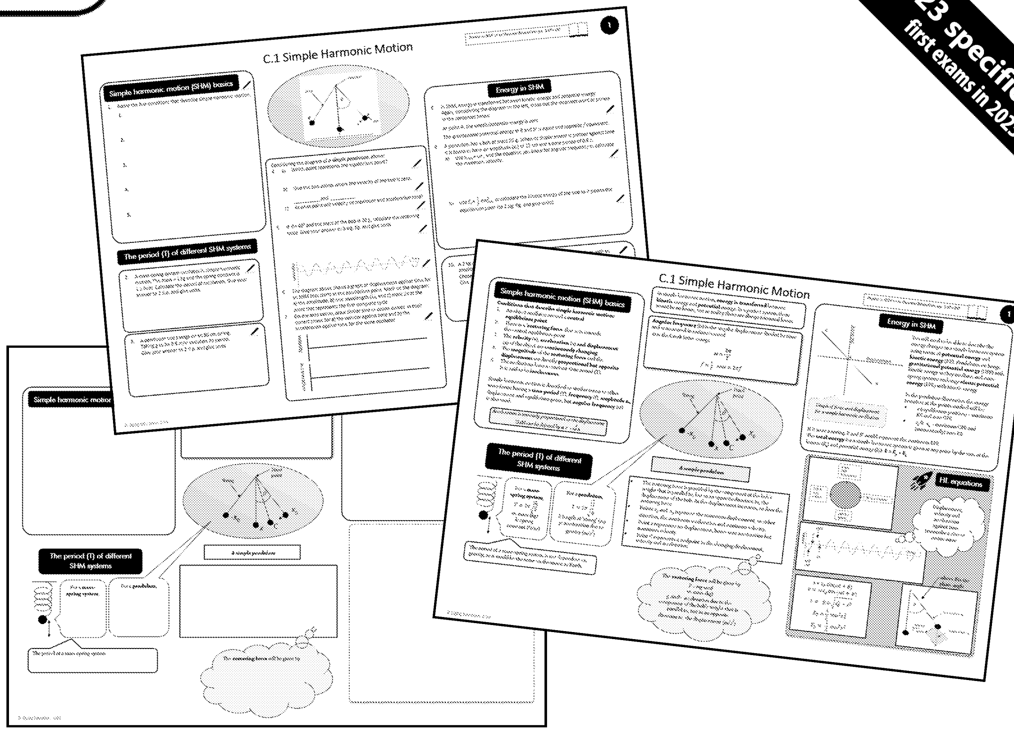
Physics International Baccalaureate Diploma Programme

2023 specification
first exams in 2025



Topic on a Page

for IB Physics

Theme C: Wave Behaviour

zigzageducation.co.uk

POD 12557

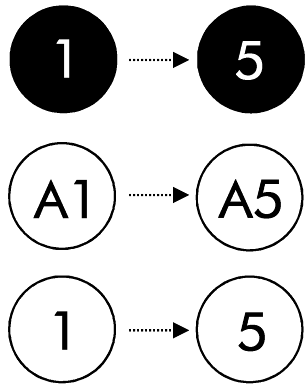
Contents

Teacher's Introduction

This topic-on-a-page resource has been designed to help your students revise the key points of each topic and test their knowledge after you have taught each section of the **IB Physics: Theme C – Wave behaviour** specification from topics 1 to 5. Each page is closely tied to the IB specification, ensuring all aspects of the course are covered.

There are five sections to this resource, each with its own features:

1. **Summary posters**: these are the main pages which intend to clearly consolidate and recap all the key information from the IB Physics course.
2. **Activity worksheets**: these are similar to the summary posters, but contain a variety of tasks, from choosing the correct words to performing calculations. The activity worksheets aim to ensure the student understands all the key knowledge required of them and gives them the opportunity to demonstrate how well they have remembered and understood the content of the course.
3. **Outline-only pages**: these are the summary posters, but with most of the content removed. Students can research the topics, e.g. for homework, and fill in as much information as they can.
4. **Mark scheme**: full answers for the activity worksheets.



The 'summary', 'activity' and 'outline-only' sheets are designed to be A3 size, although they are still usable at A4 with no loss of detail. When photocopying activity worksheets on A3, we suggest photocopying the relevant summary poster on the reverse. If using at A4 size, we suggest photocopying each A3 'activity worksheet' (for writing answers) as a double-sided A4 page to avoid shrinking the space available for answers.

Higher Level content is clearly marked so Standard and Higher Level students can both use the resource as needed.

Each page presents information in a variety of ways, including:

- **Bold key words** – essential terminology in bold, allowing students to skim and revise main points quickly.
- **Bullet-point processes** – complex processes and lists have been summarised into quick, easy-to-learn points.
- **Illustrative diagrams** – detailed diagrams that visually represent a concept or an event.
- **Method and calculation boxes** – concisely state the equations used in required calculations.
- **Thought and speech bubbles** – to link information and develop ideas.
- **Tips and tricks** – extra useful information that can help students when solving problems.

We hope you find these pages useful during your teaching and your students' revision.

October 2024

C.1 Simple Harmonic Motion

Simple harmonic motion (SHM) basics

Conditions that describe simple harmonic motion:

1. An object oscillates around a **central equilibrium point**
2. There is a '**restoring force**' that acts towards the central equilibrium point
3. The **velocity** (v), **acceleration** (a) and **displacement** (x) of the object are **continuously changing**
4. The **magnitude** of the **restoring force** and the **displacement** are directly **proportional but opposite**
5. The oscillations have a constant time period (T). It is said to be **isochronous**.

Simple harmonic motion is described in similar terms to other wave forms having a **time period** (T), **frequency** (f), **amplitude x_o**, displacement and equilibrium point, but **angular frequency** (ω) is also used.

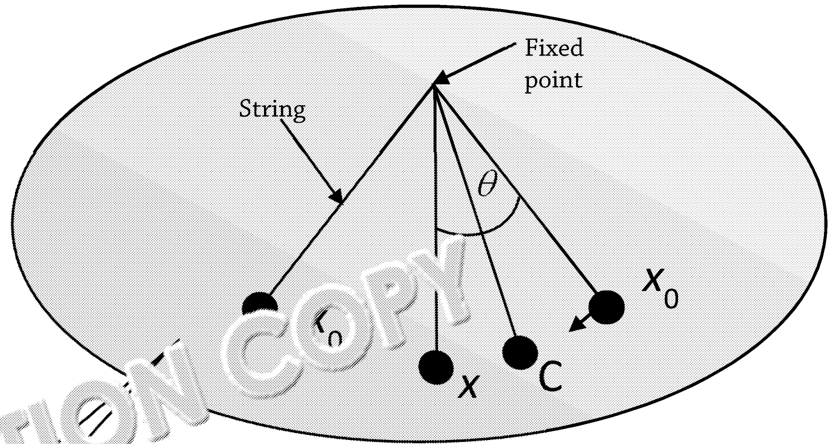
Acceleration is inversely proportional to the displacement
SHM can be defined by $a = -\omega^2 x$

In simple harmonic motion **energy is transferred** between **kinetic** energy and **potential** energy. In a perfect system there would be no losses but in reality there are always frictional losses.

Angular frequency (ω) is the angular displacement divided by time and is measured in radians/second
ω is the Greek letter omega

$$\omega = \frac{2\pi}{T}$$

$$f = \frac{1}{T} \text{ so } \omega = 2\pi f$$

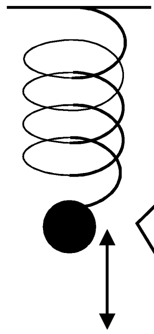


A simple pendulum

- The restoring force is provided by the component of the bob's weight that is parallel to, but in an opposite direction to, the displacement of the bob. As the displacement increases, so does the restoring force.
- Points x_0 and $-x_0$ represent the maximum displacement, in either direction, the maximum acceleration and minimum velocity.
- Point *x* represents no displacement, hence zero acceleration but maximum velocity.
- Point C represents a midpoint in the changing displacement, velocity and acceleration.

The **restoring force** will be given by
$F = mg \sin\theta$
m: mass (kg)
$g \sin\theta$ – acceleration due to the component of the bob's weight that is parallel to, but in an opposite direction to, the displacement (m/s^2)

The period (T) of different SHM systems



For a **mass-spring system**,
$$T = 2\pi\sqrt{\frac{m}{k}}$$
m: mass (kg)
k: spring constant (N/m)

For a **pendulum**,
$$T = 2\pi\sqrt{\frac{l}{g}}$$
l: length of 'string' (m)
g: acceleration due to gravity (m/s^2)

The period of a mass-spring system is not dependent on gravity, so it would be the same on the moon as Earth.

C.2 The Wave Model

Wave basics

Travelling waves are characterised by a **continuous** disturbance or **oscillation** in a medium that results in **energy transfer**. The medium is not transferred. The direction of the wave is given by the **direction of energy transfer**.

In **transverse waves**, the direction of the oscillation is **perpendicular** to the direction of **energy transfer**.

In **longitudinal waves**, the direction of oscillation is **parallel** to the direction of **energy transfer**.

