The Ear – Medical Physics Option - Answers

1. A ear drum [or tympanic membrane] **(1)**
transfers sound waves from the outer ear to the
ossicles of the middle ear **(1)**

B ossicles [or bones of the middle ear] **(1)**
system of levers with a mechanical advantage (of 1.5) [or amplification]
[or which links two membranes (ear drum and oval window)
or transmits sound vibrations from outer to inner ear] **(1)**

C windows: oval <u>and</u> round **(1)**
allow sound vibrations to enter the fluid of the inner ear
[or allows sound vibrations to be transmitted around the cochlea
or contain the inner ear's fluid while allowing the fluid to move] **(1)**

D cochlea **(1)**
convert (pressure) waves [or vibrations] in the fluid into electrical signals
[or stimulates (auditory) nerves to send signals to the brain] **(1)**

[8]

2. (a) lowest level of sound (intensity) which the ear can detect **(1)**
1 kHz **(1)** 2

(b) ear has a logarithmic response
[or log scale chosen to match (perceived) response of the ear] (*)
to accommodate very wide range of sound intensities to which ear can respond (*)
perceived change in loudness is proportional to fractional change in intensity (*)
10- fold increases in intensity are perceived as steps of equal increase in loudness (*)
log scale means that numerical values on the scale represent ratios of
two sounds, expressed as the log of that ratio (*)
(*) any two **(1) (1)** 2

(c) the dBA scale takes account of the frequency dependence of the sensitivity of the ear
[or to match the ear's frequency response
or meters calibrated on a dBA scale give frequency-weighted readings] **(1)** 1

(d) (i) $2.0 = 10\log\left(\frac{I_2}{I_1}\right)$ **(1)**

$\frac{I_2}{I_1} = 1.58$ **(1)**

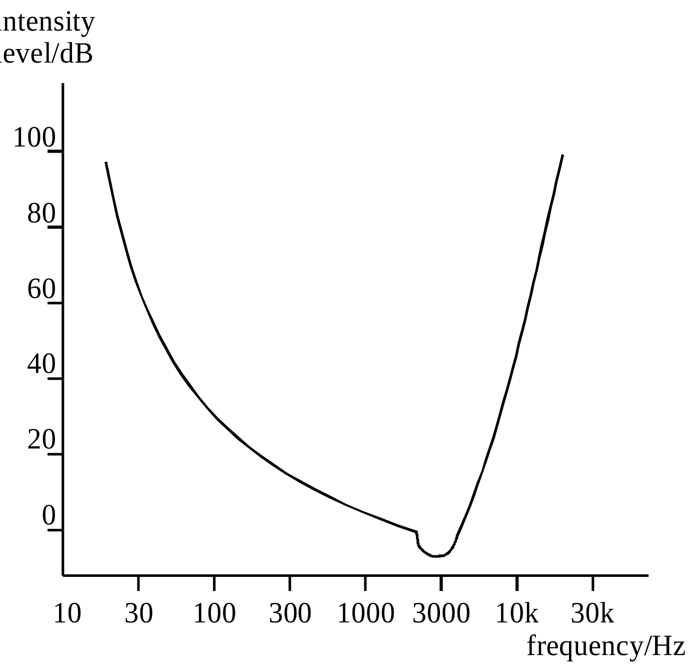
(ii) 10 steps = 10 × 2dB = 20dB **(1)**
$\frac{I_2}{I_1} = 100$ **(1)**
[1.58^{10} **(1)** = 100 **(1)**] 4

[9]

3. (a) threshold of hearing – lowest intensity of sound detected by human ear **(1)**
reference intensity (1.0×10^{-12} W m^{-2}) is taken at 1 kHz **(1)** 2

(b) basic shape **(1)**
range (30Hz – 20kHz approx) **(1)**
minimum between 1 kHz and 3 kHz **(1)**

scale, including units **(1)**
logarithmic **(1)**



5

(c) (i) $I_2 = 10^6 I_1$ **(1)** $= 10^6 \times 1.0 \times 10^{-12} = 1.0 \times 10^{-6}$ W m^{-2} **(1)**

(ii) number of dB $= 10\log_{10}\left(\frac{I_2}{I_1}\right) = 10\log_{10}\left(\frac{112}{100}\right)$ **(1)** = 0.5(dB) **(1)** 4

[11]

4. (a) ear has logarithmic response **(1)**
accommodates wide range of intensities **(1)** 2

(b) dB scale has a flat response with frequency **(1)**
dBA scale is frequency compensated **(1)**
for dBA, threshold intensities are different for different frequencies **(1)** 3

(c) (use of intensity level $=10 \log\left(\frac{I}{I_0}\right)$ gives) $94 = 10 \log\left(\frac{I}{1.0\times10^{-12}}\right)$ **(1)**

$I = 1.0 \times 10^{-12} \times 10^{9.4}$ **(1)** $= 2.5 \times 10^{-3}$ W m^{-2} **(1)** 3

