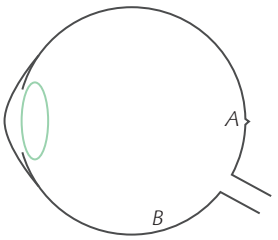
Original Questions

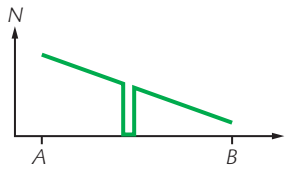
Book 9

Chapter Exercise

Multiple-choice Questions

1. The figure shows two points *A* and *B* on the retina. Which of the following diagrams best represents the distribution of cones from *A* to *B*?
(*N*: number of cones)



A.


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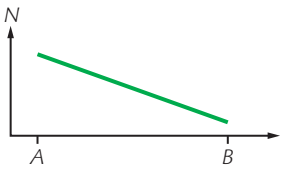

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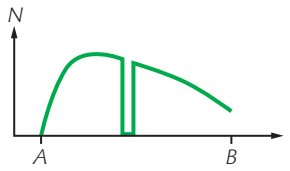
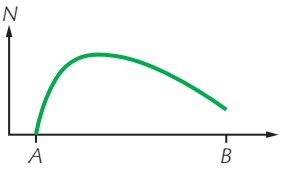


D.


2. Ben is staring at a moving object. The thickness of his lens gradually increases as the object moves. Which of the following statements is correct?

A. The object is moving away from him.
B. The ciliary muscle gradually contracts.
C. The power of his eye gradually decreases.
D. The focal length of the lens gradually increases.

3. A lens has a power of +0.5 D. Which of the following statements about the lens are correct?

(1) It is a convex lens.
(2) Its focal length is 200 cm.
(3) It can be used to correct long sight.

A. (1) and (2) only
B. (1) and (3) only
C. (2) and (3) only
D. (1), (2) and (3)

4. A lens forms a virtual image at a distance of 5 m from it. The linear magnification of the image is 3. What is the power of the lens? Is the lens corrective for short sight or long sight?

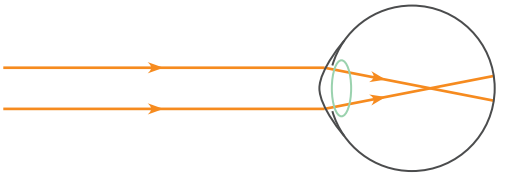
A. +0.4 D, short sight
B. +0.4 D, long sight
C. +0.8 D, short sight
D. +0.8 D, long sight

5. Timothy is suffering from short sight and his far point is 2 m. Which of the following statements are correct?

(1) When he views an object 1 m away from him, the image is formed behind the retina.
(2) When he views an object 4 m away from him, the image is formed in front of the retina.
(3) The focal length of the lens to correct his defect should be 2 m.

A. (1) and (2) only
B. (1) and (3) only
C. (2) and (3) only
D. (1), (2) and (3)

6. The figure shows how parallel light rays enter a defective eye of a person. Which of the following statements are correct?



(1) The far point of the eye is NOT at infinity.
(2) The person may suffer from long sight.
(3) A concave lens can be used to correct the defect.

A. (1) and (2) only
B. (1) and (3) only
C. (2) and (3) only
D. (1), (2) and (3)

7. Jenny has a near point 4 m from her eyes. Find the power of the lens that can correct the near point to 0.25 m.

A. +3.75 D
B. +0.267 D
C. −0.267 D
D. −3.75 D

8. The intensity level of a sound is increased from 20 dB to 35 dB. What is the intensity ratio of the initial sound to the final sound?

A. 1 : 1.2
B. 1 : 1.8
C. 1 : 15
D. 1 : 32

9. The sound intensity level in an empty classroom is 30 dB. When 40 physics students are in the room, the intensity level becomes 70 dB.

What is the intensity level if there are only 20 students? Assume that all students are equally noisy. Take the threshold of hearing to be 10^{-12} W m^{-2}.

A. 35 dB
B. 50 dB
C. 60 dB
D. 67 dB

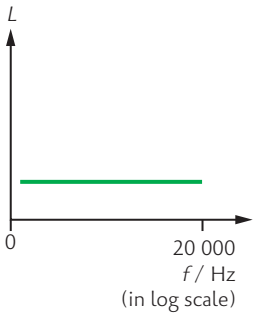
10. Which of the following statements about the threshold of hearing are correct?

(1) A sound of 0 dB is the softest sound a human can hear for all frequencies.
(2) The intensity of a sound at 0 dB is 0 W m^{-2}.
(3) The threshold of hearing is different for sounds of different frequencies.

A. (3) only
B. (1) and (2) only
C. (1) and (3) only
D. (1), (2) and (3)

11. Which of the following graphs best shows the threshold of hearing of a normal person?
(L: sound intensity level, f: frequency of sound)

A.



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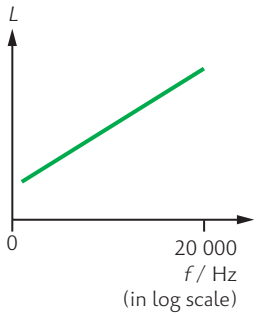
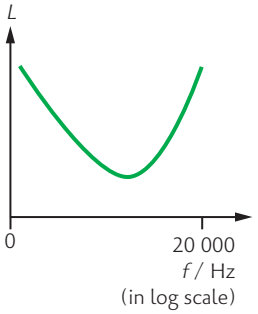
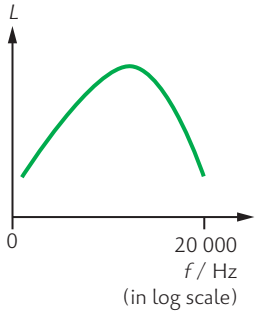


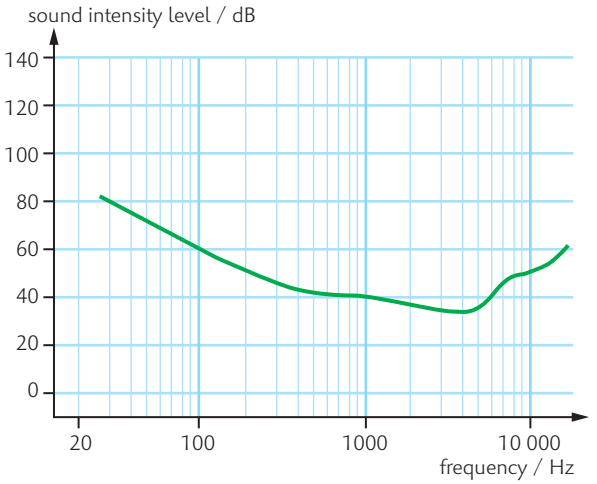
C.



D.



12. The figure below shows a curve of equal loudness.

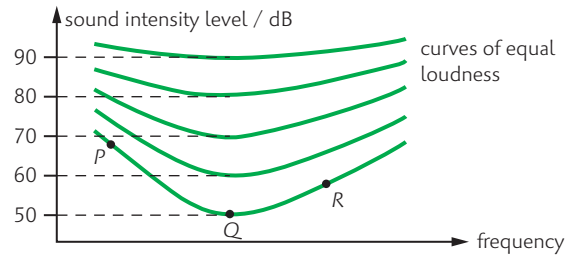


Which of the following statements is/are correct?

(1) The curve represents sounds of loudness of 60 phons.
(2) A 60 dB sound at 10 000 Hz is louder than a 60 dB sound at 100 Hz.
(3) When the frequency of a 60 dB sound increases from 100 to 1000 Hz, its loudness decreases.

A. (1) only
B. (2) only
C. (1) and (3) only
D. (2) and (3) only

13. **HKDSE 2012** Three musicians play three different notes P, Q and R. The loudness of these notes as heard by an audience is the same and the notes are shown in the equal loudness graph below. Their play is picked up by a microphone and is then reproduced by a loudspeaker at 20 dB above the original sound intensity level. Which of the following is the order of the loudness of the reproduced sound?

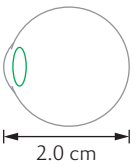


A. $P = Q = R$
B. $P > R > Q$
C. $R > Q > P$
D. $Q > R > P$

14. **HKDSE 2013** Two point objects of separation 5 mm emitting green light of wavelength 550 nm are observed by Jacky. Assume that the diameter of the pupils of his eyes is about 3 mm in normal daylight. Estimate the maximum distance of the two objects from him such that he can still resolve them.

A. 42.4 m B. 24.2 m
C. 22.4 m D. 20.4 m

15. **HKDSE 2013** The diagram shows an eyeball of a person suffering from an eye defect. The distance between the retina and optical centre of the refracting parts is 2.0 cm while the minimum power of the refracting parts is +55 D. What is the power of the spectacles required to correct the defect?