Both types obey the **wave equation** ➜

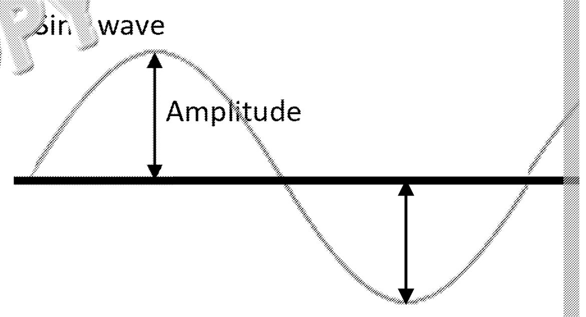
$$v = f\lambda = \lambda/T$$

v is wave speed (m/s), f is frequency (Hz), λ is wavelength (m) and T is the period (seconds)

Property	Longitudinal waves	Transverse waves
The oscillation is perpendicular to the transmission of energy	×	[illegible]
The oscillation is parallel to the transmission of energy	✓	×
No [illegible] transmit in a vacuum	✓	×
Changes the density and pressure within the transmitting medium	✓	×
The speed depends on the medium it travels through	✓	✓
The energy moves, but the medium of transmission doesn't	✓	✓
Can reflect off some surfaces	✓	✓

Two types of travelling waves – **mechanical waves** that need a **medium** to propagate the wave, and **electromagnetic waves** which can transfer energy through a **vacuum**.

The points of maximum displacement in transverse waves are called **peaks** and **troughs**; this name takes its inspiration from the classic sine wave (see diagram, right) whereas the corresponding points in a longitudinal wave, like a sound wave where the particles are vibrating, are known as **compressions** (the particles are compressed together) and **rarefaction**.



Wavelength (λ) is the distance from any poi
Amplitude is the distance from the maximu
Frequency is the number of oscillations in o
Period is the time for one oscillation, measu
Wave speed (v) is given by $v = f\lambda = \lambda/T$

Travelling wave: is an oscillation in which energy is transferred
Standing wave: is an oscillation where the energy is not transmitted but stored
Oscillation: the repeated variation of displacement from an equilibrium position

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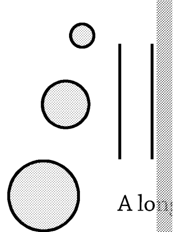
pr
The

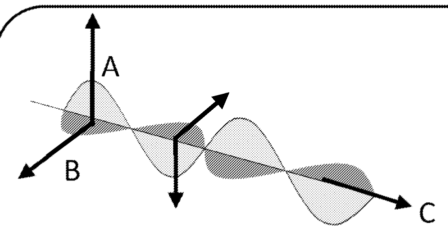


A lon

Electromagnetic spectrum

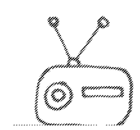
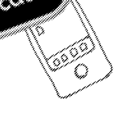
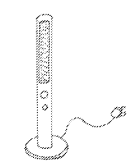
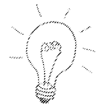
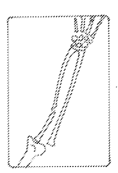
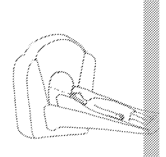
Transverse waves

- Do not require a physical medium of transmission and can propagate in a vacuum
- Have a range of frequencies from 10^{20} Hz to 3 Hz (humans can detect visible light $10^{14} – 10^{17}$ Hz)
- Transmit through the electromagnetic field



A. Oscillation in the magnetic field
B. Oscillation in the perpendicular electrical field
C. The transmission of energy

Sound travels at an approximate speed of **340 m/s** in air. Humans can hear sound in the frequency range 20 Hz to 20 000 Hz. Low-frequency sounds have a lower pitch.

Electromagnetic spectrum	Radio waves	Microwaves	Infrared	Visible light	Ultraviolet	X-rays	Gamma rays
Frequency Hz	< 3 × 10^{11}	3 × 10^{11} – 10^{13}	10^{13} – [illegible] 10^{14}	[illegible] × 10^{14} – 7.5 × 10^{14}	10^{14} – 10^{17}	10^{17} – 10^{20}	10^{20} – 10^{24}
Wavelength	> 1 mm	[illegible] – 2.[illegible]	[illegible]m – 750 nm	750 nm – 400 nm	400 nm – 1 nm	1 nm – 1 pm	< 10 pm
							

C.3 Wave Phenomen

What happens to waves when they meet boundaries, obstacles or other waves?

When waves meet **boundaries** between different media they can be **reflected**, **transmitted** or **absorbed** (sometimes more than one).
Waves meeting an **object within the medium** of transmission may be curved or **diffracted** around the object.
Waves passing through the **same medium** or field can **interact**.
Their **combined effect** is the **sum** of their individual oscillations.

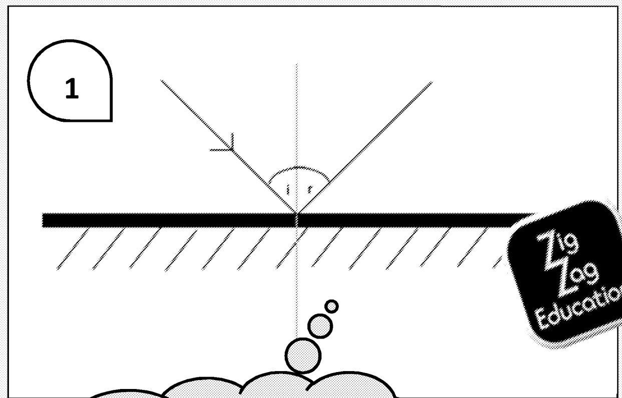
Examples

1. When light shines on a swimming pool, a small amount will be reflected, but most energy will continue to be transmitted by the water as it changes speed and direction at the boundary; we call this refraction.
2. Light moving from a more to a less dense medium will be transmitted, with angles of incidence les than the critical angle resulting in trans ion an angles of incidence greater thar t angle causing internal reflecti
3. Light can be held a ma d, like a fibre-optic o otal internal reflection.
4. Ga ys lded by a thick lead box will be abs y the lead.
5. hen the mechanical waves on the sea meet an bstacle like a groyne or a breakwater, they are momentarily disrupted, but the wave pattern reforms.
6. Comparable waves meeting in 2D or 3D space can enhance or diminish each other.
7. Light flooding through a narrow slit spreads out to form a fan shape.
8. Light passing through two adjacent slits can create interference patterns.

$v = f\lambda$
In **refraction** the speed (v) and wavelength (λ) change, but the frequency remains the same, so there is no colour change (compare to Doppler shift).

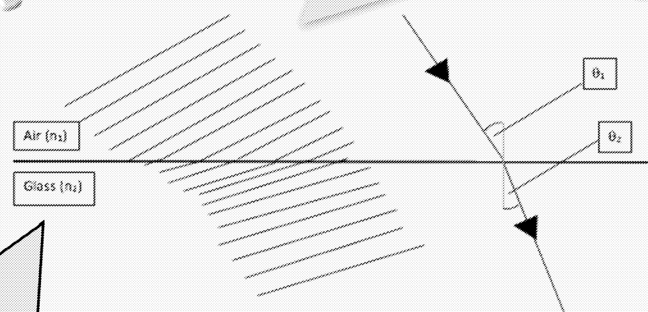
Reflection

1



Law of reflection:
Angle of incidence = Angle of reflection

Waves can be illustrated by arr sho rays (of light, for instanc on able points on adjacent rays e joi to depict wave fronts. A single wave fronts are ill ac g below.



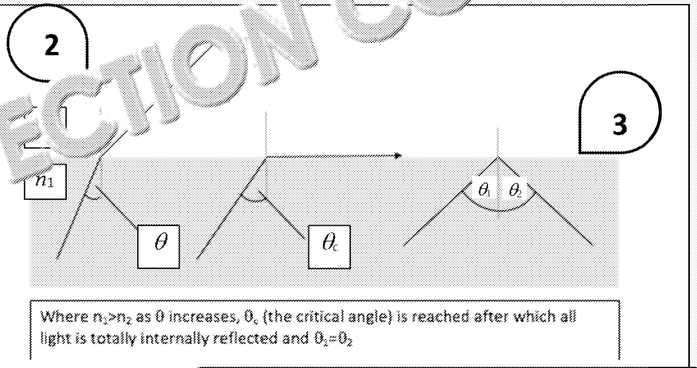
Snell's law
gives $n_1/n_2 = \sin\theta_2/\sin\theta_1 = v_2/v_1$
where v is the wave speed in that medium, n is the refractive index of the media, and θ (theta) represents an angle

Light moves at different speeds in different mediums. It moves more slowly in more dense mediums and faster in less dense ones. The refractive index (n) of a material is the ratio of the speed of light in a vacuum to its speed in that medium. This slo and speeding up nd the light to tak t p or to bend. The wa lecrease in denser mediun e frequency remains the same.

Refraction

2

3

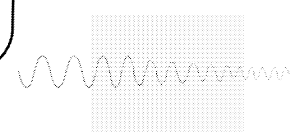


Total internal reflection

Other wave phenomena

Not all waves are **transmitted**; some or all c **absorbed**. Partial absorption can reduce the intensity of the transmitted wave – see below

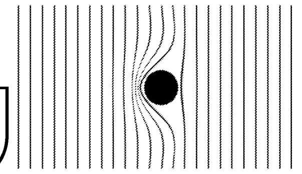
4



Coloured mat wavelengths or tran

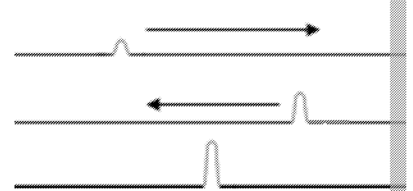
Waves meeting o medium of transmission can be curved or **diff** is illustrated by wave front diagrams – see bel

5



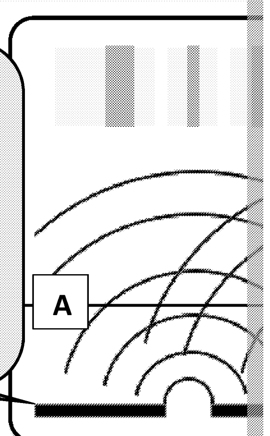
Constructive in *path difference i which indicat number of wa*

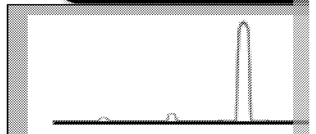
When **coherent** pulses meet in 2D or 3D spa effects of their combined disturbance is the s individual disturbances.



