

# SEP

Science Enhancement Programme

## SOUND



# SOUND

The Science Enhancement Programme is a part of Gatsby Technical Education Projects. It is developing curriculum resources to support effective learning in science, and providing courses and professional development opportunities for science teachers. This booklet is part of the series 'Innovations in practical work', exploring ways in which low-cost and novel resources can be used in secondary science.



Science Enhancement Programme



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## HEALTH AND SAFETY

For practical activities, the Science Enhancement Programme has tried to ensure that the experiments are healthy and safe to use in schools and colleges, and that any recognised hazards have been indicated together with appropriate control measures (safety precautions). It is assumed that these experiments will be undertaken in suitable laboratories or work areas and that good laboratory practices will be observed. Teachers should consult their employers' risk assessments for each practical before use, and consider whether any modification is necessary for the particular circumstances of their own class/school. If necessary, CLEAPSS members can obtain further advice by contacting the Helpline on 01895 251496 or e-mail [science@cleapss.org.uk](mailto:science@cleapss.org.uk).

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## What's in this booklet?



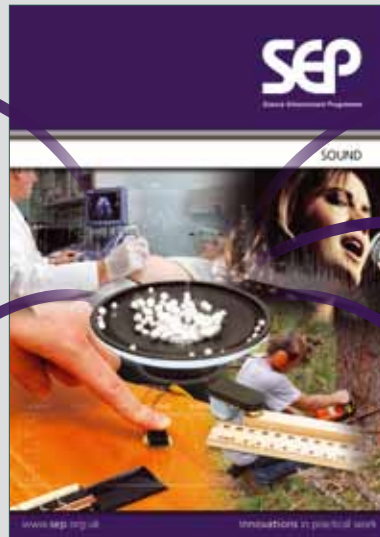
### Sound in the classroom

An 'illustrated overview' of the topic with ideas for practical activities



### Student activities

Photocopiable activity sheets for students with detailed teachers' notes



### Curriculum links



### References and further reading



### Background science

## Further resources

DOWNLOADING **DIGITAL RESOURCES** FROM THE SEP WEBSITE

[www.sep.org.uk](http://www.sep.org.uk)

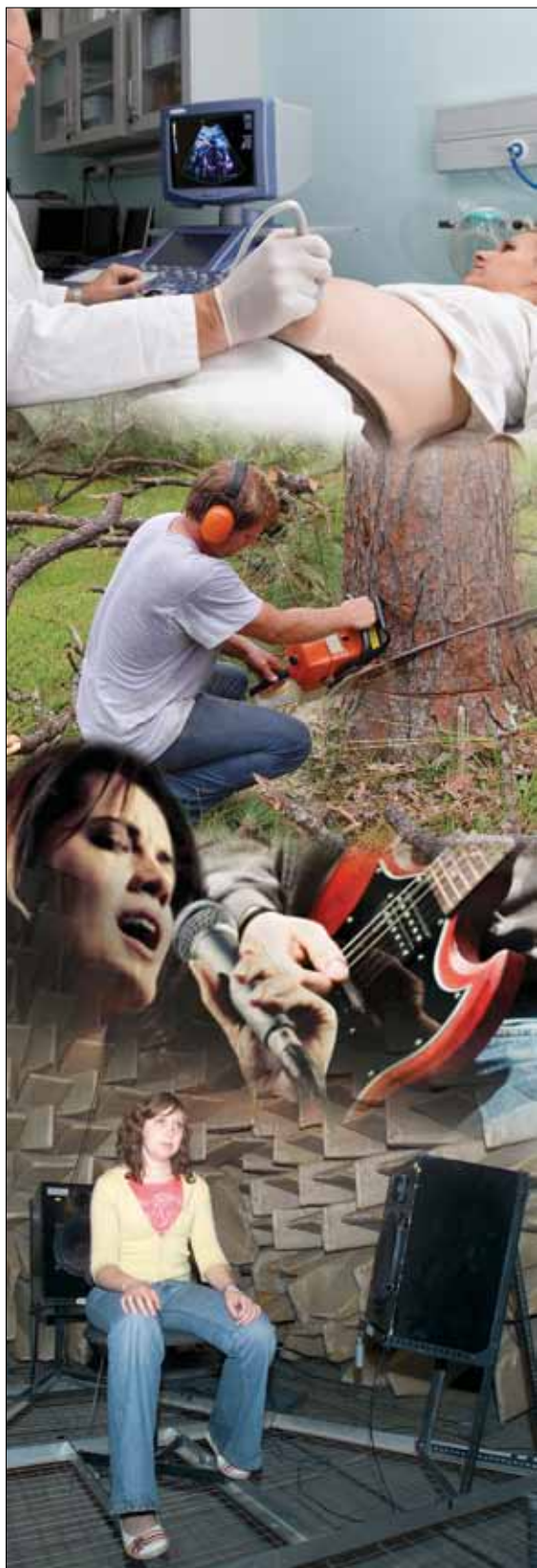


ORDERING **PRACTICAL RESOURCES** FROM MUTR

[www.mutr.co.uk](http://www.mutr.co.uk)



See pages 51 - 52 for further details



## INTRODUCTION

**Sound is an important part of our lives. Many people enjoy listening to music, and watching television would not be the same without sound. On the other hand, noise – loud or unwanted sounds – can make our lives miserable.**

One of the first things most people learn to do as babies or toddlers is to use drums and rattles to make a lot of noise. From childhood onwards, many people spend a significant part of each day listening to music, sometimes so loudly that it eventually damages their hearing. We use sound to make sense of our environment whether we are conscious of the process or not, and we use our experience of sound to control sound levels in our environment, by covering our ears, or closing windows or moving further away from the source.

The emphasis of this booklet is on providing teachers with an overview, a sense of 'story'. The activities are intended to offer opportunities to apply ideas about sound and vibrations rather than to introduce these ideas. Some of the activities also provide opportunities to consider 'How Science Works' aspects such as sources of uncertainty, or the limitations of sensing equipment.

The practical activities are intended for GCSE students but would be accessible to KS3 and might also be developed for work with older students. They are accompanied by a series of low-cost practical resources, which are available to purchase from Middlesex University Teaching Resources (MUTR).

## CURRICULUM LINKS

The following table shows the relevant sections for selected examination specifications (references to GCSE are for the 2011 specifications). In addition to the subject content links, the activities in the booklet address 'How Science Works' aspects. Some activities could also be adapted for older or for younger students, or used as the basis for Science Club activities.

Specification	Sections particularly related to sound
AQA GCSE	Unit Physics 3: 13.5 What is sound? 13.6 What is ultrasound and how can it be used?
AQA Additional Applied Science GCSE	Unit 1 Science in the Workplace: 10.2 Investigating how science is used; 10.3 Working safely in science.
AQA Applied Double Science GCSE	Unit 1 Science in the Workplace: 10.2 Investigating how science is used; 10.3 Working safely in science. Unit 2 Science for the Needs of Society: 11.6 Transport and Communication. Unit 3 Developing Scientific Skills: 12.5 How materials scientists investigate the properties of materials. Unit 4 Using Scientific Skills for the Benefit of Society: 13.4 Assembling an electronic/electrical device.
Edexcel GCSE	Unit P1: Universal physics: Topic 1 Visible Light and the Solar System; Topic 4 Waves and the Earth. Unit P3: Physics to help medicine: Topic 1 Radiation in treatment and medicine.
Edexcel BTEC First Certificate in Applied Science	Unit 2 Energy and Our Universe: 2 Know the properties and applications of waves and radiation. Unit 5 Applications of Physical Science: 3 Be able to investigate light and sound waves. Unit 14 Science in Medicine: 1 Be able to investigate the range of scientific procedures used in diagnosing illness; 2 Be able to investigate the scientific principles of treating illnesses and health conditions. Unit 15 Using Mathematical Tools in Science: 1 Be able to use mathematical tools in science; 2 Be able to collect and record scientific data; 3 Be able to display and interpret scientific data.
OCR Twenty First Century Science GCSE	Module P1 The Earth in the Universe: P1.2 What do we know about the Earth and how it is changing?
OCR Additional Applied Science GCSE	Unit A191 Science in Society: Topic A2 Health care. Unit A192 Science of Materials and Production: Topic B2 Stage and Screen.
OCR Gateway GCSE	Module P4 Radiation for life: P4d Ultrasound. Module P5 Space for reflection: P5f Nature of waves; P5g Refraction of waves.
WJEC Science GCSE	Physics 1 Energy, radiation and the Universe: 5 The characteristics of waves. Physics 3 Electromagnetism, waves, kinetic theory, nucleosynthesis: 2 Properties of waves.

## SOUND IN THE CLASSROOM: IDEAS AND SUGGESTIONS

Every time we talk on a mobile phone, we are using a device which includes a microphone to turn sounds into electrical signals and a loudspeaker (or headphones) to turn electrical signals back into sounds. Sound is a topic to which everyone can relate, but it is also an important area of scientific study. While some scientists make use of sound to learn more about materials, other scientists and engineers study how to control the level of sound in built spaces. Yet others research the causes of hearing loss, or the uses of ultrasound for medical diagnosis and treatment.

The 'story' running throughout this booklet has three broad themes:

- *Sources* – how sounds are produced, and the characteristics of sound
- *Journeys* – how sound interacts with materials, about using sounds to find out about materials and about the environment, and about manipulating the sound environment
- *Detectors* – how sounds and vibrations are detected, and about the range and characteristics of human hearing.

A concert illustrates all of these ideas. The way a performance sounds to a member of the audience depends on the sound source (the performer's voice or instrument), and on the acoustics of the venue. In an amplified concert, it will also depend on how well the sound is captured by the microphone and relayed by loudspeakers. The voice, instruments and speakers are all sound sources; the microphones on stage and the listeners' ears are detectors; the journey made to the listeners is affected by the way that the sound is absorbed or reflected by the surroundings.

Sources, journeys and detectors in action.



This section gives an 'illustrated overview' of how practical resources and computer software can be used in the classroom to develop an understanding of sound. In the margin, references are given to student activities – these resources and the accompanying teachers' notes can be found later in the booklet.

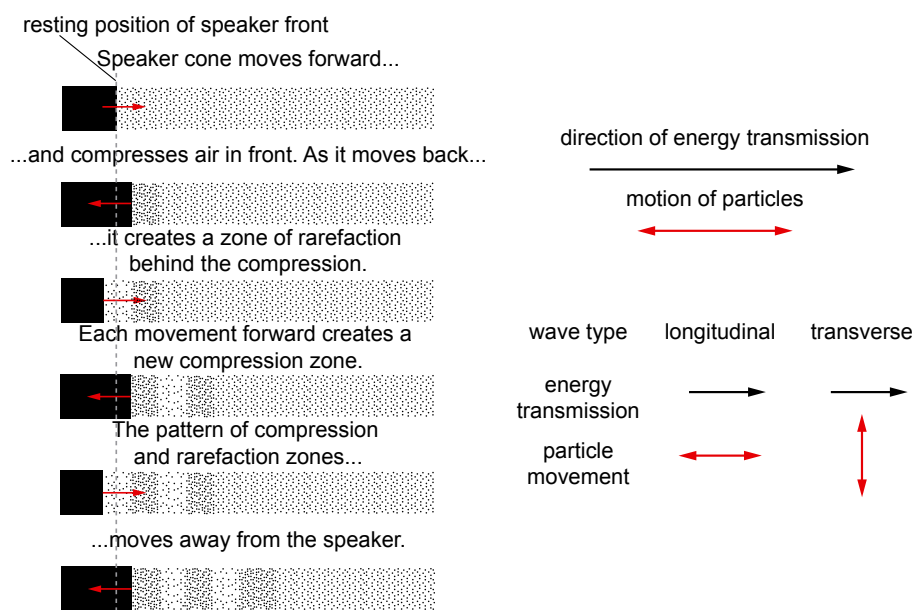


VIBRATIONS AND SOUND SOURCES

Everyday experience shows that there is a link between sounds and vibrations. Banging a drum, plucking a guitar string or ‘twanging’ a ruler all show that sound is produced by vibrations, that bigger vibrations produce louder sounds and that faster vibrations produce sounds with a higher pitch. Stopping the vibrations stops the sound. Most people also know that there must be something to carry the vibration, and so sound does not travel through a vacuum.

Sound waves propagate through a medium (which could be a solid, liquid or gas) away from a vibrating source; the wavefront is a region of disturbance, and the energy is transmitted through the medium, but the particles themselves do not travel away from their mean or average ‘undisturbed’ position. In the case of sound being produced by a vibrating speaker cone, the moving speaker compresses the air in front of it as it moves forward, producing a region of increased pressure; when it moves back the region in front of it has a lower pressure. For simplicity, the diagrams below show the sound propagating in a single direction and producing a planar wavefront (in reality the wavefront should be spherical as sound should propagate evenly in a uniform medium).

Zones of compression and rarefaction moving away from the vibrating cone of a speaker (left). The motion of the particles which are transmitting the energy by their movement (right) is in the same direction as the energy transmission, making this a longitudinal wave.



**Classroom activities**

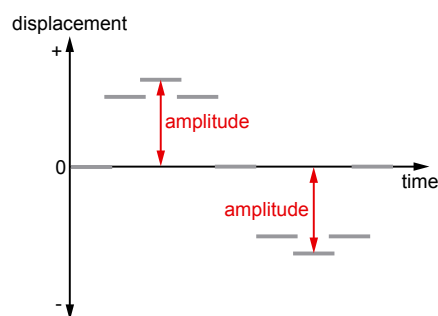
It is useful to remind students of basic ideas about sound and vibrations through an introductory series of teacher demonstrations with ‘audience participation’ by making the vibrations ‘visible’ in some way, so that they can be discussed more easily.

Vibrations which produce sound are not usually visible directly, but it is often possible to show the vibration indirectly because it makes something else move (for example, a polystyrene bead). The key ideas in this introduction are the frequency and amplitude of vibration: it is relatively easy to see that bigger vibrations are associated with louder sounds and that the slower the vibrations, the lower the pitch of the sound produced. Students could be asked to define what is meant by ‘amplitude’. Many students may think of amplitude as the

**See Activity A1**  
Sounds and vibrations  
(page 32)

distance from one extreme position to the other, and need to be reminded that it is the distance from the mid-point or 'undisturbed' position to an extreme position: in other words, the maximum displacement.

Louder sounds make the polystyrene beads bounce more vigorously (left) because the amplitude of vibration of the speaker cone is greater. How the displacement of the centre of a loudspeaker cone varies with time (right).



A camera which takes high-speed sequences would be useful for recording the motion of different tuning forks, of a loudspeaker cone as different frequencies are played through it, or of a guitar or violin string after being strummed, bowed or plucked. Students can also see the vibration of a string produced by using a signal generator and vibration generator: this allows them to identify the frequencies when the vibrations are largest and to see that different frequencies produce different wave patterns.

A string being made to vibrate at one of its resonant frequencies using a vibration generator.



As students cannot see the particles vibrating when sound is transmitted through a medium, it is necessary to make use of larger scale models of wave motion.

Typically, this is done using a wire helix ('Slinky'):

- To generate a longitudinal wave, two students hold the ends of a 'slinky' so it is stretched out between them, hanging freely.
- One student compresses several coils together near one end, and waits for any vibrations to die down.
- Suddenly releasing the compressed coils (but still holding on to the ends) causes a compression wave to travel to the other end.

The compression wave is usually reflected at least once, but once any reflections have died down all the coils are in their original place: a wave can travel through a medium without causing a permanent displacement of material from its original position.

## SOUNDS AND WAVEFORMS

Much work on sound involves comparing how a sound's intensity varies with time. Changes in loudness are easy to hear, but they are transient and subjective. An objective way of comparing sound levels over time is to use sound sensors (or microphones) connected to a computer with suitable software. Bigger changes in pressure (louder sounds, or higher sound intensity) cause bigger changes in the voltage produced by the microphone or sensor.

