Waves

Model answers and marking points

GCSE science 6-mark questions

This topic online

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1 Amira and Callum stretch a long, loose spring (a slinky) along a smooth floor. First Amira moves her end quickly from side to side. Then she pushes and pulls her end backwards and forwards along the length of the spring.

Compare the two waves made in the spring. In your answer refer to the direction of the oscillations, what the waves look like and real examples of each type.

(6 marks)

Model answer

Both waves carry energy along the spring from Amira to Callum. In both, each coil just oscillates about its own position and the coils do not travel along the spring with the wave.

When Amira moves her end from side to side she makes a transverse wave. The coils oscillate at right angles to the direction the energy travels. When she pushes and pulls along the spring she makes a longitudinal wave, where the coils oscillate parallel to the direction the energy travels.

The transverse wave looks like a series of peaks and troughs. The longitudinal wave has compressions, where the coils are bunched together, and rarefactions, where they are spread out. Both waves have an amplitude, a frequency and a wavelength, and both obey wave speed = frequency x wavelength. For the transverse wave the wavelength is from one peak to the next, but for the longitudinal wave it is from one compression to the next.

Ripples on water and light are examples of transverse waves. Sound waves in air are an example of longitudinal waves.

Marking points (credit any 6 relevant points, linked in a sensible order)

- Both are waves that transfer energy from one end of the spring to the other
- In both waves the coils oscillate about a fixed position and do not travel along with the wave
- Side to side movement makes a transverse wave: oscillations are perpendicular to the direction of energy transfer
- Backwards and forwards movement makes a longitudinal wave: oscillations are parallel to the direction of energy transfer
- The transverse wave has peaks and troughs
- The longitudinal wave has compressions (coils close together) and rarefactions (coils spread out)
- Both have a wavelength, frequency and amplitude, and obey wave speed = frequency x wavelength
- Wavelength of a transverse wave is peak to next peak; of a longitudinal wave is compression to next compression
- Examples of transverse waves: ripples on water, light and other electromagnetic waves
- Example of a longitudinal wave: sound waves travelling through air

How it is marked

- 5-6 marks: gives clear point-by-point similarities and differences covering oscillation direction, appearance and examples, including that the coils do not travel with the wave.
- 3-4 marks: correctly identifies which wave is transverse and which is longitudinal with some differences explained, but similarities or examples are limited.
- 1-2 marks: names the two types or gives an example, with little correct description of the oscillations.

What loses marks

- Saying the coils or water particles travel along with the wave
- Mixing up perpendicular and parallel
- Writing about each wave separately without making comparisons

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2 **Higher tier**

A ray of light travels through air and enters a rectangular glass block at an angle to the normal. Inside the block the ray bends towards the normal. When the ray leaves the far side of the block it bends away from the normal again.

Explain why the light changes direction at each surface. Use ideas about wave speed and wave fronts in your answer.

(6 marks)

Model answer

Light refracts because it changes speed when it passes from one medium into another. Light travels more slowly in glass than in air. Its frequency does not change, so from v = f x wavelength its wavelength becomes shorter inside the glass.

Wave fronts are lines across the wave where all the points are in step, and they are at right angles to the ray. When the ray hits the block at an angle, one end of each wave front reaches the glass first and slows down, while the other end is still travelling faster in air. The part in the glass covers less distance in the same time, so the wave front swings round and the ray bends towards the normal.

At the far side the opposite happens. One end of each wave front reaches the air first and speeds up, while the rest is still in the slower glass. The wave front swings the other way, so the ray bends away from the normal.

If the ray entered along the normal, the whole wave front would slow down at the same moment, so it would change speed but not direction.

Marking points (credit any 6 relevant points, linked in a sensible order)

- Refraction happens because light changes speed when it moves into a different medium
- Light travels more slowly in glass than in air because glass is optically denser
- The frequency stays the same, so the wavelength gets shorter in glass (v = f x wavelength)
- Wave fronts are lines joining points on the wave that are in step, at right angles to the ray
- When the ray hits the block at an angle, one end of each wave front reaches the glass first
- That end slows down first while the rest of the wave front is still moving faster in air
- This makes the wave front swing round, so the ray bends towards the normal
- On leaving the block, one end of the wave front reaches the air first and speeds up first
- This swings the wave front the other way, so the ray bends away from the normal
- If the ray hit along the normal, the whole wave front would change speed at once, so the speed changes but the direction does not

How it is marked

- 5-6 marks: links the change in speed to the turning of wave fronts at both surfaces, explains which way the ray bends each time and mentions wavelength or the normal case.
- 3-4 marks: explains that light slows in glass and speeds up in air, with some attempt to use wave fronts, but the explanation for one surface is unclear.
- 1-2 marks: states that light refracts or bends because glass is denser, with no explanation using speed or wave fronts.