Two pulses (above) will create a single momen their combined amplitude when they meet. T then continue in their original direction.

In **Young's double slit interference**, the separation of the fringes (s) is given by $s = \lambda D/d$ where D = distance from slits to screen and d = separation of the slits.





Single slit diffractio

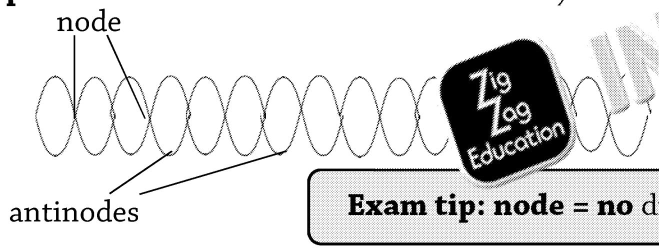
- pattern with a cen smaller peaks
- because diffracted have different pha
- $\theta = \lambda/b$ (where b is
- interference patte diffraction grating

C.4 Standing Waves and Resona

Standing waves

Standing waves are a special type of **interference**. The oscillations of waves and pulses occupying the same space in a medium can add or subtract to give **constructive** or **destructive** interference. This is called **superposition**.

A **standing wave pattern** is the result of two waves of the same frequency and wavelength travelling in **opposite directions** in the **same medium**. They are often dr[illegible]



Exam tip: node = no displacement

The drawing represents areas of **no displacement (nodes)** and areas of **maximum displacement (antinodes)** that appear to be stationary in the medium.

- The **phase difference** between the two waves creating a standing wave must be zero.
- Their amplitudes summate.
- The distance between any two successive nodes or antinodes will be λ/2 or half a wavelength.

A **standing wave** could be described as 'perfectly timed interference'. It appears to be standing still!

A **travelling wave** moves energy through a medium. Successive points are either displaced or still at any given time as the wave passes. With the standing wave, fixed points within the medium are either oscillating or still.

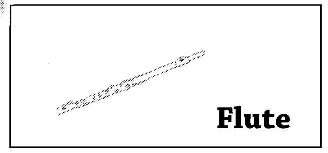
At the **nodes**, no disturbance can be perceived.

Musical instruments

Many
natu
prop

Such a string has fixed ends; these are the boundary conditions. A string with two fixed ends is described as **two fixed boundaries**.
The string cannot move at these fixed ends, so **fixed boundaries create nodes**.
If the length of the string is L, the wavelength of the **first harmonic will be 2*L*** with node at the closed boundaries.
Having determined the wavelength (λ), if the wave spee is known, frequency can be determined by $v = f\lambda$

Wind instruments depend
a free boundary, so antinode
another antinode and affects
A **flute** has **two free bound**
Its harmonics are given by: λ

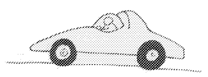


Flute

Resonance

Nodes – areas where the destructive interference [illegible] the [illegible] waves is total
Antinodes – areas where the constructive int[illegible] between the two waves is maximal

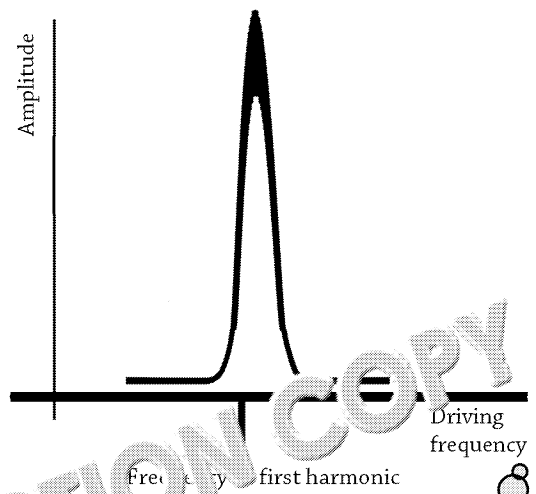
Resonance is not always desirable. Sometimes parts of a car can 'rattle' at certain speeds, when the driving force of the car's motion matches the natural frequency of the rattling part.



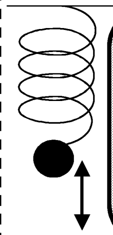
There's an old trick where an opera soprano sings a clear note at a wine glass, causing it to shatter. The sung note provides the driving force and the wine glass vibrates at its natural frequency, breaking itself!

An **oscillation** can be forced by a **driving force**.
(The blowing ov[illegible]e's r[illegible] is the driving force[illegible]s a resonance in the air column[illegible]ns to oscillate with an increased a[illegible]plitude.)
All bodies have a **natural frequency** or set of frequencies with which they vibrate.
(The flute vibrates with a single frequency and produces a pure tone; other instruments, for instance a tuba, will oscillate with a series of frequencies that have a mathematical relationship and produces a rich tone.)
Other objects vibrate with many frequencies that have no relationship to each other; we call this **noise**.

Graph to show amplitude of resonance against driving force

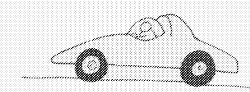


The diagram (above) illust[illegible]rce that is forcing a **resonance** in an o[illegible] single natural frequency.
As th[illegible]ing force** reaches the **natural f[illegible]** the [illegible]plitude of the **resonance increases**.
If [illegible]ncy of the driving force increases **beyond the na[illegible]equency**, the **amplitude** of the resonance will **decrease**.
Further increase in frequency of the driving force can give **additional harmonics**.



Remember the springs and pendulum bobs of simple harmonic motion? These objects oscillate at their natural frequencies which depends on their length.

The driving frequency of a violin bow is derived from it having just enough friction to create a stick/slip oscillation.



D

To ensure a smooth ride, a car h
springs which help to prevent t
and passenger feeling every bu
road. However, the springs have
natural resonance and could re
'bouncing'. This would be nause
worse the car cannot be control
tyres are not in contact with the
The oscillation of the springs ar
by the shock absorbers which ar
like devices that take energy ou
springs, lessening the compress
and extensions.

If you have ever pushed a child o
will know that pushing with the
swing is most effective. If you sto
swing slows down due to the
the mechanism damping the

C.5 The Doppler Effect

The basics

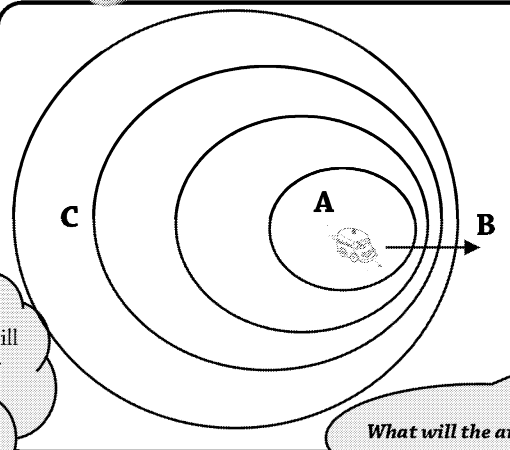
The phenomenon by which the **frequency** of waves is altered if there is **relative movement** between the **source** of a wave and any **observer** was first explained by **Christian Johann Doppler** in 1842 and takes his name.
The Doppler effect is observed when:
- the source of the waves moves closer to or away from the observer,
- the observer moves closer to or away from the source,
- or when they are both moving.
It applies to all types of **travelling wave**, though we usually give two examples: sound waves and light.

Distance between source and observer **diminishing**: Frequency of the travelling wave appears to **increase** to the observer.

THE WAVE IS COMPR...

Distance between sour... observer i...reas...: Freq... the ... wave ... **decrease** to the ob...

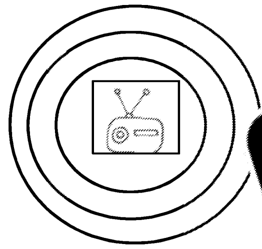
THE WAVE IS STRETCHED



- An ambulance A is heading in the direction of the arrow, sirens blaring.
- An observer at B will see the ambulance coming towards them and hear a high frequency / high pitch sound.
- When the ambulance has passed and the observer is at position C relative to the ambulance, they will hear a lower frequ... lower pi... sou...d.

What will the ambulance driver hear?

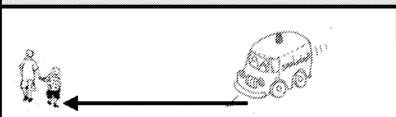
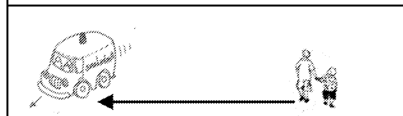
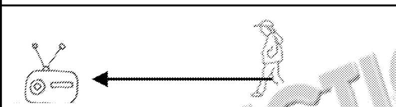
Any calculations will only involve either the **source** or the **observer** moving, not both.



Similar changes in fre... ...the **observer is m**... ...the source. ...g t... ...ce, more wavelengths ...our... ...any given time, so the ...t frequency is increased. ...ely, when the observer moves away, the ...parent frequency decreases.