(d) intensity $= 2 \times 2.5 \times 10^{-3}$ (W m^{-2}) **(1)**
(allow C.E. for *I* from part (c))

intensity level $= 10 \times \log\left(\frac{5.0\times10^{-3}}{1.0\times10^{-12}}\right)$ = 97 dB **(1)** 2

[10]

5. (a) (i) $Z_{air} = 330 \times 1.3 = 430$ kg m^{-2} s^{-1} **(1)**

(ii) $Z_{tissue} = 1540 \times 1100 = 1.7 \times 10^6$ (kg m^{-2} s^{-1}) **(1)**

(iii) (use of $\frac{I_r}{I_i} = \left[\frac{(Z_2 - Z_1)}{(Z_2 + Z_1)}\right]^2$ gives) $\frac{I_r}{I_i} = \left[\frac{1700000 - 430}{1700000 + 430}\right]^2 = 0.999$ **(1)**

(allow C.E. for values from (i) and (ii)) 3

(b) without gel, air between probe and tissue **(1)**
reflects nearly all the ultrasound or very little enters the body **(1)**
with gel air excluded and require $I_r = 0$ **(1)**
$\therefore Z_{gel} = 1.7 \times 10^6$ or equals that of skin/tissue **(1)** max 3

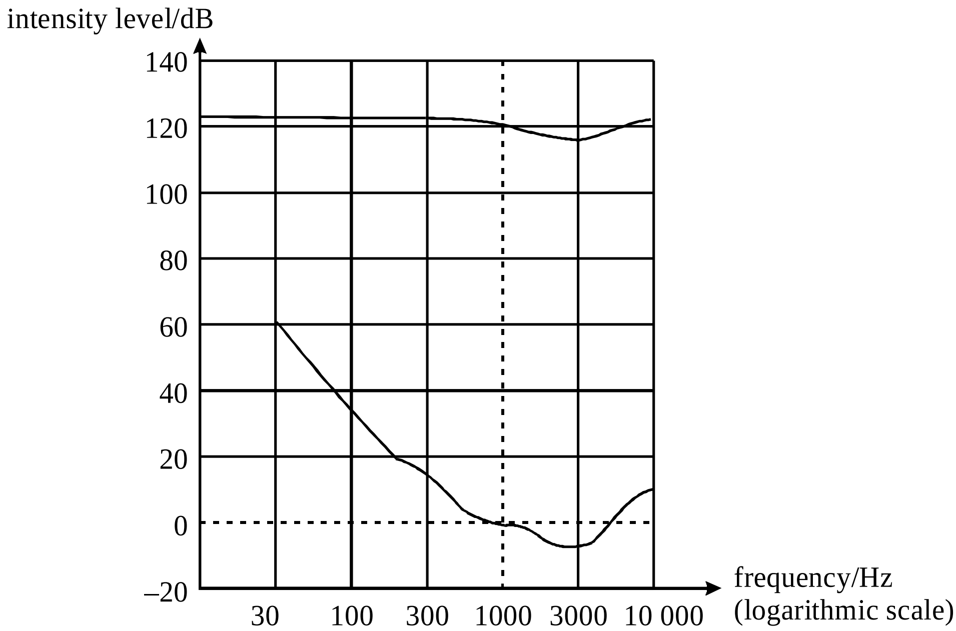
(c) (i) transmitter produces <u>short</u> pulses
at internal boundary some reflected, rest transmitted to next boundary
reflected pulse received by probe and signal sent to oscilloscope
oscilloscope sweep started when pulse is first transmitted
(any two) **(1) (1)**

(ii) time taken between pulses from front and back of organ
(from oscilloscope) **(1)**

distance = $\text{speed} \times \frac{\text{time}}{2}$ **(1)** 4

[10]

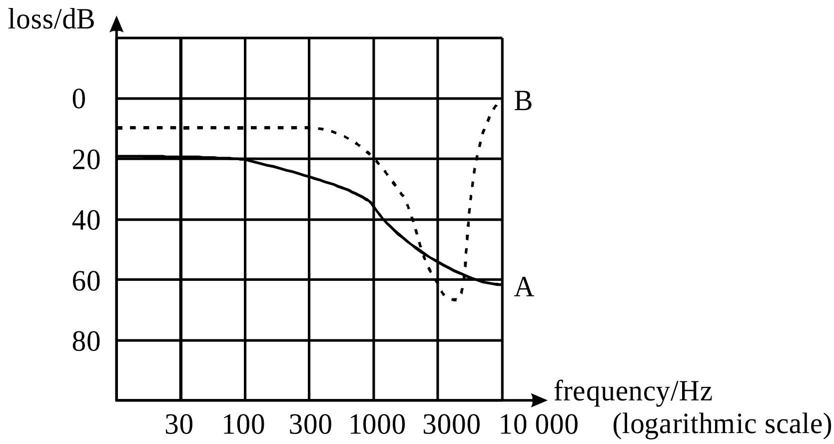
6. (a) (i)



general shape flatter and passing through 120, 1000 **(1)**

(ii) both most sensitive at ≈ 3000 Hz **(1)** 2

(b)



