**P4.1 Magnets and magnetic fields**

- Describe how magnets behave and link this behaviour to magnetic field lines.
- Describe the difference between permanent and induced magnetism.
- Explain the behaviour of compasses.
- Describe evidence for a magnetic field around a wire.
- Describe the factors affecting the strength and direction of the magnetic field around a wire.
- Explain why the field of a solenoid is bigger than the field of a wire.

**P4.2 Uses of magnetism**

- Describe the forces between a magnet and a current-carrying conductor.
- Use Fleming’s left-hand rule.
- Apply the equation for the force on a current-carrying conductor in a magnetic field.
- Describe how you can use a current-carrying wire and magnets to make a coil rotate.
- Explain why the coil rotates in terms of magnetic fields.
- Describe electromagnetic induction, and explain the direction of the induced p.d.
- Describe how to increase the size of the induced p.d.
- Describe how electromagnetic induction is used to produce a.c. and d.c.
- Describe how a transformer works.
- Explain the link between the p.d. and number of turns on each coil of a transformer.
- Apply the equation linking the p.d. across the primary and secondary coils of a transformer, and the number of turns on the primary and secondary coils.
- Explain how a microphone and loudspeaker work.

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**Magnetic fields**

- Magnetic field lines = model
- Arrows show direction of force
- Behave like elastic bands (flux)
- Could also be gravitational or electric field lines

**Earth’s magnetic field**

- Like a bar magnet in the middle

**Permenant and induced magnetic fields**

- Permanent magnetic materials, permanently magnetic
- Induced metal (e.g., steel paper clip) made into magnet

**Currents and Fields**

- Notice direction of field
- Field gets weaker further from wire
- Strong magnet you can turn on and off
- Stronger with ↑ coils, ↑ current, added core

**Transformers**

\[
\frac{V_p}{V_s} = \frac{N_p}{N_s} = N = \text{no. of turns}
\]

- \(V_p < V_s\) = step-up transformer
- \(V_p > V_s\) = step-down transformer
**Currents and Forces**

- The field due to a wire + field due to a magnet = force (motor effect)
- Field lines try to straighten → force on wire
- Shown by Fleming’s Left Hand Rule
  - Force on a conductor = flux density (T) × current (A) × length (m)
- Force on a conductor = flux density (T) × current (A) × length (m)

**Electromagnetic induction**

- If you have a circuit a current flows → makes an electromagnet → electromagnet has a field → field opposes the motion that caused it
- Moving wire or magnet produces p.d.

**Generators**

- Generator → a.c.
  - Voltage vs. time graph
- Dynamo → d.c.
  - Voltage vs. time graph

**Loudspeakers**

- Changing current in coil → changing force on coil/cone → cone moves in and out → sound produced

**Microphones**

- Sound waves move diaphragm → diaphragm moves coil → induces p.d. → produces changing current

**Simple motors**

- Current, stronger field, ↑ wire (length and number of coils) make coil spin faster
- Split-ring commutator keeps coil spinning
Learning outcomes
After studying this lesson you should be able to:

- describe wave motion in terms of amplitude, wavelength, frequency, and period
- define wavelength and frequency
- describe differences between transverse and longitudinal waves
- describe how to use ripples on water surfaces to model transverse waves, and why ripples cannot model sound waves
- describe evidence that in both cases it is the wave and not the water or air itself that travels.

Specification reference: P5.1a, P5.1b, P5.1e, P5.1j, P5.1k

Water waves are fun to play in, but large waves, such as those during storms or tsunamis, can cause great damage by shifting huge amounts of energy (Figure 1).

What are waves?
Every time you speak on your phone vibrations in your vocal cords produce sound waves. A wave is an oscillation that transfers energy. The microphone in your phone produces a signal that varies in the same way. Then electromagnetic waves are used to communicate between the two phones. Sound and water waves are mechanical waves and need a medium (matter) to travel through. Electromagnetic waves do not.

A Write down the names of three other types of wave.

Sound waves are longitudinal. The direction of vibration of individual air molecules is the same as the direction of the wave. Figure 2 shows the motion of air molecules when the wave is moving through the air. In transverse waves the direction of vibration is at right angles to the direction of travel of the wave (Figure 3). If you make a transverse wave on a spring the individual coils move up and down but the energy is transferred horizontally.

What are wave properties?
Table 1 shows other properties of waves, some of which are shown in Figures 4 and 5.