Equations you need to know

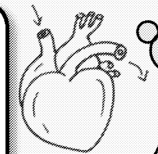
HL Only

Situation	Equation	Notes	Towards or away?	Plus or minus?
The source is moving, and the observer is stationary.	$f' = f\left(\frac{v}{v \pm u_s}\right)$	f' – observed frequency f – actual frequency v – velocity of the waves u_s – velocity of the moving force		f^1 will increase So $(v \pm u_s)$ needs to be smaller – use minus
				f^1 will decrease So $(v \pm u_s)$ needs ... ...ger ...s
The observer is moving, and the source is stationary.	$f' = f\left(\frac{v \pm u_o}{v}\right)$	f', f and v as above u_o – velocity of moving observer		f^1 ...rease So ...$_o$) needs to be bigger – use plus
				f^1 will decrease So $(v \pm u_o)$ needs to be smaller – use minus

Regarding **electromagnetic waves**, as opposed ... mechanical waves: $\frac{\Delta f}{f} = \frac{\Delta\lambda}{\lambda} \approx \frac{v}{c}$ where v is the speed of separation of source and observer and $v << c$ (c being the speed of light). It doesn't matter which is moving; source, observer or both.

...ou...d (around 20 000 Hz) is used for **medic**... Mo... ...rgans in the body stay still, but blood moves ...ometimes it is important to know the velocity of ... within the vessels and heart.
- Too fast: can indicate congenital heart defects ... damage to the heart valves
- Too slow: can indicate blocked arteries

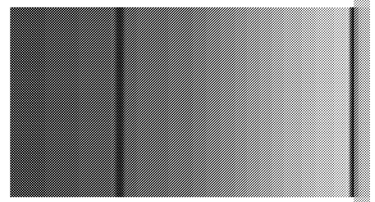
The **incident frequency** of the ultrasound is know... Measuring the **observed frequency** can indicate ... and **direction** of blood flow.



Normal flow is proportional to th... cross-sectional area of the bloo... vessels, so blood flows faster in th... arteries than the capillaries. Normal blood flow through the he... is around 32–35 cm/s and it differ... men and women.

Emission spectra

- Atoms in a light source emit different wav...
- Characteristic emission spectra for any ele...
- The intensity and composition of the spect...
- Emission spectra can allow scientists to de...



The Doppler shift

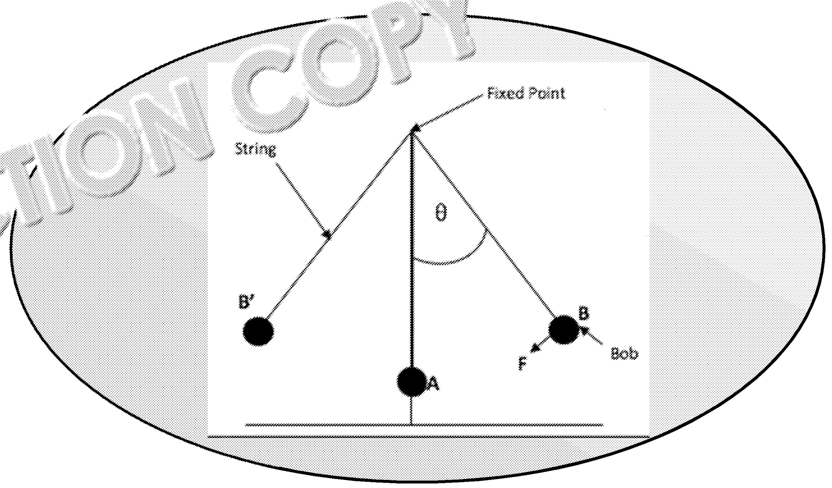
The stars of Alpha Centauri triple star system are moving towards Earth and so their emission spectra are slightly shifted towards the blue end of the spectrum.

Did you know? The universe... stars are getting closer because o... their gravitational attraction over... local stars and the Andromeda G...

C.1 Simple Harmonic Motion

Simple harmonic motion (SHM) basics

1. Name the five conditions that describe simple harmonic motion:
   1.
   2.
   3.
   4.
   5.



Considering the diagram of ***a simple pendulum***, above:

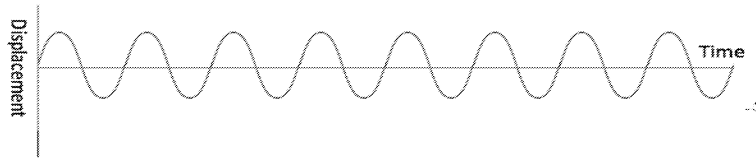
4. a) Which point represents the equilibrium point?

   b) Give the two points where the velocity of the bob is zero.

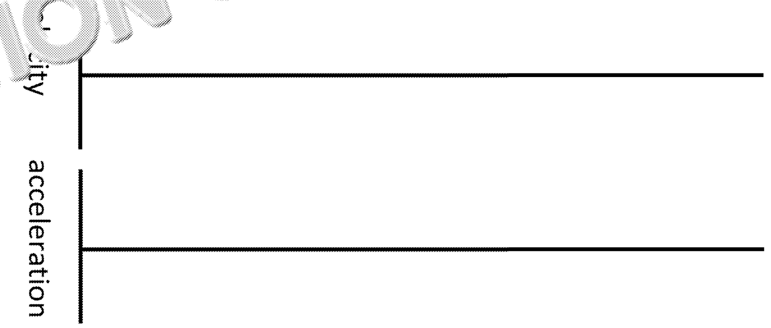
   ___________ and ___________

   c) At what p... velocity be maximum and acceleration zero?

   ...θ = ...C and the mass of the bob is 20 g, calculate the restoring force. Give your answer to 3 sig. fig. and give units.



6. The diagram above shows a graph of displacement against time for an SHM that starts at the equilibrium point. Mark on the diagram: a) the amplitude, b) one wavelength (λ), and c) mark 2π at the point that represents the first complete cycle.
7. On the axes below, draw ... sine or cosine curves, in their correct phase ... velocity against time and b) the acceleration against ... for the same oscillator.



The period (T) of different SHM systems

2. A mass-spring system oscillates ... harmonic motion. The mass = 1 kg and the spring constant is 1.2 N/m. Calculate the period of oscillation. Give your answer to 2 d.p. and give units.

3. A pendulum bob swings on an 80 cm string. Taking g to be 9.8 m/s^2 calculate its period. Give your answer to 2 d.p. and give units.

C.2 The Wave Model

Wave basics

1. Cross out the wrong word or words in the following statements, e.g. *perpendicular/~~transverse~~*

   Travelling/Standing waves are characterised by a continuous disturbance or oscillation in a medium that results in energy *store/transfer.* The medium *is / is not* transferred. The direction of the wave is given by *the up and down movement of the medium / the direction of energy transfer*.
   In transverse waves, the direction of th[illegible] oscilla[illegible] *perpendicular/parallel* to the direc[illegible] energy [illegible], whereas in *longitudinal/sound wa*[illegible] opposite.

   Mechanical/Physical waves need a [illegible] to propagate the wave. *All electromagnetic waves / Only light* can transfer energy through a vacuum.

   The points of maximum displacement in transverse waves are called *peaks and troughs / peaks* and the corresponding points in a longitudinal wave, like a sound wave where the particles are vibrating, are known as compressions and *rarefaction/refractions.*

   Some/All types obey the wave equation $v = f\lambda = \lambda/T$ where v is wave speed measured in m/s, f is frequency measured in *Hertz/Heinz*, λ (lambda) represents *distance/wavelength* (m), and T is the *duration/period* measured in *time/seconds*.

2. Complete the chart by placing [illegible] (✓) or a cross (✗) in each cell.

[illegible]	Longitudinal waves	Transverse waves
[illegible] oscillation is [illegible]rpendicular to the transmission of energy		
The oscillation is parallel to the transmission of energy		
No waves of this type can transmit in a vacuum		
Changes the density and pressure within the transmitting medium		
The speed depends on the medium it travels through		
The energy moves, but the medium of transmission doesn't		
Can reflect off some surfaces		

3. Here's a quick quiz to test your waves basics.

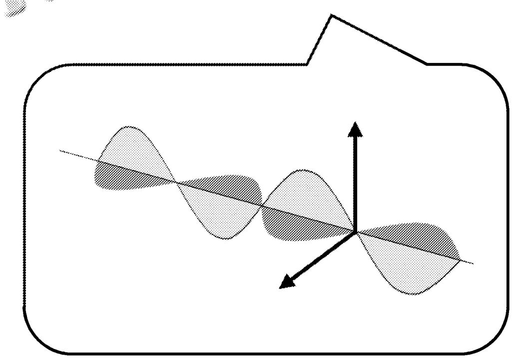
   a) This is a longitudinal wave; it has a speed of approxim[illegible] 34[illegible] m/[illegible], and dogs can hear it at frequencies between 67 and 45 000 Hz: ____________________
   b) These waves can be caused by the m[illegible] Earth's structure, perhaps movement along a fault between tectonic plat[illegible] ____________________
   c) These waves can t[illegible] in a vacuum and have very high frequencies and short wavelengths. They are used to make ima[illegible] ken [illegible]: ____________________
   d) The[illegible]es of the EMS that can be used for cooking and communication: ________________
   e) These waves are caused by the relative motion of Earth and its moon: ______________________
   f) These huge mechanical waves can cause disasters. They occur when there are earthquakes under the sea: _______________
   g) These longitudinal waves are used for medical imaging: ___________________
   h) These waves can result from radioactive decay of some nuclei: __________________
   i) This spectrum of waves can propagate through a vacuum: ________________
   j) These waves of the EMS have very long wavelengths and [illegible] tim[illegible] [illegible]smit the news: ___________

Electromagnetic spectrum

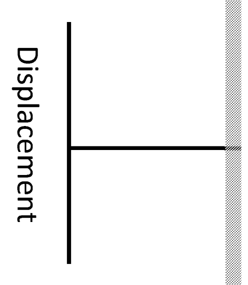
4. The diagram in the speech bubble (ri[illegible]) atte[illegible] ate the propagation of electromagnetic waves using the[illegible] of e[illegible] [illegible]agnetic fields.

   a) Can these electromagnetic f[illegible] n a vacuum?

   b) What is the name of the particle postulated to oscillate in these fields?



