitar string stretched between points **X** and **Y**. The string vibrates at a frequency of 330 Hz.



(a) State the phase relationship between points **A** and **B** on the string.

____

(1)

(b) Points **X** and **Y** are 0.66 m apart.

Calculate the speed of the wave along the string.

speed = ____________________ m s^{-1}

(2)

(c) The total mass of the string is 3.1 g and the total length of the string is 0.91 m.

Show that the tension in the string when it is sounding the harmonic shown in the diagram above is about 70 N.

(3)

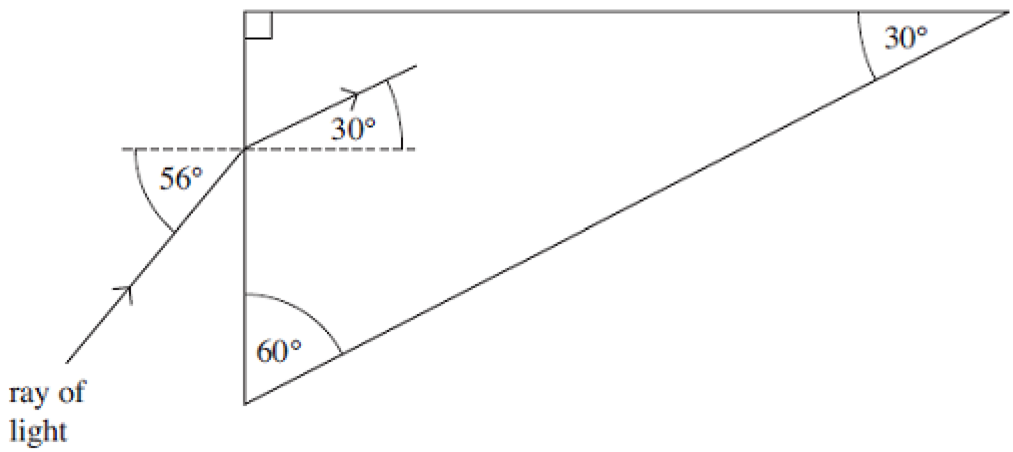
(d) The string is fixed at one end and wrapped around a tuning peg of radius 3.0 mm at the other. The tuning peg needs to be turned through 3 complete rotations to increase the tension in the string from 0 to 70 N in part **(c)**.

Discuss, by estimating the energy stored in the string, whether there is a significant risk to the guitar player when the string breaks.

(3)

(Total 9 marks)

3 The figure below shows a glass prism. Light is directed into the prism at an angle of 56°. The path of the ray of light is shown as is it enters the prism.



(a) (i) Calculate the refractive index of the glass.

answer = ______________________

(2)

(ii) Calculate the critical angle for the glass-air boundary.

answer = ______________________ degrees

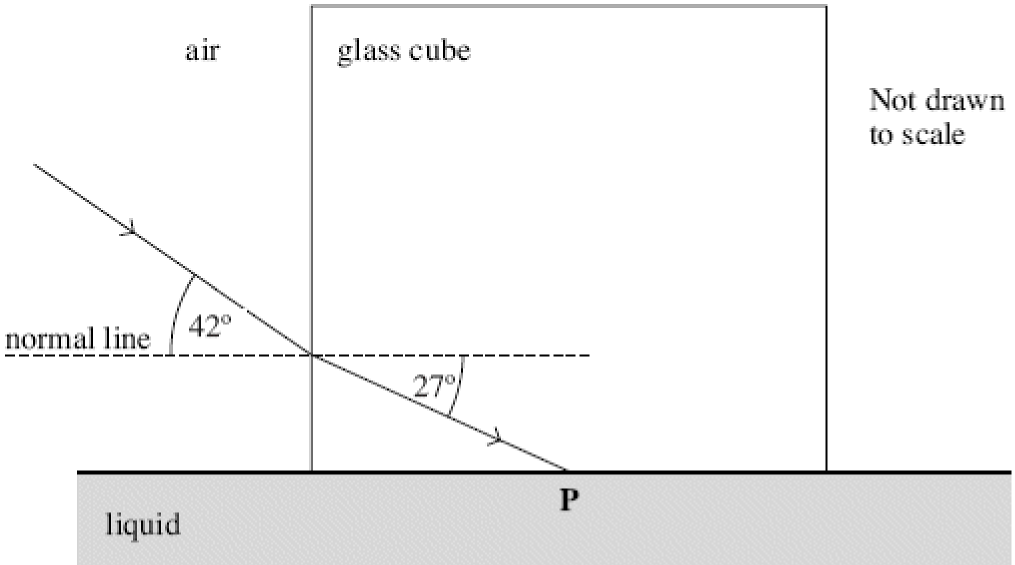
(2)

(b) On the figure above, continue the path of the ray of light until it emerges from the prism.