A. −5 D B. −10 D
C. +5 D D. +10 D

16. **HKDSE 2013** The sensitivity of the human ear is high because the pressure change in a sound wave is greatly amplified before reaching the inner ear. Which of the following facts contribute to this large amplification?

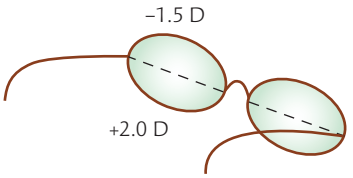
(1) When the ear bones transmit the vibrations from the eardrum to the oval window of the inner ear, lever action occurs.
(2) The eardrum has a much larger area than the oval window of the inner ear.
(3) The inner ear is filled with a liquid which has a much higher density than that of air outside.

A. (1) and (2) only B. (1) and (3) only
C. (2) and (3) only D. (1), (2) and (3)

17. **HKDSE 2013** A speaker is connected to an amplifier to produce sound. When the power supplied to the speaker is 50 W, the resulting sound intensity level at a certain location is 100 dB. Assume that there is no other sound source and the speaker has a fixed efficiency of converting electrical energy to sound. What is the power required to produce a sound intensity level of 110 dB at the same location?

A. 52 W B. 55 W
C. 100 W D. 500 W

18. **HKDSE 2014** Mr. Lee wears a pair of bifocal lenses as shown. The respective powers of the upper half and the lower half of each lens are −1.5 D and +2.0 D. Which of the following statements is/are correct?



(1) The upper half is for viewing distant objects while the lower half is for viewing objects at a close distance.
(2) Mr. Lee only suffers from old sight (presbyopia).
(3) Without the spectacles, Mr. Lee CANNOT see an object clearly no matter how far it is placed from him.

A. (1) only B. (3) only
C. (1) and (2) only D. (2) and (3) only

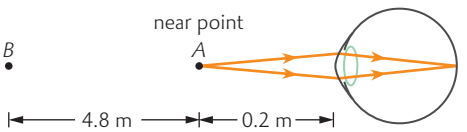
Structured Questions

19. A Snellen chart is used to test how acute your vision is. Vicky is now 6 m away from the chart and attempts to view the letter E of height 88 mm.

Take the pupil's diameter to be 5 mm and the wavelength of light to be 550 nm.

(a) For two objects that are 6 m from a viewer to be resolvable, what is their minimum angular separation? (2 marks)
(b) What is the angle, in radians, subtended by the letter E from Vicky's eye? Do you think she can resolve the letter if her eye is normal? (2 marks)
(c) Besides diffraction, state another factor that may affect how acute a person's vision is. (1 mark)
(d) Suppose the cornea is 2 cm away from the retina for Vicky's eye and assume all refraction takes place at the cornea.
(i) Suppose Vicky's eye is normal. What is the power of her eye when it accommodates to the chart? (2 marks)
(ii) Suppose Vicky's eye is defective and has a far point of 4 m. Should a convex lens or concave lens be used to correct the defect? What is the power of her eye when she accommodates to the chart with the corrective lens? (3 marks)

20. Two objects, *A* and *B*, are 0.2 m and 5 m away from an eye, respectively. The near point of the eye is 0.2 m. Assume all refraction takes place at the air–cornea boundary.



(a) Briefly describe what a near point is. (1 mark)

(b) At the instant shown, the image of *A* is formed on the retina, which is 2 cm behind the cornea.

(i) What are the power and the effective focal length of the eye? (3 marks)

(ii) At this moment, where is the image of *B*? Is it in front of, behind or on the retina? Explain briefly. (2 marks)

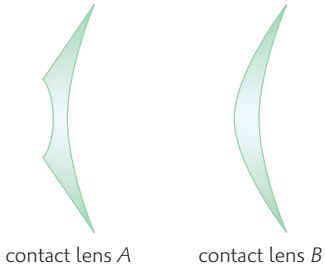
(c) The eye now changes its focus on *B*.

(i) Name the process. (1 mark)

(ii) Describe how the ciliary muscle and the lens change in the process. (2 marks)

(iii) Find the change in power of the eye. (2 marks)

21. The figure shows the cross-sections of two contact lenses, *A* and *B*.



(a) One of the lenses is used to correct short sight.

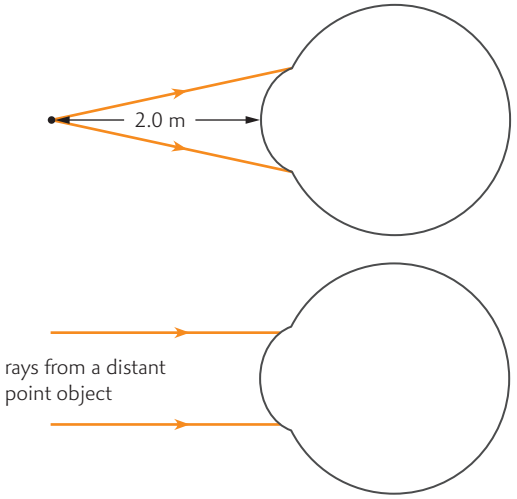
(i) Which one is it? (1 mark)

(ii) Suggest TWO possible causes for short sight. (2 marks)

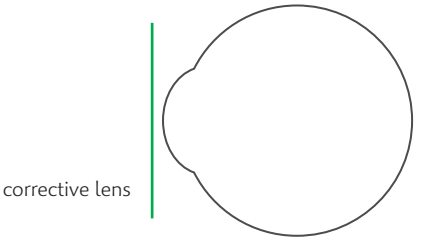
(b) The lens in (a) is used to correct the far point of a person from 2.0 m to infinity.

(i) What should the power of the lens be? (2 marks)

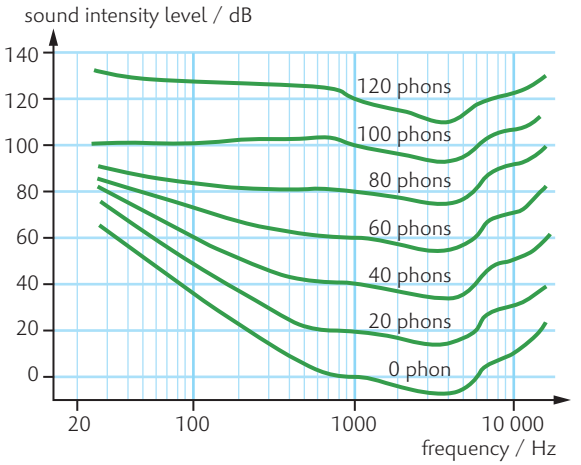
(ii) Complete the ray diagrams below for the eye of the person. (2 marks)



(iii) Sketch a ray diagram to show how the lens can correct the defect. (2 marks)



22. The figure shows several curves of equal loudness.



(a) What is a curve of equal loudness? (1 mark)

(b) Give TWO factors that determine the loudness of a sound. (2 marks)

(c) What is the threshold of hearing in dB when the frequency of a sound is 1000 Hz? (1 mark)

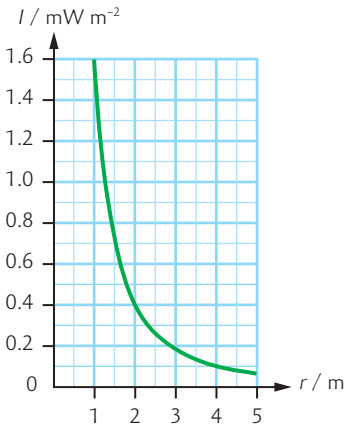
(d) By what factor has the intensity changed when the frequency of a 40 phon sound changes from 30 Hz to 1000 Hz. (3 marks)

(e) A man suffers from hearing loss as he gets older. Sketch a curve of 0 phon to represent his hearing. (1 mark)

23. This question is about human hearing.

(a) Briefly describe the physical processes in the ear that produces a sense of hearing, starting from the incidence of sound on the eardrum. (4 marks)

A loudspeaker connected to a signal generator is producing a tone of 1000 Hz at a constant power. The graph on the next page shows how the sound intensity I varies with the distance r from the loudspeaker. The threshold of hearing is $I_0 = 10^{-12}$ W m^{-2}.



(b) James is initially 1 m in front of the loudspeaker.