### Table 1 Properties of waves.

<table>
<thead>
<tr>
<th>Property</th>
<th>Definition</th>
<th>Symbol</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>amplitude</td>
<td>distance from the middle to the top (crest) or bottom (trough) of a wave</td>
<td>$A$</td>
<td>depends on the wave (e.g. metres or volts)</td>
</tr>
<tr>
<td>wavelength</td>
<td>distance from one point on a wave to the same point on the next wave.</td>
<td>$\lambda$ (lambda)</td>
<td>metres, m</td>
</tr>
<tr>
<td>frequency</td>
<td>number of waves, or oscillations, per second</td>
<td>$F$</td>
<td>hertz, Hz</td>
</tr>
<tr>
<td>time period</td>
<td>the time for one wave to pass a given point</td>
<td>$T$</td>
<td>seconds, s</td>
</tr>
</tbody>
</table>

Unit prefixes
You may need to use many different prefixes for frequency and wavelength, for example, MHz or μm.
There are two ways to represent a wave. A time trace shows how displacement varies with time at a particular position (Figure 4). A snapshot of a wave shows how displacement varies with distance at a particular time (Figure 5).

**Figure 4** The time for a wave to complete one oscillation is the time period of the wave.

![Figure 4](image)

**Figure 5** The distance from one point (X) on a wave to the same point (Y) on the next wave is the wavelength.

![Figure 5](image)

**B** Write down the time period and the wavelength for the waves in Figures 4 and 5.

In the time trace in Figure 4 you could measure the period from any point on a wave to the same point on the next wave.

On the snapshot in Figure 5 you can measure wavelength from any point on the wave to the same point on the next wave.

On either diagram you can measure wavelength from the middle to the top or the bottom (trough) of a wave.

Waves also have a **wave velocity**.

**How do you model waves?**

You have learned that you can model electric circuits with rope, and field lines with rubber bands.

Another important model is using ripples on water waves to model transverse waves. For example, you can show how waves are reflected, as shown in Figure 6.

The surface of the wave moves up and down as the wave moves through the water. You can see that by putting a small cork on the surface. The wave travels but the water does not.

This is the same for sound waves. The wave moves away from your mouth but the air does not.

1. **Describe how to make transverse and longitudinal waves on a long slinky spring.**
   
   **(2 marks)**

2. **Explain how you know that when a sound wave moves through the air the air does not move.**
   
   **(1 mark)**

3. **You make a transverse wave on a piece of rope.**
   
   a. **Describe how you would find the wavelength.**
      
      **(3 marks)**
   
   b. **Describe how you would find the amplitude.**
      
      **(1 mark)**

4. **A wave has a frequency of 20 kHz. Use the definitions in Table 1 to calculate the time period.**
   
   **(2 marks)**

**Study tip**

Check the x-axis of a graph showing a wave so you know whether you can find wavelength or time period from the graph.
P5.1.2 Wave velocity

Learning outcomes
After studying this lesson you should be able to:

- describe and apply the relationship between frequency, wavelength, and wave velocity
- recall and apply formulae relating velocity, frequency, and wavelength
- describe how to measure the speed of ripples on water surfaces and the speed of sound.

Specification reference: P5.1c, P5.1d, 5.1j

You can see an aircraft that is travelling faster than sound because water droplets form a cone behind it (Figure 1).

Figure 1 A plane travelling very fast produces a shock wave like the wake behind a boat.

How do you calculate wave velocity?
Imagine running along a track. Your stride is 1.5 metres long and you take 2 strides each second. From this information, you could calculate that you have travelled 3 m/s.

In terms of waves, your ‘stride’ represents the wavelength, and the ‘strides per second’ represent the frequency. You need to recall and apply this equation:

\[
\text{wave velocity (m/s)} = \text{frequency (Hz)} \times \text{wavelength (m)}
\]

The unit of frequency is the unit of number of waves per second. There is no unit for number of waves, so 1 Hz = 1/s.

Calculating wavelength
A singer sings a note with a frequency of 256 Hz. The velocity of sound in air is 330 m/s. Calculate the wavelength.