The 'classic' image of a wave on an oscilloscope screen is that of a sine wave, produced by a sound with a single frequency. If the vertical scale is kept the same, it is easy to see that quieter sounds produce sine waves with a smaller amplitude. Similarly, if the time-base setting or timescale remains the same, then it is easy to see that higher frequency sound shows more complete cycles in the same time.

Note that the patterns on an oscilloscope or computer screen look like transverse waves, so it is important to remind students that they are not looking at the sound waves themselves (which are longitudinal waves), but at *representations of changes in sound intensity with time*.

**See Activity A2**

Sounds from different sources (page 33)

**Classroom activities**

Traditionally, a microphone and an oscilloscope have been used to demonstrate the waveforms produced by different sounds, but students could also compare waveforms by using a single microphone and a computer running suitable software (for example, *Audacity*, which is free open-source software for recording and editing sounds). Using a computer allows students to save screenshots for later reference as well as providing the possibility of working with the recorded data. It also allows teachers to present visual information to the whole class using an interactive whiteboard (IWB) or a data projector.

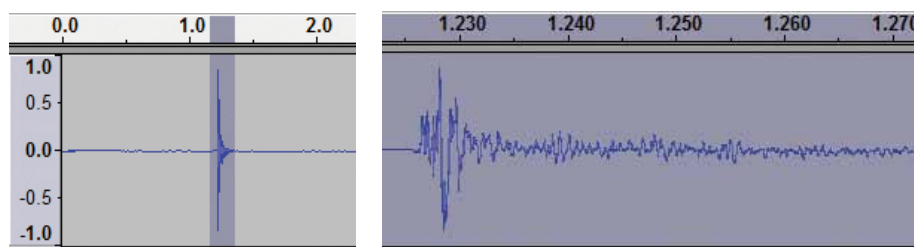
A microphone connected to a computer running Audacity



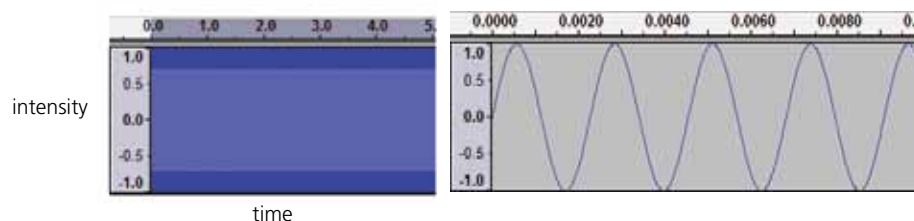
The focus of the activity is on allowing students to compare the differences between waveforms of sounds from different sources. The activity also introduces students to the basic features of the software. Students can compare different waveforms on the computer screen by recording a sound while other waveforms are still visible: this is useful for comparing two notes of similar frequency.

Many of the sounds students use typically have a frequency of a few hundred to a few thousand hertz (Hz), so a 'real-time' or 'raw' waveform shows only the broader changes in intensity over the recording period. To see the details of the waveform, the time scale of the display can be expanded.

Screenshots showing the 'raw' recording of a single clap (left) and the highlighted section viewed with the timescale expanded (right). (N.B. The intensity scales shown are relative (linear) rather than dB scales.)



Screenshots showing a 'raw' unexpanded recording (5 seconds) of a 440 Hz tone (left) and with the timescale expanded to show 5 individual oscillations (right). Note the change in the timescale shown above each trace.



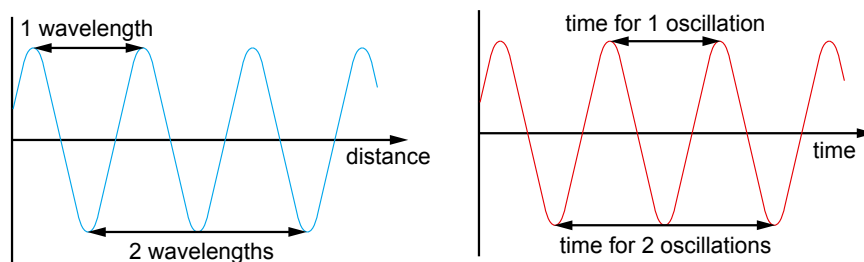
Using expanded traces of tones, such as the one for a 440 Hz tone above, it is easy for students to measure the time for 10 oscillations onscreen. They can then calculate the average time for one oscillation from this and find the frequency using:

$$\text{time (s) for 1 oscillation} = \frac{1}{\text{frequency (Hz)}}$$

They could compare their own calculated values with the value on the tuning fork.

In this activity, the emphasis is on differences in *frequency* rather than *wavelength*. Some students may misinterpret the representation of a wave: as a result of seeing vibrating strings or diagrams showing waves on which amplitude and wavelength have been marked, they may associate horizontal axes with *distance* and *wavelength*. It is important that students understand that the horizontal axis produced in Audacity when they record sounds is a *time scale* not a distance scale: they cannot measure a wavelength directly from this.

When the horizontal timescale is distance (left) a peak to peak measurement gives the wavelength; when the horizontal scale is time (right), then a peak to peak measurement gives the period (time for 1 oscillation).



CONVERTING ELECTRICAL SIGNALS INTO SOUNDS

Converting electrical signals into sounds: a loudspeaker (1), earphones (2), a public-address system (3) and a piezo sounder (4).



Loudspeakers can range in size from tiny buzzers and earphones to the huge loudspeakers associated with rock concerts and carnivals. What they all have in common is that a varying electrical input causes vibrations of a membrane, setting up sound waves. In each case, the faster the changes in the electrical input signal, the higher its frequency, and the higher the frequency of the sound output.

The most familiar type of loudspeaker is a 'moving coil' loudspeaker, based on an application of the motor effect. The basic construction of this type of loudspeaker consists of a powerful magnet, a coil of wire which is connected to the electrical signal source and a cone of material.

When a current flows in the coil of wire, the magnetic field around it interacts with the magnetic field of the permanent magnet, causing the coil to move; reversing the direction of the current reverses the direction of the motion. The coil is behaving like an electromagnet, so the more turns on the coil, the better the effect; the stronger the permanent magnet, the bigger the force on the coil, so rare earth magnets ('supermagnets') produce a louder sound than a conventional magnet would.

The coil is attached to the narrow end of a paper cone so that as the coil moves it also makes the cone move: the cone transmits this vibration to the air, and if it is torn or prevented from moving then the loudspeaker will not work properly. The size of loudspeaker cone affects how quickly or slowly it can vibrate. Small speakers are good for higher frequency sounds but not low frequency ones, while large speakers are good for low frequency sounds but cannot vibrate fast enough for higher frequency sounds.

Some buzzers – often called 'piezo sounders' – make use of a different phenomenon, the piezoelectric effect, to convert electrical signals into mechanical vibrations. When a voltage is applied across a thin sheet of piezoelectric material, it causes the material to deform: rapid changes in the electrical signal make the material vibrate.

**See Activity A3**

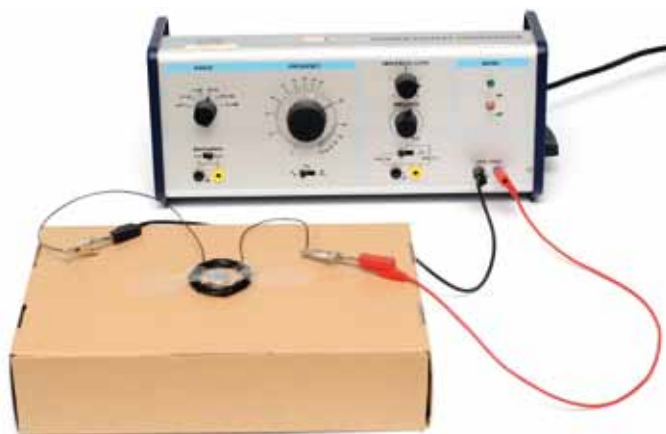
How loudspeakers produce sounds (page 35)

A 'DIY' loudspeaker, made from a coil, a supermagnet and a cardboard box.

**Classroom activities**

In order to understand the underlying physics of a moving coil loudspeaker, students need to have experienced the 'motor effect', and may need to be reminded that the movement is due to an interaction between the magnetic field of the magnet and the changing magnetic field around the wire.

An effective way to introduce work on loudspeakers is with a demonstration of the 'DIY' loudspeaker connected up to an audio signal generator without any preamble, as it is a surprise to many students that something so simple can produce this effect.



Students could then be shown what 'real' loudspeakers consist of: the wider the range of sizes the better, but the most important aspect is to be able to show that the construction includes a magnet, a coil of wire and a part which picks up the vibration. Students could use a paper clip to find out what parts of the loudspeaker are magnetic. Speaker cones are easily damaged, but it is worth keeping a damaged cone to allow students to examine the construction, and to show that the torn cones don't work well.

Students could go on to construct simple loudspeakers based on variants of a magnet and coil combination. The basic construction is simply a coil of insulated wire, taped to a box or an inflated balloon, with a supermagnet at the centre. Students might also try disposable cups or other containers to see which ones work best. They could connect the coil to an audio signal generator and could use this to observe the effect of changing the frequency of the electrical signal. They could also try out the effect of replacing the supermagnet with an ordinary bar magnet.

**SPEED OF SOUND**

When people talk about the speed of sound, they are usually talking about the speed of sound in air, because that is what most experience of sound involves. However, sound also travels through other materials, its speed depending on the nature of the material: it travels fastest in solids and slowest in gases. The speed of sound in solids depends on the density and stiffness of the material. For gases and liquids the speed of sound increases with temperature, so values are usually accompanied by information about the temperature and, in the case of gases, the pressure.

The constant speed of sound within a material allows scientists to compare distances travelled from a source to different observers by comparing the times taken for the sound to arrive. The source of the sound can then be pinpointed by triangulation: this is how seismologists locate the source of an earthquake, by comparing arrival times of seismic waves. Arrival times are also affected by the materials the sounds have travelled through, as different materials will change the speed at which the sound travels. The fact that the speed of sound changes from one material to another means that sound will be refracted at boundaries, just as light is.

The speed of sound in air does not depend on the frequency: if it did, then sounds of different frequencies from the same source would arrive at different times (giving a falling pitch if higher frequencies travelled faster), a phenomenon known as dispersion. For solids, the speed does depend on the frequency of the sound, but the difference in speed is not a big enough effect to impact on everyday experience.

### Classroom activities

A simple 'low-tech' way of calculating the speed of sound in air is to time the echoes from a reflecting wall a hundred metres or so away. If  $t$  is the time between creating a sharp clap and hearing its echo, and  $d$  is the distance to the wall, then the sound must have travelled a distance  $2d$ , and the speed of sound  $v$  is given by:

$$v = \frac{2d}{t}$$

The 'clap-echo' time can be an average based on timing a sequence of at least 10 claps and echoes: the problems with the method are mostly to do with getting the clapping synchronised with the echo of the previous clap and the reaction time of whoever is doing the timing.

Another standard method is to use two microphones connected to an electronic timer to measure the time between a sound arriving at the microphone next to the source and arriving at a microphone further away: the distance travelled is the distance between the two microphones, and the time taken is measured automatically, by triggering timer 'start' and 'stop'. Because much smaller time intervals can be measured, the method can be used to find the speed of sound in solids as well as in air. However, even in air the two microphones are so close that students cannot detect any time between the 'start' and the 'stop', so for some students there is no real sense of what they are measuring.

In a third method, students could use Audacity software to find the difference in arrival time of a sound at two microphones connected to the audio input of a computer (set up for stereo recording), and use this to determine the speed of sound in air. The microphones should be placed as far apart as possible and the distance between should be measured, before recording as someone claps once close to one of the microphones.

A similar method could then also be used to try to find the speed of sound through a solid, by attaching the microphones as far apart as possible on the sample.

### See Activity A4

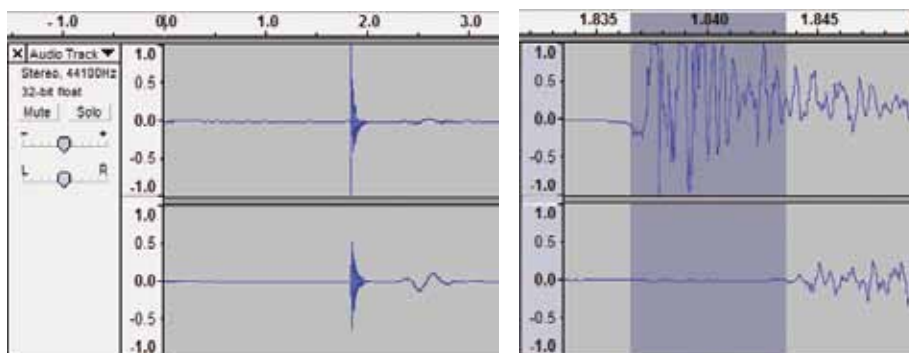
How fast does sound travel? (page 36)

SEP sound locator microphones connected to a laptop (left); microphone attached to a solid sample (right).



Recording a single clap gives a trace similar to the one shown on the left below: using 'zoom' several times to expand the time axis allows students to see the detail of the waveforms in order to measure the time difference.

Speed of sound in air: The screenshot on the left is the unexpanded trace; the one on the right has been expanded and the difference in arrival times has been highlighted.



This method has the advantage that students can see the two events – sound arriving at each microphone - on the computer screen. Furthermore, the software allows students to expand the time axis so that they can see the waveforms in more detail, which can support a discussion of how to improve the accuracy of measurement and of judging what to measure.

## ULTRASOUND

'Ultrasound' refers to vibrations which have a frequency beyond the range of human hearing, which usually includes anything with a frequency of 20 kHz and above. The ultrasonic vibrations are usually produced by a piezo transducer, in which a thin sheet of a piezoelectric material vibrates in response to a changing electrical input signal. Ultrasound applications can be divided into two broad groups, according to the characteristic that is being used:

- using the reflection of ultrasound to provide *information* about the distance, motion or nature of the reflecting surface
- using ultrasound as a means of transferring *energy* to an object.



Within these broad groups there are a range of applications, depending on the frequency range and intensity of the ultrasound.

The 'reflection' group of applications includes sonar (SOund Navigation And Ranging) used to map the sea bed and detect underwater objects, and other distance/motion sensors, industrial scanning for structural defects and medical imaging techniques such as foetal scans. These all make use of the fact that ultrasound is partially reflected at the boundaries between different materials, and the strength of the reflection depends on the material; the greater the time between a signal being emitted and a reflection being detected, the further away the reflecting surface. The gel applied to skin before medical scans provides good transmission from the scanner to tissue.

Ultrasound scans make use of reflected ultrasound beams.



The higher the frequency, the finer the detail which can be resolved. The frequencies used for medical scans are typically around 10 MHz for breast scans and other 'near surface' details, slightly lower for scans of the liver and other 'deep' scans, because higher frequency waves do not penetrate as effectively at greater depths. These correspond to a resolution of less than 1 mm. Industrial scans use similar frequencies for metals and plastics, but lower frequencies – below 500 kHz – for concrete and wood.

Doppler scans or Doppler sonography make use of the Doppler effect to measure the speed of blood in major blood vessels: as blood surges periodically in an artery, there is a corresponding shift in the observed wavelength of the ultrasound.

Medical imaging using ultrasound does not carry the risks of tissue damage associated with X-rays and uses beams of relatively low intensity. Medical treatment using ultrasound uses a lower frequency of ultrasound in a high intensity beam to break up kidney stones or gallstones, or to treat some tumours. This is an example of the use of ultrasound to transfer energy to an object. Other examples are the use of high-intensity beams of ultrasound with frequencies of 20 – 100 kHz for welding plastics and for cleaning. Ultrasonic cleaning is used in dentistry and for cleaning jewellery and other delicate items. Mist-makers or humidifiers also use high intensity beams of ultrasound.