What loses marks

- Saying the frequency changes in glass
- Saying light speeds up when it enters glass
- Describing the bending without explaining it using wave fronts

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3 A factory packs frozen vegetables into sealed plastic bags. The manager wants to use electromagnetic waves to do two jobs: kill bacteria on the conveyor belt surfaces, and check inside sealed boxes for metal fragments. The table gives some information.

Wave	What it passes through	Effect on living cells
Infrared	Air; absorbed by most surfaces	Heating only
Ultraviolet	Air; absorbed at surfaces	Damages DNA in bacteria and skin cells; can cause skin cancer and eye damage
X-rays	Plastic and food; mostly absorbed by metal	Ionising; can cause mutations and cancer

Evaluate which waves should be used for each job. Include any safety precautions needed for workers.

(6 marks)

Model answer

For killing bacteria on the conveyor belt, ultraviolet is the best choice. The table shows it is absorbed at surfaces, so its energy is delivered right where the bacteria are, and it damages their DNA, which kills them. Infrared would only heat the belt, which might not kill all the bacteria and could start to thaw the frozen food.

For checking inside sealed boxes, X-rays should be used. They pass through plastic and food but are mostly absorbed by metal, so any metal fragment would show up as a shadow on a detector. Ultraviolet and infrared would be absorbed by the outside of the box, so they cannot show what is inside.

However, both ultraviolet and X-rays can damage workers' cells: UV can cause skin cancer and eye damage, and X-rays can cause mutations and cancer. The UV lamps should be shielded and switched off when people work near them, and workers should wear eye protection and cover their skin. The X-ray scanner should be enclosed in lead shielding, with workers kept outside it.

Overall, ultraviolet should sterilise the belt and X-rays should check the boxes, as long as both are properly shielded.

Marking points (credit any 6 relevant points, linked in a sensible order)

- Ultraviolet is absorbed at surfaces, so its energy is delivered to bacteria on the belt surface
- Ultraviolet damages the DNA of bacteria, so it can kill them and sterilise the belt
- Infrared only heats, so it would not reliably kill bacteria and could damage the frozen food
- X-rays pass through plastic and food but are absorbed by metal, so metal fragments show up as shadows on a detector
- Ultraviolet and infrared would not pass through the boxes, so they cannot be used to look inside
- Both ultraviolet and X-rays can damage human cells, so workers must be protected
- UV lamps should be shielded or switched off when people are near, and workers should wear eye protection and cover skin
- The X-ray scanner should be enclosed in lead or other shielding and workers kept outside it to reduce exposure
- Conclusion: ultraviolet for sterilising the belt, X-rays for checking boxes, each with shielding

How it is marked

- 5-6 marks: uses the table to choose a suitable wave for each job with reasons, explains why at least one other wave is unsuitable, gives specific precautions and reaches a clear conclusion.
- 3-4 marks: chooses suitable waves for both jobs with some reasons from the table, but precautions or reasons for rejecting other waves are thin.
- 1-2 marks: chooses a wave for one job, or lists dangers, with little use of the information.

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What loses marks

- Choosing X-rays to sterilise surfaces without considering the extra risk and the job
- Forgetting safety precautions, or giving vague ones like be careful
- Not using the information in the table to justify the choices

4 Railway engineers use ultrasound to find hidden cracks inside steel rails. A probe on top of the rail sends short pulses of ultrasound down into the steel and detects any echoes that come back.

Describe how ultrasound can be used to find a crack and work out how deep it is below the top of the rail.

Separate science only

(6 marks)

Model answer

Ultrasound is sound with a frequency above 20 000 Hz, which is too high for humans to hear. The probe sends a short pulse of ultrasound down into the steel rail.

When the pulse reaches a boundary between two different materials, part of it is reflected. A crack contains air, so there is a boundary between steel and air and some of the ultrasound reflects back up as an echo. The rest carries on, and another echo comes back from the bottom of the rail.

