ELECTRICITY FROM SQUEEZING MINERALS?

Piezoelectricity: crystals generate a voltage when a mechanical stress is applied to them.

Piezoelectricity was discovered by Pierre Curie and the word is derived from the Greek piezein, meaning to squeeze or press.

You've probably come across piezoelectric crystals in lighters for gas fires or cookers. Squeezing a trigger or pressing a button puts pressure on the piezoelectric crystal and it produces a voltage. The reverse effect is possible – if you apply a voltage to a piezoelectric crystal it changes size slightly. If you have an electronic watch with an alarm, the alarm will almost certainly use a piezo transducer to produce the alarm sound.

An early application of piezoelectricity was SONAR (Sound Navigation and Ranging). During World War I, French physicist Paul Langevin developed an underwater microphone (a hydrophone) made of thin quartz crystals carefully glued between two steel plates. This picked up the echoes of very high frequency sounds that bounced back from other ships and submarines.

WHAT YOU HAVE TO DO

You are going to make a microphone using a small piezo transducer. You are then going to investigate the frequency response of your microphone.

EQUIPMENT

- tin can or a *Pringles* tube (the bottom of the tin or tube must have a flat section big enough for the piezo transducer you are going to use)
- 1 x piezo transducer
- some wire (thin stranded instrument wire is best)
- multi-purpose glue or double sided sticky tape
- electrical insulation tape
- oscilloscope
- signal generator and loudspeaker
- pair of wire strippers and cutters
- 2 x stands and clamps
- access to electricity supply

SAFETY NOTES

If you are using a tin can, choose one with a pull-off top. This saves using a tin-opener and produces a safer edge. Make sure that the tin is thoroughly cleaned and dried before use.

METHOD: PREPARATION

The cans

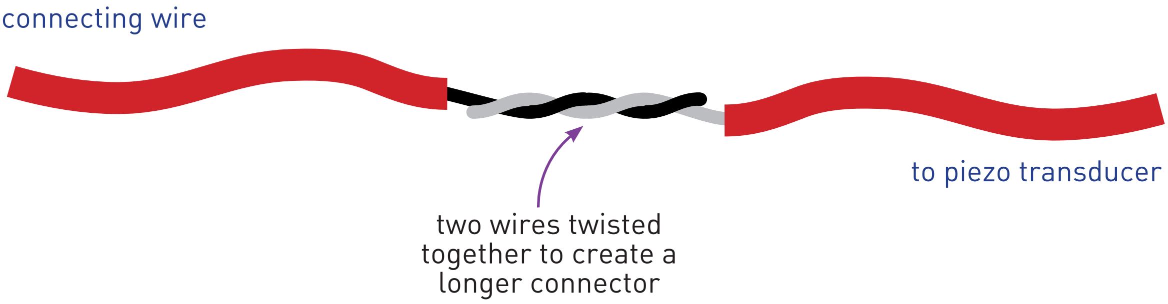
1. Remove the top of the can or remove the lid, if you are using a tube. Take care with sharp edges; *Pringles* tubes or drinking chocolate drums are much easier to handle.
2. Clean the can or tube.

If you have time, you might compare which type of can works best.

The piezo

The piezo element must be stuck to the bottom of your tin or tube. The simplest way to do this is with double-sided sticky tape, but you can use multi-purpose glue. Make sure that the two wires attached to the piezo transducer are on the top.

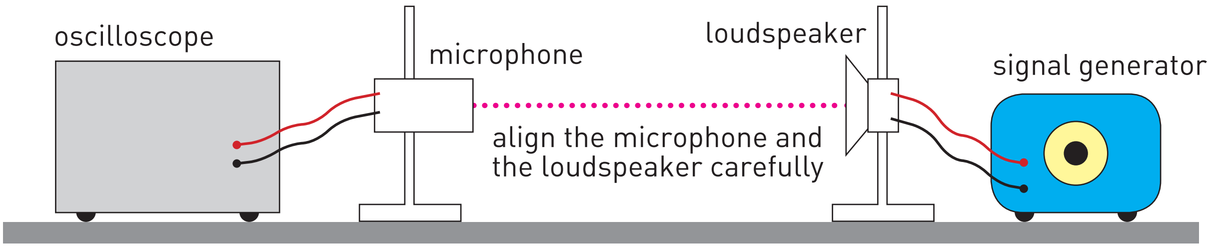
You may need to lengthen the red and black wires to make it more convenient to connect to the oscilloscope. Do this as shown:



Use wire strippers to remove some of the plastic insulation from the wires. Twist the extra wires together connecting red to red and black to black. Cover the join with electrical insulation tape.