(i) trace A (——), basic shape correct **(1)**

(ii) trace B (------), basic shape correct **(1)**

(iii) loss due to age increases with frequency **(1)**
loss due to noise is maximum at 4000 Hz **(1)** 4

[6]

7. (a) A ear drum or tympanic membrane **(1)**
transfers vibration of sound waves into mechanical oscillations

B ossicles **(1)**
system of levers to multiply the force **(1)**
[or system of levers to link outer and inner ear]

C cochlea **(1)**
converts pressure wave in fluid into electrical signal **(1)** 6

(b) (use of *intensity level* = 10 log $\frac{I}{I_o}$ gives) 42 = 10 log $\frac{I}{1.0 \times 10^{-12}}$ **(1)**

$I = 1.6 \times 10^{-8}$ W m^{-2} **(1)** 2

[8]

8. (a) (i) intensity : power per unit cross-sectional area (in path of wave) **(1)**

(ii) attenuation : reduction in intensity/energy/power as wave travels through a medium **(1)**
due to absorption/scattering/diffraction **(1)** 3

(b) (use of intensity level = 10 log $\frac{I}{I_0}$ gives)

intensity = 10 log $\left(\frac{1.3 \times 10^{-4}}{1.0 \times 10^{-12}}\right)$ **(1)**
= 81 dB **(1)** 2

[5]

9. (a) (i) dBA scale is frequency dependent (dB scale is not) **(1)**

(ii) dB graph: flat - same response at all frequencies **(1)**
dBA graph: correct general shape **(1)**
most sensitive at 3 kHz **(1)**
slightly higher than dB curve at 3 kHz **(1)**
crosses dB line at 1 kHz **(1)** max 5

(b) (use of *intensity level* = $10 \log \frac{I}{I_0}$ gives) $85 = 10 \log \frac{I}{1.0 \times 10^{-12}}$ **(1)**

$I = 3.2 \times 10^{-4}$ (W m^{-2}) **(1)** (3.16×10^{-4} (W m^{-2}))
P (= IA) = $3.16 \times 10^{-4} \times 65 \times 10^{-6} = 2.1 \times 10^{-8}$ W **(1)** (2.06×10^{-8} W)
(allow C.E. for value of I) 3

[8]

10. (a) (i) listen to sound at f = 1 kHz and intensity level 10 dB **(1)**
listen to sound at different f and loudness and alter loudness **(1)**
switch between 1 kHz, 10 dB and new f and loudness until same loudness is perceived **(1)**
repeat for f between 20 Hz and 14 – 20 kHz **(1)**

QWC 1

(ii) equal loudness curve to show:
line almost flat at 100 dB **(1)**
with dip at 3 kHz **(1)** max 5

(b) (i) minimum of intensity of sound heard by normal ear **(1)**
at frequency of 1 kHz **(1)**

(ii) intensity level = $10 \log \left(\frac{1.3 \times 10^{-3}}{1.0 \times 10^{-12}}\right)$ **(1)**
= 91(.1) dB **(1)** 4

[9]

11. (i) thickness needed to reduce intensity by half **(1)**
for X-rays of specific energy **(1)**

(ii) $\mu = \frac{\ln 2}{x}$ **(1)**
= 58 m^{-1} **(1)** (57.8 m^{-1})

(iii) (use of $I = I_0 e^{-\mu x}$ gives) $0.05 = e^{-57.8x}$ **(1)**
x = 0.052 m (or 52 mm) **(1)** (51.8 mm)
(allow C.E. for value of μ from (ii)) 6

[6]

12. (a) 3 kHz **(1)** 1

(b) (i) (age related) as f increases, loss increases **(1)**

(ii) (noise related) loss is maximum at 4 kHz **(1)** 2

(c) (i) (use of *intensity level* = $10 \log \frac{I}{I_0}$ gives)

$I = 1.0 \times 10^{-12} \times 10^{86/10}$ **(1)**
$= 3.98 \times 10^{-4}$ W m^{-2} **(1)**

(ii) (use of same equation gives)

intensity level = $10 \log \left(\frac{3.98 \times 10^{-4} - 7.0 \times 10^{-5}}{1.0 \times 10^{-12}} \right)$

= 85(.2) dB **(1)**
(allow C.E. for incorrect *I* from (i)) **(1)** 4

[7]

13. (i) density of the material **(1)**
speed of sound in the material **(1)**

(ii) large difference in acoustic impedance **(1)**

(iii) (position) between probe and skin **(1)**

(reason for gel): without it, trapped air gives large difference in acoustic impedance **(1)**
gel has similar acoustic impedance to tissue **(1)**
air excluded and maximum transmission **(1)**

max 3 for (iii)

[6]