inkPhysics

ANSWER BOOK

The physics of the ear

Medical physics · Year 13

AQA 3.10.2.1, 3.10.2.2, 3.10.2.3

17 questions · 51 marks

NAVY EDITION

SECTION A · Warm-up

A1 Intensity is the power carried by the wave through unit area at right angles to its direction of travel (1). $I = P/A$, measured in $W\ m^{-2}$ (1). [2]

A2 The minimum intensity that a normal ear can detect, quoted at a frequency of 1 kHz (1). Its value is $I_0 = 1.0 \times 10^{-12}\ W\ m^{-2}$ (1). The frequency is part of the definition, and answers that omit it lose the mark. [2]

A3 Outer ear: the pinna collects the sound and funnels it along the ear canal to the eardrum, which vibrates (1). Middle ear: the three ossicles carry the vibration from the eardrum across to the smaller oval window. Inner ear: the oval window drives the fluid in the cochlea, where hair cells convert the vibration into nerve impulses (1). [2]

A4 It joins the combinations of frequency and intensity level that a listener judges to be equally loud (1). Intensity level in dB is plotted against frequency, on a logarithmic frequency axis (1). [2]

A5 Intensity level = $10 \log(I/I_0) = 10 \log[(1.0 \times 10^{-6})/(1.0 \times 10^{-12})]$ (1) $= 10 \log(10^6) =$ **60** dB (1). [2]

A6 About 20 Hz to 20 kHz (1). The upper limit falls with age long before the lower one does. [1]

SECTION B · Standard

B1 $I/I_0 = (3.0 \times 10^{-5})/(1.0 \times 10^{-12}) = 3.0 \times 10^7$ (1). Intensity level = $10 \log(3.0 \times 10^7)$ (1) = **75** dB (1). [3]

B2 $85 = 10 \log(I/I_0)$, so $I/I_0 = 10^{8.5}$ (1) $= 3.16 \times 10^8$ (1). $I = 3.16 \times 10^8 \times 1.0 \times 10^{-12} =$ **3.2** $\times 10^{-4}\ W\ m^{-2}$ (1). [3]

B3 $I = I_0 \times 10^{6.6} = 4.0 \times 10^{-6}\ W\ m^{-2}$ (1). $A = 55\ mm^2 = 55 \times 10^{-6}\ m^2$ (1). $P = IA = 4.0 \times 10^{-6} \times 55 \times 10^{-6} =$ **2.2** $\times 10^{-10}$ W (1). The area conversion carries a factor of 10^{-6}, and using 10^{-3} is the standard slip. [3]

B4 The three ossicles are linked as a lever, so the force delivered to the oval window is larger than the force the eardrum receives (1). The eardrum also has roughly twenty times the area of the oval window, so the force acts over a much smaller area and the pressure is correspondingly greater (1). It is necessary because the cochlea beyond the oval window is filled with fluid: without the gain almost all the sound would reflect at the air-to-fluid boundary rather than entering (1). [3]

B5 Relative intensity level = 10 log(I_B/I_A) (1). I_B/I_A = $(8.0 \times 10^{-5})/(4.0 \times 10^{-6})$ = 20 (1). 10 log 20 = **13** dB (1). Neither sound has to be referred to the threshold: the difference of two levels is the log of their ratio. [3]

B6 The audible range runs from about 1.0×10^{-12} W m^{-2} up to about 1 W m^{-2}, twelve powers of ten, and no linear axis can show both ends usefully (1). The ear also judges by ratio rather than by difference, so multiplying the intensity by a fixed factor is heard as a fixed step of loudness (1). A logarithmic scale turns those equal ratios into equal intervals, so equal steps in decibels correspond to equal steps in perceived loudness (1). [3]

B7 A reference tone of 1 kHz is set to a chosen intensity level (1). A test tone at some other frequency is played and its intensity is adjusted until the listener judges the two tones to be equally loud; the intensity level it needed is recorded at that frequency (1). This is repeated across the audible range and the points joined, and the results are averaged over many listeners; the curve is labelled by its own intensity level at 1 kHz (1). [3]

SECTION C · Stretch

C1 The two levels differ by 60 - 30 = 30 dB (1). 30 = 10 log(I_{100}/I_{1000}), so the ratio is 10^3 = **1000** (1). The 100 Hz tone must carry a thousand times the intensity to be heard as equally loud, so the ear is far less sensitive at 100 Hz than at 1 kHz (2). The curves dip lowest between about 2 kHz and 5 kHz, near 3 kHz, and that is where the ear is most sensitive (1). [5]

C2 Intensities add, not levels: two identical machines give twice the intensity (1). 10 log 2 = 3.0 dB, so the new level is 92 + 3.0 = **95** dB (2). For 102 dB the level has risen by 10 dB above one machine (1), which is a factor of 10^1 in intensity, so **10** machines are needed (1). Adding the decibel figures themselves would predict 184 dB, which is above the threshold of pain and plainly wrong. [5]

C3 The reduction in intensity level is 10 log 250 = 24 dB (2). The level inside is therefore 96 - 24 = **72** dBA (1). A reading in plain dB weights every frequency equally, so it overstates the effect of low-frequency rumble that the ear barely registers (1). The dBA scale applies a standard weighting curve, drawn to approximate the ear's response at moderate levels, before the level is computed, so its single number counts the frequencies the ear is sensitive to most heavily; that makes it an exposure metric rather than a measurement of perceived loudness, and an exposure metric is the fair basis for a limit (1). [5]

C4 The threshold curve of the damaged ear lies above that of the normal ear everywhere, so a greater intensity is needed before anything is heard at all (1). The lift is uneven: the high-frequency end rises far more than the middle of the range, and noise damage typically leaves the worst loss around 4 kHz (1). The higher curves change much less, so loud sounds still seem loud and the loss is easy to overlook (1). Consonants such as s, f and t carry their information at high frequency and low intensity, so those are lost first and following speech in a noisy room becomes difficult (1). [4]