(2)

(Total 6 marks)

4 A glass cube is held in contact with a liquid and a light ray is directed at a vertical face of the cube. The angle of incidence at the vertical face is then decreased to 42° as shown in the figure below. At this point the angle of refraction is 27° and the ray is totally internally reflected at **P** for the first time.



(a) Complete the figure above to show the path of the ray beyond **P** until it returns to air.

(3)

(b) Show that the refractive index of the glass is about 1. 5.

(2)

(c) Calculate the critical angle for the glass-liquid boundary.

answer = ______________________ degrees

(1)

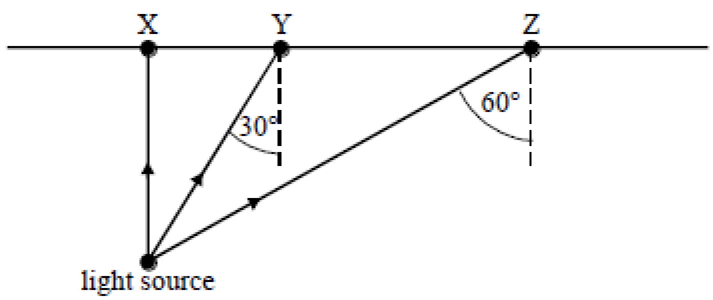
(d) Calculate the refractive index of the liquid.

answer = ______________________

(2)

(Total 8 marks)

5 A small intense light source is 1.5 m below the surface of the water in a large swimming pool, as shown in the diagram.



(a) Complete the paths of rays from the light source which strike the water surface at X, Y and Z.

(b) Calculate the diameter of the disc through which light emerges from the surface of the water.

speed of light in water = 2.25×10^8 m s^{-1}
speed of light in air = 3.00×10^8 m s^{-1}

____

____

____

____

____

____

(Total 7 marks)

6 A student has a diffraction grating that is marked 3.5×10^3 lines per m.

(a) Calculate the percentage uncertainty in the number of lines per metre suggested by this marking.

percentage uncertainty = ____________________ %

(1)

(b) Determine the grating spacing.

grating spacing = ____________________ mm

(2)

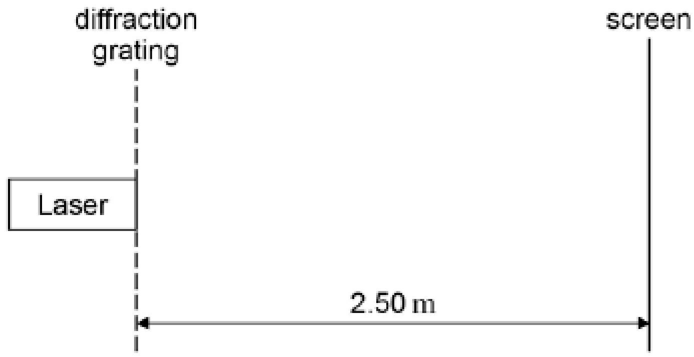
(c) State the absolute uncertainty in the value of the spacing.

absolute uncertainty = ____________________ mm

(1)

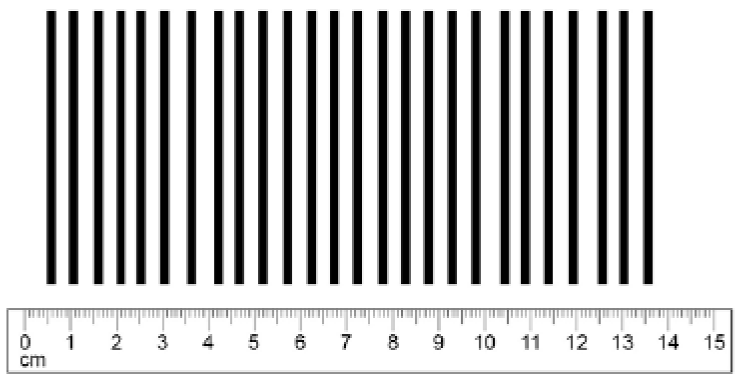
(d) The student sets up the apparatus shown in **Figure 1** in an experiment to confirm the value marked on the diffraction grating.

Figure 1



The laser has a wavelength of 628 nm. **Figure 2** shows part of the interference pattern that appears on the screen. A ruler gives the scale.

Figure 2



Use **Figure 2** to determine the spacing between two adjacent maxima in the interference pattern. Show all your working clearly.

spacing = ____________________ mm

(1)

(e) Calculate the number of lines per metre on the grating.

number of lines = ____________________

(2)

(f) State and explain whether the value for the number of lines per m obtained in part (e) is in agreement with the value stated on the grating.