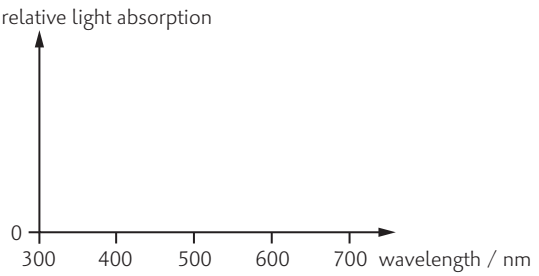
(i) What is the sound intensity level heard? (2 marks)

(ii) How far backwards should he step so that the sound intensity level heard is reduced by 6 dB? (2 marks)

(c) Jane stands at a certain distance from the loudspeaker. Suggest TWO ways to adjust the signal generator so that the loudness of the sound heard is reduced. (2 marks)

24. **AQA A-level PHA6 Jun 2008** The fovea (yellow spot) in the human eye consists only of cones which have an average diameter of 1.5 μm.

(a) On the axes sketch and clearly label THREE curves to show how the response of each of the three types of cone in the fovea varies with the wavelength of light. (3 marks)



(b) An eye looks directly at two point sources of light which are 8 mm apart and 40 m distant from the eye. The fovea is 19 mm behind the eye lens at the centre of the retina.

(i) Calculate the separation of the two images at the fovea. (2 marks)

(ii) State, with a reason, whether the eye would be able to resolve the two images formed at the fovea. (2 marks)

25. **IB Higher level Nov 2010** This question is about sound intensity.

(a) Define

(i) intensity of sound. (1 mark)

(ii) sound intensity level. (1 mark)

(b) State TWO ways by which the sound pressure at the eardrum is amplified before reaching the cochlear fluid. (2 marks)

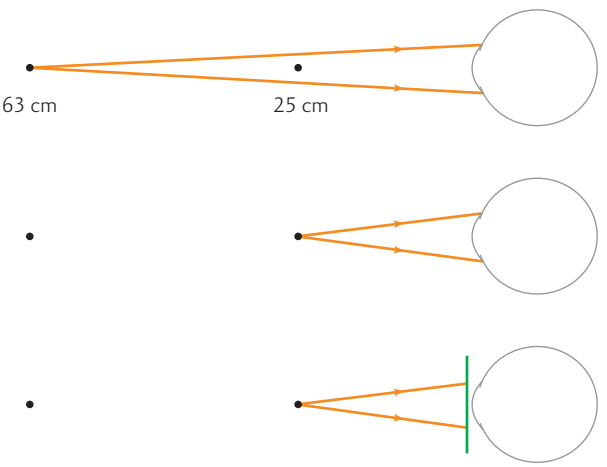
(c) A student with a hearing problem can hear sounds clearly when the sound intensity level is 65 dB or higher. In a large lecture hall, at a distance of 25 m from the lecturer, the sound intensity level is 55 dB.

Determine the maximum distance from the lecturer at which the student can hear clearly.

The intensity of sound a distance d from a source of power P is given by $I = \frac{P}{4\pi d^2}$. (4 marks)

26. **AQA A-level PHYA5/2B Jun 2011**

(a) A person suffering from long sight has an unaided near point 63 cm from the eye. The figure shows three diagrams not drawn to scale. The first two diagrams show rays incident on the unaided eye. The third diagram shows rays incident on the correcting lens which will allow the person to have an aided near point 25 cm from the eye. Complete the diagrams to show the passage of the rays to the retina. You may assume that for the eye there is only a single refraction at the cornea of the eye. (2 marks)



(b) Calculate the focal length of the correcting lens, stating the answer to the appropriate number of significant figures. (3 marks)

(c) Explain what is meant by persistence of vision and state a practical situation where it is important. (2 marks)

[**Note:** This part is out of the current syllabus.]

27. **AQA A-level PHYA5/2B Jun 2013**

(a) Sound waves are incident on the ear canal of a normal human ear. Describe the physical processes involved in the transmission of the energy from the air through to the inner ear.

Include an outline of how the variations in air pressure in the ear canal are amplified to produce greater pressure variations in the inner ear.

The quality of your written communication will be assessed in your answer. (6 marks)

(b) Define *intensity* of sound. (2 marks)

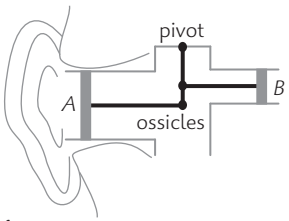
(c) A human ear has a threshold of hearing of 54 dB at a given frequency. Calculate the intensity of sound incident on the ear at this frequency.

Give your answer to an appropriate number of significant figures.

$I_0 = 1.0 \times 10^{-12}$ W m^{-2} (3 marks)

28. **IB Higher level May 2013** This question is about the human ear.

(a) The diagram on the right is a schematic of a model to represent the ear. (ossicles = ear bones)



(i) Identify the parts of the ear represented by *A* and *B*. (1 mark)

(ii) Outline, with reference to the diagram, the mechanism by which amplification is carried out in the middle ear. (2 marks)

(b) Explain, with reference to the acoustic properties of the media concerned, why sound CANNOT be transmitted directly from air to the inner ear efficiently. (2 marks)

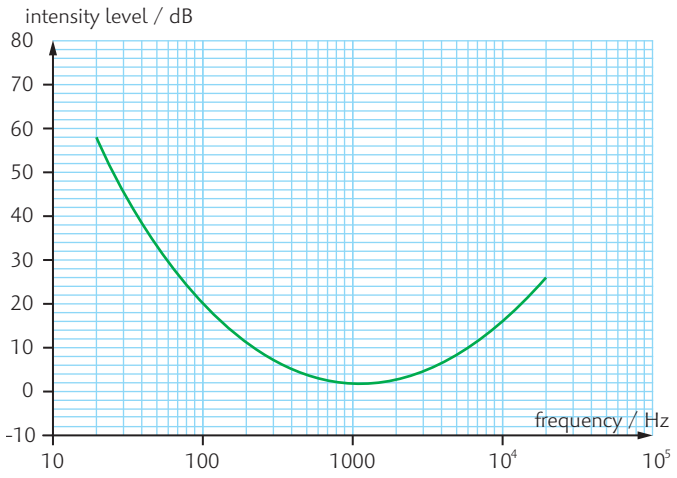
[**Note:** This part will be introduced in Ch. 2.]

(c) Distinguish between loudness and intensity. (2 marks)

(d) As a result of exposure to noise, a person has suffered a hearing loss of 15 dB at 10 kHz. At low frequencies, the person's hearing remains normal.

The graph shows the variations with frequency of the threshold of hearing for this person.

Draw a line on the graph to show the threshold of hearing for a person with normal hearing. (2 marks)



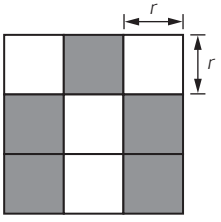
29. **HKDSE 2014** [Part (a) belongs to Ch. 2.]

(a) (i) In medical imaging using ultrasound, a piezoelectric transducer is employed to scan the patient. Describe how a piezoelectric transducer generates ultrasound waves. (2 marks)

(ii) State ONE advantage and ONE disadvantage of using ultrasound of higher frequencies in medical imaging. (2 marks)

(b) (i) John has normal eyesight and the power of his eye is +59 D in viewing distant objects. Estimate the separation between the lens and the retina of his eye. Assume that the refracting power is mainly contributed by the eye lens. (2 marks)

(ii) The display panel of a smart phone *X* is made up of numerous tiny square pixels as shown.



square pixels of part of the display panel

John is looking at the graphics on the display panel of smart phone *X*. The diameter of his eye's pupil is 4.0 mm. Estimate the resolving power θ (in radians) of his eye for graphics in green colour.

Given: wavelength of green light = 5.35×10^{-7} m. (2 marks)

(iii) The pixels of smart phone *X* are so small that the human eye is unable to distinguish two adjacent pixels at a typical viewing distance $L = 0.30$ m. Using the result of (b) (ii), estimate the maximum length of a side of a square pixel, *r*, on the display panel of smart phone *X*. You may assume that for small angle θ in radians, $\tan\theta \approx \theta$. (2 marks)

Chapter Exercise

Multiple-choice Questions

1. Which of the following statements about the acoustic impedance of a medium is/are INCORRECT?

(1) It depends on the density of the medium.
(2) It depends on the sound speed in the medium.
(3) It depends on the thickness of the medium.

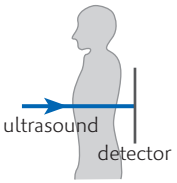
A. (1) and (2) only B. (1) and (3) only
C. (2) and (3) only D. (1), (2) and (3)

2. Given that the intensity reflection coefficient between fat and liver is 1%. Estimate the acoustic impedance of liver if the acoustic impedance of fat is 1.38×10^6 kg m^{-2} s^{-1}.