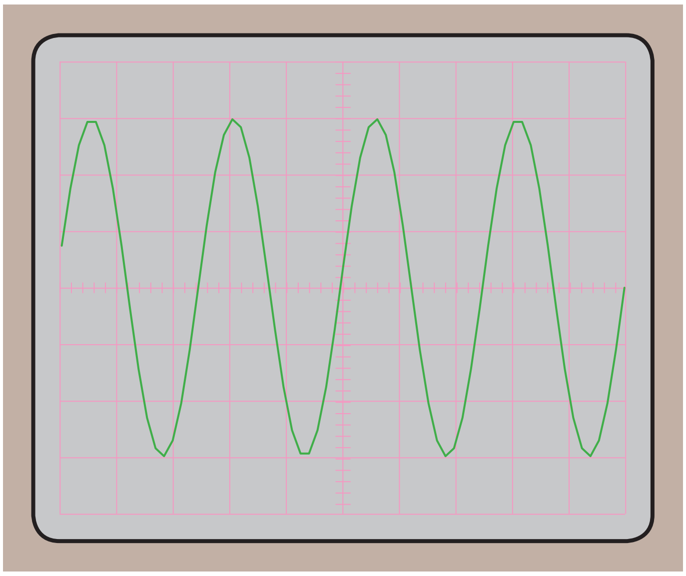
METHOD: SETTING UP

1. Set up the microphone in a stand and clamp. Connect it to the input of an oscilloscope.
2. Set up the loudspeaker in a stand and clamp and position it about 50–80 cm from your microphone. Measure the distance carefully and make a note of it.



METHOD: TESTING THE FREQUENCY RESPONSE

1. Set the frequency of the signal generator to 200 Hz.
2. Turn the oscilloscope on. Set the time/div to 2 ms/div and the volt/div to 20 mV/div
3. Turn the signal generator on. Adjust the frequency to 200 Hz. Adjust the volume until you have a trace on the oscilloscope that nearly fills the screen, like in the diagram.



You are going to test how a microphone system works at different sound frequencies. You will keep the volume control constant but vary the frequency of the sound produced.

4. Measure the amplitude by counting how many divisions (squares) the signal trace occupies from top to bottom. (Use the grid on the oscilloscope screen to estimate this to one decimal place.)
5. Multiply the number of divisions by the volt/div setting on the oscilloscope.

Here is an example:

On the diagram above, the top-to-bottom height is six divisions.
The volt/division setting is 20 mV/div.

$$6 \text{ div} \times 20 \text{ mV/div} = 120 \text{ mV}$$

Therefore, the amplitude is **60 mV** (half the top-bottom or peak-to-peak voltage).

6. Calculate the frequency of the signal by measuring the period. Multiply the number of divisions (again, estimate this to one decimal place) by the time/div setting on the oscilloscope – this will give you the period in milliseconds.

On the diagram above, the width for one cycle is 2.5 divisions.
The time/division setting is 2 ms/div.

$$2.5 \text{ div} \times 2 \text{ ms/div} = 5 \text{ ms}$$

Therefore, the period is **5 ms**

7. Now calculate the frequency using:

$$f = \frac{1}{T}$$

The frequency will be in hertz if T is measured in seconds; since T will be measured in milliseconds the frequency will be in kilohertz.

8. Change the frequency setting on the signal generator and repeat the measurements needed to find the amplitude and frequency of the signal detected by piezo microphone.
9. Repeat the measurement for a range of frequencies up to 5 kHz.

As you change the frequency you will need to speed up the time/div setting on the oscilloscope (in other words, set it to a smaller time/div), otherwise the waveforms on the screen will become too bunched up for measurements to be made easily and accurately.