5. An oscilloscope i[illegible] The oscilloscope[illegible]
   a) Draw scales[illegible] of the wave[illegible]



   b) The speed of the[illegible] be 5 m/s. On the[illegible] right, draw this w[illegible] mark one wavele[illegible]

6. The rubber duck[illegible] pass from right t[illegible]
   a) Draw a dou[illegible]
   b) If you were[illegible] on the surfa[illegible]

7. Circle the c[illegible]
   What happ[illegible]
   The waves [illegible]
   The waves [illegible]
   The waves [illegible]

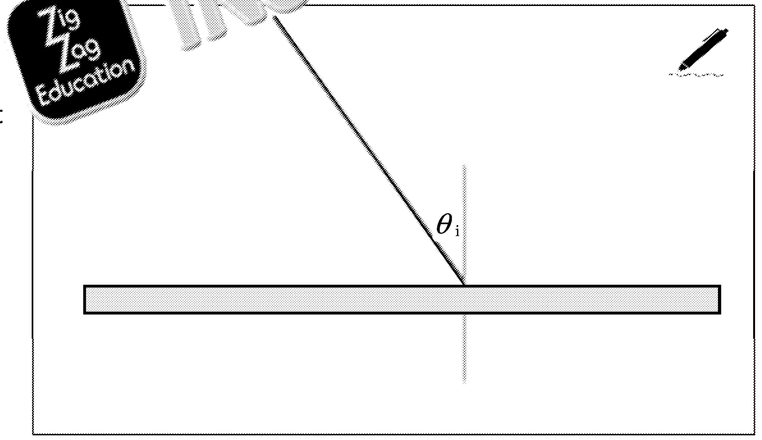
C.3 Wave Phenomen

What happens to waves when they meet boundaries, obstacles or other waves?

1. Cross out the incorrect word or words in the following statements, e.g. *reflected/~~refracted~~*
   a) When waves meet *edges/boundaries* between different media they can be reflected, transmitted or *consumed/absorbed* (sometimes more than one).
   b) Waves meeting an object within the medium of transmission may ... *ea... ...cted* around the object.
   c) Waves passing through the same medium or field c... Th... combined effect is the *product/sum* of their individual oscillatior...

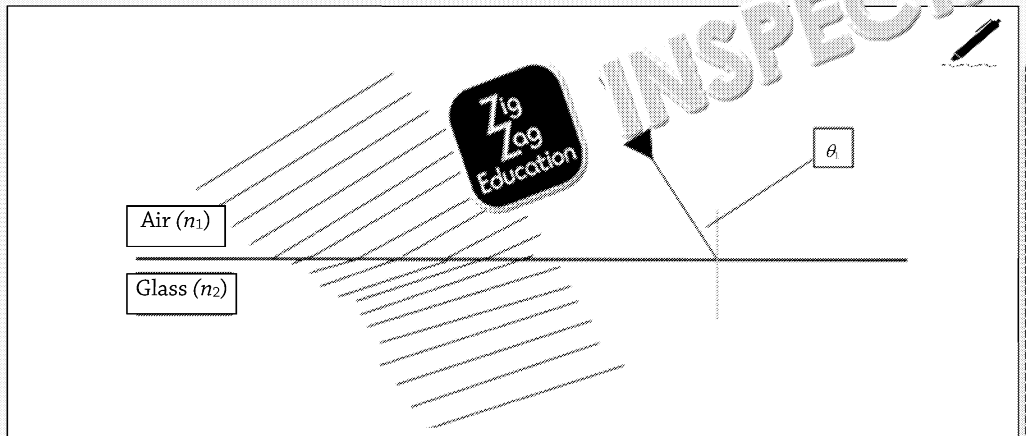
Reflection

2. The diagram shows a ray of light incident on a plain mirror.
   a) Show the reflected ray
   b) Give the angle of reflection θ_r in terms of the angle of incidence θ_i



Refraction

3. The diagram shows both wave fronts and a ray of light incident or transparent glass bock.
   a) Show the refracted ray
   b) Give the angle of refraction θ_2 in terr... ...f incidence θ_1



4. a) Give Snell's law.

   b) Complete the wave equation $V=$ __________
   c) Wave fronts of blue light pass from air to the glas...
   What will happen to:
   i) their speed?

   ii) their frequency?

   iii) their wavelength?

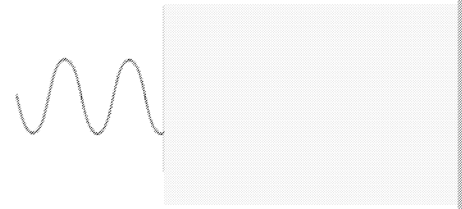
d) The refractive index of air (n_{air}) is 1.00 and the refractive index of glass (n_{glass}) is 1.7. If the angle of incidence θ_1 is 25°, what is the angle of refraction?
Give your answer to the nearest degree.

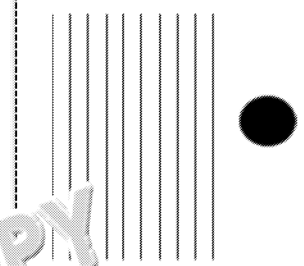
HL Only

Other wave phenomena

The diagram below represents a gamma ray i... lead block. Lead will absorb the energy of gar...

6. Draw a continuation of the sine wave to...





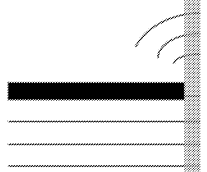
7. The diagram above shows wave fronts ... solid obstacle; maybe a wave in the sea... sign or similar structure. Complete the ... how the waves might behave around th...

Total internal reflection

5. Match the words/phrases in the table (right) to the correct numbered space in the paragraph below:

When light transmits from a (1) medium to a (2) medium, under certain circumstances the light can (3) internally and be 'trapped' within the material. As the angle of incidence increases, the (4) moves closer to th... ...undary. At the (5) angle, the ra... ...cte... along the boundary. At gre... ...gle ...ht is (6). (7) c...mm...nic... ...depend on this phenomenon.

refract
refl
crit
less c
totally intern
der
Fibre



C.4 Standing Waves and Reson

Standing waves

1. Cross out the incorrect word or words in the following statements, e.g. ~~wave~~/interfer nce

   a) Standing waves are a special type of *wave/interference*.
   b) The oscillations of waves and pulses occupying the same spa … can *multiply/add* to give constructive or destructive interference.
   c) This is called *superposition/isoprovision*.
   d) A standing wave pattern is th… of … the same frequency and wavelength travelling in the *opposite/s*… ion … e same medium.
   e) The phase difference betwe… waves creating a standing wave must be *positive/zero*.
   f) Nodes are areas where the *d…tive/constructive* interference between the two waves is total.
   g) Antinodes are areas where the *destructive/constructive* interference between the two waves is maximal.
   h) The distance between any two successive *nodes / nodes or antinodes* will be $\lambda/2$ or half a wavelength.

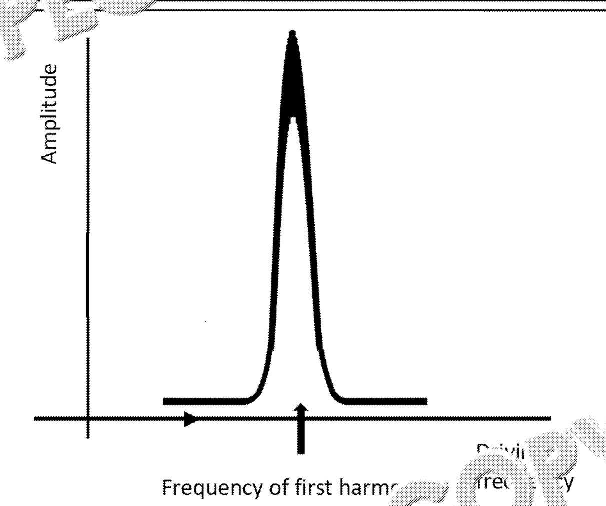
2. In the space (right) draw a representation of a standing wave, labelling some nodes and antinodes.

Resonance

The diagram (right) shows the resonance response of a harmonic oscillator when the frequency of the driving force is increased both up to a… ond … natural frequency.

3. Explain what is happening to th… as the driving frequency increases:

Gra… sh… amplitude of …onc… against driving force



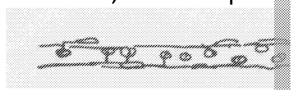
4. Give one example of a resonance that is considered useful, and on… … wh… t is a problem. Identify the driving force in each case.

Musical instruments

Many musical instruments rely on standing … has a **natural frequency** that is determined …

5. a) On the two strings below, draw th…

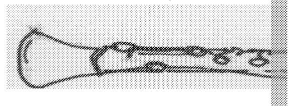
   b) On the 'tube' below, which represe…



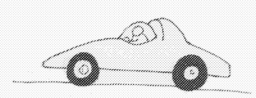
free

   c) i) On the 'tube' below, which re…

free



   ii) Why can a clarinet only give …



Damp…

7. The springs on a car help gi… what prevents the springs … of the bumps at their natur…

C.5 The Doppler Effect

The basics

1. Insert the correct word or phrase from the following list to complete these paragr...h
light, relative movement, **source, frequency, observer, sound waves**, **Dopp'...**

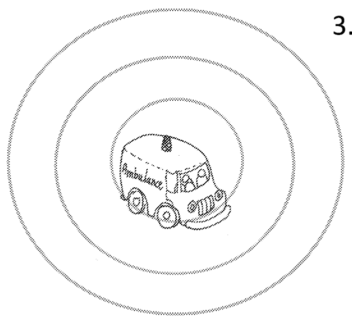
The phenomenon by which the __________________ of wav... is altere... ...here is a

_____________________ between the ____ ... wave and any

____________________ was fir... ...d b... ...ristian Johann __________________ in 1842 and takes his name. It appl... ...pes of travelling wave, though we often give two

examples: ____________________________ and _____________________.