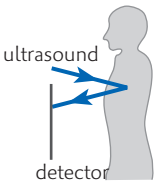
A. 1.6×10^6 kg m^{-2} s^{-1} B. 1.7×10^6 kg m^{-2} s^{-1}
C. 1.8×10^6 kg m^{-2} s^{-1} D. 1.9×10^6 kg m^{-2} s^{-1}

3. Which of the following diagrams best illustrates how an ultrasound scan is carried out?

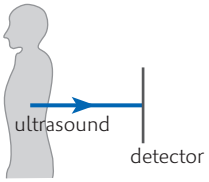
A.



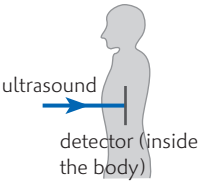
B.



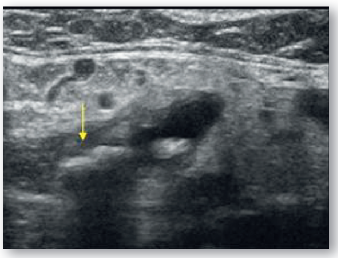
C.



D.



4. An acoustic shadow may sometimes be seen on an ultrasound image. Shown below is a photo of a salivary stone (pointed by the arrow) found around a salivary gland. An acoustic shadow appears beneath the salivary stone. Given that the transducer is located at the top of the photo.



Which of the following statements about the shadow MUST be correct?

(1) The acoustic impedance of the region in the shadow is very high.
(2) Ultrasound of a very low intensity is transmitted into the shadow.
(3) Most ultrasound is reflected by the front surface of the object that creates the shadow.

A. (1) and (2) only B. (1) and (3) only
C. (2) and (3) only D. (1), (2) and (3)

5. The figure below shows an ultrasound image of a foetus of 12 weeks.

Which of the following statements about the image is/are correct?

(1) It is an A-scan image.
(2) The brightest areas are regions where ultrasound is most attenuated.
(3) The transducer is placed above the top of the image.

A. (1) only B. (3) only
C. (1) and (2) only D. (2) and (3) only

6. Which of the following combinations best describes the frequencies of ultrasound used for medical imaging of the breast and the kidney?

	breast	**kidney**
A.	100 kHz	400 kHz
B.	400 kHz	100 kHz
C.	4 MHz	10 MHz
D.	10 MHz	4 MHz

7. The refractive index of the cladding of an optical fibre is 1.46. It is known that the critical angle at the core–cladding boundary is 75.5°. What is the refractive index of the core?

A. 1.41 B. 1.43
C. 1.51 D. 1.53

8. A coherent fibre bundle contains 10 000 fibres. Given that the average distance between the centres of two adjacent fibres is 0.05 mm. What is the approximate diameter of fibre bundle?

A. 0.3 mm
B. 0.6 mm
C. 3 mm
D. 6 mm

9. Which statement about fibre optic endoscopes is INCORRECT?

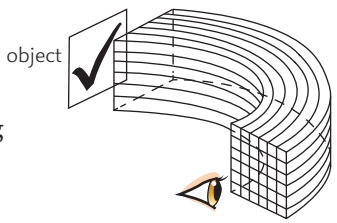
A. A coherent fibre bundle is mainly used for transmitting images.
B. Light travels more slowly in a non-coherent fibre bundle, as compared with its speed in a coherent bundle.
C. Both coherent and non-coherent fibre bundles can function normally when bent slightly.
D. The relative positions of the fibres at the two ends inside a coherent fibre bundle are the same.

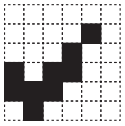
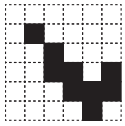
10. Which of the following are the advantages of using endoscopy?

(1) Endoscopy is non-invasive.
(2) No ionization radiation is involved.
(3) Samples of tissues can be taken out of the organ being examined.

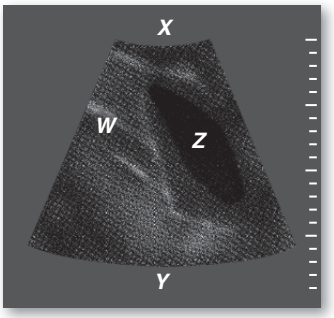
A. (1) and (2) only
B. (1) and (3) only
C. (2) and (3) only
D. (1), (2) and (3)

11. **HKDSE 2012** The diagram shows a coherent bundle of optical fibres consisting of 36 square elements. The bundle is used for viewing the object shown (Drawing is not to scale). Which of the following best represents the picture as viewed by the observer?



A.
B.
C. 
D. 

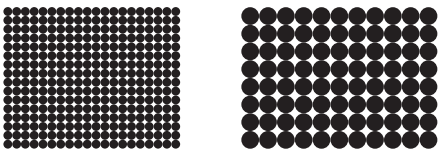
12. **HKDSE 2012** The figure shows an ultrasound B-scan image. Which statements are correct?



(1) *X* is closer to the scanner than *Y*.
(2) Area *Z* is low in brightness because it absorbs more ultrasound.
(3) Area *W* is high in brightness because it reflects more ultrasound.

A. (1) and (2) only
B. (1) and (3) only
C. (2) and (3) only
D. (1), (2) and (3)

13. **HKDSE 2013** The diagram below represents two coherent optical fibre bundles *X* and *Y* used in endoscopes. Their cross-sections have the same dimensions but *X* has more and finer fibres. Which statements are correct?



(1) *X* gives a much brighter image than *Y*.
(2) *X* can be bent more than *Y*.
(3) *X* gives an image of higher resolution than *Y*.

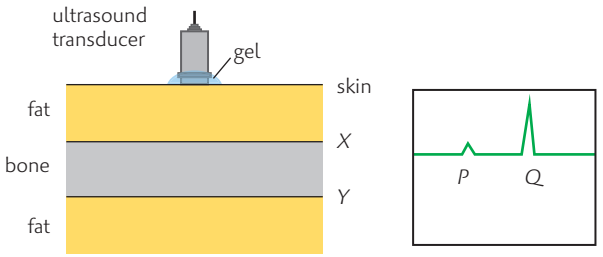
A. (1) and (2) only
B. (1) and (3) only
C. (2) and (3) only
D. (1), (2) and (3)

14. **HKDSE 2013** Which of the following statements about ultrasound medical imaging is/are correct?

(1) Ultrasound is potentially hazardous as it is a form of ionizing radiation.
(2) Ultrasound is NOT suitable for lung scanning as it is almost totally reflected when it reaches the tissue–air boundary in the lungs.
(3) High frequency ultrasound has a greater penetrating power but provides images of lower resolution.

A. (l) only
B. (2) only
C. (1) and (3) only
D. (2) and (3) only

15. **HKDSE 2014** An ultrasound transducer is placed on the skin over a certain position of the human body to perform an A-scan. The signal received contains two spikes *P* and *Q* as shown. Which of the following statements is/are correct?



(1) There is almost no reflection from interface *Y* because the bone absorbs nearly all of the ultrasound.

(2) There is almost no reflection from interface *Y* because interface *X* reflects nearly all of the ultrasound.

(3) The spikes *P* and *Q* correspond to the reflections at interfaces *X* and *Y* respectively.

A. (1) only B. (2) only

C. (1) and (3) only D. (2) and (3) only

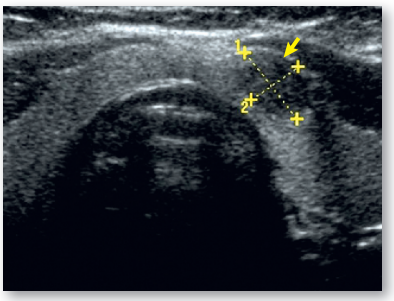
Structured Questions

16. The photo below shows a patient receiving ultrasound scan for his thyroid.

(a) Should high frequency (> 5 MHz) or low frequency (< 5 MHz) be used for the scan? Briefly explain why. (2 marks)

(b) Suggest ONE advantage of using ultrasound rather than X-ray imaging scan to diagnose the thyroid. (1 mark)

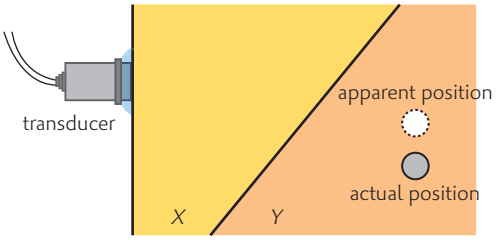
(c) Shown below is a photo of the scan image.



(i) There are some bright and dark regions in the image. Briefly explain how they are formed. (2 marks)

(ii) A suspicious structure is noticed (pointed by the yellow arrow). How large is it (the lengths of the yellow dotted lines)? The width of the photo represents a length of 4 cm. (2 marks)

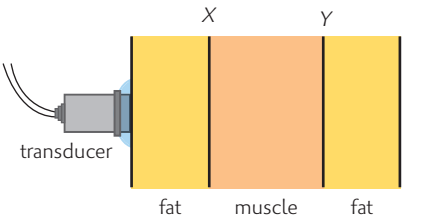
(d) Sometimes, ultrasound scan may falsely determine the position of a structure. Shown below is a possible situation.