**See Activity A5**

Using ultrasound (page 38)

**Classroom activities**

Students could be shown two readily-available devices that use ultrasound to produce vibrations in materials: a mist-maker (humidifier) and an ultrasound cleaning bath. Cleaning baths need water to transmit the vibrations to dislodge dirt from the surfaces to be cleaned and often use a small amount of wetting agent to ensure that the water wets surfaces as effectively as possible. Both these devices should be used for demonstration only. They not only provide examples of ultrasound-based devices, they also provide an opportunity to consider safe working practice and safety precautions.

The mist-maker (top left) uses an ultrasound beam to create a 'mist' of water (bottom left). The contours of a surface can be scanned using an ultrasound distance sensor (right).



Students could go on to use a distance sensor, which emits an ultrasound beam and detects the reflections, to measure the distance to two different-sized targets. They could also use the distance sensor to scan the surface of the bench.

They can compare this to a sonar scan of the seabed, or a medical scan. The scan along the bench provides a profile of the surface along a single line, instead of the multiple scans which are needed to build up a complete image as in a medical scan. Also, the information the distance sensor provides is about only the surface, rather than about different layers beneath the surface.

**USING SOUND TO FIND OUT ABOUT OUR ENVIRONMENT**

Bats and dolphins use echolocation to detect prey and features of their environment. Humans are not quite so adept, but can still distinguish open spaces from empty corridors or small furnished rooms, simply by listening to the quality of sound: strong reflections need smooth, hard surfaces, while people, curtains and soft furnishings absorb the sound; a longer delay between a sound and its echo suggests that the reflecting surface is further away.

It is also possible to evaluate the condition of objects by listening for differences in sound. For example, tapping then listening to the sound produced can be used to distinguish rotten wood from sound wood, 'blown' plaster from sound plaster, or a watermelon which is crisp and ready to eat from one which is too ripe and has gone mushy.

**See Activity A6**  
 Information from sounds  
 (page 40)

All of the above examples are 'live' activities using our unaided hearing, but using recorded sound can allow analysis of detail and simultaneous visual comparisons of sounds. This might have applications in forensic work or form part of the quality control procedure in food production. Comparisons of sound samples can involve not only how the overall intensity changes over time but also the distribution in the intensities of different frequencies, and it may be easier to see differences between samples by comparing the frequency spectra of the samples rather than the waveforms.

**Classroom activities**

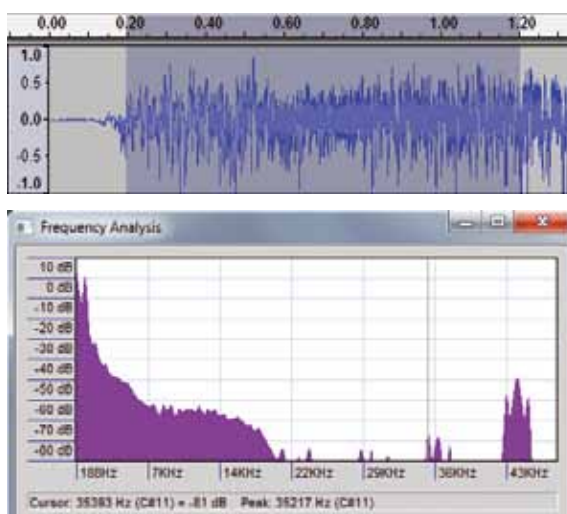
Students could begin by listening to some recordings made in different locations (for example, a living room or an open field) and trying to match each to the correct location. The samples should demonstrate features such as amount of echo and reverberation, or muffled sound. With a restricted range of distinctive locations, this is a relatively easy preliminary task which can be used to open up a discussion of what features of the recorded sounds students use to identify the locations.

If students are then asked to identify which of two sound samples was made by snapping a fresh cracker and which by snapping a stale cracker, they are likely to find this harder. This opens up the idea of using visual comparisons of the recorded sounds. It is easier to compare waveforms if students view two files in the same window. For some sounds, it is easy to see differences between unexpanded traces, but in other cases it helps to expand the scale of the time axis to show more detail.

Waveform comparisons show changes in the overall intensity over time, but frequency analysis is useful when there are differences in the predominant frequencies. The frequency analysis default setting in *Audacity* gives a view where the detail of the peaks of two similar 'musical' notes would be indistinguishable: increasing the resolution in the dropdown menu enables the separate peaks to be identified.

Begin by comparing simple sounds made by pure tones (such as those from tuning forks), so that students can gain familiarity with opening and viewing sound files that have been recorded. They can explore the menu options and their functions before going on to analyse more complex sounds.

Waveform (top) and frequency spectrum (bottom) for the same complex sound.



The key aspect of this activity is the idea of comparing different methods of presenting information: how reliably does the method distinguish between two related but different sets of samples (such as 'fresh' versus 'stale' crackers)? Students should also realise the importance of selecting settings to show up relevant detail: carefully labelled screenshots can support discussion of different methods and allow comparison of samples from more than one group.

## ACOUSTIC DESIGN AND EFFECTS

Unwanted noise and vibration can have a major impact on people's lives, and the levels of sound can vary considerably from one place to another. This variation is related both to the intensity of sound being produced and to the characteristics of the space itself. An important part of designing rooms or public spaces, such as railway stations and theatres, is manipulating the level and quality of sound.

There are three basic ways in which sound levels rise to unacceptable levels in a room or in parts of a room:

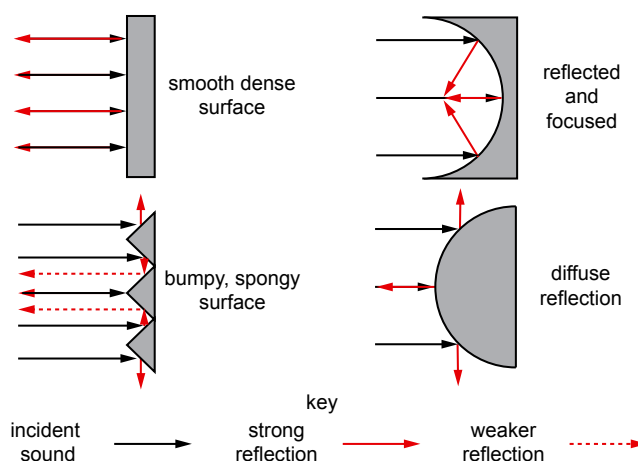
- Sound generated in the room itself is reflected strongly by the surfaces in the room.
- Sound generated outside the room enters directly through open windows or doors.
- Sound generated outside the room is transmitted through the fabric of the building.

The surfaces used for walls, floor and ceiling can affect the amount of reflected and transmitted sound. As sound passes through materials, some of the energy is transferred to the material, reducing the intensity of the sound. This reduction in intensity is least for metals, which are good conductors of sound. Hard, dense, relatively smooth surfaces like stone or concrete walls reflect sound strongly, while soft furnishings and carpets (and people) absorb and 'deaden' the sound, making a room quieter. 'Egg-box' surfaces and foam wedges break up reflections as well as absorbing some of the sound, reducing the intensity of sound reflected towards the listener or microphones. Anechoic chambers produce no reflected sound, so they can be used for making measurements of very quiet sounds, or to test sensitive recording equipment.

An anechoic chamber.  
(Acoustics Research  
Centre at the University  
of Salford.)



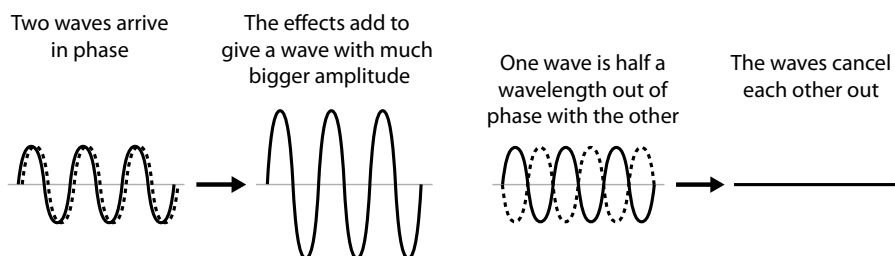
Different surfaces affect the way sound is reflected.



A combination of very reflective surfaces and long travel times between reflections increases the amount of *reverberation*, so sounds seem to take longer to 'die away'. Longer reverberation times make it difficult to understand speech, but make music sound richer, while short reverberation times can 'deaden' the sound. To reduce the reverberation time of a large space to make it better for listening to speech, acoustic engineers therefore include panels of material (diffuser panels) which will reduce the amount of strongly reflected sound.

As sounds are reflected off surfaces, the effects of the sound waves add up and create patches of more intense sound, an effect known as *superposition*. Perhaps more surprising is the possibility of sound waves coinciding and 'cancelling out':

Effects of adding waves (superposition): constructive interference (left) and destructive interference (right).



Active sound control uses this effect with loudspeakers to cancel sound at a particular frequency by producing waves at the same frequency but in the opposite phase: waves in opposite phase cancel out, so no noise is transmitted. This method is used in noise-cancelling headphones.

The amount of sound that enters or leaves a room can be reduced by increasing the amount of *acoustic insulation*, just as heat losses from a room are reduced by increasing the amount of thermal insulation. Thicker walls, thick carpets and underlay will absorb sound more effectively than thin, lightweight walls and bare wooden floors.

However, simply increasing the thickness of walls or floors is not enough, and a better solution is *acoustic isolation* – some way of producing a break in the sound’s path. Anything which can absorb some of the vibration of heavy machinery before it is transmitted to the floor will reduce the amount of noise that the floor then transmits to the ceiling of the room. The structural elements of a building may begin to resonate if the frequency of the sound matches the natural frequency of vibration of the structural element. Resonance noise can be reduced by *damping* – reducing the amplitude of vibration by using springs or spongy material to absorb the energy rapidly – or it could be actively countered by changing the material and dimensions of a structural element so it has a different resonant frequency. Not all resonance is a bad thing: the design of musical instruments exploits the phenomenon to produce bigger, better sounds.

**See Activity A7**

Managing sound in buildings (page 41)

**Classroom activities**

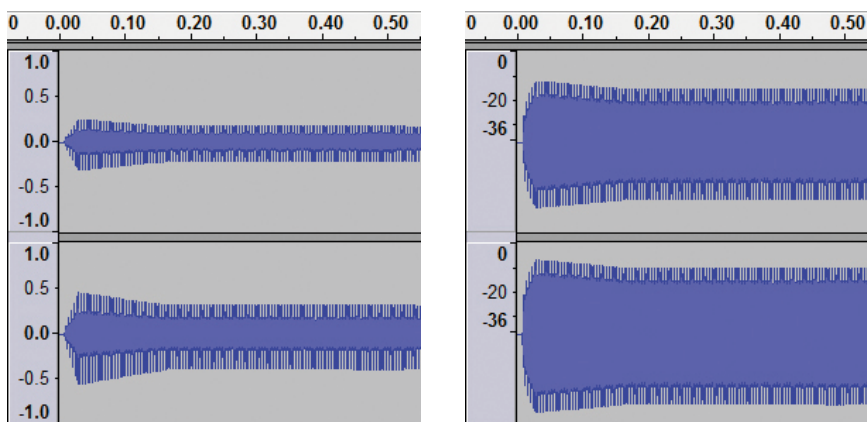
Students should get some idea of how sound levels vary around the school site, by using a sound sensor or sound meter: they could identify which areas are noisiest and suggest reasons for this.

A sound meter.



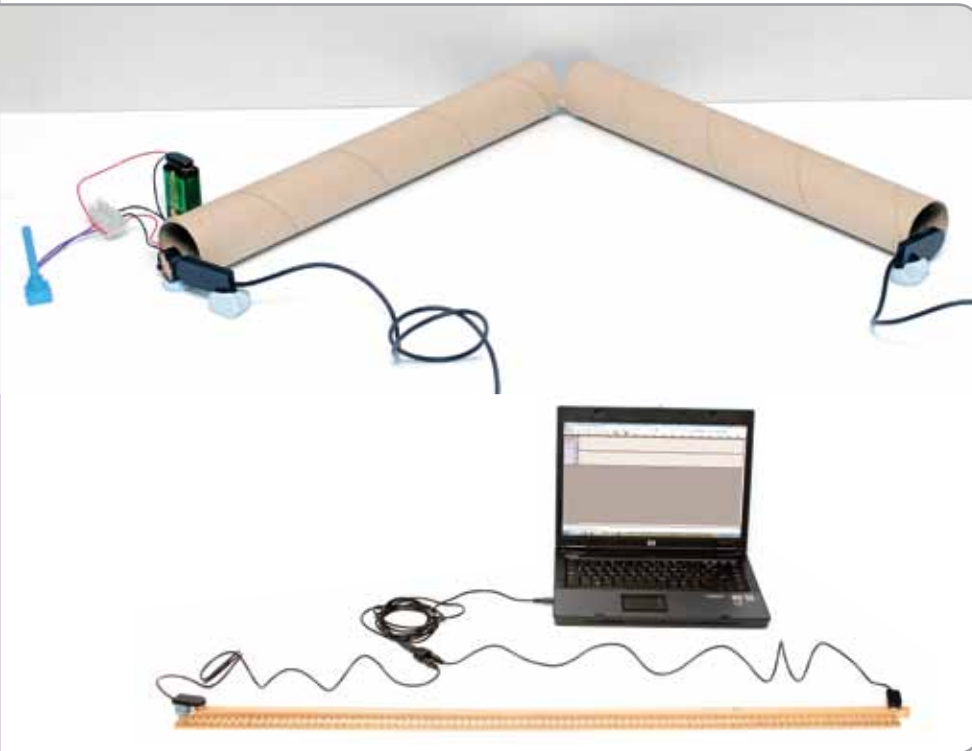
The intensity of a sound is usually measured in decibels (dB). The decibel scale is a logarithmic scale rather than a linear one, so students need to understand that doubling the intensity does *not* mean double the decibels.

Screenshots showing the difference between recorded intensity on a relative scale (left) and on a decibel scale (right).



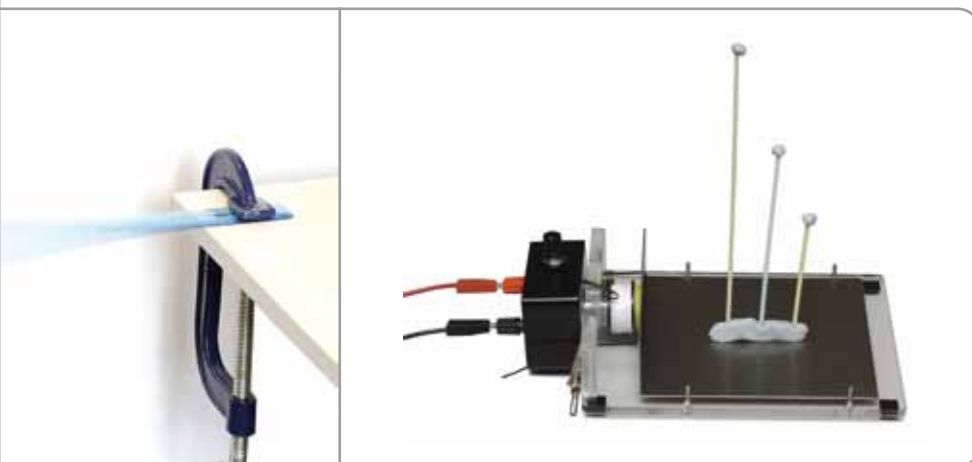
Students could compare how well different materials reflect, transmit or absorb sound by comparing the intensity of the sound near the source with the intensity after the sound has been reflected or has travelled through a sample. They could do this using two microphones with Audacity, or by using a sound sensor or sound meter in place of each of the two microphones.

Equipment set up for investigating reflection (top) and transmission (bottom) with a sound locator kit and Audacity software.



*Resonance* effects depend not only on the material but also on dimensions, as can be shown through a selection of resonance demonstrations, such as a vibrating ruler, and a shake table in which objects of different sizes resonate at different frequencies of the table.

Demonstrations of resonance: a vibrating ruler (left) and a shake table (right).