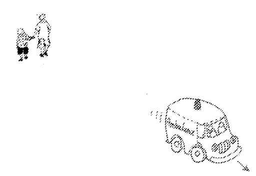
2. Tick the true statement below:
The Doppler effect is observed when:
- ☐ only the source of the waves moves relative to the observer
- ☐ only the observer moves closer to the source
- ☐ the source and the observer are moving relative to each other



3. The sound waves from an ambulance siren can be depicted by concentric rings representing wave fronts (see diagram, left).
Using a similar notation, show what happens to the sound waves as perceived by the two boys as the ambulance passes by, annotating the diagrams below.

a)

b)



Equations

4. Chose the correct form of the Doppler effect equat... ...ov... source and calculate the change in fr...uen... ...ve... ...) by the two boys when the ambulance approach... ...equ... ...the siren (f) is 900 Hz, and the boys are stationary. It's a v... ...y day so you can take the speed of sound (v) to be 346 m/s and the... ...the ambulance (u) is 60 mph (27 m/s). Give your answer to 2 d.p. and give units.

...ome modern speed 'cameras' use infrare... detect speeding cars. A signal is transmitt... to the car. It is reflected and received by t... both a transmitter and a receiver. The cha... the transmitted and returning signal allow... be calculated using $\Delta f = \frac{2fv}{c}$
where Δf = the change in frequency
f = the original source frequency
v = the car's speed
c = the speed of light (take as 3×10^8)

a) When the infrared signal is initially tr... the car, is the source or the observer...

b) When the signal is reflected back, is i... or the observer that is moving?

c) Use your answers to a) and b) to post... there is a 2 in the numerator of the e...

The Doppler shift

7. In the 1920s, it was discovered that the... Their frequencies had shifted towards t... led to the conclusion that the universe... moving away from us.

The ratio of an object's recessional velo... between the perceived change in frequ...

Light of wavelength 430.0 m has red shi...

a) Calculate the recessional velocity a...

b) The emission spectra ... spectrum as viewed fr...

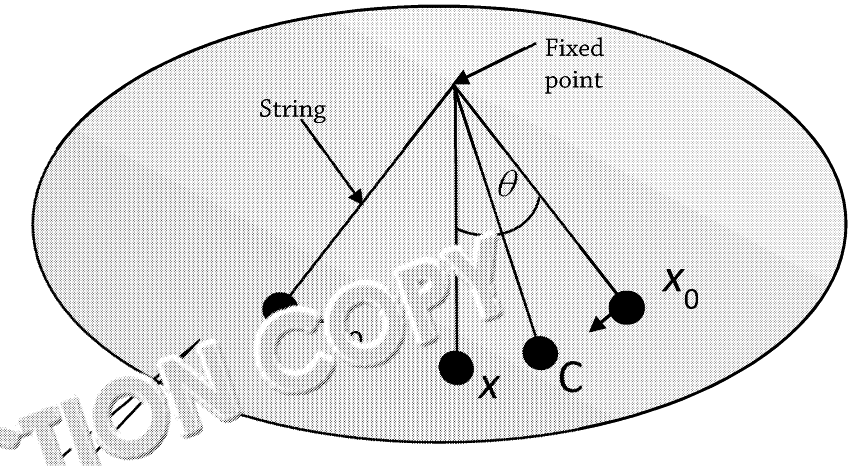
8. What did Edwin Hubbl... Hubble's law, and how...

C.1 Simple Harmonic Motion

Simple harmonic motion (SHM) basics

In simple harmonic mo[...] energy is transferred between

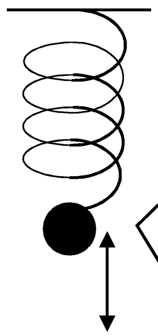
[...] frequency



A simple pendulum

The restoring force will be given by

The period (T) of different SHM systems



For a **mass-spring system**,

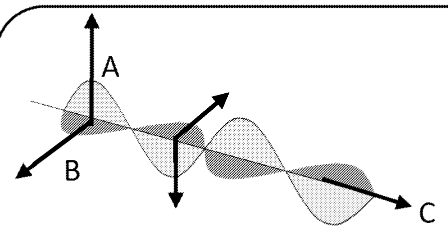
For a **pendulum**,

The period of a mass-spring system

Wave basics

Transverse waves

Electromagnetic spect



A.

B.

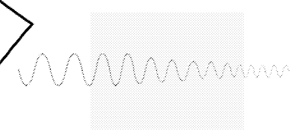
C.

C.3 Wave Phenomen

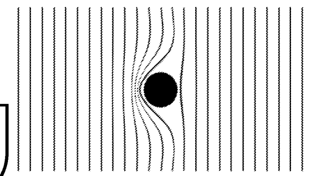
What happens to waves when they meet boundaries, obstacles or other waves?

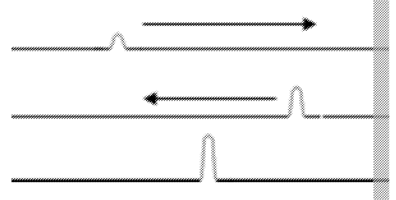
Other wave phenomena

4



5

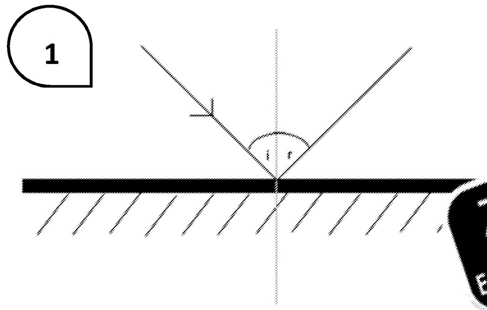


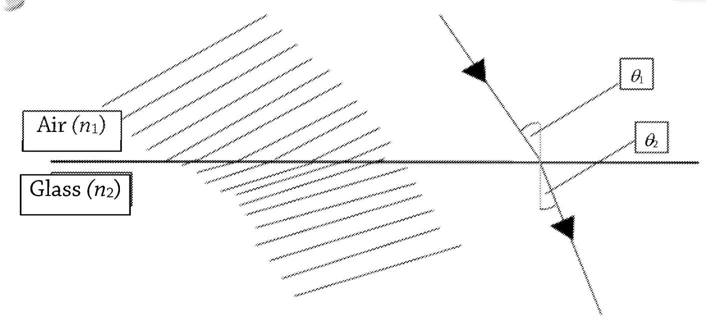


$v = f\lambda$

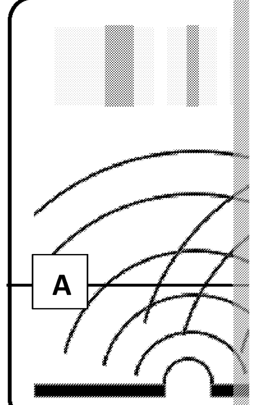
Reflection

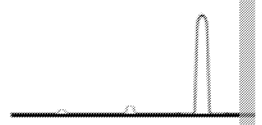
1





Refraction

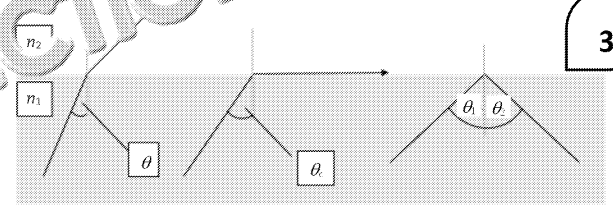




Single slit diffractio

2

3



Total internal reflection

C.4 Standing Waves and Reson

Standing waves

A **standing wave** could be described as

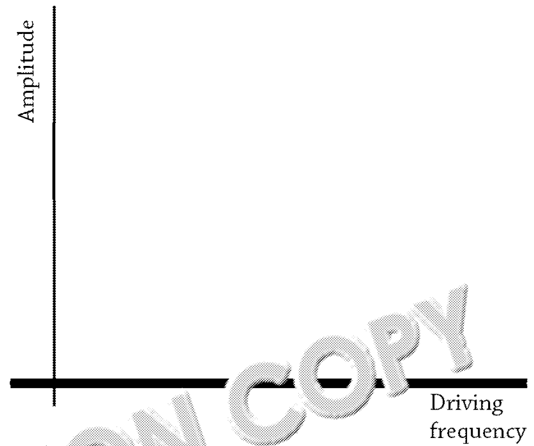
A **travelling wave**

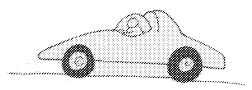
Musical instruments

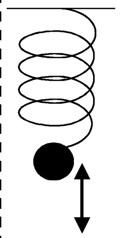
Resonance

Nodes –
Antinodes –

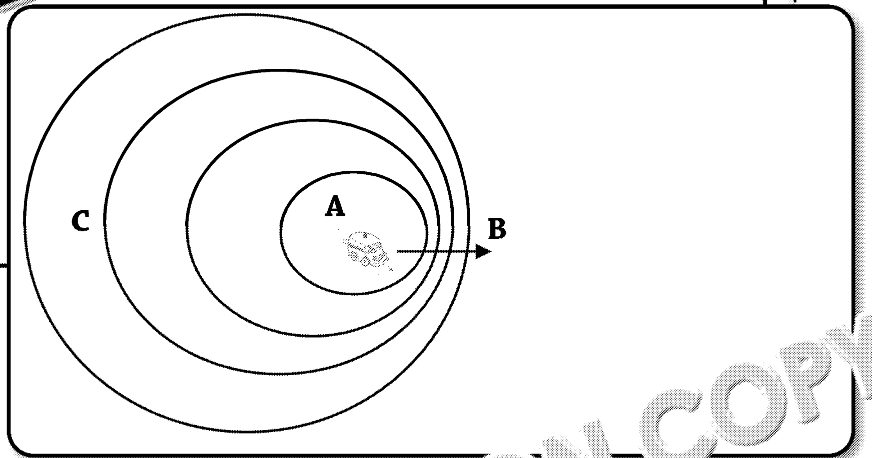
Graph to show amplitude of resonance against driving force







The basics



Equations you need to know

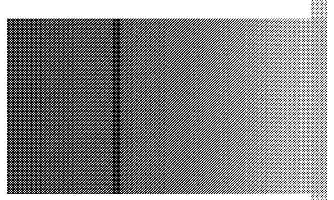
HL Only

Similar chan[illegible]uer[illegible]ear when

Situation	Equation	Notes	Towards or away?	Plus or minus?
The source is moving, and the observer is stationary.				
The observer is moving, and the source is stationary.				