Step 1: Write down what you know:
- frequency = 256 Hz
- velocity = 330 m/s

Step 2: Make wavelength the subject of the equation and work out the wavelength.

\[
\text{wave velocity} = \text{wavelength} \times \text{frequency}
\]

\[
330 \text{ m/s} = \text{wavelength} \times \frac{256 \text{ Hz}}{1 \text{ Hz}}
\]

wavelength = 1.3 m (2 significant figures)

A Explain what would happen to the wavelength if the singer sang a note of 512 Hz.
How do you measure the velocity of ripples?
If you use a ripple tank (Figure 3), you need to know the frequency of the ripples, and their wavelength, to calculate velocity.

You can find the wavelength using a flashing light (a strobe) and a ruler, and the frequency by finding the number of rotations of the motor per second. Then you can use the equation to calculate the velocity of the waves.

How do you measure the velocity of sound?
If you time how long it takes to hear an echo (reflection) of a clap when you are at a distance from a wall you can work out the velocity of sound using the equation that links distance, velocity, and time.

Alternatively, you can connect a pair of microphones a certain distance apart to an oscilloscope (Figure 4).

You can use the method with the microphones to measure the velocity of sound in a liquid or a solid.

Remember that sound is a longitudinal wave, so when you see the trace of a transverse wave on the screen of an oscilloscope it is showing the variation of pressure with time, not the sound wave itself.

The velocity of sound can vary with temperature and pressure. This is because these factors affect the velocity at which the disturbance in the wave is transferred between particles.

Modelling tsunamis
Scientists can issue tsunami warnings because they can use computer models to predict how long it will take ocean waves to reach land.

1. You make waves in a ripple tank by moving a bar up and down 2 times per second. This makes waves of wavelength 20 cm. Calculate their velocity. (2 marks)

2. a. The note ‘middle C’ has a frequency of 256 Hz. Calculate the wavelength of middle C in water, where the velocity is 1500 m/s, and in steel, where the velocity is \(5.0 \times 10^3\) m/s. (4 marks)
   
   b. Explain why the note is still middle C. (1 mark)

3. Write down and explain whether moving your hand faster when you make a transverse wave on a slinky spring will increase the velocity of the wave on the slinky. (2 marks)

4. Figure 5 shows the sound pulses produced by the microphones in Figure 4. There are 10 squares for each 2 ms. Calculate the distance between the microphones. (6 marks)
   
   The velocity of sound in air is 340 m/s.
Learning outcomes
After studying this lesson you should be able to:

- describe how changes in velocity, frequency, and wavelength are related when sound waves move from one medium to another
- describe the effects of reflection, transmission, and absorption of sound waves at the boundary between two materials.
- describe what we use ultrasound for.

Specification reference: P5.1f, P5.1g, P5.2i (part), P8.3i (part)

Why does sound travel further at night (Figure 1)?

Figure 1 Sound is refracted downwards at night.

What happens when sound travels across a boundary?
When a wave travels from one medium to another its velocity can change and so can its direction (Figure 2). This is **refraction**.

Suppose a sound wave travels into a region where it travels faster, as in Figure 3.

The direction of the sound wave changes so that it moves away from a line at 90° to the surface (called the **normal**). The wavelength of the sound waves increases.

You might think that the frequency also changes, but it stays the same. If the velocity increases, and the wavelength also increases, the frequency stays the same.

A sound wave that hits the boundary at 0° to the normal will speed up but will not change direction.

A Suggest what happens to the sound wave when it goes from hot air to cold air.

What happens to a sound wave at a boundary?
There are three things that can happen when a wave hits the boundary between two media.

The sound can be:

- reflected (an **echo**)
- transmitted (and possibly refracted)
- absorbed.

What happens to the sound depends on the densities of the regions either side of the boundary.

If the densities are very different then more of the sound will be reflected.
What is ultrasound?
Ultrasound is sound of a frequency greater than 20,000 Hz. We cannot hear ultrasound but many other animals, such as dogs, can.

Sound spreads out from a source. Ultrasound is very useful because it has a very small wavelength so you can focus it into a beam.

B Calculate the wavelength of ultrasound waves of a frequency of 30 kHz in air.
The speed of sound in air is 340 m/s.

How can you use ultrasound?
Before you were born a doctor or midwife probably made an image of you using ultrasound (Figures 4 and 5).

- The transmitter beams ultrasound waves into the mother.
- The waves reflect from the different boundaries.
- The machine calculates the distances using time and velocity, and uses those distances to produce an image.

Doctors also use ultrasound to find kidney stones, and monitor blood flow.