(2)

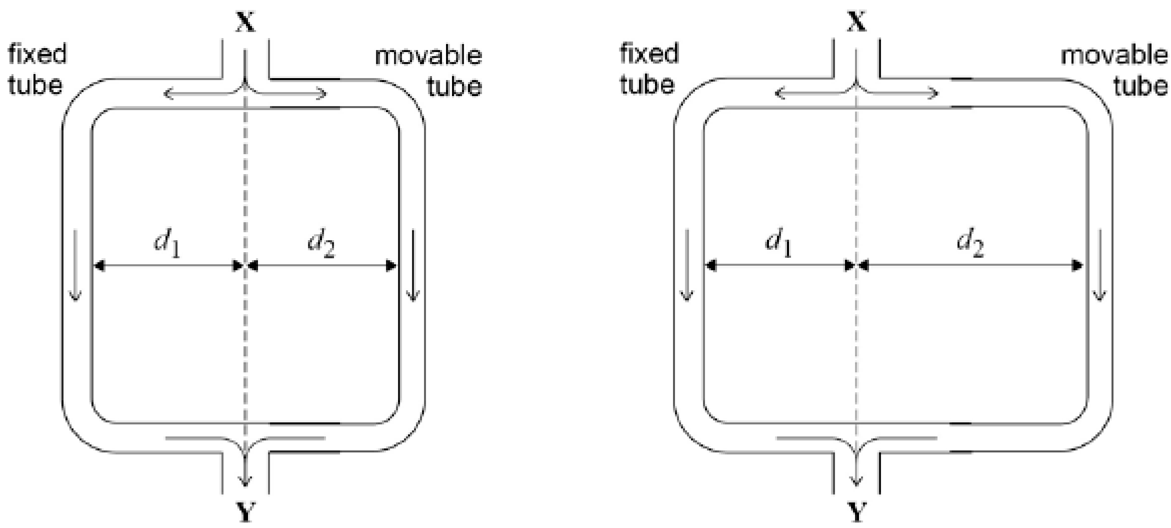
(g) State **one** safety precaution that you would take if you were to carry out the experiment that was performed by the student.

(1)

(Total 10 marks)

7 **Figure 1** and **Figure 2** show a version of Quincke's tube, which is used to demonstrate interference of sound waves.

Figure 1 **Figure 2**



A loudspeaker at **X** produces sound waves of one frequency. The sound waves enter the tube and the sound energy is divided equally before travelling along the fixed and movable tubes. The two waves superpose and are detected by a microphone at **Y**.

(a) The movable tube is adjusted so that $d_1 = d_2$ and the waves travel the same distance from **X** to **Y**, as shown in **Figure 1**. As the movable tube is slowly pulled out as shown in **Figure 2**, the sound detected at **Y** gets quieter and then louder.

Explain the variation in the loudness of the sound at **Y** as the movable tube is slowly pulled out.

____

____

____

____

____

____

____

(4)

(b) The tube starts in the position shown in **Figure 1**.

Calculate the minimum distance moved by the movable tube for the sound detected at **Y** to be at its quietest.

frequency of sound from loud speaker = 800 Hz
speed of sound in air = 340 m s^{-1}

minimum distance moved = ____________________ m

(3)

(c) Quincke's tube can be used to determine the speed of sound.

State and explain the measurements you would make to obtain a value for the speed of sound using Quincke's tube and a sound source of known frequency.

____

____

____

____

____

____

____

____

____

(4)

(Total 11 marks)

8 (a) A laser emits *monochromatic light*.