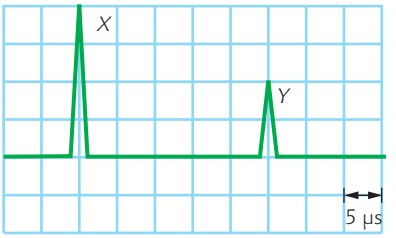


(i) Name the phenomenon that causes the false determination. (1 mark)

(ii) Compare the ultrasound speeds in tissues *X* and *Y*. (1 mark)

17. The figure below is an A-scan CRO trace, which shows the echoes from boundaries *X* and *Y* inside a human body.





(a) The transducer is responsible for generating and detecting ultrasound pulses.

(i) Name the effect applied to the detection of ultrasound pulses. (1 mark)

(ii) Briefly describe how the transducer can generate and detect ultrasound. (2 marks)

(b) The echoes from boundaries *X* and *Y* have different intensities. Suggest TWO reasons. (2 marks)

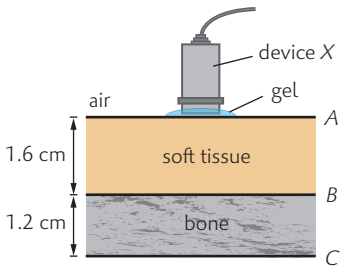
(c) Ultrasound has speeds 1550 m s^{-1} and 1450 m s^{-1} in the muscle and the fat, respectively. The density of the fat is 950 kg m^{-3}.

(i) How thick is the layer of muscle? (2 marks)

(ii) Find the acoustic impedance of the fat. (1 mark)

(iii) When the ultrasound pulse crosses boundary *X*, its intensity drops by 0.7%. Neglecting any absorption of energy by the media, estimate the density of the muscle. (2 marks)

18. In an ultrasound scan, a device *X* is used to produce ultrasound pulses and to detect the echoes. The device is in contact with the skin. A bone of thickness 1.2 cm is 1.6 cm below the skin. *A*, *B* and *C* are the boundaries air–soft tissue, soft tissue–bone and bone–soft tissue, respectively. The ultrasound speeds in soft tissue and bone are 1500 m s^{-1} and 4000 m s^{-1}, respectively.



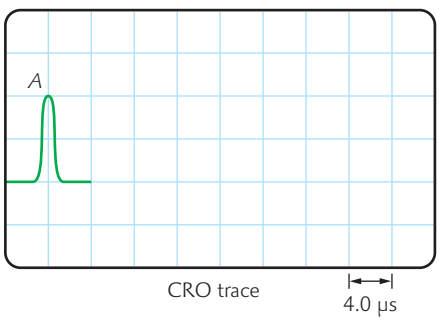
(a) Name device *X*. (1 mark)

(b) Calculate the time taken for an ultrasound pulse to travel from

(i) boundary *A* to *B*. (2 marks)

(ii) boundary *B* to *C*. (1 mark)

(c) The figure below shows a CRO trace of a pulse received after its reflection from boundary *A*. The time-base setting is 4.0 μs per division.

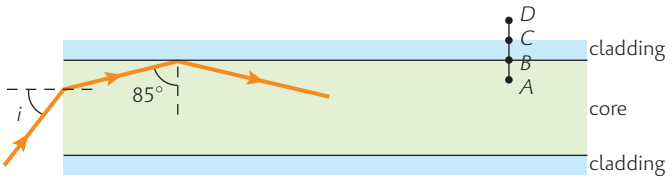


(i) Complete the CRO trace to show the reflected pulses from boundaries *B* and *C*. Neglect the amplitude change of the echoes. (2 marks)

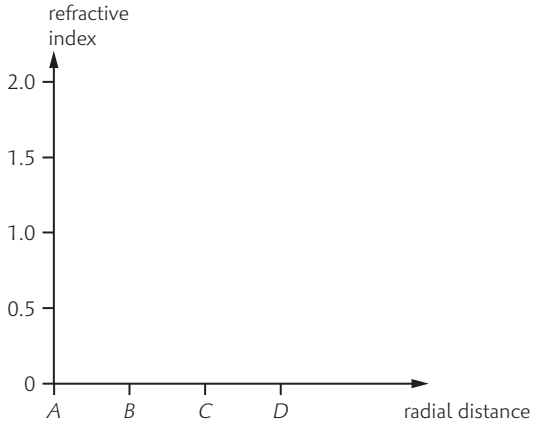
(ii) If the gel is NOT applied, how does your answer in (c)(i) change? Briefly explain. (2 marks)

(d) The intensity reflection coefficient on boundary *B* is 35%. What is the density ratio of the bone to the soft tissue? (2 marks)

19. The figure below shows an axial cross-section of an optical fibre. The core is made from glass with a refractive index of 1.5. The critical angle at the core–cladding boundary is 85°.



(a) Complete the following graph to show how the refractive index changes with the radial distance along the line *AD*. (2 marks)



(b) What is the value of the maximum angle of incidence *i* if the incident light ray has to be totally reflected on the core–cladding boundary? (2 marks)

(c) Such fibres are bundled in an endoscope to transmit images. Illustrate, with the aid of a diagram, how images can be transmitted. (4 marks)

(d) Give ONE advantage and ONE limitation of endoscopy. (2 marks)

20. Read the following article about endoscopic ultrasound and answer the questions that follow.

Endoscopic ultrasound

Endoscopic ultrasound (EUS) combines endoscopy and an ultrasound scan to obtain images of the internal organs in the chest and abdomen.

In EUS, a small ultrasound transducer is installed on the tip of the endoscope. By inserting the endoscope into the upper or the lower digestive tract, one can obtain images of the organs inside the body. Since the EUS transducer is placed close to the organs of interest, the images obtained are generally more accurate and more detailed than the ones obtained by a conventional ultrasound scan.

EUS can also obtain information about the layers of the intestinal wall as well as adjacent areas such as lymph nodes and the blood vessels. Cancer staging of some organs, e.g. the oesophagus, stomach and lung, using EUS is becoming popular. This is because EUS can provide useful information regarding the depth of penetration of the cancer and the spread of cancer to adjacent tissues and lymph nodes.

(a) Briefly explain why a conventional ultrasound scan CANNOT be used to obtain images of the stomach or intestine. How can images of such organs be produced with EUS? (3 marks)

(b) Based on your knowledge about endoscopy, suggest ONE limitation and ONE possible risk to patients using EUS. (2 marks)

21. **IB Higher level Nov 2011** This question is about the use of ultrasound for diagnostic imaging.

(a) Outline how ultrasound is produced for use in diagnostic imaging. (3 marks)

(b) In order to look for damage to the chambers of the heart, ultrasound is used to form an image of the heart.

Suggest why it is better to use ultrasound rather than X-rays. (2 marks)

(c) The speed of sound in skin is about five times the speed of sound in air. Given that the density of skin is about 700 times that of the density of air, compare the acoustic impedance of skin to that of air. (2 marks)

(d) Explain, using your answer to (c), why, in using ultrasound for imaging, a layer of gel is placed between the transducer and the skin. (2 marks)

(e) A wide range of frequencies of ultrasound may be used to image internal body organs. The choice of frequency for imaging a particular organ is determined by the depth of the organ beneath the skin.

Outline, with reference to attenuation and resolution, why the depth of the organ determines the choice of ultrasound frequency. (4 marks)

22. **IB Higher level May 2012** This question is about ultrasonic imaging.

(a) Describe how a piezoelectric crystal in an ultrasound transmitter is made to generate a pulse of ultrasound. (2 marks)

(b) The table gives the velocity of sound in, and the densities of, the materials.

	velocity of sound / m s^{-1}	density / kg m^{-3}	acoustic impedance
air	330	1.3	
gel	1420	980	
muscle tissue	1580	1080	

(i) State the SI unit for acoustic impedance. (1 mark)

(ii) Calculate the acoustic impedance for each material and write your answers in the table above. (2 marks)

(iii) The fraction of the reflected intensity when ultrasound in a medium of impedance Z_1 is incident on a medium of impedance Z_2 is given by the following equation.