You can use the same method to find other distances, such as the depth of water (Figure 6). The transmitter sends out a pulse and calculates the distance from the time of the echo picked up by the receiver.

Echo-sounding and sonar (sound navigation and ranging) use this method. Sonar is usually used by submarines and fishermen to find distances using the time for an echo and the speed of sound in water.

Study tip
When you are working out what happens to waves at a boundary look carefully to see if they are speeding up or slowing down.

Synoptic link
You learned about the refraction of light at Key Stage 3.

1 Write down three things that can happen to a sound wave at a boundary. (1 mark)

2 a Calculate the distance to a shoal of fish under a boat if the time for the echo is 0.1 seconds, and the speed of sound in water is 1500 m/s. (2 marks)
   b Suggest why the receiver might detect two echoes. (1 mark)

3 Describe in terms of its properties what happens to a sound wave that travels from a liquid into a solid. (5 marks)

4 Estimate the time for the reflection from a fetus in an ultrasound scan. Assume the wave is moving through water. (2 marks)
Learning outcomes
After studying this lesson you should be able to:
- describe processes that convert wave disturbances between sound waves and vibrations in solids, such as in the human ear
- explain why such processes work only over a limited frequency range
- explain how this is related to human hearing.

Specification reference: P5.1h, P5.1i

The ossicles in your ear (Figure 1) are the only bones that do not grow. They are the same size now as they were when you were born.

What happens when a sound wave hits a solid?
If you stand in a large room and shout you hear echoes. Eventually the sound dies away. Where does it go? After being reflected many times, the sound is eventually absorbed.

When sound is absorbed it makes the particles in the wall vibrate. The wall gets a bit hotter.

A wall cannot move, but the diaphragm of a microphone can move.
When the microphone absorbs the sound wave it produces a changing electrical signal.

How does your ear detect sound?
Your ear (Figure 2) is designed to detect, amplify, and convert sound to an electrical signal.

The outer ear (pinna and auditory canal) gathers the sound wave and directs it to the ear drum, which vibrates.

A Explain why your ear drum vibrates when a sound wave hits it.
As the ear drum vibrates it makes the ossicles vibrate. They act like small levers to amplify the vibration and pass it on to the inner ear through the oval window.

The cochlea is shaped like a snail shell and contains fluid which transmits the movements of the oval window to small hairs (Figure 3) on the inside wall of the cochlea. These hairs are attached to sound-detecting cells that release chemical substances, which makes nerves send a signal down the auditory nerve to your brain. Your brain processes the signal and you hear the sound.

**Why do you hear only a particular range of frequencies?**

You hold a ruler on the edge of desk, pull it down, and let it go. It will vibrate with a frequency that depends on the length of the ruler hanging off the desk. It is the natural frequency of the ruler.

Objects that can vibrate, like hairs in your cochlea, have a natural frequency. If you apply a vibration to them at their natural frequency they will vibrate with a very big amplitude (Figure 4). This is called resonance.

The hairs inside the cochlea in your ear have different lengths and resonate at different frequencies of sound. That is how your ear puts together an electrical signal that contains all the different frequencies in the sound wave.

The range of frequencies that you can hear depends on the range of lengths of hairs in your cochlea.

**B** Dogs can hear much higher frequencies than humans can hear.

Suggest one difference between the cochlea of a human and the cochlea of a dog.

As you get older you lose the shorter hairs. This means that you find it more difficult to hear higher frequencies.

**Loud music**

Scientists have found evidence that listening to loud music can affect the range of frequencies that you hear as you get older, or damage your hearing in other ways (Figure 5). It is the responsibility of scientists working for governments and health organisations to warn people of the risks to their hearing.

1. Suggest one difference between an empty classroom after a lesson and an empty classroom before a lesson as a result of the noise during the lesson. (2 marks)

2. Suggest what is happening inside your cochlea when you are listening to a sound with a single frequency. (1 mark)

3. Explain the link between the hairs in the cochlea and the range of frequencies that you can hear. (2 marks)

4. Suggest why you cannot hear every single possible frequency of sound. (1 mark)

**Go further**

The ‘R’ in MRI scanning stands for ‘resonance’. Find out what is resonating.
Waves in matter

P5.1 Wave behaviour

Summary questions

1. Match the phrases to make sentences about waves. Write the matched letters and numbers to show your answer.
   a. a sound wave moves through air…
   b. a sound wave is refracted at a boundary…
   c. when a sound wave is absorbed by a wall…
   1. … the wall heats up a bit.
   2. … but the air does not travel.
   3. … when it slows down.