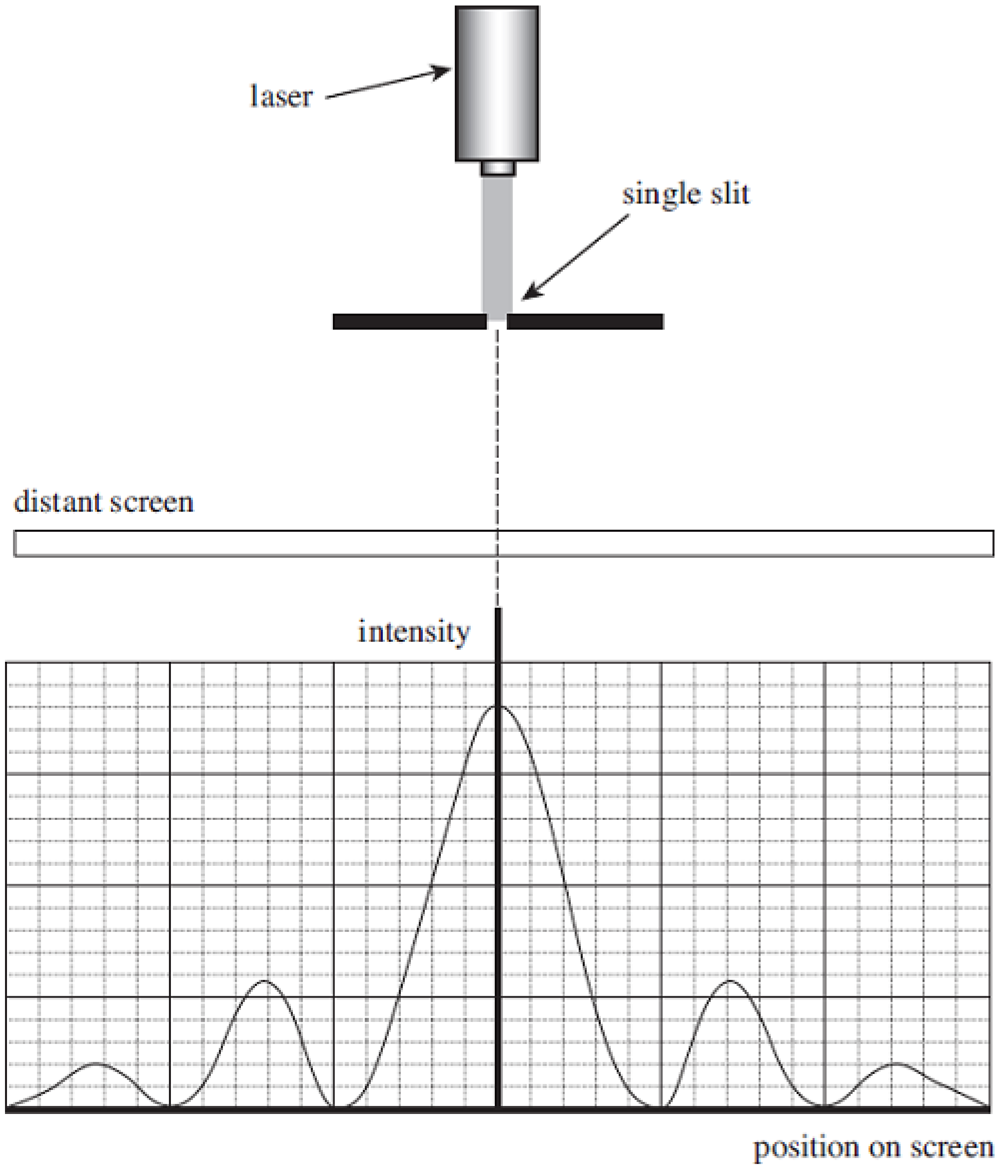
Explain the meaning of the term monochromatic light.

____

____

(1)

(b) The diagram below shows a laser emitting blue light directed at a single slit, where the slit width is greater than the wavelength of the light. The intensity graph for the diffracted blue light is shown.



The laser is replaced by a laser emitting red light.

On the axes shown in the diagram above sketch the intensity graph for a laser emitting red light.

(2)

(c) State and explain **one** precaution that should be taken when using laser light

____

____

____

(2)

(d) The red laser light is replaced by a non-laser source emitting white light.

Describe how the appearance of the pattern would change.

(3)

(Total 8 marks)

9 (a) Describe the structure of a step-index optical fibre outlining the purpose of the core and the cladding.

(3)

(b) A signal is to be transmitted along an optical fibre of length 1200 m. The signal consists of a square pulse of white light and this is transmitted along the centre of a fibre. The maximum and minimum wavelengths of the light are shown in the table below.

Colour	Refractive index of fibre	Wavelength / nm
Blue	1.467	425
Red	1.459	660

Explain how the difference in refractive index results in a change in the pulse of white light by the time it leaves the fibre.

(2)

(c) Discuss **two** changes that could be made to reduce the effect described in part (b).

(2)

(Total 7 marks)

10 A progressive wave of frequency 150 Hz travels along a stretched string at a speed of 30 m s^{-1}.

What is the phase difference between two points that are 50 mm apart on the string?

A	zero	○
B	90°	○
C	180°	○
D	360°	○

(Total 1 mark)

11 Which of the following statements about the behaviour of waves is **incorrect**?

A	All waves can be diffracted.	○
B	All waves can be made to undergo superposition.	○
C	All waves can be refracted.	○
D	All waves can be polarised.	○

(Total 1 mark)

12 Two radio transmitters emit waves at a frequency of 1.4 MHz. A stationary wave is set up between the two transmitters due to the superposition of the radio waves.