The point in this context is simply to show examples of resonance and illustrate the idea that unwanted vibrations in a structure could be reduced by changing the natural frequency of vibration of a structural element, or by isolating the source, absorbing the energy before it can be transmitted any further.

## CONVERTING SOUNDS INTO ELECTRICAL SIGNALS

A great deal of modern life depends on the use of microphones and loudspeakers. Microphones, sound sensors and electric pickups do the opposite task to loudspeakers: they convert sounds into electrical signals. These signals can then be recorded, transmitted over long distances or manipulated before being amplified to produce sounds at one or more loudspeakers. Different detectors vary in their sensitivity to particular frequencies of sound, just as different sizes and designs of loudspeaker are used for producing different frequency ranges.

Electro-acoustic microphones produce an electrical signal when vibrations move a magnet relative to a coil – an application of the dynamo effect. Piezoelectric microphones (or guitar pickups) produce electrical signals when pressure waves stress the piezoelectric material.

A microphone and an electric guitar pickup both convert vibrations into electrical signals.



Whichever method is used, the electrical signal usually needs to be amplified before being passed to a loudspeaker. Detectors usually pick up noise as well as the desired signal: amplification amplifies the noise as well as the signal, so recorded sound is usually modified before playback to remove unwanted background noise. One way of doing this is by filtering out sounds with frequencies above or below a certain threshold (low pass and high pass filtering respectively): this takes out everything within that frequency range, so it can take out some of the 'signal' as well as the 'noise'.

### Classroom activities

Sound sensors and microphones all produce electrical signals in response to vibrations, but are not equally sensitive to particular frequencies. The SEP 'vibration detector' models the way electro-acoustic microphones work, and students can also use a vibration detector with Audacity to explore the effect of different sounds and vibrations on the output signal. The vibration detector responds well to vibrations through solids rather than sounds transmitted through the air.

Students could then go on model the way electric pickups are used on instruments: they could compare the waveforms and frequency spectra produced by playing a guitar when the vibration detector is placed directly on the soundbox of the guitar or when there is a layer of foam in between; they could also listen to the recorded sound and compare it to the original. They could then replace the vibration detector with a piezo transducer linked to an amplifier and loudspeakers, and listen to the sound produced.

**See Activity A8**  
Microphones and pickups  
(page 43)



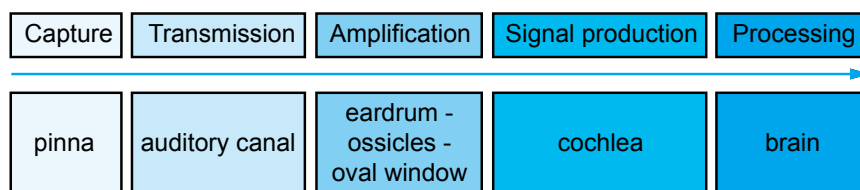
The vibration detector connected to a laptop (left), and a piezo transducer placed on the soundbox of a guitar (right).



As a final task, students could explore the use of filters and other features on a recorded sound file: this can provide a brief practical introduction without any detail on signal detection theory or sound engineering. Students could do this by examining waveforms and frequency spectra and listening to the difference in quality of manipulated sounds. It would be useful for students to keep screenshots of the effects for comparisons, particularly if there is the opportunity to try out some 'noisy' files with different kinds of background noise.

## HEARING

'Hearing' is what happens when parts of the brain are activated as a result of sound waves arriving at the ear:



- The pinna, the part of the ear outside the skull, helps to capture sound over a larger area than a simple hole could.
- The external auditory canal acts a resonant tube and enhances transmission of frequencies between 2 and 5 kHz.
- The eardrum is a thin membrane which transfers energy through the ossicles to another much smaller membrane, the oval window. The reduction in area between the two membranes makes this part of the ear act as an amplifier.
- The oval window transmits pressure into the fluid-filled cochlea, where sensor cells are activated and send electrical impulses along the auditory nerve to the brain.

Most people are aware that hearing deteriorates with age, and that prolonged exposure to loud noise can lead to early loss of hearing. The need for ear protection when working in particularly noisy environments has long been recognised. Recently, there have been attempts to limit exposure to loud noise through work as a professional musician, but voluntary prolonged exposure caused by listening to loud music through headphones remains a hazard. In particular, there are concerns about the damage this causes to young people's hearing.

Hearing protection should be worn when working in a noisy environment.



The frequency range of audible sounds is generally said to extend over a range from around 20 Hz to 20 000 Hz, but most teenagers and young adults can hear high frequency sounds which older adults cannot. The loss in sensitivity to high frequencies as we get older is mostly due to damage to the hair cells of the cochlea. Undamaged human hearing is not equally sensitive to the whole range of frequencies, so two sounds with the same intensity in decibels but with different frequencies may not be perceived as equally loud:

- Our hearing is most sensitive in the middle of the range. This enhancement is related to the structure of the external auditory canal.
- Our hearing is less sensitive to low frequency sounds, and we perceive low frequency sounds to be quieter than higher frequency sounds at the same number of decibels: the difference gets worse the quieter the sounds.

#### Classroom activities

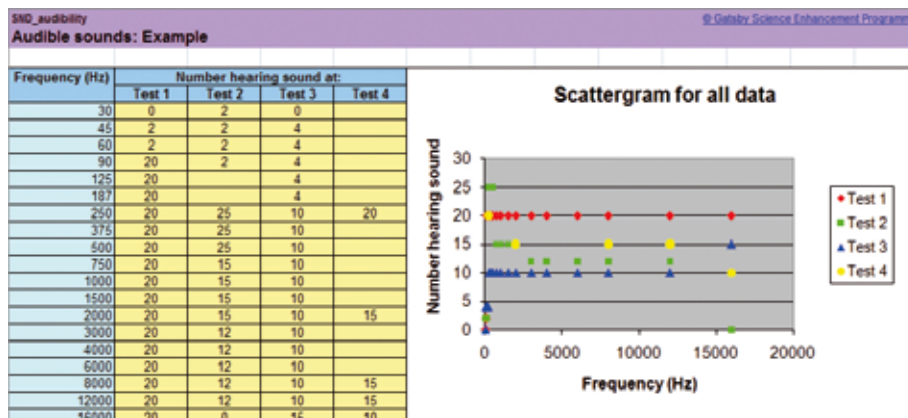
An investigation of hearing could begin with a class survey to identify the range of audible frequencies using sounds at the same volume. The intensity setting for this needs to be clearly audible but not excessively loud in the middle frequency range, where students' hearing will be most sensitive (although they will not have found this out yet), so that students can hear sounds towards the extremes of the range but notice that they sound quieter.

An audible frequencies survey is usually done as a demonstration using an audio signal generator, but in this activity the sounds are produced by a digital source, a hearing test page from the UNSW (University of New South Wales) website. The advantage of using a digital source like this is that sounds at the same volume can be selected simply by clicking on buttons on the same horizontal line, so different frequencies can be selected quickly and less predictably.

**See Activity A9**  
Sensitivity of hearing  
(page 45)

Using a spreadsheet for recording results allows a summary chart to be displayed, once all the frequencies have been tested at least once.

Screenshot showing how the survey results could be recorded and displayed using the 'Audibility' spreadsheet from the SEP website.



A further investigation is to use the same digital sound source to explore individual sensitivity to different frequencies. This can be done as a teacher demonstration with student participation. (We do not recommend that hearing investigations are done as individual activities using headphones, because of the difficulty of ensuring that they are being used sensibly in a classroom context.)

## SOURCES, JOURNEYS AND DETECTORS

This section has used the broad themes 'Sources, journeys and detectors' to organise the ideas, and these are summarised below.

The 'sources' theme has included examples of the different ways that sounds are produced, including how loudspeakers convert electrical signals into sounds. Simple sounds can differ in terms of frequency, wavelength and amplitude, the first two being related to the pitch of a sound and the third being related to how loud the sound is (the sound intensity). Oscilloscopes and computer software can help us to visualise changes in sound intensity with time, and are particularly useful for looking at changes which happen over very short timescales.

For 'journeys', this section has considered how materials affect how much sound is transmitted, and how fast sounds travel. Different surfaces and materials affect how much sound is reflected or absorbed, and this can be used to control the level and quality of sound. Differences in sound, including ultrasound, can provide information about objects or our environment, and ultrasound can be used to transfer energy to materials for welding or cleaning, or for medical treatment.

The 'detectors' theme has looked at how microphones and pickups convert sound into electrical signals, and how sound detectors, including our own auditory system, vary in sensitivity to different frequencies.

Throughout all these themes, the way that computer software can be used as a powerful analytical tool has been illustrated. Using this technology, students are now able to explore and manipulate sounds in a way not previously possible, and gain a deeper understanding of the nature of the sound.

# STUDENT ACTIVITIES

## SOUND

## Teachers' notes

The student activities provide a practical introduction to some basic ideas about sound. The activities also provide opportunities to consider the advantages and disadvantages of different experimental arrangements, sources of uncertainty, and the effect of repeated readings in relation to variability of results.

The key ideas are:

- Sound is produced by vibrations.
- The greater the amplitude of vibration, the louder the sound.
- The higher the frequency of vibration, the higher the pitch of the sound.
- Ultrasound is sound with a frequency above the range of human hearing.
- Ultrasound has uses including scanning, distance measurement and cleaning.
- Loudspeakers convert electrical signals into sounds.
- Sound travels at different speeds in different materials.
- Different materials reflect and absorb sound to different extents.
- Sound transmission and reflection, and phenomena such as resonance and reverberation, affect the quality and level of sound in buildings.
- Microphones and 'pickups' convert sound and vibrations into electrical signals.
- Software can manipulate the signals to change the characteristics of the sound output.
- Human hearing ranges from a few Hz to around 20 000 Hz, and is more sensitive to some frequencies than others
- Hearing deteriorates with age and prolonged exposure to loud sounds.

The practical activities use standard laboratory apparatus and materials that are readily available in secondary schools, plus free open-source software and a number of items which can be obtained from Middlesex University Teaching Resources.

Visit the SEP website [www.sep.org.uk](http://www.sep.org.uk) for supporting resources including image files and editable versions of the student sheets. See page 52 for information on obtaining the practical resources.

## An overview of the activities

The activities are:

- **Activity A1** Sounds and vibrations
- **Activity A2** Sounds from different sources
- **Activity A3** How loudspeakers produce sounds
- **Activity A4** How fast does sound travel?
- **Activity A5** Using ultrasound
- **Activity A6** Information from sounds
- **Activity A7** Managing sound in buildings
- **Activity A8** Microphones and pickups
- **Activity A9** Sensitivity of hearing

There is one resource sheet:

- **Resource R1** Audible sounds

The following resource is also available on the SEP website:

- **Web Resource WR1** Downloading and using the Audacity software.

## Audacity software and sound files

*Audacity* is free open-source software for recording and editing sound which can be downloaded from <http://audacity.sourceforge.net/>. Activities which refer to the use of Audacity may not always be possible with other software, or may need to be adapted.

The web resource *WR1 Downloading and using the Audacity software* can be downloaded from the SEP website. It provides additional practical detail to supplement the instructions and information in the student activity sheets and related teachers' notes.

Also downloadable from the SEP website is a zip file (SND\_files.zip) which contains Audacity and MP3 files for use with Activities A2, A4, A6 and A7.

## Health and safety

### **Volume of signal generators and other sound sources**

CAUTION: Avoid using loud sounds, which could cause discomfort or lead to damaged hearing.

Always return the volume to a low setting before you change the frequency setting of a signal generator, or other sound source.

Keep exposure to loud sounds to a minimum.

Remember that students are likely to be more sensitive to some sounds than you are.

### **Supermagnets**

Two of the activities (A3 and A8) use supermagnets, which give a much more impressive result than ordinary bar magnets.

CAUTION: The strong forces produced by supermagnets can cause personal injury and physical damage to other equipment or to the magnets themselves. Supermagnets are brittle and can break to produce hazardous splinters. They may snap together suddenly and pinch your fingers or move rapidly towards and collide with other objects. The strong magnetic fields produced by supermagnets may adversely affect some equipment that relies on electromagnetic effects for correct and safe operation. Keep supermagnets away from devices such as heart pacemakers, hearing aids, watches, identity and bank cards, audio equipment, computer hardware (particularly disks and screens) and similar electronic apparatus.

### **Ultrasound devices**

CAUTION: *Ultrasound cleaners and mist makers should be only be used for demonstration. Carry out a risk assessment before using as part of a demonstration, and follow any additional safety advice supplied with these and other ultrasound devices.*

These devices must only be operated with water in the tank or trough.

Ultrasound mist makers generate an intense beam of ultrasound. Do not allow students to put their hands into the water when the mist maker is switched on, as contact with the beam would be very painful. Fresh clean water should be used to reduce the risk of anything harmful being present in the mist that is produced.

Ultrasound cleaners for use in laboratories tend to be fairly expensive. Inexpensive ultrasound jewellery cleaners are available but may give relatively disappointing results.

## Notes on the activities

### Activity A1: Sounds and vibrations

This is an introductory activity to review prior knowledge and understanding. Students observe the vibration of loudspeakers and strings using a range of methods. (See also page 4 of this booklet 'Vibrations and sound sources'.)

<p><b>LEARNING OBJECTIVES</b> Students will:</p> <ul style="list-style-type: none"> <li>• observe the vibration of speakers and strings as sounds are produced</li> <li>• relate higher frequency of vibration to higher pitch of sound</li> <li>• relate larger amplitude of vibration to louder sound</li> <li>• observe that there are limits on the frequencies of vibrations that we can hear and that we can see.</li> </ul> <p><b>NOTES</b> These are teacher demonstrations to review basic ideas about sound and vibrations by making the vibrations 'visible' in some way, so that they can be discussed more easily.</p> <p>For Task A, instead of using the polystyrene beads, you could attach aluminium foil to the loudspeaker and bounce a narrow beam of light off it and up to the ceiling.</p> <p>For Task B, the idea is simply to show vibration of a string at a range of frequencies: you could compare this to vibrations on a real stringed instrument. Students should notice that it is more difficult to see the vibration at higher frequencies which still give audible sounds.</p> <p><b>CAUTION:</b> Eye protection should be worn if using a sonometer for Task B, as the string is held under tension.</p>	<p><b>RESOURCES NEEDED</b></p> <p><b>TASK A:</b></p> <ul style="list-style-type: none"> <li>• Sound source: signal generator</li> <li>• Range of loudspeaker cone(s), preferably including a large cone to give a better response for low frequencies</li> <li>• Polystyrene beads.</li> </ul> <p><b>TASK B:</b></p> <ul style="list-style-type: none"> <li>• Signal generator</li> <li>• Vibration generator</li> <li>• String</li> <li>• Clamp stand, bosshead and clamp</li> <li>• Pulley</li> <li>• Mass hanger</li> <li>• G clamp to clamp the stand to the bench</li> <li>• Guitar or other stringed instrument (optional).</li> </ul>
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### Activity A2: Sounds from different sources

Students use a single microphone and a computer running Audacity to compare the waveforms produced by different sounds. (See also page 6 of this booklet 'Sounds and waveforms'.)

<p><b>LEARNING OBJECTIVE</b> Students will:</p> <ul style="list-style-type: none"> <li>• compare waveforms produced by different sounds.</li> </ul> <p><b>NOTES</b> It is best to use an interactive whiteboard (IWB) to demonstrate the task using a tuning fork and for a plenary discussion. The activity provides a good opportunity for students to explore the software and sound sources individually or in small groups to get an idea of broad features and differences.</p> <p>Demonstrate using a tuning fork with everyone quiet, and again when there is more background noise so that students can see the difference this makes to the chart.</p> <p>Students could compare the waveforms of synthesised sounds – either by using a keyboard or by using a second computer and speaker to play some of the sound files provided.</p>	<p><b>RESOURCES NEEDED</b></p> <ul style="list-style-type: none"> <li>• Computer running Audacity</li> <li>• Data projector or IWB.</li> <li>• External microphone to plug into the computer</li> <li>• Tuning forks (for 'single frequency' sounds)</li> <li>• Other sound sources (to provide sounds based on several frequencies)</li> <li>• <i>Web resource WR1 Downloading and using the Audacity software.</i></li> </ul> <p>You may also find the following useful:</p> <ul style="list-style-type: none"> <li>• Folder SND_files_synth (in the zip file SND_files downloadable from the SEP website) – this contains some MP3 files of synthesised instruments.</li> </ul>
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### Activity A3: How loudspeakers produce sounds

Students construct simple loudspeakers based on a magnet and coil combination. (See also page 8 of this booklet 'Converting electrical signals into sounds'.)

