7 Read the passage below and answer the questions that follow.

As scientists and engineers work to reduce noise pollution from aircraft, a thorough understanding of the Physics of sound is necessary.

Speed of sound

Sound is produced by vibrating objects, and it can be transmitted through solids, liquids, or gases. As it propagates through different mediums, it travels at different speeds as shown in Fig. 7.1.

	solid steel	sea water	air
speed of sound at 30° C	5200 m s^{-1}	1500 m s^{-1}	350 m s^{-1}

Fig. 7.1

The speed of sound is also dependent on temperature. For example, as the temperature of air increases, the speed of sound in air increases. For air at sea level, the expected speed of sound v, in m s^{-1}, is related to the temperature of the air T by the following equation:

$$v = 331\sqrt{\frac{T}{T_0}}$$

where T_0 is the temperature, in Kelvin, at which ice melts.

Intensity of sound

An isotropic sound source emits sound wave equally in all directions. The relative "loudness" of sound is often expressed in the unit decibel.

The decibel (dB) expresses the relative intensity of a sound. The difference in intensity I of the sound with respect to a reference intensity I_{ref} is given by the following equation:

$$\text{Difference in sound level (in decibel)} = 10\lg\frac{I}{I_{ref}} \text{ dB}$$

As sound is usually measured using microphones, which respond proportionally to the varying sound pressures, the difference in sound level (in decibel) can also be expressed in terms of the pressure amplitudes p of the sound with respect to a reference pressure amplitude p_{ref}. This is given by the following equation:

$$\text{Difference in sound level (in decibel)} = 20\lg\frac{p}{p_{ref}} \text{ dB}$$

The faintest sound that a typical human ear can detect has an intensity of 1.0 pW m^{-2}. This is taken as standard reference level, and a sound at this intensity is at 0 dB.

Sonic boom

When an aircraft travels at supersonic speed of greater than the speed of sound, the effect of noise pollution becomes an issue. As it exceeds the speed of sound, it creates shockwaves that propagate as sonic booms. These sonic booms can be heard as loud, explosive noises.

One example of an aircraft capable of such speed is the Concorde. It is the world first supersonic passenger-carrying commercial aircraft that could fly at Mach 1.78, or 1.78 times the speed of sound. Regulations permitted the Concorde to cruise at supersonic speeds only over the ocean at its designated cruising altitude.

The X-59, a cutting-edge experimental aircraft, cruises at Mach 1.4 without producing the loud sonic boom typical of supersonic flights like the Concorde. This capability could open up new flight routes currently restricted.

(a) Sound is transmitted as a wave from the source.

(i) State and explain if sound can be polarised.

……………………………………………………………………..…………………………..

……………………………………………………………….…………………… [2]

(ii) Fig. 7.1 shows that the speed of sound is faster in solid steel than in air.

Suggest why.

……………………………………………………………………..…………………………..

……………………………………………………………….…………………… [1]

(iii) State the relationship between the intensity of sound I and the distance r from an isotropic sound source.

……………………………………………………………….…………………… [1]

(iv) Fig. 7.2 shows the cross-section of a human ear. The eardrum is a sensitive organ that can be damaged if the force on it is too large.

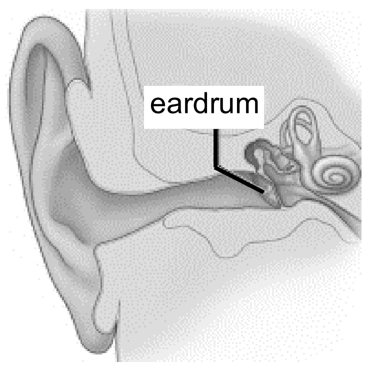

Fig. 7.2

When sound waves enter the ear, it vibrates the eardrum which converts the sound to electrical signal that is sent to the brain. The faintest sound that a typical human ear can detect at 0 dB has a pressure amplitude of 20 μPa.

1. Determine the intensity and pressure amplitude of a sound at 120 dB.

intensity = ………………… W m^{-2}

pressure amplitude = …..…………………. Pa [2]

2. Estimate the area of a typical eardrum.

area = …..………………… m^2 [1]

3. Hence estimate the maximum force on a human eardrum at 120 dB.

maximum force = …..………………… N [2]

(b) The Concorde cruises at an altitude of 18 km above sea level. At this height, sound travels at 295 m s^{-1}.

(i) Suggest why the Concorde was only permitted to cruise at supersonic speed when it was flying over the ocean.

……………………………………………………………..…………………………..

……………………………………………………………..…………………… [1]

(ii) Suggest why the Concorde cruises at an altitude of 18 km above sea level.

……………………………………………………………..…………………………..

……………………………………………………………..…………………… [1]

(iii) Calculate the cruising speed of the X-59 when it cruises at the same height as the Concorde.

speed = ………………… m s^{-1} [2]

(c) An experiment was conducted to measure the speed of sound through air. Fig. 7.3 shows the setup. A speaker is placed near the opening of a burette that is initially filled with water.

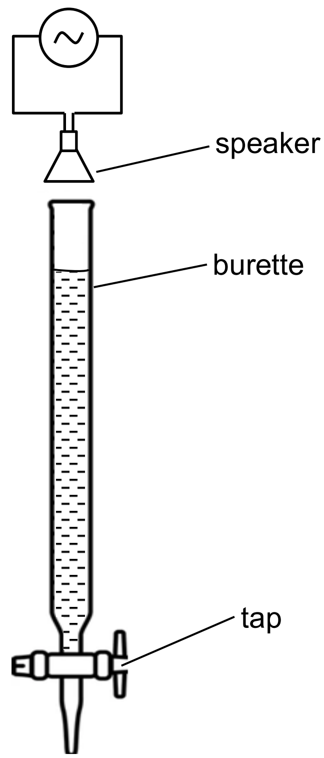

Fig. 7.3

The speaker, connected to a sinusoidal signal generator, emits a continuous sound with a frequency of 480 Hz. Water flows out of the burette when the tap at the base is opened.

As the water drains out, a series of loud and soft sounds are heard. Successive loud sounds are heard when the water level is at 54 cm and 91 cm from the opening of burette.

(i) State the phenomenon occurring when a loud sound is heard.

……………………………………………………………..…………………… [1]

(ii) Determine the wavelength of the sound measured.

wavelength = ………………… m [2]

(iii) Hence calculate the speed of sound measured.

speed = ………………… m s^{-1} [2]

(iv) The experiment was conducted at a temperature of 22 °C.

Calculate the expected speed of sound at this temperature. Show your working clearly.

speed = ………………… m s^{-1} [2]