What is the minimum distance between two nodes in the stationary wave?

A	107 m	○
B	214 m	○
C	428 m	○
D	857 m	○

(Total 1 mark)

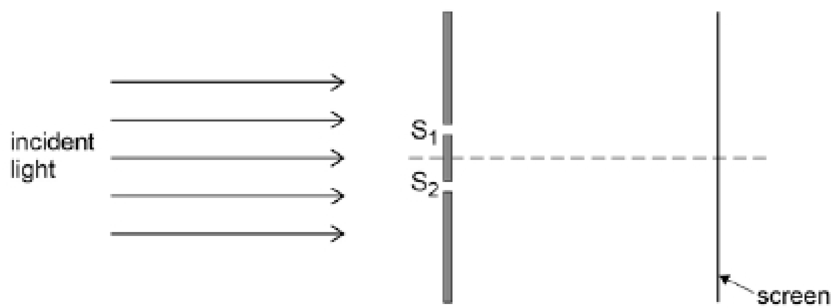
13 Two loudspeakers emit sound waves.

Which line in the table gives the correct frequency condition and the correct phase condition for the waves from the loudspeakers to be coherent?

	Frequency condition	**Phase condition**	
A	same frequency	variable phase difference	⬭
B	constant frequency difference	constant phase difference	⬭
C	constant frequency difference	in phase	⬭
D	same frequency	constant phase difference	⬭

(Total 1 mark)

14 When a parallel beam of monochromatic light is directed at two narrow slits, S_1 and S_2, interference fringes are observed on a screen.

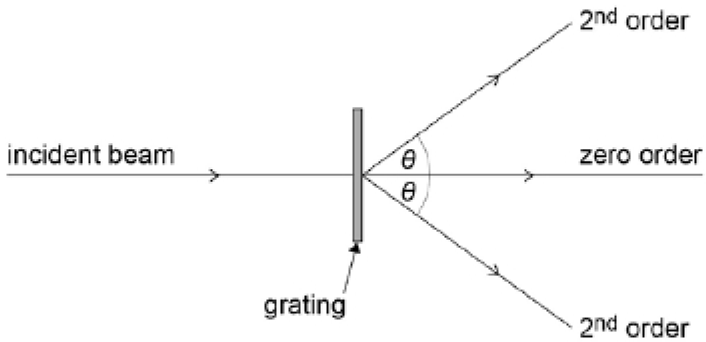


Which line in the table gives the changes that will increase the spacing of the fringes?

	Slit spacing	**Distance from slits to screen**	
A	halved	halved	⬭
B	halved	doubled	⬭
C	doubled	halved	⬭
D	doubled	doubled	⬭

(Total 1 mark)

15 A parallel beam of monochromatic light is directed normally at a plane transmission grating which has N slits per metre. The second order diffracted beam is at angle θ to the zero order transmitted beam.



The grating is then replaced by a plane transmission grating which has $2N$ slits per metre.

Which one of the following statements is correct?

A	With the first grating, the first order beam is at angle 0.5θ to the zero order transmitted beam.	○
B	With the second grating, the first order beam is at angle 0.5θ to the zero order transmitted beam.	○
C	With the second grating, the first order beam is at angle θ to the zero order transmitted beam.	○
D	With the second grating, the second order beam is at angle θ to the zero order transmitted beam.	○

(Total 1 mark)

16 A layer of liquid of refractive index 1.6 covers the horizontal flat surface of a glass block of refractive index 1.5. A ray of light strikes the boundary between them at an angle such that it travels along the boundary afterwards.

How does the ray strike the boundary?

A	it travels in glass at an angle of 70° to the boundary	○
B	it travels in glass at an angle of 20° to the boundary	○
C	it travels in the liquid at an angle of 70° to the boundary	○
D	it travels in the liquid at an angle of 20° to the boundary	○

(Total 1 mark)

17 Electrons and protons in two beams are travelling at the same speed. The beams are diffracted by objects of the same size.

Which correctly compares the de Broglie wavelength λ_e of the electrons with the de Broglie wavelength λ_p of the protons and the width of the diffraction patterns that are produced by these beams?

	comparison of de Broglie wavelength	diffraction pattern	
A	$\lambda_e > \lambda_p$	electron beam width > proton beam width	⬭
B	$\lambda_e < \lambda_p$	electron beam width > proton beam width	⬭
C	$\lambda_e > \lambda_p$	electron beam width < proton beam width	⬭
D	$\lambda_e < \lambda_p$	electron beam width < proton beam width	⬭

(Total 1 mark)

Mark schemes

1 The marking scheme for this question includes an overall assessment for the quality of written communication (QWC). There are no discrete marks for the assessment of QWC but the candidate's QWC in this answer will be one of the criteria used to assign a level and award the marks for this question.