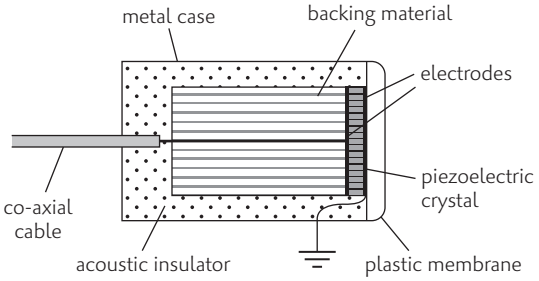
$$\frac{(Z_1 - Z_2)^2}{(Z_1 + Z_2)^2}$$

This is called the reflection coefficient. Calculate the reflection coefficient for ultrasound that is incident on muscle tissue from air. (2 marks)

(iv) Using your answer to (iii), explain why it is necessary to use gel in between an ultrasound transducer and a patient's skin. (2 marks)

23. AQA A-level PHYA5 Jun 2013

(a) The figure shows an ultrasound transducer used in an A-scan.



Outline, with reference to the diagram, the process by which the transducer produces a short pulse of ultrasound. (4 marks)

(b) Ultrasound is incident on the boundary between two materials. Some of the ultrasound is reflected at the boundary and the remainder is transmitted across the boundary. The ratio of the intensity of the reflected ultrasound, I_r, to the intensity of the incident ultrasound, I_i, is given by the equation

$$\frac{I_r}{I_i} = \frac{(Z_2 - Z_1)^2}{(Z_2 + Z_1)^2}$$

where Z_1 and Z_2 are the acoustic impedances of the two materials.

(i) Calculate the percentage of the incident ultrasound which would be transmitted into the skin when incident on an air–skin boundary. (2 marks)

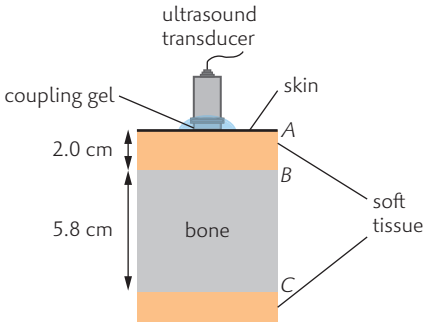
acoustic impedance of air
$= 4.29 \times 10^2$ kg m^{-2} s^{-1}

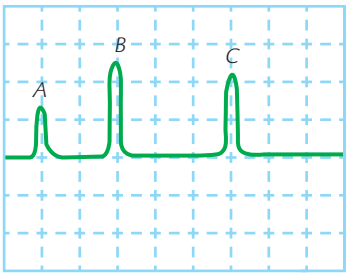
acoustic impedance of skin
$= 1.65 \times 10^6$ kg m^{-2} s^{-1}

(ii) When obtaining the ultrasound image of an unborn foetus, a coupling gel is used. Explain why a coupling gel is needed and state the property of the gel that ensures a good quality image. (2 marks)

24. HKDSE 2012

(a) The figure shows a cross-section of a piece of bone with 5.8 cm thickness situated below a layer of soft tissue that is 2.0 cm thick. An ultrasound transducer with coupling gel is applied to the skin. The ultrasound pulses reflected from various boundaries *A*, *B* and *C* are displayed on a CRO.





(i) Find the ratio of the speed of ultrasound in bone to that in soft tissue. (2 marks)

The values of acoustic impedance of various body tissues to the ultrasound used are tabulated below.

tissues	acoustic impedance / kg m^{-2} s^{-1}
soft tissue (average)	1.63×10^6
bone	7.78×10^6

(ii) If the speed of ultrasound in soft tissue is 1580 m s^{-1}, estimate the density of bone. (3 marks)

(b) (i) Describe the working principles of ultrasound B-scan imaging. (3 marks)

(ii) State ONE advantage and ONE limitation of using ultrasound scans in the context of medical imaging. (2 marks)

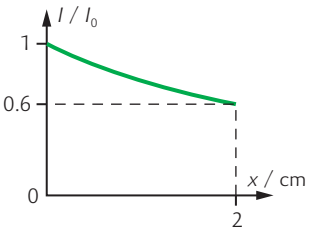
Chapter Exercise

Multiple-choice Questions

1. An X-ray beam passes through a material that is 4 cm thick. Suppose its final intensity drops to 1/3 of its initial value. What is the linear attenuation coefficient of the material?

A. 0.119 cm^{-1} B. 0.275 cm^{-1}
C. 4.40 cm^{-1} D. 1.91 cm^{-1}

2. A beam of X-rays travels in a medium. The graph below shows how the intensity of the beam changes as it travels through a distance x in the medium. The initial intensity of the beam is I_0.

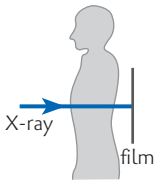


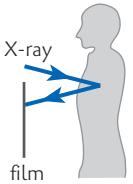
Which of the following statements are correct?

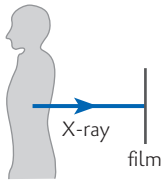
(1) The linear attenuation coefficient of the medium is about 25.5 m^{-1}.
(2) The half-value thickness of the medium is about 2.71 cm.
(3) The intensity of the beam decreases to 1/4 of the initial value when it travels a distance of 5.43 cm in the medium.

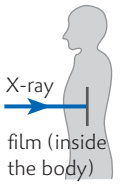
A. (1) and (2) only B. (1) and (3) only
C. (2) and (3) only D. (1), (2) and (3)

3. Which of the following sketches best represents a patient having an X-ray image taken with the aid of an artificial contrast medium?

A.


B.


C.


D.


4. Which of the following statements about ultrasound imaging and X-ray radiographic imaging is/are correct?

(1) Both images are obtained as maps of attenuation of the respective waves.
(2) Ultrasound is non-ionizing but X-ray is ionizing.
(3) Both images are good for examining soft tissues.

A. (2) only B. (3) only
C. (1) and (2) only D. (1) and (3) only

5. Endoscopic imaging and X-ray radiographic imaging can both be used to examine the colon of a patient. Which of the following statements about the two methods is/are correct?

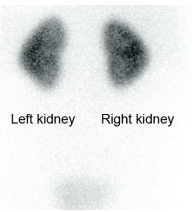
(1) Both require a detector or a probe to be put inside the body of the patient.
(2) NEITHER can be used to evaluate the function of the colon.
(3) NEITHER method requires cutting a large hole in the body.

A. (2) only B. (3) only
C. (1) and (2) only D. (2) and (3) only

6. The biological half-life and physical half-life of a radionuclide P are 3 days and 4 days, respectively. P is injected into a patient as a tracer for radionuclide imaging. How long does it take for the activity of P inside the patient's body to be reduced to 1/4 of the original?

A. 2.0 days B. 3.4 days
C. 4.0 days D. 10 days

7. A small amount of Tc-99m is injected into Jimmy's body to study the function of his kidneys. The half-life of Tc-99m is about 6 hours.



Which of the following statements are INCORRECT?

(1) The black dots are due to the emission of β and γ radiation.
(2) From this single picture, we can conclude whether the kidney is functioning properly or not.
(3) The radioactivity inside the body decreases to zero after 6 hours.

A. (1) and (2) only B. (1) and (3) only
C. (2) and (3) only D. (1), (2) and (3)

8. Which of the following statements correctly compare(s) acute and latent effects?

(1) Both effects are due to the damage done to living cells by ionizing radiation.
(2) All acute effects are fatal, but not all latent effects are fatal.
(3) Latent effects always occur randomly.

A. (1) only
B. (2) only
C. (1) and (3) only
D. (2) and (3) only

9. Which of the following statements correctly compare(s) ultrasound imaging and RNI?

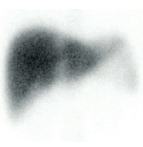
(1) Both use ionizing radiation.
(2) Only ultrasound imaging is suitable for scanning a foetus.
(3) Only RNI can assess how well the organs function.

A. (2) only
B. (3) only
C. (1) and (2) only
D. (2) and (3) only

10. Shown below are three images taken using different imaging techniques.

P

Q



R

Which of the following correctly describes the waves used?

	P	***Q***	***R***
A.	X-rays	ultrasound	γ-rays
B.	γ-rays	ultrasound	X-rays
C.	ultrasound	X-rays	γ-rays
D.	ultrasound	γ-rays	X-rays

11. **HKDSE 2012** The figure shows a thyroid scan using iodine-131 tracer. The darker part represents the area with higher intensity detected by a gamma camera. Which deduction about area *X* is correct?

A. It is something with abnormally high attenuation of γ radiation.
B. It is something with abnormally low attenuation of γ radiation.
C. It absorbs an excessive amount of iodine.
D. It cannot absorb iodine normally.

12. **HKDSE 2012** Which statements best explain why technetium-99m is suitable for the use of medical radionuclide imaging ?

