8 The range of frequencies which can be heard by different people varies, but most can hear sounds in the range 20 Hz to 20 kHz.

Loudness is the human mental response to the intensity of sound. For a sound frequency of 1 kHz, the lowest sound intensity which can be heard by normal healthy adult is 1.0×10^{-12} W m^{-2}. This intensity is known as the *threshold intensity* I_o and any increase from this intensity will be perceived as an increase in the loudness of the sound.

The *intensity level* of a sound is a comparison of its intensity and the threshold intensity, and is given by

$$\text{Intensity Level} = 10 \lg \frac{I}{I_o}$$

where I is the intensity of the sound incident on the eardrums. The unit of intensity level is the *decibel* (dB).

Fig. 8.1 below shows the typical values of intensity levels for a sound frequency of 1 kHz from a variety of sources measured at various distances.

Source	distance from source / m	Intensity Level / dB
Jet engine at takeoff	30.0	140
Speakers at a rock concert	10.0	120
Diesel generator	3.0	100
Vacuum Cleaner	1.0	80
Normal conversation	1.0	60
Whispered conversation	1.0	30
Healthy hearing threshold	-	0

Fig. 8.1

For a sound frequency of 1 kHz, long term exposure to intensity levels above 90 dB may result in noise-induced deafness. The onset of pain in eardrums typically occurs at an intensity level of 120 dB while an intensity level of 160 dB will cause eardrums to rupture.

(a) The earphones attached to a portable music player can produce up to 0.30 μW of power. When the earphones are fitted to the ears, all the sound energy propagates through the auditory canal and is collected by the eardrums with an effective area 1.8×10^{-5} m^2.

For a sound of frequency 1 kHz,

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

intensity = ... W m^{-2} [2]

(ii) Determine the intensity level of the sound incident on the eardrums.

intensity level = ... dB [1]

(iii) Using your answer obtained in **(a)(ii)**, comment on the use of the earphones at maximum power.

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..... [1]

(b) Show that if the intensity of sound is doubled, the change in intensity level is 3 dB.

$$\Delta \text{ intensity level} = 10\lg\left(\frac{2I}{I_0}\right) - 10\lg\left(\frac{I}{I_0}\right) \quad \text{[M1]}$$

$$= 10\lg\left(\frac{2I}{I_0} \times \frac{I_0}{I}\right)$$

$$= 10\lg 2$$

$$= 3.01 \quad \text{[A1]}$$

(c) (i) Using data in Fig. 8.1, determine the sound power of the diesel generator. Assume that the sound is emitted uniformly in all directions

sound power = ... W [3]

(ii) For occupational health and safety reasons, all personnel are required to wear ear protection if the intensity level at the ear exceeds 85 dB.

Determine the minimum distance from the diesel generator such that no ear protection is required.

minimum distance = ... m [2]

Question 8 continues on the following page.

The loudness of a sound not only depends on the intensity level of the sound but also on its frequency. The *phon* is the unit of measurement of *loudness level*. In order to define this unit of measurement, sound frequency of 1 kHz is chosen as the standard for comparison. Hence, a source is said to have a loudness of 40 phon if a 1 kHz standard source has an intensity level of 40 dB.

Sounds of different frequencies having the same loudness fall on the same equal-perceived-loudness contour. Fig. 8.2 shows different equal-perceived-loudness contours for a healthy 18-year-old man, as a function of frequency of the sound.

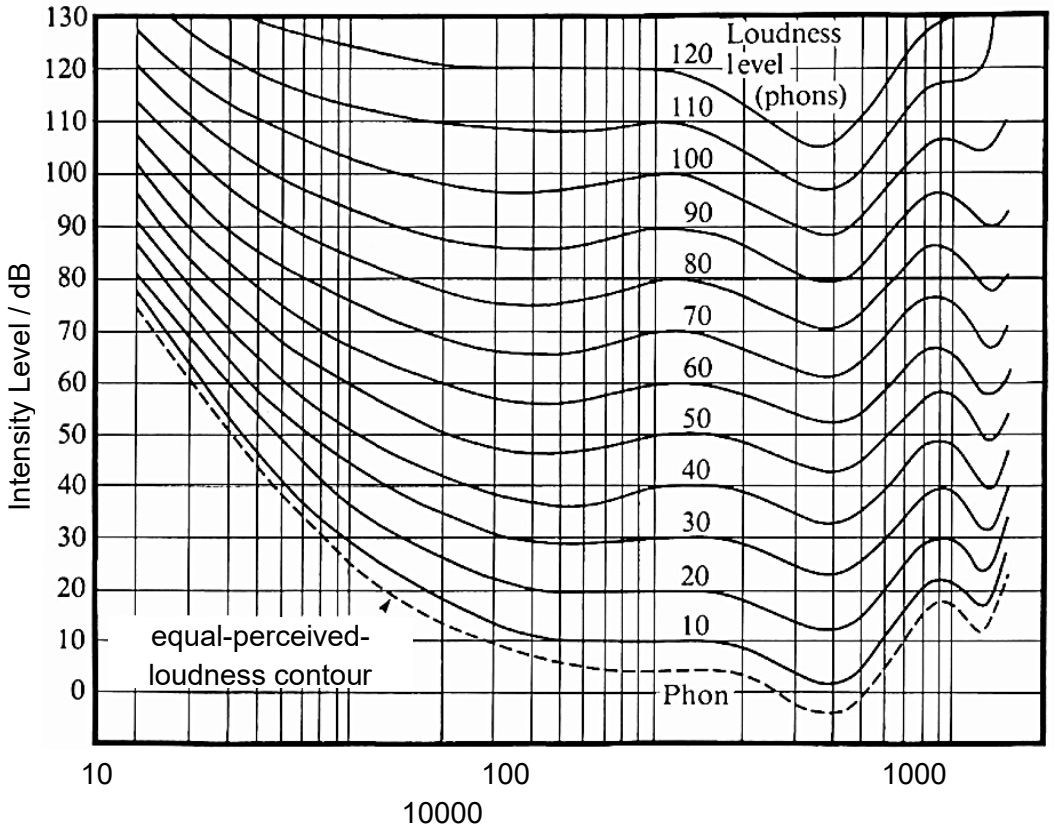

Fig. 8.2

(d) (i) The frequency axis on Fig. 8.2 is plotted on a logarithmic scale. Suggest why this is so.

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..... [1]

(ii) Using Fig. 8.2,

1. state the intensity level for a sound wave of 100 Hz for it to have the same perceived loudness as a sound wave of 1000 Hz at 50 dB.

intensity level = ... dB [1]

2. state and explain which of the following sounds louder:
a sound wave of 50 Hz at 60 dB, or
a sound wave of 2000 Hz at 45 dB

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..... [2]

(iii) Suggest and explain any changes in the equal-perceived-loudness contours for a 80-year-old man when compared to that for a healthy 18-year-old man.

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..... [2]

(e) (i) Using Fig. 8.2, state and explain the frequency range that a human will be most sensitive to.

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..... [2]

(ii) In movie theatres, sound of all frequencies may be heard with equal loudness. Suggest how this is achieved.

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.... [1]

End of Paper