Descriptor – an answer will be expected to meet most of the criteria in the level descriptor.
Level 3 – good
-claims supported by an appropriate range of evidence
-good use of information or ideas about physics, going beyond those given in the question
-argument well structured with minimal repetition or irrelevant points
-accurate and clear expression of ideas with only minor errors of grammar, punctuation and spelling
Level 2 – modest
-claims partly supported by evidence,
-good use of information or ideas about physics given in the question but limited beyond this the argument shows some attempt at structure
-the ideas are expressed with reasonable clarity but with a few errors of grammar, punctuation and spelling
Level 1 – limited
-valid points but not clearly linked to an argument structure
-limited use of information about physics
-unstructured
-errors in spelling, punctuation and grammar or lack of fluency
Level 0
-incorrect, inappropriate or no response

Level 3
Response will give a sensible diagram, suggestion of length of string and sensible range details of range of tension, the procedure to obtain data and the analysis of the data. The response may include a calculation of *f* for the chosen apparatus.

Level 2
All bullet points will be addressed but may lack essential detail. The response will include a sensible diagram and procedure but the procedure may be poorly explained. It should include how the data is analysed to demonstrate the relationship.

Level 1
Attempt will contain some relevant detail of a sensible experiment. The diagram may be poorly drawn. The range for the tension may be given but not be sensible. Their procedure and analysis may be only superficially described.

Level 0
Response will contain no relevant information about an appropriate experiment.

Points that may be included

- *Labelled diagram including string , weights, pulley, metre rule,*
- *method using signal generator (calibrated) and magnets to cause oscillation of the string*
- *method using tuning forks*
- *Length 1-2 m*
- *e.g Weights up to 12 N in 2 N increments (range of at least 6)*
- *Frequencies different by detectable amount on sig gen / use of range of tuning forks*
- *Calculation to show approx f value for selected T and l*
- *Method of changing T*
- *How frequency is determined for each T*
- *Graph of f against √T*

[6]

2 (a) π / 180° out of phase ✓

*Do **not** allow "out of phase".*

1

(b) wavelength = 0.44 m ✓

c (= $f\lambda$) = 145 (m s^{-1}) ✓

2

(c) First harmonic frequency = 110 Hz✓

$$T = 4 \times 110^2 \times 0.66^2 \times \left(\frac{3.1 \times 10^{-8}}{0.91}\right)$$ ✓

71.8 N✓

3

(d) Extension of string = $3 \times 2\pi \times 3.0 \times 10^{-3}$ (= 5.65 cm)✓

energy stored = 0.5 × 71.8 × 0.0565 = 2.03 (J)✓

Compares calculated energy quantitatively to another energy and draws correct inference, e.g. wire would be moving at about 80 mph so a risk / 2 J is the equivalent of 1 kg mass dropped through 0.2 m so a risk✓

3

[9]

3 (a) (i) sin 56 = n_{glass} sin 30 ✓

(n_{glass} = sin56/sin30) (= 1.658) = 1.7 ✓

2

(ii) $\sin \theta_c = 1/1.658$ ✓ ecf from ai

θ_c = (37.09 or 37.04) = 37 (degrees) ✓

accept 36 (36.03 degrees) for use of 1.7

2

(b) TIR from the upper side of the prism ecf from part aii

and correct angle ✓

refraction out of the long edge of the prism away from the normal ✓

2

[6]

4 (a) reflects at correct angle by eye (use top of '27' and bottom of '42' as a guide) **or 27**° or **63**° correctly marked **(1)**

refracts away from normal at glass/air **(1)**

symmetrical by eye or refracted angle (42°) correctly marked and at least one normal line added **(1)**

3

(b) $(n_g) = \frac{\sin 42}{\sin 27}$ **(1)** DNA 42/27 = 1.56

= 1.47 (1.474) 3 sf shown **(1)**

2

(c) 63 (°) **(1)**

allow 62 to 62.99 ***with*** *reasoning, allow 'slightly less than 63' without reason given*

1

(d) $\left(\frac{n_l}{n_g} = \frac{\sin 63}{\sin 90}\right) n_l$ = 1.474 sin (c) **(1)** or use of n = 1.5

= 1.3(1) or 1.34 if n = 1.5 used **(1)**

2

[8]

5 (a) ray straight through at X **(1)**
ray refracted at >30° at Y **(1)**
ray <u>totally internally</u> reflected at Z **(1)**