If there is no crack, the probe only detects the echo from the bottom of the rail. If there is a crack, an extra echo arrives earlier than this one. The time from sending the pulse to receiving that earlier echo is measured.

The engineers then use distance = speed x time, with the speed of ultrasound in steel. Because the pulse travels down to the crack and back up again, the depth of the crack is half of this distance. By sliding the probe along the rail and repeating, they can find where the crack starts and ends.

Marking points (credit any 6 relevant points, linked in a sensible order)

- Ultrasound is sound with a frequency higher than 20 000 Hz, above the range of human hearing
- The probe sends a short pulse of ultrasound down into the rail
- When the ultrasound reaches a boundary between two different materials, such as steel and the air in a crack, some of it is reflected
- The reflected pulse (echo) travels back to the probe and is detected
- With no crack, the only echo comes from the bottom of the rail
- A crack gives an extra echo that arrives earlier than the echo from the bottom of the rail
- The time between sending the pulse and receiving the echo is measured
- Distance travelled = speed of ultrasound in steel x time
- The pulse goes down and back, so the depth of the crack is half the distance travelled
- Moving the probe along the rail and repeating shows where the crack starts and ends

How it is marked

- 5-6 marks: describes the full sequence from sending a pulse to calculating depth, including partial reflection at a boundary, timing the echo, using speed x time and halving the distance.
- 3-4 marks: describes reflection of ultrasound from the crack and timing the echo, but leaves out halving the distance or the role of the boundary.
- 1-2 marks: states that ultrasound bounces off the crack, with little detail of how depth is found.

What loses marks

- Forgetting to halve the distance for the there-and-back journey
- Saying all of the ultrasound is reflected at the crack
- Defining ultrasound as a very loud sound

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5 After a large earthquake, seismometers all around the world record the waves that arrive. P-waves are detected at almost every station, but there is a band of stations, on the far side of the Earth from the earthquake, where no P-waves arrive. S-waves are not detected at any station on the far side of the Earth.

Explain what these observations tell scientists about the structure of the Earth.

Separate science only

(6 marks)

Model answer

P-waves are longitudinal and can travel through both solids and liquids. S-waves are transverse and can only travel through solids. Because no S-waves are detected anywhere on the far side of the Earth, something inside must stop them. This shows that the outer core is liquid.

The speed of seismic waves depends on the density of the material they pass through. As the density changes with depth, the waves change speed and their paths curve. At the boundary between the solid mantle and the liquid outer core, P-waves suddenly change speed, so they refract. This bends them away from certain parts of the surface, leaving a shadow zone where no P-waves arrive.

By measuring the size and position of the shadow zones, scientists can work out how big the core is. Weak P-waves are also detected inside the shadow zone. These have been refracted again at another boundary, which suggests there is a solid inner core at the very centre.

This evidence matters because nobody can drill down far enough to see the inside of the Earth directly.

Marking points (credit any 6 relevant points, linked in a sensible order)

- P-waves are longitudinal and can travel through solids and liquids
- S-waves are transverse and can only travel through solids
- S-waves are not detected on the far side, so something inside the Earth stops them
- This shows that part of the core, the outer core, must be liquid
- The speed of seismic waves changes as the density of the rock changes, so their paths curve
- P-waves change speed suddenly at the boundary between the mantle and the core, so they refract
- This refraction bends P-waves away from some regions, causing a shadow zone where no P-waves arrive
- The size and position of the shadow zones let scientists work out the size of the core
- Faint P-waves found inside the shadow zone suggest there is a solid inner core
- This evidence is used because the inside of the Earth cannot be observed directly

How it is marked

- 5-6 marks: links the properties of P and S waves to each observation, explains refraction at the core boundary causing the shadow zone, and concludes the outer core is liquid and its size can be found.
- 3-4 marks: explains that S-waves cannot pass through liquid so the outer core is liquid, with some reference to P-waves refracting, but the shadow zone is not clearly explained.
- 1-2 marks: states that the Earth has a core or a liquid layer, with little link to the wave observations.

What loses marks

- Swapping the properties of P-waves and S-waves
- Saying P-waves cannot travel through liquid, which would not explain the observations
- Saying the waves reflect off the core to explain the shadow zone instead of refracting

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