Physics of the eye and ear

Q1.

(a) The fovea in a typical human eye consists of cones which have an average diameter of 1.5×10^{-6} m

An eye looks directly at two point sources of light which are 12 mm apart at a distance of 61 m from the centre of the eye lens. The fovea is at the centre of the retina a distance of 21 mm behind the centre of the eye lens.

Deduce whether the eye would be able to resolve the two images formed at the fovea.

_____

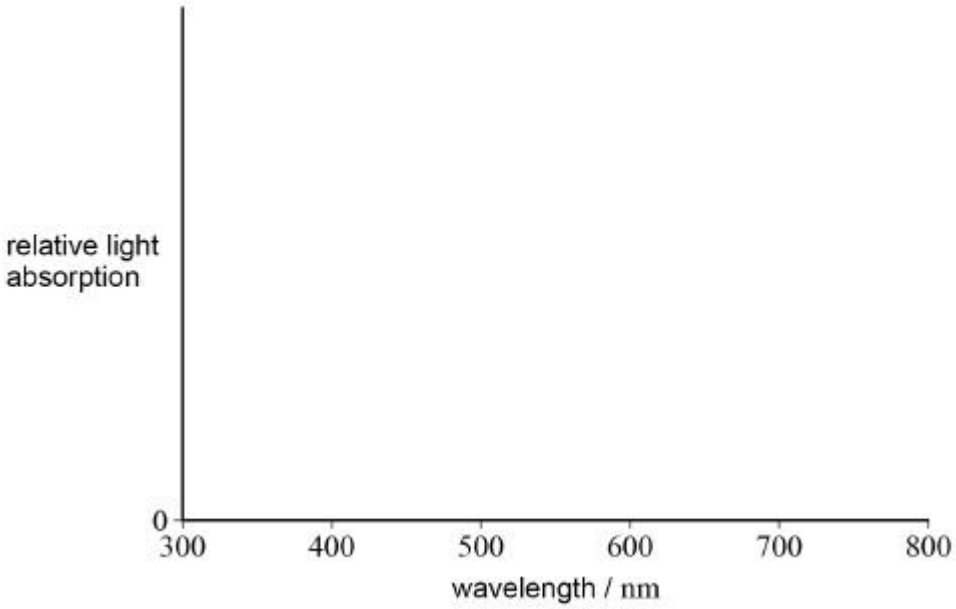
_____

_____

(4)

(b) Three types of cone are present at the fovea.

On the axis below sketch and clearly label **three** curves to show how the relative light absorption of each type of cone varies with wavelength.



(3)

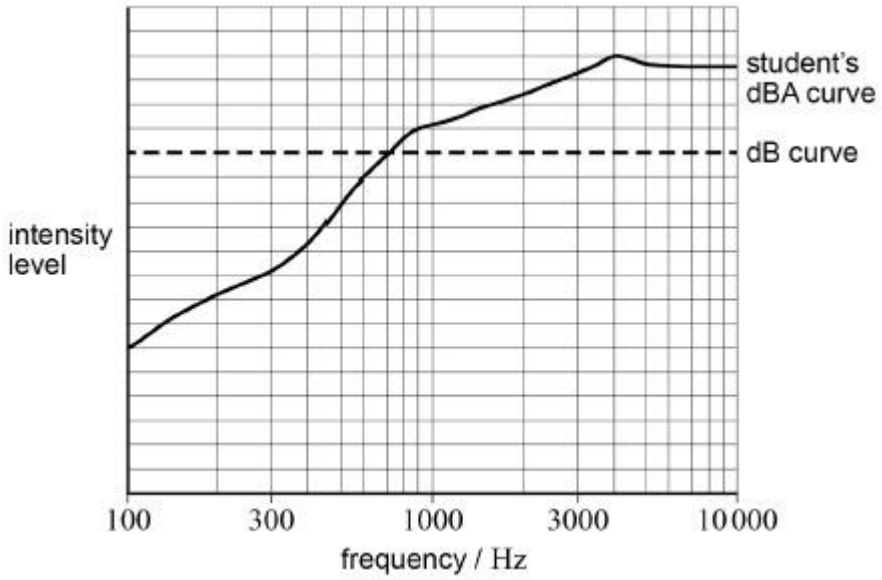
(Total 7 marks)

Q2.

(a) A source of constant output power is used to generate a sound which is measured using a sound meter.

The dashed line in the graph shows the intensity level curve over a range of

frequencies with the meter set to the dB setting.



A student sketches a curve, over the same frequency range, which he thinks would be obtained when the meter is changed to the dBA setting. The curve drawn by the student is shown as the solid line in the graph.

Discuss whether the dBA curve drawn is correct.