(b) $\frac{\sin \theta_{water}}{\sin \theta_{air}} = \frac{c_{water}}{c_{air}} \left[\text{or} = \frac{2.55 \times 10^8}{3.00 \times 10^8}\right]$

at critical angle $\sin\theta_{air} = 1$ **(1)**
$\sin\theta_{water} = 0.75$, $\theta_{water} = 48.6°$ **(1)**
radius = 1.5tan48.6° **(1)** =1.7m, ∴ diameter = 3.4m **(1)**

[7]

6 (a) 2.9% ✓

Allow 3%

1

(b) $\frac{1}{3.5 \times 10^3}$ seen ✓

1

0.29 mm or 2.9 x 10^{-4} m✓ must see 2 sf **only**

1

(c) ± 0.01 mm ✓

1

(d) Clear indication that at least 10 spaces have been measured to give a spacing = 5.24 mm✓

spacing from at least 10 spaces
Allow answer within range ±0.05

1

(e) Substitution in $d\ sin\theta = n\lambda$✓

The 25 spaces could appear here as n with sin θ as 0.135 / 2.5

1

d = 0.300 x 10^{-3} m so
number of lines = 3.34 x10^3✓

Condone error in powers of 10 in substitution

Allow ecf from 1-4 value of spacing

1

(f) Calculates % difference (4.6%) ✓

1

and makes judgement concerning agreement ✓

Allow ecf from 1-5 value

1

(g) care not to look directly into the laser beam✓
OR
care to avoid possibility of reflected laser beam ✓
OR
warning signs that laser is in use outside the laboratory✓
ANY ONE

1

[10]

7 (a) Initially the path difference is zero/the two waves are in phase when they meet/the (resultant) displacement is a maximum ✓

Alternative:

Constructive interference occurs when the path difference is a whole number of wavelengths and the waves are in phase

1

As the movable tube is pulled out, the path difference increases and the two waves are no longer in phase, so the displacement and loudness decrease ✓

Destructive interference occurs when the path difference is an odd number of half wavelengths and the waves are in antiphase

1

When the path difference is one half wavelength, the two are in antiphase and sound is at its quietest. ✓

Initially the path difference is zero and the sound is loud

1

As the path difference continues to increase, the two waves become more in phase and the sound gets louder again. ✓

As the pipe is pulled out the path difference gradually increases, changing the phase relationship and hence the loudness of the sound

1

(b) Use of *wavelength = speed / frequency*

The first mark is for calculating the wavelength

1

To give: 340 / 800 = 0.425 m ✓

Path difference = one half wavelength = 0.21 m ✓

The second mark is for relating the wavelength to the path difference

Path difference = 2 ($d_2 - d_1$) = 2 (distance moved by movable tube)

1

Distance moved by movable tube = 0.10 m. ✓

The final mark is for relating this to the distance moved by the tube and working out the final answer.

1

(c) Start with d1 = d2

(Alternative mark scheme involving changing frequency and measuring to first min for each one can gain equal credit)

Measure distance moved by movable tube for each successive minima and maxima✓

Start with d1 = d2

Measure distance moved by movable tube for first minimum.

1

Each change in distance is equal to one quarter wavelength. ✓

Distance is equal to one quarter wavelength

1

Continue until tube is at greatest distance or repeat readings for decreasing distance back to starting point. ✓

Repeat for different measured frequencies.

1

Use speed = frequency x wavelength ✓

Use speed = frequency x wavelength)

1

[11]

8 (a) single frequency (or wavelength or <u>photon</u> energy) ✓

not single colour
accept '<u>very</u> narrow band of frequencies'

1

(b) subsidiary maxima (centre of) peaks further away from centre ✓

For second mark: One square tolerance horizontally. One whole subsid max seen on either side.

subsidiary maxima peaks further away from centre **AND** central maximum twice width of subsidiaries **AND** symmetrical ✓

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

2

(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 ✓

allow green goggles for red laser, 'high intensity goggles', etc.

not 'goggles', 'sunglasses'

eye / skin damage could occur ✓

2

(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 centre
- Fringe spacing less / maxima are wider / dark fringes are smaller (or not present)

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'
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

3

[8]

9 (a) Core is transmission medium for em waves to progress (by total internal reflection) ✓

Allow credit for points scored on a clear labelled diagram.

1

Cladding provides lower refractive index so that total internal reflection takes place ✓

1

And offers protection of boundary from scratching which could lead to light leaving the core. ✓

1

(b) Blue travels slower than red due to the greater refractive index

Red reaches end before blue, leading to material pulse broadening ✓

The first mark is for discussion of refractive index or for calculation of time difference.