You will also need to adjust the volts/div setting: If the top-bottom height of the trace gets too small, use a more sensitive setting (i.e. a smaller voltage/division); if the height is too big to see all the trace on the screen, use a larger voltage/division.

10. Record your results.

amplitude / mV	nominal frequency / kHz (as shown on the signal generator)	measured period / ms	calculated frequency / kHz
	0.2		
	0.6		
	etc.		

Draw a graph of your results. Plot amplitude on the vertical *y*-axis and frequency on the horizontal *x*-axis. Comment on your results.

SOME QUESTIONS

1. The sound from the loudspeaker to the microphone travels by a number of routes: the main routes are directly through the air and through the stands/the solid bench surface; sound will also reach the microphone via reflections from surfaces around the experimental area.

   Keeping all other variables unchanged (separation distance, alignment, signal frequency and loudness), place foam pads (or expanded polystyrene tiles) beneath the stands supporting the loudspeaker and microphone. Does this affect the amplitude of the signal picked up by the microphone? Offer an explanation for your observations.

   Try repeating the experiment with this new arrangement. Plot a second graph on the same axes. Comment on your results.
2. Do you think that the sound produced by the loudspeaker is of the same loudness at all the frequencies you tried? Run through the tested frequencies again and give a subjective measurement of loudness – say if some frequencies produce a particularly quiet output and if others produce a distinctly louder output. Is there any correlation between these observations and the measured peaks from your first experiment?
3. How well does your microphone detect sounds from different directions?
4. Think of some suitable uses for piezoelectric microphones.

HEALTH AND SAFETY

A risk assessment must be made before starting any practical work.

If tin cans are used, they should be of the ring-pull type (where the whole end comes off), to minimise risk from sharp edges being left on the can. Tops should be removed and the insides thoroughly cleaned.

All equipment should be PAT tested.

Students should be aware of dangers from mains electricity.

NOTES

For the sound source, students could use tuning forks but it is preferable to use a signal generator and a loudspeaker. Tuning forks will need to be placed quite close to the microphone.

The graph is likely to show several peaks at different frequencies. The piezo device itself has a resonant frequency but the arrangement of the experiment will produce others – it is worth using Pringles tubes of different lengths to see how this affects the shape of the frequency response graph. Different groups could investigate different aspects of tube length and type of can.

For **SOME QUESTIONS**, question two, a more scientific answer can be found by using a sound level (dB) meter, if one is available.

Time required

This activity will take one session to complete. Additional time will be needed for writing up and evaluation.

FURTHER INVESTIGATION

Maplin sells a range of different sizes of piezo device and these could be compared using the same set-up, ensuring settings such as separation distance, location, tube length etc. are kept as closely constant as possible.

A discussion of what is measured by sound meters and how the readings compare with subjective loudness may raise some interesting points for further research.

Internet research on the different ways that microphones work could start at:

https://microphones.audiolinks.com/

Students might create a chart to show how each works/similarities/advantages and disadvantages/appropriate uses.

Internet research on the piezo electric effect and sonar are possible homework activities. This could start at:

http://www.ndt-ed.org/EducationResources/CommunityCollege/Ultrasonics/EquipmentTrans/piezotransducers.htm

TECHNICIAN EQUIPMENT LIST

per group

- tin can or a Pringles tube (the bottom of the tin or tube must have a flat section big enough for the piezo transducer; tubes may need to be cut to different lengths; cans should have their tops and any sharp edges removed; they should be clean)
- 1 x piezo transducer, available from Maplin, Rapid or MUTR
- some wire (thin stranded instrument wire is best)
- multi-purpose glue or double sided sticky tape
- electrical insulation tape
- oscilloscope
- signal generator and loudspeaker or selection of tuning forks
- pair of wire strippers and cutters
- 2 x stands and clamps
- access to electricity supply

for **SOME QUESTIONS**, question 1

- 2 x foam pads (or expanded polystyrene tiles) to fit under clamp stands

TECHNICIAN NOTE

To extend the connecting wires, students will need to strip a reasonable amount of insulation, to make a good join. Extra wire could be soldered, to give a secure join, using non-lead solder. Older soldering irons may not get hot enough for non-lead solder. Do not use solder with colophony (rosin) flux.