(4)

(b) Mesh barriers are set up to keep pedestrians at a safe distance from a noisy drill.
The maximum noise level which pedestrians should be subjected to is 110 dB
The drill emits sound with a power of 7.8 W and acts as a point source.
The mesh barriers are set up a distance of 2.0 m from the drill.

Discuss whether this will keep pedestrians at a safe distance from the sound source.

_____

_____

_____

_____

_____

_____

_____

_____

(4)

(Total 8 marks)

Q3.

A person suffers from hypermetropia (long sight).
Use of a spectacle lens of power +2.0D allows the person to just see clearly an object placed 24 cm away from the eye.

(a) Explain why the unaided defective eye cannot form a clearly focused image of the object placed 24 cm from the eye.

_____

_____

_____

_____

_____

_____

(2)

(b) An object is placed 24 cm from the spectacle lens.

Calculate the distance of the image formed from the spectacle lens.
Give your answer to a suitable number of significant figures.

image distance = _____ cm

(3)

(c) What is the name for the position where the image is formed by the spectacle lens?

Tick (✓) the correct box.

The eye's aided far point	☐
The eye's aided near point	☐
The eye's unaided far point	☐
The eye's unaided near point	☐

(1)

(d) Draw a ray diagram to show how this spectacle lens forms an image of the object placed 24 cm from the spectacle lens.
On your diagram clearly label the object, image and a principal focus of the lens.
Your diagram does not have to be drawn to scale.

(3)
(Total 9 marks)

Q4.

(a) A converging (convex) lens is placed 0.25 m from an object. The focused image produced is virtual and formed 0.64 m from the lens.

Calculate the power of the lens. Give a suitable unit for your answer.

power = _____ unit = _____

(3)

(b) Calculate the magnification produced.

magnification _____

(1)

(c) State the defect of vision that this lens can correct.

_____

_____

(1)

(d) A defective eye is found to suffer from astigmatism.

Discuss the cause, effect and correction of astigmatism.

_____

_____

_____

_____

_____

_____

(3)

(e) Give **two** values needed for the manufacture of a lens suitable for the correction of astigmatism.

1. _____

_____

2. _____

_____

(2)

(Total 10 marks)

Q5.

(a) Define the threshold of hearing.

_____

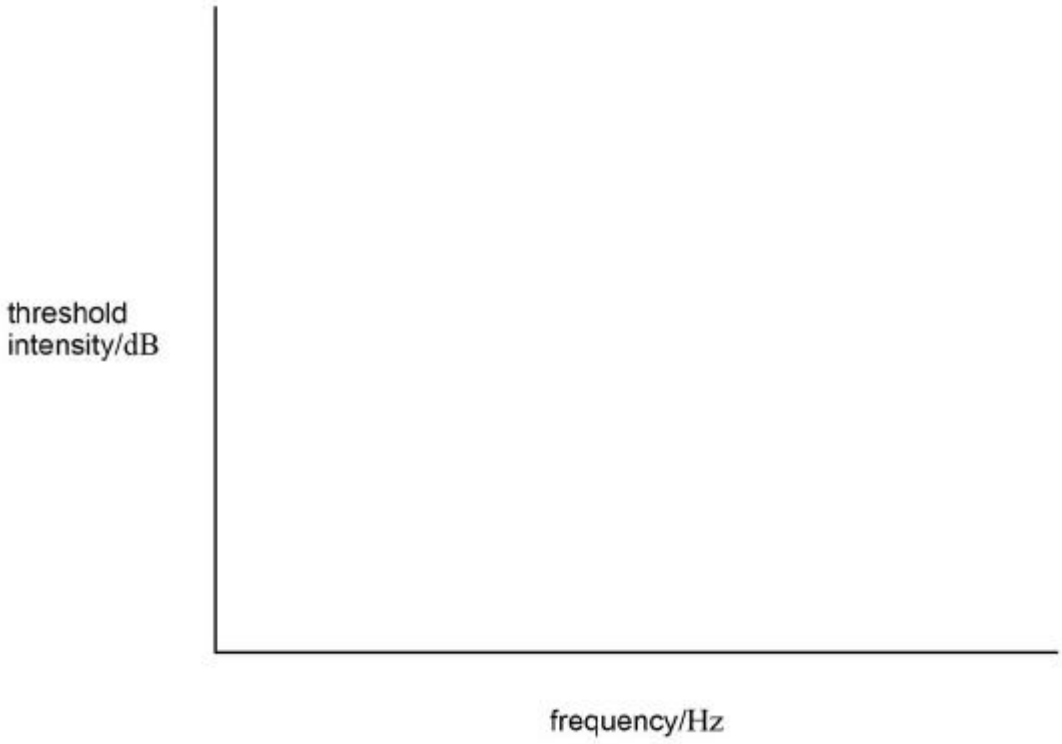
_____

_____

_____

(2)

(b) Sketch a graph to show how the threshold intensity, measured in dB, varies with frequency for a young person with normal hearing. Include scales on both axes.