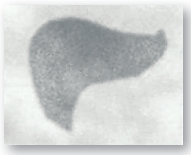
(1) It can be combined with a wide range of chemicals and proteins to form radioactive tracers.
(2) Radiation exposure to patients can be kept low as the half-life of technetium-99m is short.
(3) It emits suitable γ radiations that can be attenuated by different tissues to give a radiographic image.

A. (1) and (2) only
B. (1) and (3) only
C. (2) and (3) only
D. (1), (2) and (3)

13. **HKDSE 2013** Technetium-99m is a radioisotope which undergoes γ-decay with a half-life of 6 hours. Some technetium-99m was combined with a substance which can be easily absorbed by liver. The compound was taken by a patient and a series of images were taken by a gamma camera at different times. Which of the following statements is/are correct?

1 hour after intake

3 hours after intake


6 hours after intake

(1) The darker part of the images corresponds to the part of the liver causing a greater attenuation of γ-rays.
(2) This series of images provides functional information about the liver of the patient.
(3) The difference between the images is solely due to the decay of technetium-99m.

A. (1) only
B. (2) only
C. (1) and (3) only
D. (2) and (3) only

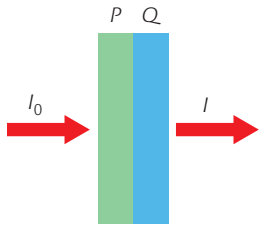
14. **HKDSE 2013** The patient of a car accident was suspected to have internal bleeding in the brain. In order to locate where the bleeding might have occurred, which medical imaging method is the most suitable to be used?

A. Ultrasound scanning
B. Endoscope
C. X-ray radiography
D. Computed tomography (CT)

15. **HKDSE 2014** A patient is going to take a needle aspiration biopsy in which a fine needle is inserted into his liver through the skin to take a tiny living tissue for testing. In order to minimize the risk of internal bleeding, it is important to locate the large blood vessels of the liver near the place where the needle is inserted. Also, as the liver can displace slightly inside the body, real-time imaging is therefore needed during needle insertion. The most suitable imaging method is

A. X-ray planar imaging.
B. computed tomography.
C. ultrasound imaging.
D. radionuclide imaging.

16. **HKDSE 2014** An object is made up of two different materials P and Q of 1 cm equal thickness as shown. The linear attenuation coefficients of P and Q for X-rays are 0.05 cm^{-1} and 0.68 cm^{-1} respectively. An X-ray beam of intensity I_0 is incident on the object and emerges from the object with an intensity I. Which of the following expressions gives the ratio $\frac{I}{I_0}$?



A. $\frac{0.05}{0.68}$
B. $\frac{(0.68-0.05)^2}{(0.68+0.05)^2}$
C. $e^{-\frac{0.05}{0.68}}$
D. $e^{-(0.05+0.68)}$

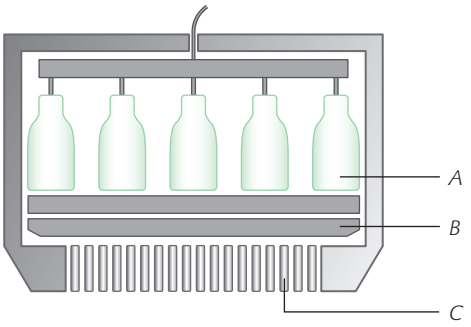
Structured Questions

17. A beam of X-rays travels through a material. The table below shows how the intensity I of the beam changes with the thickness x of the material.

x / cm	0.000	0.040	0.080	0.120	0.160	0.200	0.240	0.280	0.320
I / W m^{-2}	12.0	10.9	9.82	8.89	8.00	7.28	6.60	5.96	5.40

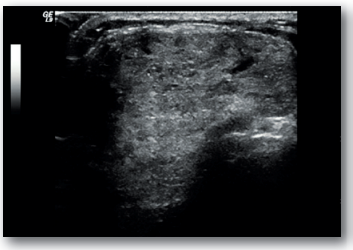
(a) Plot a graph of I against x. (3 marks)
(b) Find the half-value thickness of the material from (a). Hence find the linear attenuation coefficient of the material. (4 marks)
(c) Apart from the property of the material, suggest ONE more factor that will affect attenuation. (1 mark)

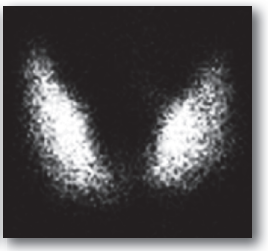
18. The structure of a gamma camera is as shown.



(a) What is the function of a gamma camera in radionuclide imaging? (1 mark)
(b) Name A, B and C and state their functions. (6 marks)
(c) Radionuclide imaging involves γ rays while X-ray imaging involves X-rays. Concerning the position of the source and the principle, state the differences between obtaining images by these two methods. (2 marks)
(d) Suggest TWO safety precautions for the workers operating a gamma camera. (2 marks)

19. Fig. a and Fig. b show two different scans of thyroids.


Q19a


Q19b

(a) Give ONE factor that determines the image resolution in each scan. (2 marks)
(b) Briefly describe how these two scans are performed. (6 marks)
(c) Which scan can tell whether the thyroid is functioning normally? (1 mark)

20. X-rays and gamma rays are two common EM waves used in medical imaging. Transmission imaging and emission imaging are the two common imaging principles.

(a) Give ONE difference between the two waves. (1 mark)

(b) (i) What is transmission imaging? Give ONE common example. (2 marks)

(ii) What is emission imaging? Give ONE common example. (2 marks)

(c) A man is admitted to a hospital after a car accident. He has a head injury and is suspected to be suffering internal bleeding inside the brain.

(i) An X-ray radiographic image of the head cannot show any abnormalities. Briefly explain why. (1 mark)

(ii) A CT is performed and the site of internal bleeding is identified. Briefly describe how a CT scan is carried out and how a CT image is reconstructed. (4 marks)

21. An old woman has had right lower back pain for more than 2 weeks. She has received X-ray imaging of the abdomen and a small white opaque area at the right kidney region is shown on the film. It is suspected that she is suffering from kidney stones. She then receives a special examination using a gamma camera to assess the function of both kidneys. She lies on an imaging table with the gamma camera placed behind her back. She is then injected with a radioactive tracer. Both her kidneys are imaged continuously over a period of 30 minutes. Then the images are displayed on the computer monitor. Regions of interest (ROI) are drawn over both kidneys and functional curves are generated. Radioactivity changes within the ROIs are shown by two curves. Outflow tract obstruction of the right kidney is diagnosed and the left kidney is functioning normally.

(a) (i) Suggest ONE reason why she should receive an X-ray first before the next method. (1 mark)

(ii) Explain why the right kidney stone is shown as a white opaque area on the X-ray film. (1 mark)

(b) (i) Can ultrasound imaging detect the kidney stone? If yes, explain how the stones can be shown. If not, why not? (3 marks)

(ii) State ONE advantage and ONE disadvantage of using ultrasound to detect kidney stones as compared with X-ray imaging. (2 marks)

(c) (i) Suggest ONE common radionuclide suitable for the radioactive tracer. (1 mark)

(ii) Sketch the functional curves for both kidneys over the 30 minute period. (2 marks)

22. Read the following article about a thallium scan and answer the questions that follow.

Thallium scan

Thallium-201 (Tl-201) can be used to evaluate the blood supply to the heart muscle. The scan is performed together with an exercise stress test. At the end of the stress test (when the patient has reached the highest level of exercise he or she can comfortably achieve), a small amount of Tl-201 is injected into the patient's bloodstream. The patient then lies down under a gamma camera, which takes photographs from the γ radiation emitted by the thallium.

The thallium attaches itself to the red blood cells and is carried throughout the body. It enters the heart muscle by way of the coronary arteries and is taken up by the cells of the heart muscle that come into contact with the blood.

(a) What is the radionuclide used in the mentioned test? (1 mark)

(b) Pregnant women are not advised to take a thallium scan. Suggest ONE reason. (1 mark)

(c) Suggest ONE possibility if cold spots appear in the image of a thallium scan. Briefly explain your answer. (2 marks)

23. **IB Physics Higher level Nov 2012** This question is about X-rays.

(a) Define the attenuation coefficient as applied to a beam of X-rays travelling through a medium. (2 marks)

(b) Derive the relationship between the attenuation coefficient μ and the half-value thickness $x_{\frac{1}{2}}$. (2 marks)

(c) Aluminium is often used to filter out the low energy X-rays in a beam of X-rays. The following data are available for a particular X-ray beam.

X-ray energy / keV	half-value thickness of aluminium / mm
15	0.70
30	3.5

Assuming equal initial intensities, determine, after the X-ray beam has passed through an aluminium sheet 6.0 mm thick, the following ratio. (3 marks)

$$\frac{\text{intensity of 15 keV X-rays}}{\text{intensity of 30 keV X-rays}}$$

(d) Outline why X-rays are not suitable to image an organ such as the liver. (2 marks)

24. **IB Physics Higher level Nov 2012** This question is about the use of radioactive isotopes in medicine.