#### LEARNING OBJECTIVES

Students will:

- construct a simple loudspeaker based on a magnet and coil
- relate the vibration of the loudspeaker to a changing electrical input to the coil
- recognise this as an application of the motor effect
- compare their own loudspeakers to real ones.

#### NOTES

**CAUTION:** Supermagnets produce strong forces and care needs to be taken in their handling and in ensuring that they are kept away from devices affected by strong magnetic fields (see the health and safety notes on page 25).

A demonstration of a ready-assembled DIY loudspeaker connected to an audio signal generator is a good introduction to this activity.

If you use enamelled copper wire rather than plastic insulation it may not be obvious that any insulation is still present: students should try scraping the ends again if the loudspeaker does not work when it is first connected.

#### RESOURCES NEEDED

For the demonstration:

- A selection of different sized loudspeakers
- Paper clips to identify magnetic parts of loudspeakers (optional)
- DIY loudspeaker already assembled.

Each group will need:

- Thin insulated copper wire (2 metres)
- Battery (C size) or similar to wrap the wire around
- Wire strippers
- Supermagnet (12.5 mm x 5.5 mm)
- Ordinary bar magnet (for comparison)
- Adhesive tape
- 2 croc-plug leads (1 red, 1 black)
- Access to objects which could be used to vibrate (e.g. plastic or paper drinks cup, cereal box, balloon)
- Access to audio signal generator with amplified output.



### Activity A4: How fast does sound travel?

Students determine the speed of sound in air and through one or more solids by using Audacity to find the difference in arrival time of a sound at two microphones. (See also page 9 of this booklet 'Speed of sound'.)

#### LEARNING OBJECTIVES

Students will:

- record arrival times of a sound at two microphones with a known separation
- use data on arrival times to calculate the speed of sound in different materials
- compare the results for different materials with known values
- relate the different speeds to the structure of the materials.

#### NOTES

N.B. In order to use the Sound source locator kit your computer needs to have a stereo soundcard, and you need to have stereo recording enabled. Check that you can see two different traces in the two channels when you clap near to one of the microphones. If the two traces appear identical, then the input from only one of the microphones is being used.

For speed in air, use adhesive putty or Plasticine to stick the microphones onto the bench, so that the vibrations travelling through the air are recorded, rather than those transmitted through the bench. For speed of sound in solids, the microphones need to be fixed in place so that they are in contact with the wood or metal sample.

This is a good activity for students to carry out themselves, and encourages comparison of results using the same samples but different experimenters. If you have limited equipment then doing this as a demonstration using the computer linked up to an IWB or data projector offers an opportunity for lots of active student involvement. You can look at how much variation there is between repeated recordings with each sample, and ask different students where they would measure the intervals for each recording.

If students are able to compare the speed of sound in several materials, this allows for some discussion of the relationship between the speed of sound and the structure of materials. Students could go on to consider how they might investigate whether different frequencies of sound travel at the same speed in a material. They might suggest timing different frequencies separately over the same sample length or might suggest sending them all at the same time: students should be able to suggest that 'if lower frequencies travel faster than higher frequencies, then if they all start at the same time, the lower frequency waves should arrive first'. They might then be prompted to describe how they would analyse a recording of the sound and what evidence they would look for; would they expect to find a measurable effect for sounds travelling through solid samples only a metre or two long?

#### RESOURCES NEEDED

Each group will need:

- Computer running Audacity
- Sound source locator kit (available from MUTR)
- Tape measure or metre rule(s)
- Bars of metal or wood, each about a metre long (longer if possible)
- Adhesive putty for fixing microphones in place
- *Web resource WR1 Downloading and using the Audacity software.*

You may also find the following useful:

- Connection to IWB or data projector
- Folders SND\_files\_speed\_air and SND\_files\_speed\_solids (in the zip file SND\_files downloadable from the SEP website). These contain example Audacity files of sound travelling through a range of solids for calculating speed of sound in air and in a range of solids.

### Activity A5: Using ultrasound

This activity includes a number of demonstrations about how ultrasound is used for cleaning, to generate 'mist', and for measurement. (See also page 11 of this booklet 'Ultrasound'.)

<p><b>LEARNING OBJECTIVES</b> Students will:</p> <ul style="list-style-type: none"> <li>observe practical examples of how ultrasound can be used</li> <li>relate the use of an ultrasound distance sensor to the way that ultrasound scans are produced.</li> </ul> <p><b>NOTES</b> CAUTION: Tasks A and B, using ultrasound mist makers and cleaners, are for demonstration only (see the health and safety notes on page 25).</p> <p>You only need the computer for Task D, to take continuous readings as you sweep across a surface, but you may also want to use it for Task C.</p> <p>For the scan in Task D, make sure the objects in the 'scanning' area include different sizes (notebook, pens, pencils, and ruler) and different materials (such as a sponge or a cloth). It may be easier to put items in a tray and drag the tray rather than the sensor.</p> <p>These are relatively short tasks; a more extended activity on practical limitations to using the sensor with different targets and surfaces is described in the SEP booklet, '<i>Light and matter: models and applications</i>'.</p>	<p>Where time allows, students might investigate the observed change in frequency of a rotating, audible sound source, to model the use of Doppler scans in monitoring blood flow. Details of how students could do this using a Doppler effect unit and examining the recorded sound using Audacity software are given in the SEP booklet '<i>Light and matter: models and applications</i>'.</p> <p><b>RESOURCES NEEDED</b></p> <ul style="list-style-type: none"> <li>Fog/mist maker</li> <li>Trough of fresh water for mist maker</li> <li>Tray to stand the trough in (to catch the spray)</li> <li>Ultrasonic cleaner</li> <li>Small item to clean</li> <li>Datalogger with ultrasound distance sensor</li> <li>Computer to connect to datalogger</li> <li>Target card (20 cm square)</li> <li>Target card (5 cm square)</li> <li>Range of objects for scanning (see notes)</li> <li>Metre rule(s) or tape measure.</li> </ul>
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### Activity A6: Information from sounds

Students listen to sounds recorded in different locations and identify how the quality of sound varies. Students use waveforms and frequency spectra to compare sounds and identify characteristic features. (See also page 13 of this booklet 'Using sound to find out about our environment'.)

<p><b>LEARNING OBJECTIVES</b> Students will:</p> <ul style="list-style-type: none"> <li>compare quality of sounds recorded in different spaces</li> <li>compare quality of sounds produced by different 'versions' of a source</li> <li>identify significant characteristics</li> <li>compare the use of waveforms and of frequency spectra for distinguishing sounds.</li> </ul> <p><b>NOTES</b> There is a PowerPoint presentation (downloadable from the SEP website) which contains embedded sound files for Task A. For Tasks B and C there are also files available of sounds recorded in different locations and sounds of two crackers being broken (or you may prefer to record your own sound samples).</p>	<p><b>RESOURCES NEEDED</b></p> <ul style="list-style-type: none"> <li>Computer running Audacity</li> <li>PowerPoint file: Sound_A6_TaskA</li> <li>Folder SND_files_comparisons (in the zip file SND_files downloadable from the SEP website). This contains the Audacity files needed for Tasks B and C.</li> </ul> <p>If you wish to record your own sound samples you will also need:</p> <ul style="list-style-type: none"> <li>Microphone</li> <li>Paired samples such as:                     <ul style="list-style-type: none"> <li>Two tuning forks (different frequencies, preferably an octave apart)</li> <li>Pieces of wood – one dry, one that has been soaked in water</li> <li>Biscuits – one fresh and one stale.</li> </ul> </li> </ul>
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## Activity A7: Managing sound in buildings

Students use a sound sensor or sound meter to monitor sound levels in different parts of a building. They compare how well different materials reflect, transmit or absorb sound, and observe demonstrations of resonance in relation to low frequency vibrations. (See also page 15 of this booklet 'Acoustic design and effects'.)

### LEARNING OBJECTIVES

Students will:

- compare intensity of sound in different parts of a building
- compare the intensity of reflected sound with sound intensity at the source for a range of reflecting surfaces
- compare the intensity of transmitted sound with the sound intensity at the source for different materials and thicknesses of material
- observe how intensity and quality of sound are affected by the dimensions of a space, the building materials and furnishing materials used
- relate these observations to phenomena such as echoes, reverberation, and resonance.

### NOTES

In Task A, try to carry out the survey at a 'quiet' time to reduce variability due to people moving around. If possible, compare sound levels in a room with heavy curtains when open and when closed.

For Tasks B and C, if you do not have access to a sound source locator kit, you could compare intensities (though not frequency spectra) by using a sound sensor or sound meter in place of each of the two microphones.

Students will need to select the dB option for the vertical (intensity) scale in Audacity. When comparing intensities, students may find it helpful to expand the vertical axis for each recorded sound, or to compare the output intensities when the recorded tracks are played back and paused.

A demonstration of superposition of sound waves would help students understand more fully why reflected sounds can be problematic. The Teaching Advanced Physics website has details of how to use two loudspeakers to show cancellation (see Episode 321: Interference patterns, TAP 321-1: Hearing superposition).

For Task C, the microphones need to be fixed in place so that they are in contact with the wood or metal sample.

As an extension to Task C, students could investigate whether some frequencies are absorbed more than others, and if different materials have different effects on this. This provides a good opening point for discussions of practical techniques and also the effects of scale: How might they ensure that the sound was only travelling through the *sample* to the second microphone and not through the bench? What materials and thicknesses are used in real situations?

In Task D, changing the shake frequency of the shake table shows that a particular frequency may make one straw vibrate strongly, but not others with different lengths. Changing the length of the vibrating ruler changes the frequency of vibration, and attaching a blob of Plasticine to the ruler at different positions also affects the vibration. Inserting a small piece of foam between the ruler and bench stops it vibrating.

### RESOURCES NEEDED

#### TASK A

- Sound meter (or sound sensor-meters or sound sensors with dataloggers)
- Sound source such as a repeated piece of music or speech, or one person speaking at a normal conversation level.

#### TASKS B and C

- Tuning forks or other simple ('single frequency') sound sources
- Metre rule
- Sound source locator kit (available from MUTR)
- Computer running Audacity
- *Web resource WR1 Downloading and using the Audacity software*
- Task B also requires:
  - Different surfaces to reflect from
  - Two cardboard tubes and something to hold them in place (e.g. adhesive putty or tape)
- Task C also requires:
  - Samples of material for absorption/transmission (e.g. blocks of wood, foam, metal: if possible, some should be available in different thicknesses)
  - Adhesive putty to fix the microphones in place.

You may also find the following useful:

- Folder SND\_files\_speed\_solids (in the zip file SND\_files downloadable from the SEP website). This contains example Audacity files of sound travelling through a range of solids.

#### TASK D

- Either or both of the following:
  - Shake table (with 6 V d.c. power supply), straws cut to different lengths, and adhesive putty or Plasticine (for mounting the straws and for the blobs on the free ends)
  - Ruler clamped to bench, piece of sponge between ruler and bench, Plasticine or adhesive putty to stick on ruler as additional mass.

### Activity A8: Microphones and pickups

Students record different sounds and vibrations using a vibration detector and Audacity, and model the use of piezo and electro-acoustic pickups with musical instruments. (See also page 19 of this booklet 'Converting sounds into electrical signals'.)

<p><b>LEARNING OBJECTIVES</b> Students will:</p> <ul style="list-style-type: none"> <li>observe the effect of sounds and vibrations on the output from a vibration detector</li> <li>relate this effect to electromagnetic induction</li> <li>model the use of electro-acoustic and piezo pickups</li> <li>observe the effects of using software to amplify and apply filters to recorded sounds.</li> </ul> <p><b>NOTES</b> CAUTION: Supermagnets produce strong forces and care needs to be taken in their handling and in ensuring that they are kept away from devices affected by strong magnetic fields (see the health and safety notes on page 25). CAUTION: Eye protection should be worn if using a sonometer for Tasks B and C, as the wire is held under tension.</p>	<p>Changing the audio track setting to Waveform (dB) instead of the default 'Waveform' should make it easier to see what amplification does.</p> <p><b>RESOURCES NEEDED</b></p> <ul style="list-style-type: none"> <li>Computer running Audacity</li> <li>Web resource <i>WR1 Downloading and using the Audacity software</i></li> <li>Vibration detector (available from MUTR)</li> <li>Radio or audio signal generator</li> <li>Acoustic guitar (or sonometer set up with wire already tensioned)</li> <li>Piece of foam</li> <li>Piezo transducer with connection lead attached</li> <li>Adhesive putty (to keep the transducer firmly attached)</li> <li>Powered amp board (available from MUTR)</li> <li>Battery (PP3, 9 V)</li> <li>External loudspeakers for connection to amplifier.</li> </ul>
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### Activity A9: Sensitivity of hearing

Students use a digital sound source to identify the number of students who can hear different frequencies of sound at the same volume. They then use a digital sound source to explore sensitivity to different frequencies for an individual. (See also page 20 of this booklet 'Hearing'.)

<p><b>LEARNING OBJECTIVES</b> Students will:</p> <ul style="list-style-type: none"> <li>test the frequency range of their hearing</li> <li>test the relative sensitivity of hearing at different frequencies</li> <li>use the outcomes of the tests to produce a survey of hearing range for the whole class and an individual hearing sensitivity profile.</li> </ul> <p><b>NOTES</b> CAUTION: <i>We do not recommend the use of headphones for hearing investigations in class.</i> Although good quality headphones would give a better response and reduce background noise, it is difficult to ensure that they are being used sensibly in a classroom context. CAUTION: Do not start with any sounds in the top third of the chart as they could be too loud. This activity uses the online hearing test resource available from the website <i>Music science at UNSW</i> (<a href="http://www.phys.unsw.edu.au/music/">www.phys.unsw.edu.au/music/</a>). Click on the link <i>Test your hearing</i> at the top right of the page.</p>	<p>There is a spreadsheet (downloadable from the SEP website) which can be used to record and display the results. It provides a template and an example of recorded data and a chart.</p> <p>Both tasks are intended to be done as teacher demonstrations with student participation. If you have several computers with loudspeakers, students could carry out Task B in small groups after an initial demonstration, or you might set Task B as homework.</p> <p><b>RESOURCES NEEDED</b></p> <ul style="list-style-type: none"> <li>Computer with internet access and with good external speakers</li> <li>IWB or data projector</li> <li>Resource <i>R1 Audible sounds</i></li> <li>Computer spreadsheet: <i>SND_audibility.xls</i>.</li> </ul>
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# SOUND: SOUNDS AND VIBRATIONS

Sound is produced when vibrations are set up and transmitted through materials. You cannot always see any vibration, even though you can still hear a sound. Your teacher will show you some examples of sound being produced where you can observe the vibration in some way. In each case, listen to the sound and watch what happens.

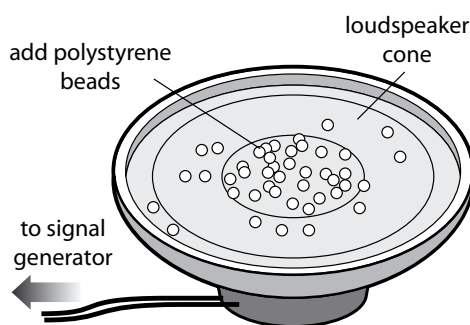
## Task A Uprturned loudspeaker cone with beads

1. What happens to the polystyrene beads when the sound is turned on?
2. How is this affected by increasing the loudness of the sound?
3. How does changing the frequency of the signal affect the pitch of the sound and the movement of the beads?
4. What do you think happens to the movement of the loudspeaker cone as a) the loudness and b) the pitch is increased?
5. Which frequencies of sound produce the best effect? Are there any frequencies that produce no visible effect?