(4)

(c) A sound of intensity 46 mW m^{-2} is incident on a soundmeter set to the dB scale. Calculate the reading on the meter.

reading = _____ dB

(2)

(Total 8 marks)

Q8.

(a) Two bright point sources of light are just resolved as individual images when viewed by a naked eye.

(i) State the condition needed for the images to be resolved by the retina.

_____

_____

(1)

(ii) The images are formed on the retina at the fovea.
Explain which type of receptor in the retina is being used to detect the images.

_____

_____

_____

(1)

(iii) The sources subtend an angle of 0.13 mrad at the naked eye. The eyeball may be assumed to be spherical with a diameter of 52 mm.
Calculate the maximum diameter of the receptor used.

diameter of receptor = _____ m

(2)

(b) (i) Describe the changes which occur in a normal eye when the eye changes from viewing a near object to viewing a distant object, both objects being viewed in bright light.

_____

_____

_____

_____

(2)

(ii) Describe the changes which occur in a normal eye as the eye changes from viewing an object in bright light to viewing the same object in very dim light.

_____

_____

_____

_____

_____

_____

_____

_____

_____

(3)

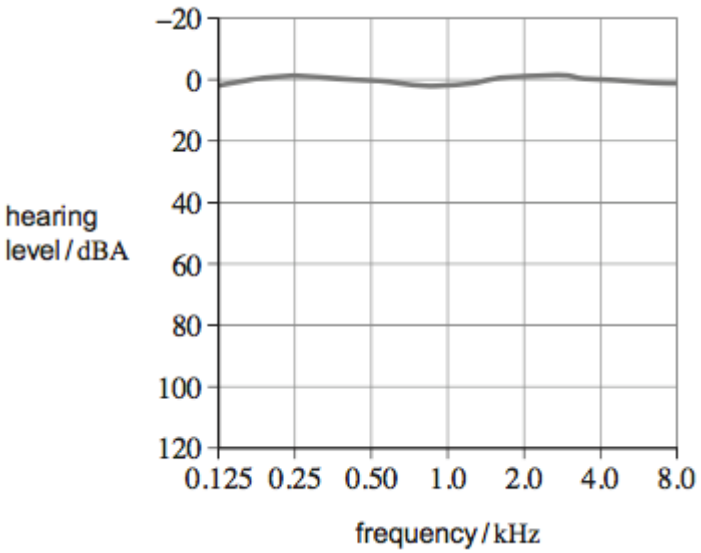
(Total 9 marks)

Q9.

Three people were given routine hearing tests. One person was found to have normal hearing and the other two were found to have defective hearing.

(a) **Figure 1** shows the variation of hearing level with frequency for the person found to have normal hearing.

Figure 1



It is known that the ear of a person with normal hearing is much more sensitive at 3 kHz than at other frequencies.
Explain why the graph indicates little variation with frequency.

_____

_____

_____

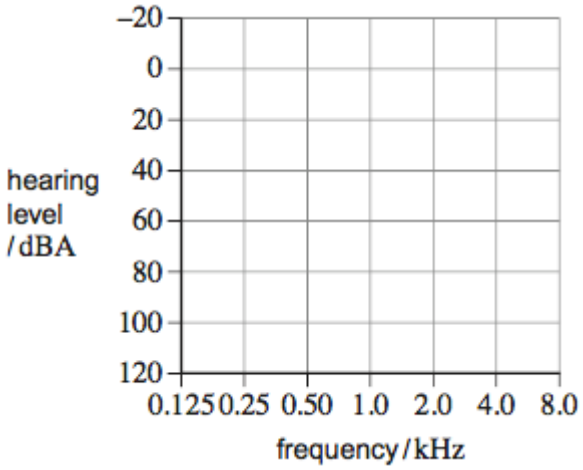
_____

(2)

(b) Of the other two people, one was found to be suffering from age-related hearing loss and the other was found to be suffering from noise-related hearing loss.

(i) Sketch on **Figure 2** the curve you would expect to see for the person suffering from age-related hearing loss.

