A. Qualitative Questions:

1. The human voice is in some ways like a musical instrument, and is used as such in many choral works, such as Mozart’s requiem.
   a. The vocal cords are like a violin’s strings, they need the resonance chambers in the throat and nose to produce speech or song. The vocal chords vibrate setting up standing waves in the resonance chambers such as the throat. The shape and size of the resonance chambers determines the sound that is produced.
   b. When someone inhales helium, their voice becomes very high pitched, and they sound like Mickey Mouse. This is because helium is much less dense than air, and the velocity of sound, which depends on density of the medium, is much greater in helium. The wavelengths of the standing waves supported by the resonance chambers is the same, so the greater speed means a greater frequency \( (v = f \times \lambda) \) and hence a higher pitched sound.

2. The outer ear canal is open to the air at one end and closed by the ear drum at the other end.
   a. The ear drum behaves like a spring which is being driven by the oscillations of the air in the ear canal. It has a natural frequency of only a few kHz, hence it will not oscillate very much in response to driving frequencies which are very much higher than this.
   d. However, even if it did, the cochlear would not respond to frequencies above about 20 kHz anyway.

B. Activity Questions:

1. Tuning forks and beats.
   The beat frequency you hear from two notes is the difference between the frequencies of the two notes, \( f_{\text{beat}} = f_1 - f_2 \). The closer the frequencies and hence the notes, the slower the beats.
   Musicians tune their instruments by sounding a known note, for example with a tuning fork, then adjusting their tuning so beats frequency decreases until the beats stop, and the note from their instrument is the same as the tuning fork.
2. **Resonance in a tube.**
When the tube is the right length, the air column inside it will resonate with the tuning fork, producing a louder sound. See diagram opposite. A trombone produces different notes by varying the length of the air column inside it.

3. **Look and listen**
Increasing amplitude increases volume (below left), increasing frequency increases pitch (below right).

4. **Visualising Speech**
The microphone has a diaphragm (transducer) that converts vibrations in the air (sound) into an electrical signal. If this diaphragm is vibrated by other means it still produces an electrical signal.
You should see a complicated wave-form, because when you speak you produce many frequencies simultaneously. A whistle gives an approximately sinusoidal signal.

C. **Quantitative Questions:**

1. A certain aircraft produces a sound intensity of 100dB when it flies over at 100m altitude.
   a. Intensity obeys the $1/r^2$ law, so the ratio of the intensity at $h$ m to that at 100 m is
      \[ I_h/I_{100} = 100^2/h^2. \]
      The ratio of intensities, I, is equal to the difference in sound level in dB.
      The change in intensity in dB is
      \[ \text{Change} = 10 \log \left( \frac{h}{100} \right)^2 = 1.5 \text{ dB} \]
      \[ 20 \log \left( \frac{h}{100} \right) = 1.5 \text{ dB} \]
      \[ h/100 = 10^{1.5/20} = 1.19 \text{ so } h = 100 \times 1.19 = 119 \text{ m.} \]
   b. If two identical aircraft fly overhead at 119 m the sound intensity will be $98.5 + 3 \text{ dB} = 101.5 \text{ dB.}$

2. The Doppler effect is used in hospitals to measure the rate of blood flow by bouncing ultrasound waves off red blood cells.
   a. If the cells are moving away from the emitter, the frequency “detected” by the cells will be lower.
   b. The cells are now acting as the source and moving away from the detector, the machine, which will detect a lower frequency again.
   c. The sound is emitted by the machine, then reflected by the red blood cells. So taking the case of cells moving away from the machine (the other case would be equally valid) we use
      \[ f_{\text{obs}} = f_{\text{emitted}} \times \frac{v_{\text{sound}} - v_{\text{blood}}}{v_{\text{sound}} + v_{\text{blood}}} \]
      \[ \Delta f = f_{\text{obs}} - f_{\text{emitted}} = (f_{\text{emitted}} \times \frac{v_{\text{sound}} - v_{\text{blood}}}{v_{\text{sound}} + v_{\text{blood}}}) - f_{\text{emitted}} \text{ which after a lot of rearranging gives:} \]
      \[ \Delta f = 2. f_{\text{obs}} \left( \frac{v_{\text{blood}}}{v_{\text{sound}}} \right) \text{ and } v_{\text{blood}} = 1.6 \text{ cm.s}^{-1}. \]
   d. The wave speed does not depend on the particle speed, only on the medium!