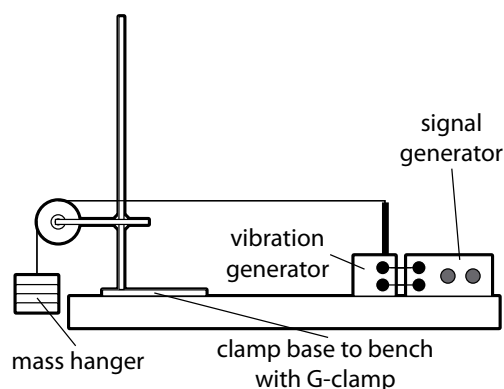
## Task B Vibrating strings

Your teacher will demonstrate how a string vibrates in a musical instrument like a guitar or violin. Watch what happens to the string as you listen to the sound.

6. What is the link between the pitch of the note and the frequency of vibration of the wire for 'musical' sounds?
7. What is the lowest frequency at which you can see the wire vibrating?
8. What is the highest frequency at which you can see the wire vibrating?
9. Is the string vibrating even if you can't see it? How do you know?



Wear eye protection if using a sonometer or wires under tension.



# SOUND: SOUNDS FROM DIFFERENT SOURCES

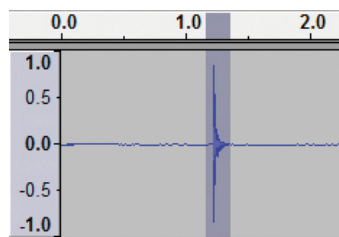
How do sounds from different sources vary? You will use a computer with a microphone and sound recording/analysis software to compare the traces obtained with sounds from different sources.

The traces displayed by the computer are called 'waveforms'. They show the change in sound intensity with time. Changes in intensity occur very rapidly, so the trace usually has to be expanded to show the detail.

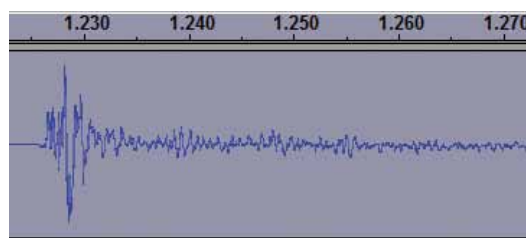
## Task A Recording sounds

It is useful to take screenshots as a record of what you have done.

1. Connect the microphone to your computer's audio input and open the Audacity program.
2. Record the sound as you clap near the microphone: it should look similar to the image on the right.
3. Record what happens as you whistle or hum near the microphone – quietly at first and then more loudly.
4. What differences can you see between:
  - loud sounds and quiet ones?
  - sudden sounds and continuous ones?
5. Clap again, then select the 'clap' part of the recorded sound and expand this part of the trace: the screenshot on the right shows the same trace after it has been expanded several times.
6. Expand the trace until you can see individual oscillations.
7. Try expanding other sound waveforms (for example, sounds you have recorded or pre-recorded files). What differences can you see between sounds using an expanded trace?



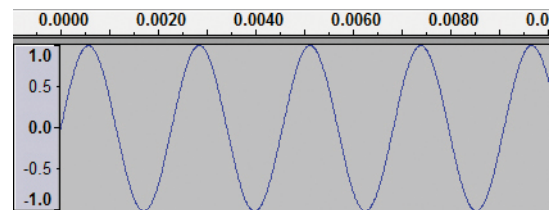
'Raw' trace



Expanded trace

**SOUND:**
**SOUNDS FROM DIFFERENT SOURCES**
**Task B Sound from a tuning fork**

8. Strike a tuning fork near to the microphone and record the sound.
9. Now try a different tuning fork with a much higher or lower frequency and record the sound it makes.
10. Expand the traces until you can see detail, not just blue bands. What differences are there between the traces from the two tuning forks?
11. How do the traces from the tuning forks differ from those you looked at in Task A?
12. Expand the traces for the two tuning forks until you can see individual oscillations, like the image on the right.
13. What differences can you see between the two expanded traces?
14. Check that the timescale is set to seconds. (Choose 'Set Selection Format' in the 'View' menu, and choose 'sec' from the drop-down menu.)
15. How long do ten oscillations take for each of the two sounds?
16. Calculate the average time taken for one oscillation (also called the *period*) of each of the sounds.
17. Use these values to calculate the frequency of each sound. Compare your calculated frequencies to the values on the tuning forks you used.
18. Why can't you find the wavelength directly from measurements of the waveform?
19. How could you calculate the wavelength from your measurements if you know the speed of sound?



Expanded trace showing individual oscillations for a 440 Hz tone

# SOUND:

## HOW LOUDSPEAKERS PRODUCE SOUNDS

There are different types of loudspeaker, though all of them convert electrical signals into mechanical vibrations. You are going to make a simple 'moving coil' loudspeaker. This consists of a wire coil, attached to something which can pick up and amplify the vibration, and a magnet.



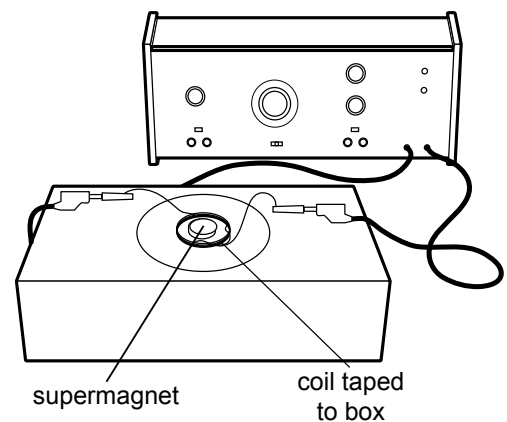
The strong forces produced by supermagnets can cause personal injury and physical damage to other equipment or to the magnets themselves. Follow any additional safety information provided by your teacher before you begin this activity.

### Task A Real loudspeakers

1. Your teacher will demonstrate a simple 'DIY' loudspeaker in action.
2. What parts does the loudspeaker consist of? Which parts seem to be moving?
3. Examine some examples of 'everyday' loudspeakers. How are they different from the 'DIY' loudspeaker?
4. How does a moving coil loudspeaker work, and how does it turn electrical signals into sounds?

### Task B Making a simple loudspeaker

5. Strip 1 – 2 cm of insulation from each end of a 2 metre length of insulated copper wire.
6. Leaving 10 cm or so free at each end, wrap the wire neatly round a 'C' battery (or something of similar size) to produce a coil of wire 2 – 3 cm in diameter.
7. Tape the coil and the supermagnet onto a small cardboard box, as shown on the right. (Instead of a box, you could also use a paper cup or an inflated balloon.)
8. Test your loudspeaker by connecting it to the output of an audio signal generator, set to around 200 Hz.
9. What happens if you change the frequency?
10. What happens if you use an ordinary magnet instead of the supermagnet? Why do you think this happens?





# SOUND: HOW FAST DOES SOUND TRAVEL?

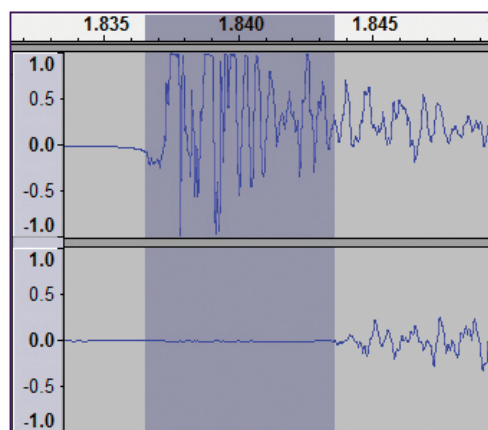
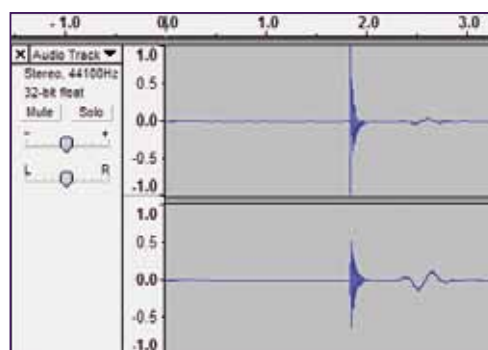
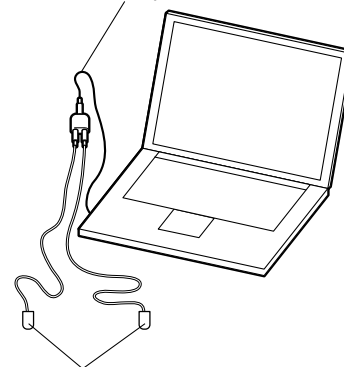
In this activity, you will find out how fast sound travels through air and some other materials using a sound locator kit. This allows you to record sound from two microphones simultaneously so you can see the difference in time taken for the same sound to arrive at each microphone.

## Task A Measuring the speed of sound in air

You will need a computer with *Audacity* installed.

1. Connect the sound locator kit to the computer and open Audacity. Check that the timescale is set to seconds.
2. Set up the two microphones so that they are as far apart as possible, and measure the distance between them. (You need a separation of at least two metres.)
3. You need to record a sound that is right next to one of the microphones:
  - press 'Record'
  - clap once next to one of the microphones
  - press 'Stop'.
4. You should see two traces, similar to the first screenshot on the right. Expand the timescale until you can see the detailed waveform showing the sound arriving at each microphone, similar to the second screenshot.
5. What differences do you notice between the two waveforms?
6. Measure the interval in seconds between the sound's arrival at the first microphone and its arrival at the second microphone.
7. Calculate the speed of sound in air from your measurements.
8. Compare this to the value for 'speed of sound in air' from a textbook or other source. Why is this value given for a stated temperature?

connection from adaptor to audio input



**SOUND:**

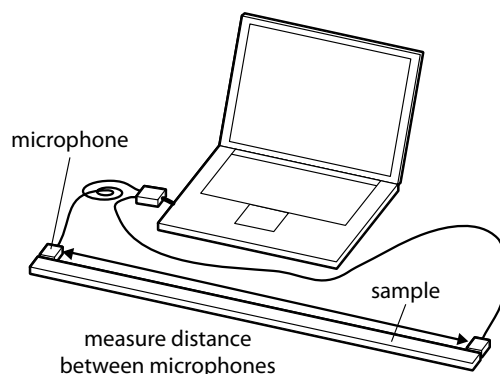
**HOW FAST DOES SOUND TRAVEL?**

**Task B Measuring the speed of sound in solids**

9. Would you expect sound to travel faster in solids or in a gas like air? Why do you think this?
10. Select a solid sample such as a metal rod or a plastic ruler. Attach the two microphones at each end of the sample, and measure the distance between them.
11. Record the sound as before as you tap the sample next to one of the microphones.
12. Measure the interval between sound arrival times and use this to calculate the speed of sound in the material.
13. Why is it better for the sample of the solid to be as long as possible? What are the sources of uncertainty in measuring the time interval? How could you try to overcome them?
14. If you have several materials, record your results in a table like the one on the right.
15. Which materials would you expect to give the fastest or slowest speeds? Do your results confirm what you would expect?
16. Compare your results with accepted values from a textbook or other source.

**Task C Different speeds for different sounds?**

17. We get dispersion spectra for light going through a prism because the different frequencies of light travel at different speeds. What evidence do you have that the speed of sound in air doesn't depend on the frequency?
18. How could you find out if the speed of sound in solids is affected by the frequency? What practical problems would you expect?



Sample	Distance between mics (m)	Time interval (s)	Velocity (m/s)
Steel rod			
Wooden dowel			
Plastic rule			
etc.			

# SOUND: USING ULTRASOUND

*Ultrasound* refers to sounds with frequencies too high for us to hear – above about 20 kHz. Ultrasound can be used to measure distances by timing the reflections from different surfaces: medical ultrasound scans and sonar imaging use this technique. Ultrasound can also be used in a high intensity beam to clean surfaces or to cause physical changes in a material. In this activity you will consider some examples of how ultrasound can be used.

## Task A Mist-making

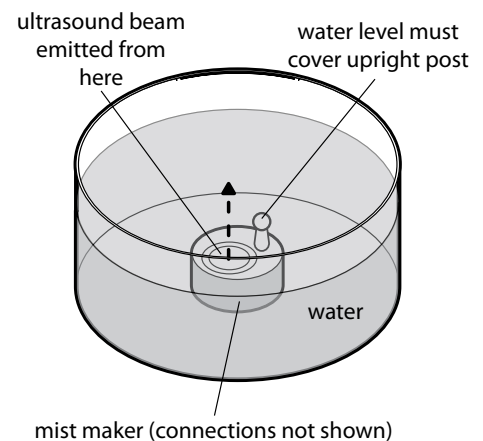
1. Your teacher will demonstrate how ultrasound is used in a mist-making machine. There is a *piezo transducer* inside the mist maker which produces the vibrations when the equipment is switched on.
2. How does this produce a mist?
3. Why must the equipment be submerged in water before it is switched on?
4. What other safety precautions are necessary, and why?

## Task B Ultrasound cleaning

5. Your teacher will demonstrate how items can be cleaned using an ultrasound bath.
6. Why must there be water in the cleaning bath?



Do not put your hand into the water trough when the mist-making machine is switched on.



**SOUND:**

**USING ULTRASOUND**

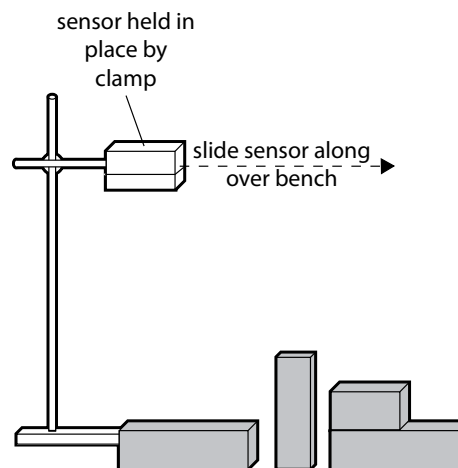
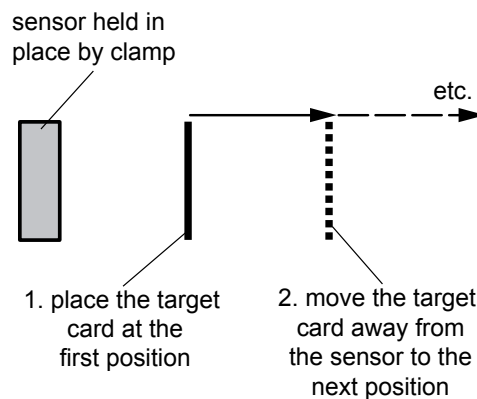
**Task C Using ultrasound to measure distances**

Many distance sensors use ultrasound, either for collecting a set of discrete measurements or for scanning continuously (actually many measurements taken at very short intervals) to build up a profile of a surface.

7. Set up the sensor and datalogger as shown on the right. Select the larger target card (20 cm square). Using a metre rule to measure the distance, put it 10 cm in front of the sensor.
8. Record the distance value given by the sensor. How does it compare with the distance you measured with the rule?
9. Move the target card to 1 metre from the sensor and take another reading. Make sure the card is still lined up with the sensor. Take further readings as you move the card out 0.5 metre at a time.
10. What is the greatest distance at which you can get a reliable reading?
11. Repeat steps 7 to 9 using the smaller target card. What is the effect of using a small target?

**Task D Scanning**

12. You need a distance sensor and datalogger connected to a computer. Using a clamp, hold the sensor near the top of a clampstand, pointing down as shown. Slowly slide the stand along the bench (or rotate it in a horizontal plane) to scan the surface of the bench.
13. What objects and details can you pick out as being above the surface of the bench?
14. How does the scanned image differ from a sonar scan of the seabed?
15. How does the scanned image differ from a pregnancy scan?