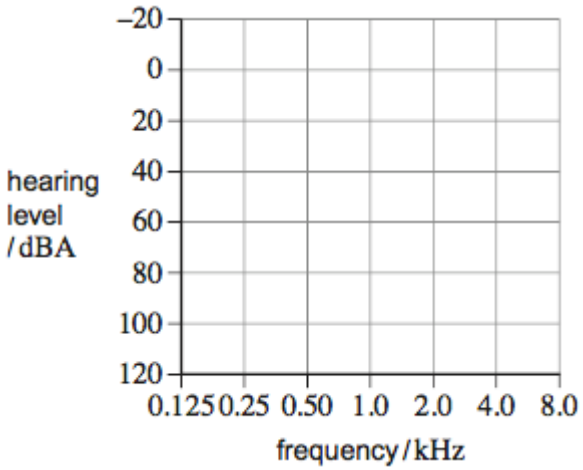
Figure 2



(1)

(ii) Sketch on **Figure 3** the curve you would expect to see for the person suffering from noise-related hearing loss.

Figure 3



(2)

(c) A foghorn at the top of a cliff produces a sound. A sound meter on the deck of a ship 400 m away from the cliff gives a reading of 92 dB.

(i) Calculate the intensity of the sound incident on the sound meter.

$I_0 = 1.0 \times 10^{-12}$ W m^{-2}

intensity = _____ W m^{-2}

(2)

(ii) The sound from the foghorn is emitted equally in all directions. Assume that the sound is not reflected at the surface of the sea and that there is no attenuation of the sound.

Estimate the power emitted by the foghorn

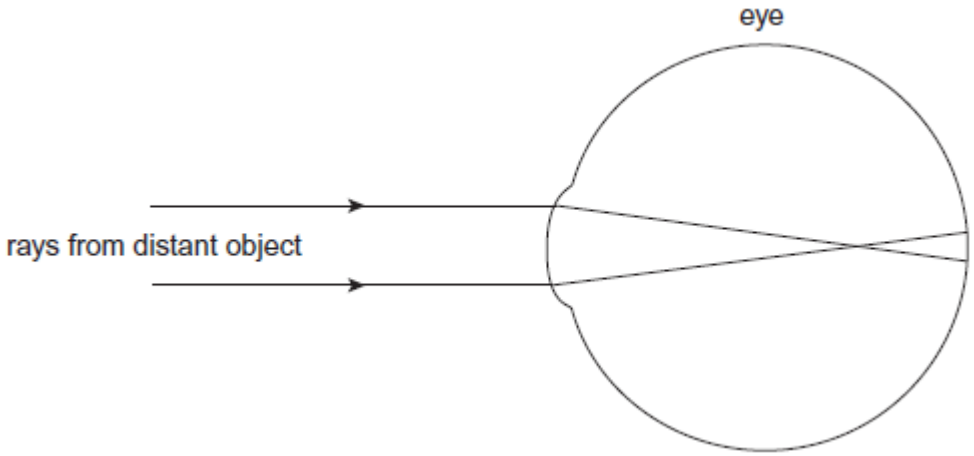
power = _____ W

(2)

(Total 9 marks)

Q10.

(a) The diagram below is a simplified ray diagram which shows light rays from a distant object being focused at a point in front of the retina.



(i) What is this defect of vision?
Tick (✓) the correct answer.

astigmatism	
hypermetropia / long sight	
myopia / short sight	

(1)

(ii) On the diagram above, draw in front of the eye a suitable lens to correct this type of defect of vision.

(1)

(iii) Complete the new diagram by drawing the path of the two rays from the distant object as they pass through the correcting lens and the eye.

(2)

(b) The unaided far point of the defective eye is 0.75 m.

(i) Explain why the focal length of the correcting lens used should be −0.75 m.

_____

_____

_____

_____

(1)

(ii) Calculate the power of this correcting lens.

power = _____ D

(1)

(iii) The unaided near point of the defective eye is 0.15 m.

Calculate the distance of the aided near point from the eye when the lens of focal length −0.75 m is used. Give your answer to a suitable number of significant figures.

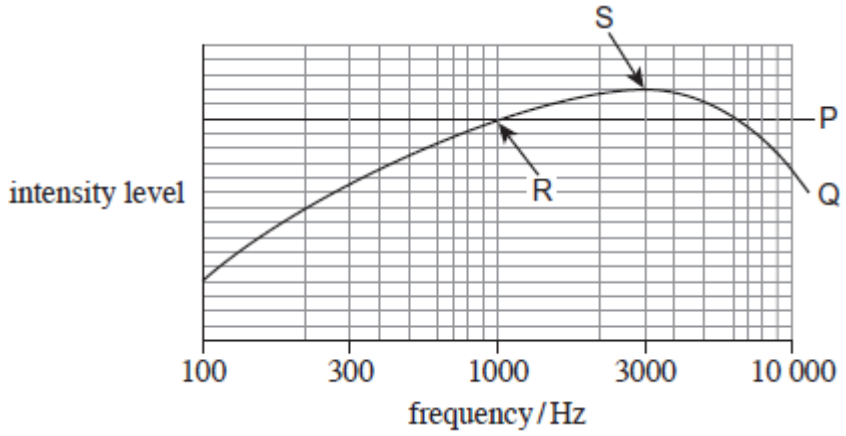
aided near point distance = _____ m

(3)

(Total 9 marks)

Q11.