1

Alternative calculations for first mark

Time for blue = $d / v = d / (c / n)$ = 1200 / (3 × 10^8 / 1.467) = 5.87 × 10^{-6} s

Time for red = $d / v = d / (c / n)$ = 1200 / (3 × 10^8 / 1.459) = 5.84 × 10^{-6} s

Time difference = 5.87 × 10^{-6} – 5.84 × 10^{-6} = 3(.2) × 10^{-8} s ✓

The second mark is for the link to material pulse broadening

1

(c) Discussions to include:

Use of monochromatic source so speed of pulse constant

Use of shorter repeaters so that the pulse is reformed before significant pulse broadening has taken place.

Use of monomode fibre to reduce multipath dispersion ✓ ✓

Answer must make clear that candidate understands the distinction between modal and material broadening.

2

[7]

10 B **[1]**

11 D **[1]**

12 A **[1]**

13 D **[1]**

14 B **[1]**

15 C **[1]**

16 D **[1]**

17 A **[1]**

Examiner reports

1 Responses to this part were very disappointing and very few seemed to have conducted or seen such an experiment performed. Diagrams of apparatus were very poor and many were quite inappropriate for the experiment. Descriptions included no way of fixing the tension in the string and those who had some idea usually quoted use of increments of 100 g masses. Many seemed to think the experiment had to be conducted in such a way as to use calculations to determine the tension. A few made sensible suggestions such as the use of a set of tuning forks, microphone and oscilloscope or a stroboscope but most responses gave no method at all or an impractical method such as timing a number of oscillations using a stopwatch. When a vibrating mechanism was suggested this was often stated to be driven by dc and / or moved to produce tension with the other end fixed. Relatively few gave a sensible way of using the data.

3 Most students got the answer to part (a) (i) correct. However, examiners were looking for correct rounding and some students lost a mark for 1.6 or 1.65. A common incorrect approach was to select the equation with the ratio of speeds and use the two angles instead of speeds.

Most students were also correct in part (a) (ii). These questions always yield high marks.

Part (b) was quite poorly answered. Rays were not drawn carefully enough. It can be difficult to draw angles well without a protractor. A protractor is often useful for PHYA2. Students who cannot judge equal angles approximately by eye should be encouraged to use a protractor. The slanted edge of the prism in this question makes the judgement more difficult than usual. In this question students lose the mark if their line is more than five degrees from the true angle. Many students thought that the ray would refract rather than undergo total internal reflection even though they had calculated the correct critical angle. Many showed the refracted rays bending towards the normal rather than away.

4 Part (a) states that reflection occurs. However, half of all candidates were unable to show the ray of light reflecting from the glass-liquid surface. Those who did do this tended to also get the second mark for showing the ray refracting away from the normal line as it entered the air.

In part (b), most were able to use the angles given to successfully calculate the refractive index of glass. Most of these also remembered to give their answer to three significant figures (1.47).

For part (c), candidates needed to realise the incident angle had **just** passed the critical angle and therefore the critical angle would be 63° to two significant figures. Some chose 27° instead of 63°. A common incorrect approach was to use $1.0/1.5 = \sin \theta_c$.

Part (d) was quite a simple question but perhaps, because it was the last question, some candidates may have been short of time. Some may not have realised that they would get full credit for a correct method if they used their answer to part (c).

5 Part (a), which should have proved to be a source of easy marks, produced too many answers in which ridiculous rays were drawn.

There were many completely correct answers to part (b), but some candidates got no further than working out a refractive index from the speeds given.

8

(a) In general, this was a well answered question apart from a tendency for candidates to add extra detail, e.g. *'single wavelength <u>and coherent</u>'*; this loses the mark. As does: *'single wavelength / colour'*; because this implies that monochromatic could be just a single colour. However, *'light of a single wavelength and therefore a single colour'* would be acceptable. It is therefore best to learn the appropriate definition and not add any further detail.

(b) Many candidates did not know what to do on this question.

The red light subsidiary maxima were often shown closer to the central maximum than the blue.

Perhaps single slit diffraction tends to be a little overlooked because the specification does not require any mathematical description. Nevertheless, students should be shown images of the single slit pattern and how it changes for different wavelengths. Images are readily available on the internet via any search engine.

(c) When talking about laser safety, it is not acceptable to say simply 'wear *goggles'*. One must say *'<u>laser</u> safety goggles'*, *'<u>laser</u> safety glasses'*, or *'<u>laser</u> safety eyewear'*. Standard laboratory goggles would not afford any significant protection against laser light.

(d) Only a few candidates were able to describe the pattern accurately. Answers tended to be vague and ambiguous. Only a small number decided to add a sketch to clarify their answer and this approach should be encouraged. Again, perhaps the single slit has been overlooked by some in favour of the 'more difficult' double slit and grating.