# SOUND: INFORMATION FROM SOUNDS

Broadcasts on the radio rely on sound to convey a sense of 'what' is happening and 'where'. Most sounds are complex with characteristics that depend on how or where they were produced. In this activity, you will identify important features for distinguishing between different sounds.

## Task A How do we distinguish between sounds?

- Your teacher will play you some samples of sound:
  - Four samples (A, B, C and D) recorded in different places – can you match the sample to the location?
  - Two samples (E and F) of snapping a fresh cracker and a stale cracker – can you identify them?
- What features of the sound did you use to decide?

## Task B Analysing simple sounds

- Open Audacity file 'tones1'. Listen to the two notes – one is constant and the other fades away. Compare the waveforms (tracks) of the two sounds. What differences can you see?
- Open Audacity file 'tones2'. Listen to the two notes – one is a higher pitch than the other. Compare the waveforms (tracks). What differences can you see?
- Now select a section of one of the tracks, and display the frequency analysis spectrum. What does this show? Repeat for the other track.

## Task C More complex sounds

- Open the Audacity file 'places' (sound samples recorded in a bathroom and an open field). Look at the waveforms and at the frequency analysis spectrum. Which is better for distinguishing between the samples?
- Open the Audacity file 'crackers' (sound samples of fresh and stale crackers being snapped). Look at the waveforms and at the frequency analysis spectrum. Which is better for distinguishing between the two samples?

Location	Sound Sample (A,B,C or D)
Bathroom	
Living room	
Courtyard	
Open field	

Snapping a cracker	Sound Sample (E or F)
Stale	
Fresh	

# SOUND: MANAGING SOUND IN BUILDINGS

Unwanted or excessive noise makes buildings and rooms unpleasant to live or work in. It can be caused by:

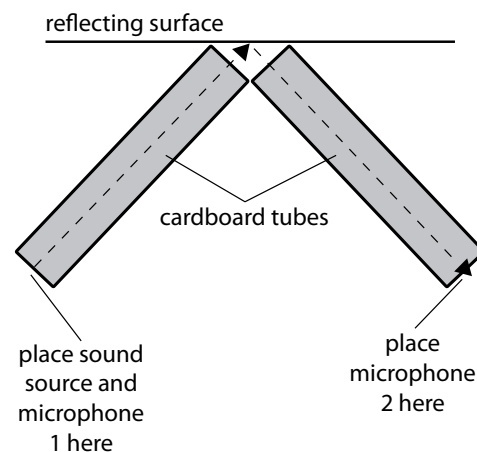
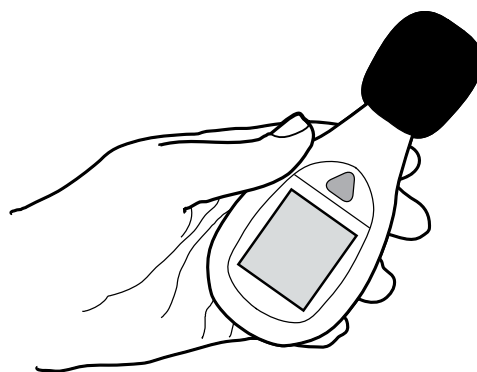
- reflection from surfaces
- transmission through walls, windows and floors
- low frequency vibration of parts of a building, through an effect called resonance.

## Task A Sound survey

1. Carry out a survey of sound levels in different parts of the school building to find out which areas are noisiest.

## Task B Surfaces and sound reflection

2. Select a surface to reflect sound from, then set up the sound source, two microphones and tubes as shown.
3. Open Audacity.
4. Record the effect of making a brief sound near microphone 1.
5. From the computer display, find the maximum intensity values of the waveform for each microphone. Record your results in a table like the one shown.
6. Repeat steps 4 and 5 for other surfaces.
7. Which types of surface are best for reflecting sounds and which worst?
8. How do curtains or carpet help to reduce the noise level in a room?
9. In your survey, what types of location were noisiest, and what makes them so noisy?
10. Why might reflected sounds be a problem in large spaces such as a theatre, concert hall or train station?



Surface	Maximum sound intensity (dB)	
	Microphone 1	Microphone 2

## SOUND: MANAGING SOUND IN BUILDINGS

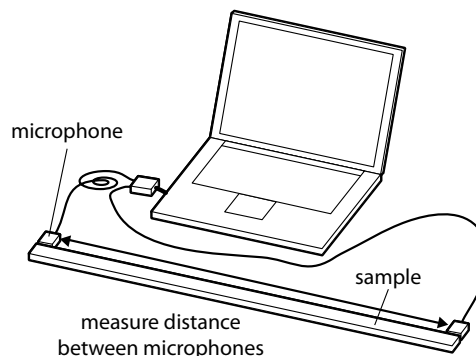
### Task C Transmission and absorption of sound

11. Set up the two microphones one metre apart.
12. Record the effect of making a sound near to microphone 1.
13. From the computer display, find the maximum intensity values of each waveform. Record your results for air in a table like the one shown.
14. Repeat steps 12 and 13 for each sample, starting with different thicknesses of the same material, then different materials.
15. How do the material and the thickness affect the amount of sound absorbed?
16. How does thick carpet help to reduce the noise level in a room?

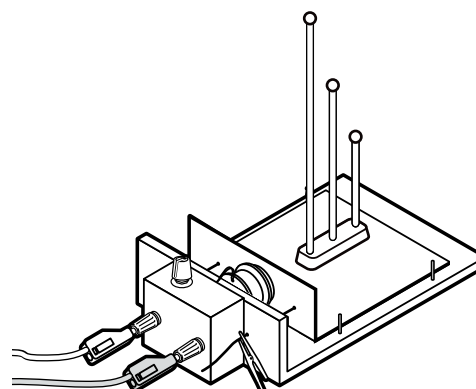
### Task D Resonance and low frequency vibrations

Low frequency sounds are a particular problem in buildings because they can cause parts of a building to vibrate: this is what happens when a passing lorry makes windows rattle, and is an example of *resonance*. Your teacher will demonstrate some other examples of resonance.

17. Why do sounds at a particular frequency make some objects vibrate strongly, while others vibrate very little?
18. How does changing the length or adding extra mass to the part that vibrates affect the vibration?
19. How can you prevent an object from resonating with a sound source at its resonant frequency?
20. How do acoustic engineers try to reduce resonance effects in buildings?



Surface		Maximum sound intensity (dB)	
Material	Thickness (m)	Microphone 1	Microphone 2
Air	1		
etc.			



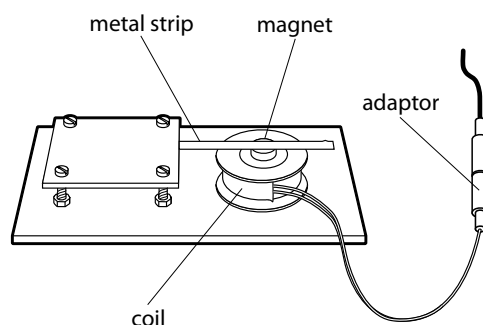
a 'shake table'

# SOUND: MICROPHONES AND PICKUPS

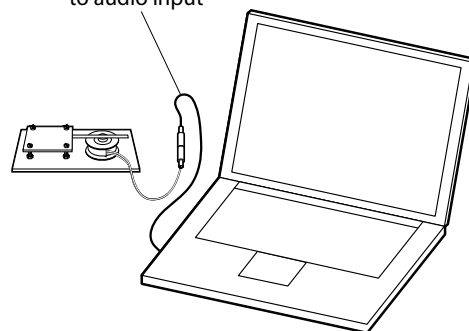
Electro-acoustic microphones produce an electrical signal when vibrations move a magnet relative to a coil – an application of the dynamo effect. Piezoelectric microphones (or guitar pickups) produce electrical signals when pressure waves stress the piezoelectric material. In this activity you will investigate how mechanical vibrations can be converted to electrical signals, and how these signals can be amplified and filtered with computer software.



The vibration detector includes a supermagnet. The strong forces produced by supermagnets can cause personal injury and physical damage to other equipment or to the magnets themselves. Follow any additional safety information provided by your teacher before you begin this activity.



connection from adaptor to audio input



## Task A Detecting sounds and vibrations

1. Connect a *vibration detector* to a computer running Audacity as shown in the second image on the right.
2. Record the effect of: tapping the bench, talking or whistling near the detector, or playing sounds from a radio nearby on the bench. Try to get a range of frequencies, and try with the radio on the bench then held above the bench.
3. For each sound, you record, look at the waveform and frequency spectrum, then re-play the recorded sound.
4. What range of sounds and vibrations does the detector detect?
5. If it detects a sound, what is the recording quality like?

## Task B Recording from a guitar

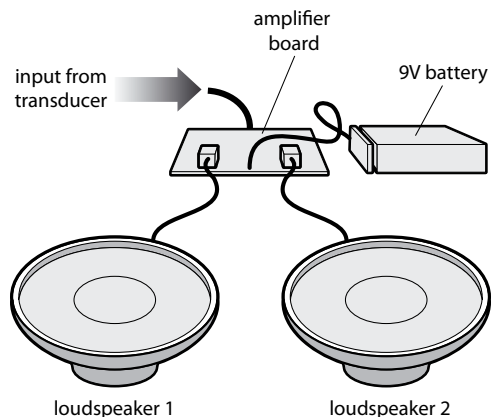
6. Put the vibration detector on the sound box of an acoustic guitar. Record the sound of a string being plucked. Repeat with some foam between the sound box and the detector. (Save the file for Task D.)
7. Look at the waveform and frequency spectrum, then listen as you re-play the recorded sounds: what is the recording quality like in each case?
8. Why does putting the detector directly on the sound box instead of on the foam make a difference?



## SOUND: MICROPHONES AND PICKUPS

### Task C Electric pickups

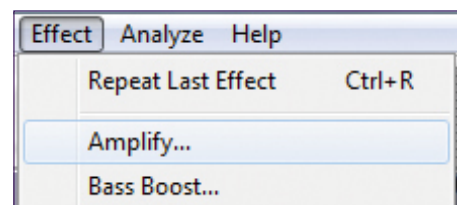
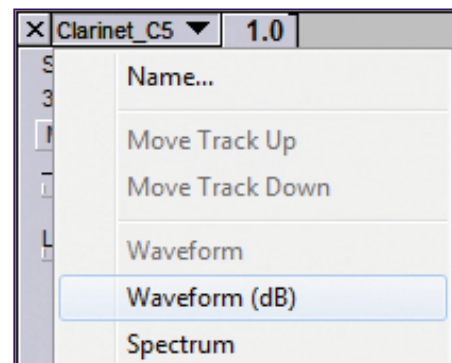
9. Connect a *piezo transducer* to a computer running Audacity. Record a plucked string with the transducer touching the sound box, and then held a little way away from it. Play it back – what difference can you hear?
10. Now place it under one of the strings – record the sound of this string being plucked, and the string next to it. Play it back – what difference can you hear?
11. Piezo transducers are used in electric guitars. To illustrate this, connect the piezo transducer to a power amp and speakers, as shown. Use a piece of adhesive putty to hold it in place on the body of an acoustic guitar. Listen to the effect as you play the instrument.
12. Why is the amplifier necessary?



### Task D Modifying the recorded sound

Real sound recordings may contain a lot of unwanted noise, and you can use various techniques to try to improve the quality of the recorded sound. Amplification, High Pass Filter, Low Pass Filter and Noise Removal are all effects which are found in the 'Effects' menu in Audacity.

13. Using Audacity, open the sound file you recorded in Task B and select Waveform (dB) from the Audio Track dropdown menu, as shown in the upper screenshot.
14. To try each effect, select part of the sound file then select the effect as shown in the lower screenshot, for Amplify.
15. Find out what each effect does to the waveform, the frequency spectrum and the replayed sound. Try repeating the effect.
16. What are the differences between these effects?
17. Which ones seem most effective for your sound sample?



# SOUND: SENSITIVITY OF HEARING

In this activity you will explore the range of frequencies which most people can hear, and investigate how an individual's sensitivity to different sounds varies within the range they can hear.

## Task A Audible frequencies

1. Your teacher will play sounds at a range of different frequencies, and ask you to put your hand up if you hear a sound being played.
2. When all the frequencies have been tested, compare the number of people who could hear each frequency.
3. What was the range of sounds that everyone could hear?
4. What sounds could only some people hear?
5. What problems are there with using this method?

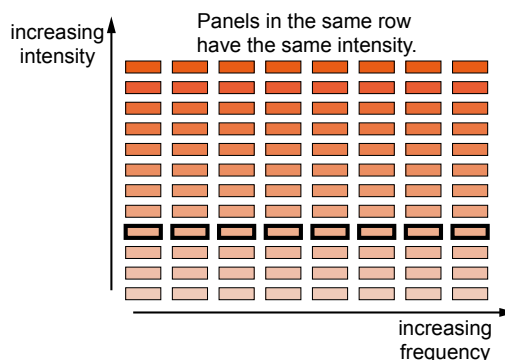
## Task B Sensitivity to different frequencies

This task uses the same sound source as the previous task, but compares sensitivity to sounds at different frequencies for an individual.

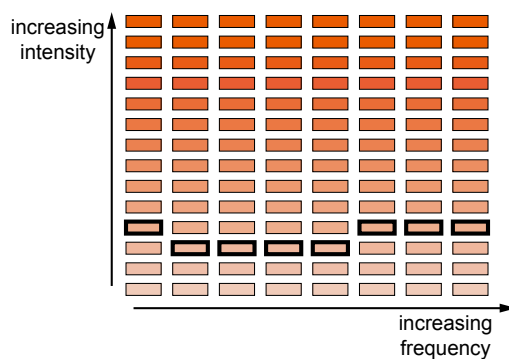
6. One student will listen to the sounds being played, while everyone else observes quietly.
7. Your teacher will ask the student to listen to a 'reference sound' and will then play another sound at a different frequency. The test sound volume will be adjusted until it seems as loud as the reference sound.
8. When the test is completed, you should see a panel selected for every frequency.
9. What range of frequencies is this individual student most sensitive to?
10. Why is a panel in the middle of the 1 kHz column used as the reference sound?



Loud sounds can be painful and damage hearing. Do not start with sound intensities in the top third of the volume range.



Key features of the UNSW Hearing test chart



How a partially completed chart might show greater sensitivity to mid-range frequencies

# SOUND:

## AUDIBLE SOUNDS

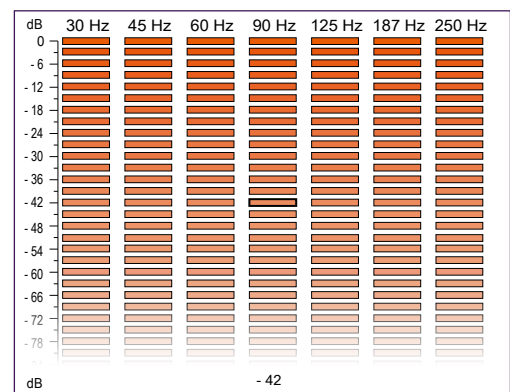
This uses the online hearing test resource from the website *Music science at UNSW* ([www.phys.unsw.edu.au/music/](http://www.phys.unsw.edu.au/music/)). Click on the link *Test your hearing* at the top right of the page.

The instructions below are for:

- a survey of which frequencies of sounds are audible at the same intensity level
- an investigation of individual sensitivity to different frequencies.