(a) A variable-frequency sound source produces sound of equal intensity at all frequencies. Two sound meters are placed at equal distances from the source. The two meters are set on different scales. Lines P and Q on the graph show how the intensity level indicated by each meter varies with frequency.



(i) State and explain which sound meter scale is used for line P.

(2)

(ii) State and explain which sound meter scale is used for line Q.

(2)

(b) (i) Explain the significance of the point R.

(1)

(ii) Explain the significance of the point S.

(1)

(c) A sound of intensity level 95 dB is incident on a human ear.
Calculate the intensity incident on the ear drum.

$I_0 = 1.0 \times 10^{-12}$ W m^{-2}

intensity = _____ W m^{-2}

(2)

(Total 8 marks)

Q1.

(a) d / 21 × 10^{-3} = 12 × 10^{-3} / 61 ✓

d = 4.1 × 10^{-6} m ✓

4.1 / 1.5 = 2.75 ✓

Eye can resolve the images as they are more than 2 cell diameters apart / a distance greater than 3 × 10^{-6} m apart / separated by at least 1 unstimulated cell ✓

Marks 3 and 4 are ECF.

4

(b) Three curves labelled blue, green, red from left to right ✓

Roughly at correct height green, red above 2/3 green, and blue less than 1/3 green ✓

Blue 375 to 500, green 425 to 675, red 475 to 725 ; all + or –30 ✓

3

[7]

Q2.

(a) Mention of ear's sensitivity starting low, increasing to maximum and then falling again resulting in convex nature of their curve which is wrong as does not fall after 5 kHz / should fall at higher frequencies and not plateau ✓

Mention of 1 kHz being the reference frequency for both scales / mention of 3 kHz being the frequency of maximum sensitivity of the ear ✓

both scales should have same reading at 1 kHz which they don't / it is wrong that the curves cross at about 750 Hz ✓

dBA curve should have maximum value at 3 kHz which it doesn't / wrong as max sensitivity of dBA scale is shown at 4 kHz ✓

4

(b) Initial use of 110 dB in correct equation –

110 = 10 log (I / I_0)

leading to correct calculation of intensity = 0.10 (W m^{-2}) ✓

Use of equation the calculated intensity = 7.8 / $4\pi r^2$ ✓

Leads to distance = 2.5 m ✓

Thus 2 m is slightly too close to the drill as it is less than 2.5ml ✓

The 4 marks are basically

1. The correct manipulation of the equation relating intensity and power.

2. The correct answer from this.

3. The correct use of the decibel equation.

4. A suitable statement relating numbers.

These marks can come in any order depending on how they attack the problem. They may do 3 before 1 and 2, as in my original mark scheme, but many are doing 1 and 2 before 3.

If 1 is wrong then this is EOP and thus 2 cannot be awarded, but 3 and 4 are ECF and are still available.

Be aware that by using the initial power and distance quoted in the question, the final answer for the intensity level is 112 dB. Some candidates may then say that to 2sf, this is 110 dB which is that quoted as the safe level. This argument must be given the credit which it deserves.

Remember that ECF is available from 2 to 3, or from 3 to 1 and 2.

The final mark is for a sensible comment based on their final answer with some numeric comparison.

4

[8]

Q3.

(a) Eye lens cannot be made powerful enough / rays cannot be bent enough / eyeball is too short ✓

cannot be brought to a focus on the retina / fovea / back of the eyeball ✓

Accept not strong / fat / convex enough

Do not accept fat enough – neutral answer

Accept rays would be / are focused behind the retina

2

(b) $\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$

$\frac{1}{0.24}+\frac{1}{v}=2$ ✓

v = (-) 46 (cm) ✓

ans to 2 sig figs ✓

Use of 2 and 1/24 is AE

Answer 0.46 gets 1 working mark

3

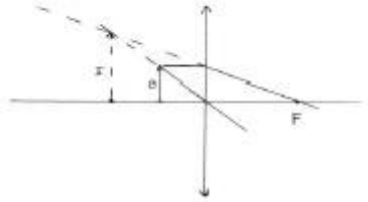
(c) **D** the eye's unaided near point

1

(d) first correct ray ✓

completed ray diagram with two rays and 'image' drawn ✓

labelled object, image and at least 1 principal focus. ✓



First two marks are for a diagram showing a virtual image

Third mark is for any diagram. Do not allow f for F unless other labelling is present.

3

[9]

Q4.