2. Figure 1 shows a graph of a wave with some measurements labelled.

   ![Graph of a wave](image)

   **Figure 1** A graph of a wave.

   a. Write down the letters that show the amplitude of the wave.
   b. If the diagram shows a snapshot of the wave (displacement against distance), write down the letters that show the wavelength of the wave.
   c. Write down what the letters in b show if the diagram shows a time trace (displacement against time).
   d. i. Explain why the diagram shows a transverse wave.
      ii. Write down an example of a transverse wave in everyday life.
   e. Explain why ‘frequency’ is not shown on the diagram.

3. a. Select the correct equation for calculating wave speed:
   - wave speed = frequency × wavelength
   - wave speed = \( \frac{\text{frequency}}{\text{wavelength}} \)
   - wave speed = \( \frac{\text{wavelength}}{\text{frequency}} \)
   b. You stand on a cliff and watch waves approaching the shore. At one point there are 1.5 waves per second and the crests of the waves are 10 m apart. Calculate the speed of the wave at that point.

4. You are standing at the bottom of the Grand Canyon in the middle. You clap, and hear an echo 1.2 seconds later.
   a. Calculate the width of the Grand Canyon where you are standing. The speed of sound in air is 330 m/s.
   b. Explain what happens to the sound when it hits the walls of the canyon.
   c. Part of the Colorado River in the Grand Canyon ends up at the Hoover Dam. A boat is on top of the water behind the dam, which is 230 m deep. Calculate the time that a sonar device records for a pulse of sound to reach the river bed and be reflected back. The speed of sound in water is 1500 m/s.
   d. Explain why the sonar device should be in the water directly above the river bed and not at an angle above it.

5. a. i. Explain the difference between sound and ultrasound
   ii. Describe how a doctor can build up an image of a fetus using ultrasound.
   iii. Explain why doctors use ultrasound and not audible sound to create an image of a fetus.
   b. i. Compare the ear and the microphone.
      ii. Explain why the human ear cannot detect ultrasound.
   c. Explain why we describe sounds, e.g. ultrasound, musical notes, using frequency and not wavelength.
Revision questions

1. Look at the following diagram of a wave.

![Diagram of a wave](image)

a. What is the amplitude of the wave?
   - A: 3 mm
   - B: 5 mm
   - C: 6 mm
   - D: 10 mm

b. What is the wavelength of the wave?
   - A: 3 mm
   - B: 5 mm
   - C: 6 mm
   - D: 10 mm

c. The frequency of the wave is 300 Hz. What is the speed of the wave?
   - A: 9 m/s
   - B: 15 m/s
   - C: 18 m/s
   - D: 30 m/s

2. Ships use sonar to check the depth of water.
   a. A ship emits waves towards the sea floor. The sound waves take 3 s to return to the ship.
      i. Suggest why the waves return to the ship. (1 mark)
      ii. Sound waves are longitudinal. Describe the differences between longitudinal and transverse waves. (2 marks)
      iii. The speed of sound in water is 1450 m/s. Calculate the depth of the water underneath the ship. (3 marks)
   b. The sound waves have a frequency of 200 kHz.
      i. Explain what is meant by the word frequency. (2 marks)
      ii. The speed of the waves is 1450 m/s. Calculate their wavelength. (2 marks)

3. Here is a statement about waves.
   ‘Water waves transfer energy but do not carry matter.’
   Use your knowledge of waves to explain how water waves can transfer energy over large distances even though the particles in them do not move very far at all. (6 marks)

4. Look at the data on hearing level loss at different ages.
   It shows the hearing loss in dB for different ages at six different frequencies.

   ![Graph of hearing level loss](image)

   a. Explain how the trends shown by the graph are linked to how changes in the ear affect hearing as a person gets older. (6 marks)
   b. Scientists are developing hearing aids to help people hear high-frequency sounds. These hearing aids can detect sounds of frequency 6000 Hz and above and change them to sounds of half that frequency.
      People aged 60 and over can have difficulty hearing sounds above 6000 Hz.
      Explain how these hearing aids can improve the hearing of people aged 60 and over. Use the data from the graph in your answer. (3 marks)