Regarding **electromagnetic waves**, as [illegible] mechanical waves:

Emission spectra



The Doppler sh[illegible]

IB Topic on a Page, Theme B: Mar

C.1 Simple Harmonic Motion

1) In any order:
   1. The object oscillates around a central equilibrium point
   2. There is a 'restoring force' that acts towards the central equilibrium po
   3. The velocity, acceleration and displacement of the object are continuo
   4. The magnitude of the restoring force and the displacement are directly
   5. The oscillations have a constant time period (T)

2) Using equation $T = 2\pi\sqrt{\frac{m}{k}}$ and m = 1 kg, k = 1.2 N/m:

   $T = 2\pi\sqrt{\frac{1}{1.2}}$

   = 5.74 seconds (to 2 d.p.)

3) Using equation $T = 2\pi\sqrt{\frac{l}{g}}$ and l = 0.8m, g = 9.8 m/s^2:

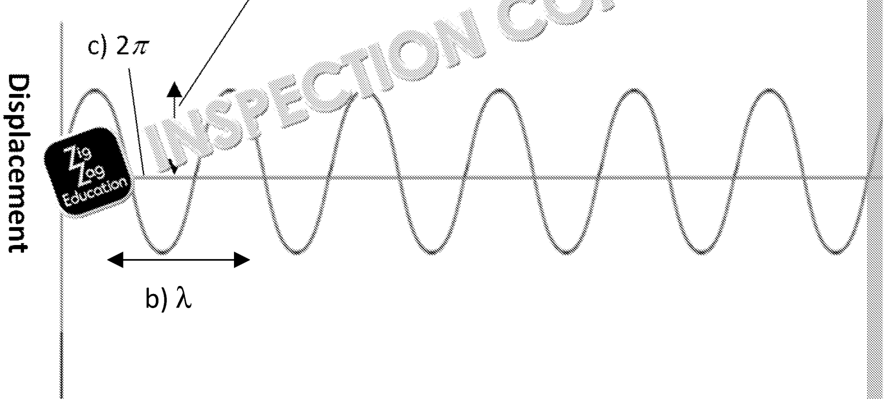
   $T = 2\pi\sqrt{\frac{0.8}{9.8}}$

   = 1.80 seconds (to 2 d.p.)

4) a) A
   b) B and B' (in either order)
   c) A

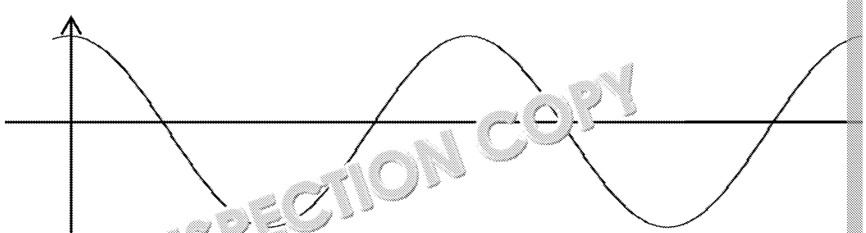
5) Using $F = mg\sin\theta$ and θ = 40°, m = 0.02 kg:
   $F = 0.02 \times 9.8 \times \sin\theta$
   = 0.126 N

6)

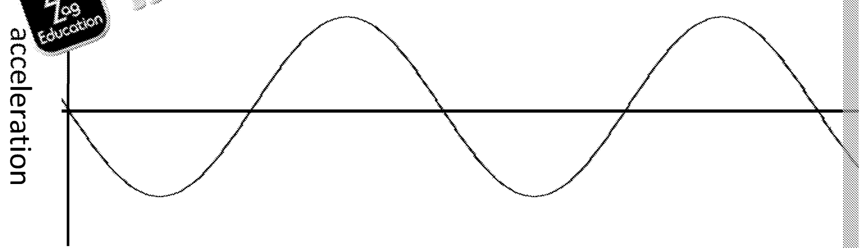


7) The shape of the curve, amplitude and wavelength need only be approxima important. For a), velocity must start at the maximum and fall to zero at π/2 curve must start at the maximum, but it is the negative of the displacemen

a)



b)



8) At point A, the ~~kinetic~~/***potential*** energy is zero.
The gravitational potential energy at B and B' is ~~*equal and opposite*~~ / ***equiva***

9) a) mass = 0.02 kg, x_o = 0.015 m, T = 0.8 s
Use equation $\omega = 2\pi/T$, and substitute into $v_{max} = \omega x_o$ to give $v_{max} = \frac{2\pi}{T} x_o$

$$v_{max} = \frac{2\pi}{0.8} 0.015$$

= 1.178 m/s

b) $E_k = \frac{1}{2} m v_{max}^2$

m = 0.02 kg
v_{max} = 1.178 m/s
= ½ × 0.02 × $(1.178)^2$
E_k = 0.000014 J = 0.14 mJ (to 2 sig. fig.)

10) **(Additional HL)**
m = 2 kg
Use equation $\omega = 2\pi/T = 2\pi/1.25$ rad/sec
x_o = 0.3 m
$E_T = \frac{1}{2} m\omega^2 x_o^2$
E_T = 2.27 J (to 3 sig. fig.)

C.2 The Wave Model

1) ***Travelling***/~~*Standing*~~ waves are characterised by a continuous disturbance or results in energy ~~*store*~~/***transfer***. The medium ~~*is*~~ / ***is not*** transferred. The direc ~~*up and down movement of the medium*~~ / ***the direction of energy transfer.*** In of the oscillation is ***perpendicular***/~~*parallel*~~ to the direction of energy transfer ~~*waves*~~ it is the opposite.

Mechanical/~~*Physical*~~ waves need a medium to propagate the wave. *All electr* can transfer energy through a vacuum.

The positions of maximum displacement in transverse waves are called ***peaks a*** corresponding points in a longitudinal wave, like a sound wave where the pa as compressions and ***rarefaction***/~~*refractions*~~.

~~*Some*~~/***All*** types obey the wave equation ***v = fλ = λ/T*** where *v* is wave speed m measured in ***Hertz***/~~*Heinz*~~, λ (lambda) represents ~~*distance*~~/***wavelength*** (m), a measured in ~~*time*~~/***seconds***.

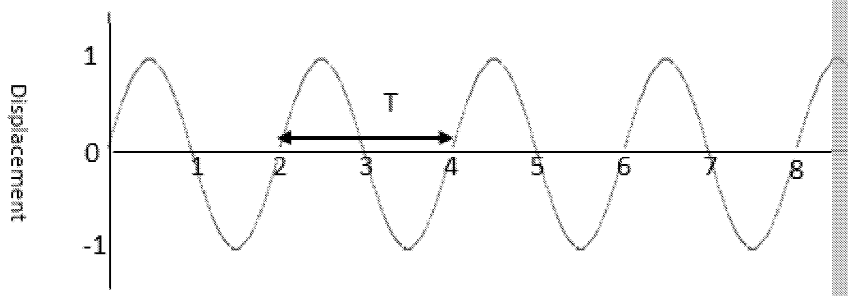
2)

Property	Longitu
The oscillation is perpendicular to the transmission of energy	
The oscillation is parallel to the transmission of energy	
No waves of this type can transmit in a vacuum	
Changes the density and pressure within the transmitting medium	
The speed depends on the medium it travels through	
The energy moves, but the medium of transmission doesn't	
Can reflect off some surfaces	

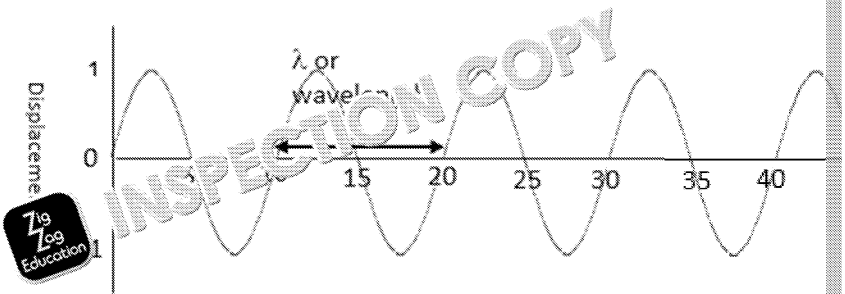
3) a) Sound wave
   b) Seismic waves – accept s and p waves
   c) X-rays
   d) Microwaves
   e) Waves in the sea, tides (not tidal waves)
   f) Tsunamis or tidal waves
   g) Ultrasound
   h) Gamma rays
   i) EMS (electromagnetic spectrur
   j) Radio waves

4) a) Yes
   b) Th to

5) a) *T* onds

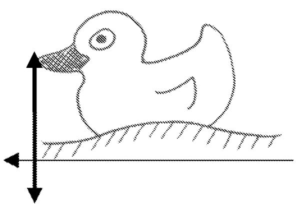


   b)



   c) f = 50 Hz and $\pi/2$ radians ≡ $\lambda/4$
      λ = 4 × 0.002 metres = 0.008 m
      $v = f\lambda$ so 50 × 0.008 m/s
      = 0.4 m/s

6) a)



   NB The scale doesn't matter but th rr w uld demonstrate underst equally up and down from in turbed water surface (its equilibriu the direction of th
   b) A rea duc ob up and down as the wave passes, but as it can pa p s rizontal motion.