(a) $P = \frac{1}{f} = \frac{1}{u} + \frac{1}{v} = \frac{1}{.25} + \frac{1}{-.64}$ ✓

= +2.4 ✓

D ✓

Must see positive sign in answer.

3

(b) Magnification = 2.6 ✓

1

(c) "Long sight ***OR*** hypermetropia" ✓

Accept presbyopia or non-spherical cornea.

1

(d) Cause: non-spherical cornea ✓

Effect: focus in one plane, out of focus in plane at 90° ✓

Correction: cylindrical (for correction lens) ✓

3

(e) 1 power ✓

2 axis of defect ✓

2

[10]

Q5.

(a) minimum power needed for normal ear to hear a sound ✓

at frequency of 1 kHz ✓

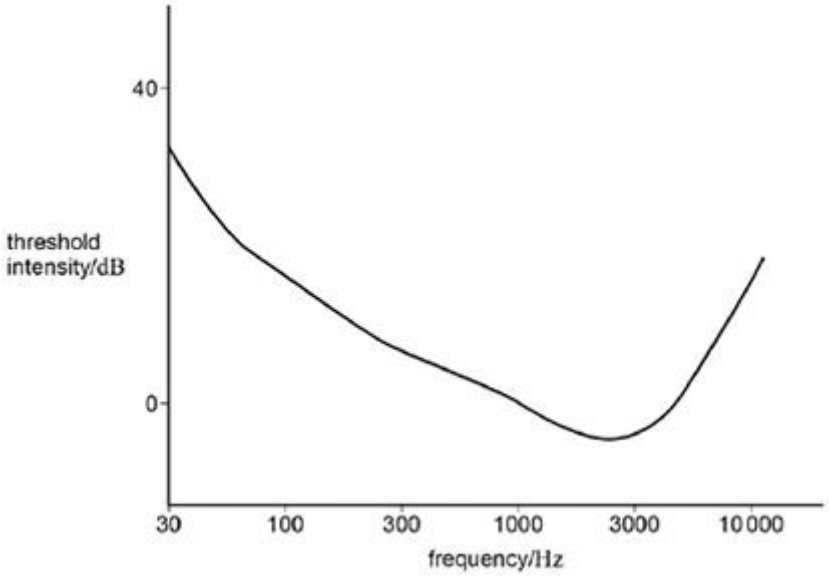
2

(b) Sensible scales ✓

General shape ✓

Point 0dB at 1000 Hz ✓

Minimum below 0 dB at frequency 3000 Hz ✓



4

(c)

$$10 \log \left(\frac{0.046}{1 \times 10^{-12}} \right)$$ ✓

110 (107) dB ✓

2

[8]

Q8.

(a) (i) The two images are formed on receptors / cells separated by at least one **unstimulated** receptor / cell

Allow images separated by at least 2 cell diameters

1

(ii) Cones are used as **ONLY** cones at fovea

1

(iii) Distance images apart on retina = 2 × cone diameter
Diameter = $(0.130 \times 10^{-3} \times 52 \times 10^{-3}) / 2 = 3.4 \times 10^{-6}$ m

Allow 1 mark for correct sep of images calc.

$(0.130 \times 10^{-3} \times 52 \times 10^{-3})$ in calc

Allow 1 mark for wrong distance calc divided by 2

for final answer / angle divided by 2

1
1

(b) (i) Ciliary muscles relax / suspensory ligaments contract
Producing lens of less power / greater focal length

Allow decreasing the curvature of the lens / flatter / thinner / less spherical

1
1

(ii) Cones stop working and rods start
enlarged pupil

Accept dilated pupil

Then the third mark for
either dark adaptation – takes some mins for rods to fully function / eye to **adapt**
or (Iris) circular muscles relax / (iris) radial muscles contract

Accept concentric for circular

1
1
1

[9]

Q9.

(a) (Intensity) measured on dBA scale / adjusted scale which mimics normal ear (so values around 0dBA) at all frequencies

1
1

(b) (i) Figure 2 - falling to larger values as frequency increases

Start must be between 0 and 20 dBA
must not consistently go above 0dBA
must cover the 0.125 to 8 kHz range
can go on after 8 kHz

1

(ii) Figure 3 – falling to larger values and then going up to smaller values as frequency increases
Maximum value at f = 4 kHz

Start must be between 0 and 20 dBA
must not consistently go above 0dBA
must cover the 0.125 to 8 kHz range
can go on after 8 kHz

1
1

(c) (i) $I = I_0 \times 10^{9.2}$ or correct substitution in formula

1

$I = 1.6 \times 10^{-3}$ W m^{-2}

1

(ii) Use of $4 \times \pi \times 400 \times 400$
Correct calc to give 3.2×10^3 W

Allow ecf from previous calculation

1
1

[9]

Q10.