### Carrying out the survey

1. Display the page with the hearing test chart, and select a sound panel somewhere near the middle to show students what the chart does. (*Don't start in the top third of the chart: sounds here could be too loud.*) When you select a panel, the sound is played and the intensity level chosen is shown at the bottom of the screen, as shown in the screenshot on the right.
2. Choose a sound level which everyone can hear, but NOT loudly, for a frequency of 90 Hz.
3. Students should not be able to see what frequency is being selected during the test. If you are using an interactive whiteboard, adjust the setting so that the image is frozen on the IWB, while you are free to work with the image on your computer.
4. Ask students to put their hands up each time they hear a short sound, and record the number of people who put a hand up. This is easiest if you have a spreadsheet open with the sound frequencies marked out, ready to fill in the numbers. If nobody can hear the lower frequency sounds, try the next layer up until someone can.
5. Work backwards and forwards along the sound intensity row you have selected, until you have played each frequency at least once and recorded how many people indicated they could hear it.
6. Display the online hearing chart to show that all the sounds were at the same intensity.
7. Display the survey results.



How the hearing test chart shows a 90 Hz sound at -42 dB

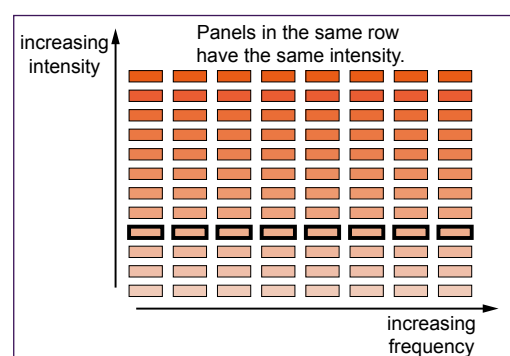


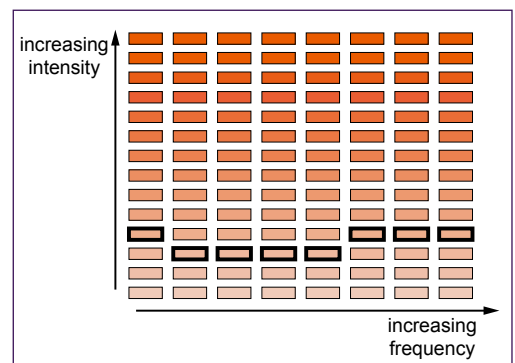
Chart after testing all frequencies at the same intensity

## SOUND:

### AUDIBLE SOUNDS

#### Investigating individual sensitivity to different frequencies

8. Use the same hearing test chart, but with any previous results cleared.
9. Select a panel in the middle of the 1 kHz column: it must not be uncomfortably loud but must be louder than the background noise. This panel is the reference sound throughout the test.
10. Ask the student to listen to the 'reference sound' and then play another sound at a different frequency but on the same row (so it is at the same dB setting). Ask them to judge whether it was the same loudness as the reference sound, or louder or quieter.
11. If the student judges the second frequency to be quieter, play the reference sound again, then play the test frequency but using the panel in the next row up.
12. Repeat step 11, each time moving up one row on the test frequency, until the student judges both sounds to be equally loud.
13. If they judge the reference and test sounds to be equally loud, go on to a new frequency and repeat steps 10 to 13.
14. The screenshot on the right shows typical results for part way through the test.
15. The test is complete when all the frequencies have been compared to the reference frequency.



*How a partially completed chart might show greater sensitivity for mid-range frequencies.*

## BACKGROUND SCIENCE

This section gives further information about some of the technical terms used in the earlier section in this booklet on 'Ideas and suggestions for using sound in the classroom'.

### DECIBELS AND SOUND INTENSITY

Sound intensity is a measure of the rate of energy transfer in a particular place and is measured in  $\text{W m}^{-2}$ , but the difference between quiet sounds and very loud ones is many orders of magnitude, making it difficult to compare a wide range of intensities on a linear scale. The decibel (dB) scale is a *logarithmic* scale: an increase of 10 dB corresponds to the intensity in  $\text{W m}^{-2}$  (or the power in W) being 10 times greater, an increase of 20 dB to the intensity being 100 times greater, an increase of 30 dB to the intensity being 1000 times greater, and so on. Conversely, doubling the intensity of the sound corresponds to an increase of just 3 dB.

### SPEED OF SOUND IN DIFFERENT MATERIALS

How fast sound travels in a material depends on the density of the material and on its bulk modulus of elasticity (a measure of how hard it is to compress). The speed of sound,  $v$ , is given by:

$$v = \sqrt{\frac{E}{\rho}}$$

where  $E$  is the bulk modulus of elasticity in  $\text{N m}^{-2}$  and  $\rho$  is the density in  $\text{kg m}^{-3}$ .

Sound travels faster through materials with higher density and through materials which are not easily compressed. For example, the speed of sound is over  $6000 \text{ m s}^{-1}$  in steel, but may be less than  $100 \text{ m s}^{-1}$  in rubber.

The speed of sound in air increases as temperature increases, so values are usually given for a specified temperature: at  $0^\circ\text{C}$  it is approximately  $330 \text{ m s}^{-1}$  and at  $20^\circ\text{C}$  it is approximately  $340 \text{ m s}^{-1}$ . The speed of sound in water also varies with temperature, and is around  $1430 \text{ m s}^{-1}$  at  $0^\circ\text{C}$  and  $1480 \text{ m s}^{-1}$  at  $20^\circ\text{C}$ .

### THE DOPPLER EFFECT

The *change in frequency* of a sound,  $\Delta f$ , is given by:

$$\Delta f = f_0 \frac{v}{v_s}$$

where  $f_0$  is the frequency when the object is stationary,  $v$  is the velocity of the moving object and  $v_s$  is the velocity of sound.

The related change in observed wavelength of sound,  $\Delta\lambda$ , is given by:

$$\lambda = \lambda_0 \frac{v}{v_s}$$

where  $\lambda_0$  is the wavelength when the object is stationary,  $v$  is the velocity of the moving object and  $v_s$  is the velocity of sound.

The observed frequency  $f_{obs}$  of a sound from a moving source is given by:

$$f_{obs} = f_0 \left( \frac{v_s}{v_s + v} \right)$$

where  $f_0$  is the frequency of the sound when the source is stationary,  $v$  is the velocity of the moving object and  $v_s$  is the velocity of sound. Take  $v$  as negative for an approaching source, and  $v$  as positive for a receding source.

## WAVELENGTH AND RESOLUTION OF ULTRASOUND IMAGES

The resolution provided by an imaging technique is limited by diffraction to the wavelength of the wave being used. The relationship between wavelength, frequency and velocity of a wave is given by:

$$v = f \lambda$$

where  $v$  is the velocity in  $\text{m s}^{-1}$ ,  $f$  is the frequency in Hz and  $\lambda$  is the wavelength in m. The resolution is therefore improved by using higher frequencies, to give shorter wavelengths.

The speed of sound changes as it travels through different media, so the effective wavelength of the sound also changes: sound travels much faster through solids than it does through air, so frequencies of around 10 MHz correspond to wavelengths (and hence resolution) of under 1 mm in materials where the speed of sound is of the order of  $1000 \text{ m s}^{-1}$ . For example, for a medical scan, taking  $v = 1540 \text{ m s}^{-1}$ , and  $f = 10 \text{ MHz}$ , then the value for the wavelength  $\lambda$  is given by:

$$\begin{aligned} \lambda &= \frac{v}{f} \\ &= \frac{1.54 \times 10^3}{10^7} \\ &= 1.54 \times 10^{-4} \text{ m} \end{aligned}$$

## REVERBERATION TIME

The *standard reverberation time* is defined as the time it takes for the level of sound to drop from its original level by 60 dB. For a classroom this would be less than 1 second, for a concert hall it is likely to be around 2 seconds.

## REFERENCES AND FURTHER READING

### Websites

Additional resources can be found on the SEP website (see page 51), where there are also links to other particularly relevant websites. Some examples are given below:

**Acoustics, Audio and Video Engineering** ([www.acoustics.salford.ac.uk](http://www.acoustics.salford.ac.uk))

A University of Salford department website including a tutorial on concert hall acoustics. Follow the Studios and labs link to find information on anechoic chambers.

**Music Acoustics: Music Science at UNSW** ([www.phys.unsw.edu.au/music/](http://www.phys.unsw.edu.au/music/))

Part of the University of New South Wales School of Physics website. Follow the 'Test your hearing' link to the online hearing test ([www.phys.unsw.edu.au/jw/hearing.html](http://www.phys.unsw.edu.au/jw/hearing.html)). There is also lots of information on acoustics and musical instruments.

**Practical Physics** ([www.practicalphysics.org](http://www.practicalphysics.org))

This has a wide range of useful practical activities related to sound.

**Teaching Advanced Physics** (<http://tap.iop.org>)

This Institute of Physics website contains detailed ideas and resources for teaching physics to students aged 16-19. There are useful practical activities, including a demonstration 'Hearing superposition' (reference 321-1) that uses two loudspeakers to show cancellation.

**How Stuff Works** ([www.howstuffworks.com](http://www.howstuffworks.com))

Useful for information on a range of acoustics topics such as 'How speakers work', 'How electric guitars work' and 'How ultrasound works' (which is about ultrasound imaging).

**Ingenia online** ([www.ingenia.org.uk](http://www.ingenia.org.uk))

This is the online version of a quarterly magazine published by The Royal Academy of Engineering which often includes articles likely to be of interest to science students at GCSE and post-16, such as '*Auralisation – Engineering sound for public spaces*' by Rob Harris (Issue 40, September 2009) and '*Surround sound from all angles*' (an article on sound perception) by Philip Nelson and Hareo Hamada (Issue 19, May 2004).

**Engineering toolbox.com** ([www.engineeringtoolbox.com](http://www.engineeringtoolbox.com))

This has technical information on topics such as speed of sound in solids and reverberation.

### Books and other publications

**Teaching Secondary Physics**

Sang D (ed.) (2000) Publisher: John Murray (ISBN 978-0719576362)

The 'Sound, light and waves' chapter of this book for beginning science teachers includes an alternative loudspeaker construction along with suggestions for practical activities to use with 11-16 year old students.

There are a number of other relevant booklets in SEP's 'Innovations in Practical Work' series. These include '*Light and matter: models and applications*' (including reflection, interference, the Doppler effect, and their applications), '*Seismology*' (what we can learn from seismic waves) and '*Motors and electromagnetism*' (including the motor effect and dynamo effect, and their applications). The SEP CD-ROM '*Sensors*' includes detailed information on activities for older students using sound sensors.

Other useful publications include *New Scientist*, which is always a good source of interesting updates for teachers and for students, such as '*Latex could silence noisy neighbours*' by Colin Barras, 20 February 2010 (or online, dated 17/02/10).

## SOURCES

The following photographs have been reproduced from BigStockPhoto.com: symphony orchestra on page 3 (© Pavel Losevsky); rock concert on page 3 (© Ahmad Faizal Yahya); man cutting down tree on front cover and pages 1 and 21 (© Fredrick Chestnut). The following photographs have been reproduced from iStockphoto.com: public address system on page 8 (© Rudi Tapper); pregnant woman having ultrasound scan on front cover and pages 1 and 12 (© Bojan Fatur); ultrasound scan of foetus on page 12 (© Isabelle Limbach); woman singing on front cover and pages 1 and 19 (© bravobravo); guitar player on pages 1 and 19 (© Robert Kohlhuber). The following photograph is from the Acoustic Research Centre, University of Salford: anechoic chamber on pages 1 and 15.

## DOWNLOADING RESOURCES FROM THE SEP WEBSITE



SEP produces a range of digital resources to accompany each of its publications. These are available from the 'SEP Associates' area of the website ([www.sep.org.uk](http://www.sep.org.uk)).

Membership of SEP Associates is free to all science teachers and technicians in UK schools. To join, fill in the online form on the website. SEP is wholly funded by the Gatsby Charitable Foundation, and joining SEP Associates entitles its members to additional benefits, including offers of free publications and other resources.

[www.sep.org.uk](http://www.sep.org.uk)



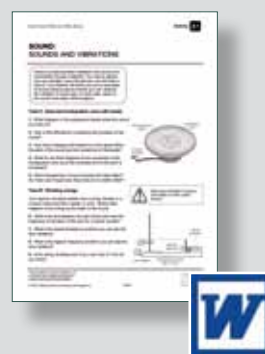
### PDF file of booklet

On the SEP website there is a downloadable PDF file of the whole booklet that can be printed or viewed on screen.



### PDF files of student sheets

In addition to the whole booklet, the student activities are available as separate PDF files.



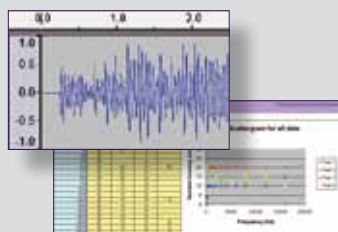
### Word files of student sheets

Each student sheet also exists as a Word file. These files can be edited in order to adapt the activities to suit individual circumstances.



### PowerPoint presentations

These contain the photographs and drawings shown in this booklet. They can be used to create custom-made presentations.



### Other resource files

A range of sound files, instructions for using Audacity, and a spreadsheet for collecting survey results can also be downloaded from the website.



### Links to other sites

The SEP website provides links to other useful websites on this topic.





MUTR.co.uk

in association with Middlesex University

## OBTAINING THE PRACTICAL RESOURCES



SEP works in close partnership with Middlesex University Teaching Resources (MUTR) in identifying and developing low-cost practical resources to accompany its publications. Many other resources for school science and technology can also be purchased from MUTR.

The latest prices of the products shown below and further information can be obtained from [www.mutr.co.uk](http://www.mutr.co.uk), or by requesting their latest catalogue. Orders can be made by post, telephone, fax or email by providing an official school order number or by credit card.



### Sound source locator SEP 173

This simple kit using two microphones can be used for investigating transmission of sound through materials and for finding the speed of sound in different materials.



### Vibration detector SEP 171

This sensor uses a magnet and coil arrangement to detect vibrations. It models the way moving coil microphones convert sounds to electrical signals (and also the way that seismometers detect seismic waves).



### Rare earth magnets

A selection of magnets of various sizes (which can be used to make DIY loudspeakers). Caution: these magnets produce strong magnetic fields – consult Health and Safety guidance.



### Mist maker 211-015

The intense beam of ultrasound produced by this device creates a continuous supply of mist when it is activated under water.



### Piezo sounder EW2 002A

A piezoelectric transducer inside the buzzer converts electrical signals into vibrations.



### Piezo transducer EW2 003A

This device converts sound vibrations into electrical signals, and can be used as a simple electric pickup.



### Stereo amplifier board (assembled) 211-200

For use with the piezo transducer, to amplify the electrical signals before they are sent to loudspeakers. (Needs 9V battery.)



### SEP Shake table SEP 174

This shake table can be used to demonstrate the effect on structures of different frequencies of vibration. (Needs 6V d.c. supply.)



### Doppler effect unit SEP 222

This unit has a rotating arm and a sound source, and used with a microphone and sound-editing software, it can be used to investigate the Doppler effect.

You can download the written materials in this booklet, and find further information from: Science Enhancement Programme [www.sep.org.uk](http://www.sep.org.uk)

The Science Enhancement Programme (SEP) is part of Gatsby Technical Education Projects. It undertakes a range of activities concerned with the development of curriculum resources and with teacher education.



Gatsby Science Enhancement Programme  
Middlesex University  
S37 Stable Yard  
Bramley Road  
London N14 4YZ  
Email: [info@sep.org.uk](mailto:info@sep.org.uk)  
**Web: [www.sep.org.uk](http://www.sep.org.uk)**

The  **Gatsby** Charitable Foundation

You can order a range of practical resources to support the teaching of sound and other topics from Middlesex University Teaching Resources.

**Middlesex  
University**



**teaching  
resources**

Teaching Resources  
Middlesex University  
Unit 10, The IO Centre  
Lea Road, Waltham Cross  
Hertfordshire EN9 1AS  
Tel: 01992 716052  
Fax: 01992 719474  
Email: [sales@muventures.co.uk](mailto:sales@muventures.co.uk)  
**Web: [www.mutr.co.uk](http://www.mutr.co.uk)**

# [www.sep.org.uk](http://www.sep.org.uk)