(a) Distinguish between the biological half-life and effective half-life of a radioactive isotope. (2 marks)

(b) The radioactive isotope iodine-131 undergoes beta decay to the stable isotope xenon-131 with a physical half-life of 8.0 days. Gamma radiation is also emitted in this decay. Iodine-131 is readily absorbed by the thyroid gland. The biological half-life is 21 days.

(i) Calculate the effective half-life of iodine-131. (2 marks)

(ii) Suggest why iodine-131 is often chosen to treat cancer of the thyroid gland. (3 marks)

[**Note:** This part is out of the current syllabus.]

(c) Iodine-131 can be used to estimate the total blood volume of a patient.

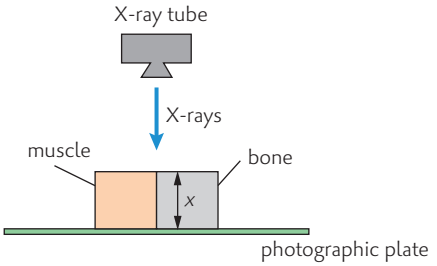
A small amount of the isotope is dissolved in 8.0 cm^3 of a solution. 4.0 cm^3 of this solution is injected into the patient. After a few minutes a 5.0 cm^3 blood sample is taken. The activity of this sample is measured to be 96 Bq.

The remaining 4.0 cm^3 of the solution is mixed with 1000 cm^3 of water. The activity of 5.0 cm^3 of this solution is measured to be 510 Bq.

Estimate the total volume of blood in the patient. (3 marks)

25. **IB Physics Higher level May 2013** This question is about the use of X-rays and ultrasound in medical imaging.

(a) The diagram below shows X-rays being used to scan a sample of bone and muscle.



(i) Outline how the arrangement differentiates between bone and muscle. (2 marks)

(ii) Use the data below to determine the ratio I_b/I_m where I_b and I_m are the intensity of X-rays reaching the photographic plate through the bone and the muscle, respectively. (3 marks)

Thickness x of sample = 10.0 cm

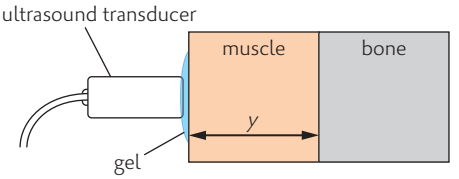
Linear attenuation coefficient of bone $\mu_b = 0.53\ cm^{-1}$

Linear attenuation coefficient of muscle $\mu_m = 0.30\ cm^{-1}$

(iii) The half-value thickness of a material increases as the energy of the radiation increases.

Discuss, with reference to penetration and effect on tissue, why using low energy X-rays in medical imaging is highly desirable but is rare in practice. (2 marks)

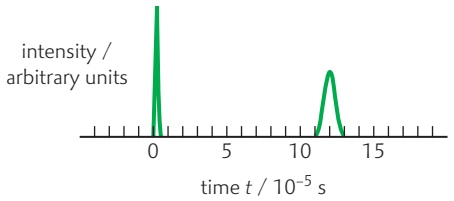
(b) The same sample is now investigated with an ultrasound A-scan from the side as shown.



(i) State ONE advantage of ultrasound over X-ray imaging. (1 mark)

(ii) State why gel is needed at the transducer–muscle boundary. (1 mark)

(iii) A short pulse is directed from the transducer into the sample at time $t = 0$. The graph shows how the intensity of the reflected signal from the muscle–bone boundary varies as a function of time. The speed of sound in muscle is 1.6×10^3 m s^{-1}.



Calculate the thickness y of the sample of muscle. (2 marks)

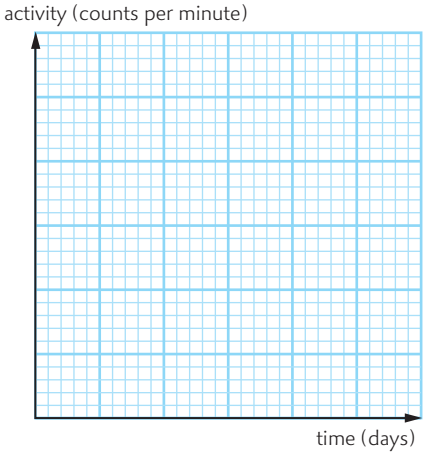
26. **AQA SC08 Jun 2013** Medical physicists consider the half-life of radioisotopes before recommending which isotope to use for diagnosis or therapy.

(a) What does half-life mean? (1 mark)

(b) A technician performed an experiment to check the physical half-life of radioisotope *A*. Her results, after correcting for background radiation, are shown in the table below.

time / days	activity / counts per minute
0	190
1	140
2	100
3	75
4	55
5	40

(i) Plot the results in the above table and draw a line of best fit. (3 marks)



(ii) Use your graph to find an accurate half-life for radioisotope *A*. (2 marks)

(c) (i) Radioisotope *B* has a physical half-life of 3 months. A hospital has bought 200 g of active radioisotope *B*. Assuming none has been used, how much active radioisotope *B* will be left after 1 year? (2 marks)

(ii) Radioisotope *C* has a physical half-life of 6 hours and a biological half-life of 12 hours. Calculate the effective half-life of radioisotope *C*. (3 marks)

(d) A doctor and a medical physicist are discussing whether or not radioisotope *C* is suitable for use as a tracer.

(i) Does radioisotope *C* have a suitable physical half-life for use as a tracer? Explain your answer. (2 marks)

(ii) What type of radiation must radioisotope *C* emit if it is suitable to use as a tracer? Explain your answer. (3 marks)

(iii) The medical physicist tells the doctor that radioisotope *C* has limited use because of its organ affinity. What does organ affinity mean? (1 mark)

[**Note:** This part is out of the current syllabus.]

(e) (i) The terms below describe some of the types of effects radioactivity can have on tissue. Explain what each term means: stochastic and somatic. (2 marks)

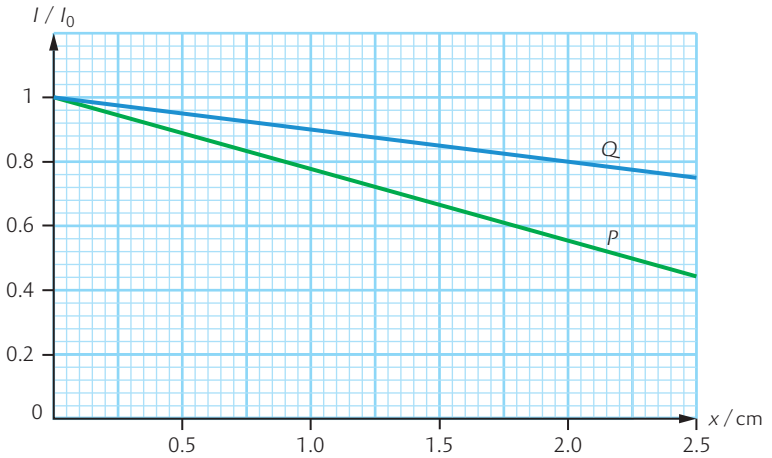
[**Note:** This part is out of the current syllabus.]

(ii) State TWO factors that can affect the amount of damage caused by exposure to radioactivity. (2 marks)

(iii) State ONE safety precaution you would take to protect yourself if you were working with radioactive sources in a school laboratory. Explain how this precaution would protect you. (2 marks)

27. HKDSE 2013

(a) The figure below shows how the intensity of an X-ray beam changes as it travels through a distance x in two media P and Q respectively. The initial intensity of the X-ray beam is I_0.

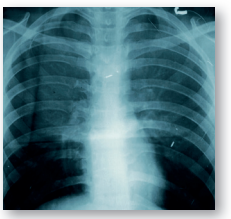


(i) What is the half-value thickness of medium P? (1 mark)

(ii) Find the linear attenuation coefficient of medium P. (2 marks)

(iii) Does medium Q have a density higher than, equal to or lower than that of medium P? (1 mark)

(b) The photo shows an X-ray radiographic image of the chest.



(i) Explain how the image is formed in terms of the effects on the passage of X-rays through different media including soft tissue and bone. (2 marks)

(ii) Briefly explain why a computed tomography (CT) image provides more detailed structural information of the body than an X-ray radiographic image. (2 marks)

(iii) Although CT images have the advantage mentioned above, give TWO reasons (other than CT scanners are more expensive) why conventional X-ray radiographic imaging has not been completely replaced by CT imaging. (2 marks)