(a) (i) Ans C; Myopia or short sight

Auto marked

1

(ii) Concave / diverging lens drawn

1

(iii) Rays diverge at correcting lens

1

Rays converge at eye and are focussed at retina

1

(b) (i) So that rays (from a distant object)appear to come from the far point (of the defective eye)

OR to form (virtual) image at the (unaided) far point

1

(ii) f = - 0.75

P = 1 / f = - 1.3 (D)

Do not accept − 4 / 3

1

(iii) $1 / u = 1 / f - 1 / v = \frac{1}{-0.75} - \frac{1}{-0.15}$

1

u = 0.19 (m)

1

2 sig figs

1

[9]

Q11.

(a) (i) The dB scale

Allow decibel scale Not DB

1

Equal response across all frequencies

Allow unaffected by / independent of frequency

1

(ii) The dBA scale

Allow adjusted / adapted decibel scale Not DBA

1

Response depends upon **frequency** as **ear's response** does

1

(b) (i) Point R has equal values on both scales (as 1kHz) is the frequency used to define threshold value

Allow reference frequency for dBA scale

1

(ii) Point S is at (3kHz as this is) the frequency at which the ear is most sensitive

Allow most sensitive as at peak of curve

1

(c) $I = 1.0 \times 10^{-12} \times 10^{9.5}$

First mark for any correct initial equation

1

$I = 3.2 \times 10^{-3}$ (W m^{-2})

Only penalise 1 sig fig

1

[8]

Q1.

The first part, (a), required the students to use the data provided to make a sensible comment on whether the eye could resolve two images on the retina. This could be done in many ways, but the final statement required a direct comparison between either two calculated values, or a comparison between a calculated value and data quoted in the question. In order to gain full marks, students needed to demonstrate that in order to ensure that two images could be resolved, the minimum distance between the two images was greater than two cell diameters. This point was missed by many students who either used one or three cell diameters as the limiting factor. Many other students could not use the data supplied in a meaningful way, with a surprising number trying to use the lens equation to work out a focal length. The mean mark on this question was 0.97 out of 4, with 8.7% of students scoring all four marks available.

Part (b) required students to sketch and label the response curves for the three colour cones of the eye. Although most students gained a mark for drawing three curves and naming the curves blue, green and red with increasing wavelength, hardly any gained either of the other marks for relative heights or range of wavelengths.

Q2.

Part (a) showed a suggested graph drawn by a student to show the response of a sound meter set to the dBA scale over a range of frequencies in relation to the curve for the dB setting, showing constant output power of the source. The students were asked to discuss whether the curve drawn by the student was correct. There were three main points which were wrong, the fact that the two curves did not cross at 1000 Hz, the fact that the peak of the dBA curve was not at 3000 Hz, and the fact that there was a 6 kHz plateau in the dBA curve. There were many good answers to individual errors, but few were able to put all the answers together and gain full marks. A noticeable number of students suggested that the dBA curve was upside down. The other noticeable error was the inability to read the logarithmic scale, suggesting that the peak of the dBA curve was 3100 or 3200 Hz. Unfortunately, just over 45% of students failed to score on this question.

Part (b) was answered well by many students, with over a quarter of them gaining all four marks. There were many ways to attempt this question and the examiners were impressed with some of the approaches used by students. The marks were awarded for different calculations which involved specific equations and a final mark for an adequate discussion comparing either the student's calculated answer with a value quoted in the question, or two calculated answers. The main source of error, which led to a two-mark penalty, was using the wrong formula for the area of a sphere when relating intensity and power. An error here was carried forward so that the remaining marks could still be gained.

Q3.

This question was on the defect of the eye and its correction.

In part (a) many students only provided one of the points needed. Students sometimes lost a mark by providing a correct answer and a wrong answer for the same point, for example 'the eyeball was too short or the lens was too strong'.

In part (b) it was pleasing to find few students who found '*u*', the object distance, rather than '*v*', the image distance. However, the units in the calculation proved to be challenging for many students. The power of lens in dioptres meant that object distance needed to be

in metres in the calculation. The final answer then needed to be converted back to centimetres. The most common wrong answer was '0.51' which only gained 1 mark for the correct number of significant figures.

Part (c) proved to be difficult, with the majority of students thinking that it was 'the aided near point' rather than the correct answer of 'the unaided near point'.

Part (d) required a ray diagram to be drawn, which a significant number of students were unable to do. Students should be aware that when using a correcting lens, objects are always real and images are always virtual. The majority of diagrams showed the formation of a real image. Many students also failed to score the labelling mark for correct labelling of object, image and a correct principal focus. The students who were able to draw the correct ray diagram were, in the main, also able to correctly label the diagram.

Q8.

(a) (i) A common incorrect answer was where the students talked about the separation of the objects rather than that of the images. The separation between the images of one receptor cell needed a statement that that receptor was unstimulated.

(ii) It was hoped that the answer of cone cells would be explained easily as there are only cones at the fovea. However, many students failed to gain this mark with a common answer stating 'cones as they are only situated at the fovea'.

(iii) The majority of students were able to gain a mark for the initial calculation multiplying angle by distance to get separation on the retina. However, few students were able to gain the final answer. The main mistakes in the initial calculation were failing to use the correct units. Several students were penalised for using the radius of the eye in the calculation which was an error of physics.

(b) (i) Most students were able to gain one mark, but many could not give the detail required for both marks. Wrong answers included 'cilliary muscles stretch the cornea', 'the eyeball becomes less spherical' and 'the cornea relaxes'.

(ii) Again the wording of answers failed to state clearly what was happening. Examples of this include 'the iris expands', the iris opens up', 'the diameter of the iris will change', 'the pupil relaxes' and 'the pupil contracts'. All of the answers mentioned above failed to give an accurate credit worthy response. Many students talked about the changes to the image rather than the changes to the eye itself; this was a problem with reading and interpreting the question rather than knowledge.

Q9.

(a) We hoped that students would recognise that the dBA scale was being used and thus explain the level nature of the graph with frequency to match the ears response with changing frequency. Most students gained the first mark stating that dBA was used, but a few students didn't for using 'bda', 'DBA', or any other wrong combination of letters. Less than half of the students were then able to give the explanation required for the second mark. Several students suggested that the flat nature of the ear's response was due to the scale on the hearing level axis being too large.

(b) (i) This should have been a straight forward answer showing increased loss of hearing with frequency. Many students failed to draw a suitable curve,

common errors involving lines which failed to cover the full frequency range, lines which started above 0 dBA and lines which were level at a reduced dBA value.

(ii) Most students were able to gain the first mark for showing an increasing loss and then a decreasing loss, but few gained the second mark for showing the maximum loss occurring at 4 kHz.

(c) (i) Many students were able to do this calculation. However, there are still a significant number of students who put the correct numbers into the basic equation, but then confused the 'log' function with the 'ln' function.

(ii) There was an ecf from incorrect answers to the previous calculation, so no student was penalised twice. However, it was sad to see that very few students were able to answer this part correctly with many using the area of a circle or the volume of a sphere rather than the surface area of a sphere.

Q10.

This question was about the short sight and its correction.

(a) (i) Nearly all students were able to show a diverging lens was required to correct the defect.

(ii) The instructions on the front of the paper state that all students should have a ruler. A lot of students lost marks due to the poor free-hand drawing of rays which showed rays curving as they neared the retina to allow them to meet at the retina. Some students lost marks as they allowed the rays to continue past the retina and out of the back of the eye. Other students lost marks as they drew the top ray and the bottom ray starting to diverge from different points relative to their lens or starting to diverge away from the lens.

(b) (i) Many responses failed to answer the question asked. There were a noticeable number of students who suggested that the correcting lens was to form an image at infinity for an object at the unaided far point, whilst others suggested that it did not matter where the object was, the virtual image would always be formed at the unaided far point.

(ii) The majority of the students gained this mark, but it was noticeable that some students ignored the negative sign, some even writing in the answer that you cannot have a negative power for a lens.

(iii) As in the past, a large number of students confused the object and the image, showing clearly that they were working out the image distance which was an error of physics. These students were still able to gain the final mark if they gave their answer to 2 sig figs. There was a significant number of students who failed to gain the last mark as they gave their answer to too many significant figures.

Q11.

This question involved the readings on meters set to different sound scales measuring the intensity level.

(a) (i) Many students lost marks through careless use of DB, Db, or db all of which showed a lack of understanding of the correct dB. Although the first mark was lost for these errors, the students were still able to gain the second mark for a

correct explanation.

(ii) The same errors as mentioned above in (a)(i) were also evident in this part.

(b) (i) Many students just stated that this was where the two lines crossed and failed to explain the significance of this frequency, 1 kHz, rather than where they cross again at 6 kHz.

(ii) Again there were too many bald answers which failed to explain the significance of the frequency at this point or incorrect answers which showed a lack of understanding. These answers included ‘the maximum level that a human ear can hear’, ‘frequency at which the ear resonates’, ‘highest frequency heard by the human ear’, and ‘the point at which’ rather that the frequency at which the ear is most sensitive.

(c) There were two main errors. The majority of students were able to put the numbers in the basic equation, but there were a noticeable number who then failed to get the correct answer as they went from log to a power of ‘e’ rather than to a power of 10. The other error was with a minority of students who used 95 as the intensity and then went on to calculate an intensity level.