7) The fol are correct:
- The crest of the wave accelerates.
- The waves become elliptical.
- The waves refract to become parallel to the shore.

(The waves speed up. ×)

C.3 Wave Phenomena

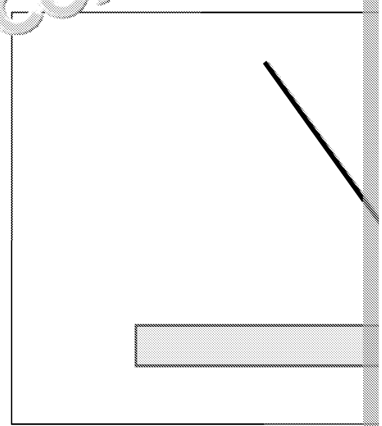
1) a) When waves meet ~~edges~~/***boundaries*** between different media they ca
~~consumed~~/***absorbed*** (sometimes more than one).

b) Waves meeting an object within the medium of transmission may be ~~cu~~
the object.

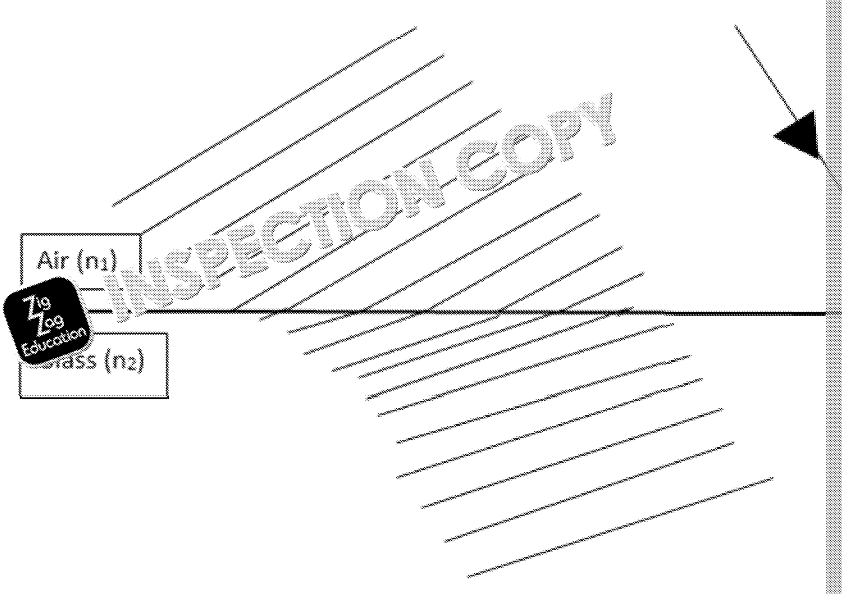
c) Waves passing through the same medium or field can interact. Their co
~~product~~/***sum*** of their individual oscillations.

2) a) Line with arrow so that θ_i approximately equals θ_r

b) $\theta_i = \theta_r$



3) a) Line with arrow so that θ_2 is less than θ_1 and the arrow is roughly perpe



b) $\theta_2 < \theta_1$

4) a) $n_1/n_2 = \sin\theta_2/\sin\theta_1 = v_2/v_1$

b) $(v =) f\lambda$

c) i) The speed will decrease

ii) The frequency will remain the sam

iii) The wavelength will decre[illegible]

d) **(Additional HL)** n_1/n[illegible] θ_1

$\theta_2 = \sin^{-1}$ (sin [illegible]

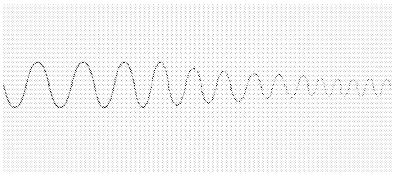
= [illegible] in [illegible] 1/1.7)

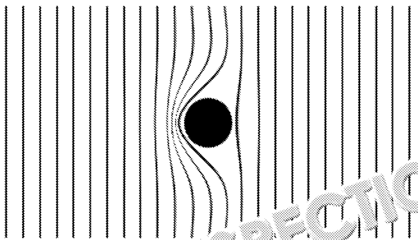
=1[illegible] o 2 d.p.)

= 14° to the nearest degree

5) When light transmits from a **denser** medium to a **less dense** medium, under can **reflect** internally and be 'trapped' within the material. As the angle of inc **ray** moves closer to the boundary. At the **critical** angle, the ray is refracted al angles, light is **totally internally reflected**. **Fibre optic** communications deper

	Number
refracted ray	4
reflect	3
critical	[illegible]
less dense	2
totally internally reflected	6
denser	1
Fibre optic	7

6) 

7) 

8) a) Superposition
   b) Constructive
   c) Coherent
   d) Complex waves

9) The arced wave fronts beyond the slits can ***interfere***. The ***amplitude*** of the di the sum of the waves passing through the ***medium*** at that point and will rang ***zero*** disturbance.

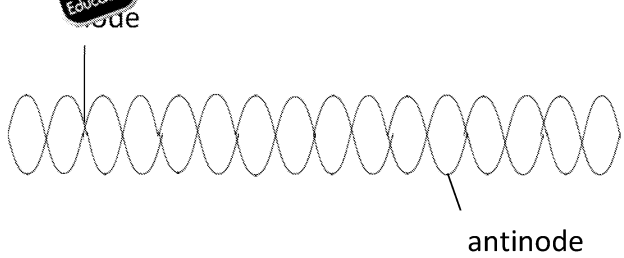
10) *D* represents the distance from the slits to the screen and *d* represents the separation of the slits

11) a) Waves incident on a narrow slit spread out to form a fan shape. This is c when the width of the slit and the wavelength are similar and is due to p propagating wave and the edge of the slit. The wave is briefly slowed an edge. The closer to the edge the wave passes, the more it is bent or diffr through the slit are unaffected.
    b) Diffraction

C.4 Standing Waves and Resonance

1) a) Standing waves are a special type of ***wave***/~~*interference*~~.
   b) The oscillations of waves and pulses occupying the same space in a med
   constructive or destructive interference.
   c) This is called ***superposition***/~~*isoprovision*~~.
   d) A standing wave pattern is the result of two waves of the same frequen
   the ***opposite***/~~*same*~~ direction in the same me...
   e) The phase difference between the two waves creating a standing wave
   f) Nodes are areas where the ...ructive/~~*constructive*~~ interference betwe
   g) Antinodes are areas where the ~~*destructive*~~/***constructive*** interference be
   maximal.
   h) The distance between any two successive ~~*nodes*~~ /***nodes or antinodes*** w

2)



3) (This background **may** be given – A harmonic oscillator has a natural frequency
A driving frequency refers to the frequency of an oscillating force that is in cont

This information is **required** – The graph shows that as the driving force incre
frequency of the harmonic oscillator, the amplitude of the resonance increas
natural frequency the resonance peaks and then dies away as the frequency

4) Useful harmonic resonance:
- Many musical instruments, especially wind or stringed – driving force in
  friction of the bow against the string, and with wind instruments the dri
  caused by blowing something vibrating a reed.
- Microwaves ... have similar frequencies to the natural frequencies o
  food ... driven by the microwave radiation passing through the food.

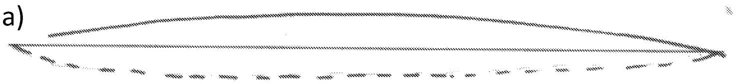
Allow any correct answers.

Unwanted resonances:
- Unwanted buzzes in acoustic equipment – driving forces come from oth
- When a car rattles, the driving force comes from oscillations from bump
- Vibration through the steering wheel at certain speeds can be caused b
  and causing a driving oscillation.

Allow any correct answers.

5)

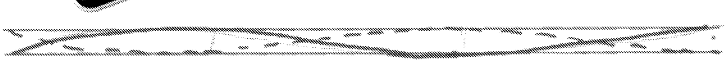
a)



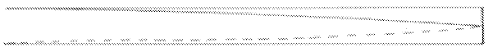
First harmo

Second har

b)



c) i)



ii) The clarinet has different boundary conditions at each end. Nodes f antinodes form at open boundaries. This means that standing wave of wavelengths cannot exist, meaning that such instruments only re 1, 3, 5, etc.

6) a) The fifth harmonic will give two and a half wavelengths; $\lambda_5 = 2/5 \times L$
Flute length = L = 0.66 m, one wavelength is 0.264 m = 26 cm

b) First harmonic: $\lambda_1 = 2/1 \times L$, so λ_1 = 1.32 m
$v = f\lambda$, which rearranges to $f = v/\lambda$
f = [illegible] Hz

7) The springs in cars help smooth the ride and stop every bump in the road bei natural frequency. On their own they would amplify the bumps close to their absorbers prevent this by dampening the resonance of the spring.

8) Light damping widens the range of frequency response and lessens the peak frequency response, but heavy damping causes a much less amplified respon frequencies. Critical damping approximates to a level of damping between th calm the oscillation so that the amplitude, range of response and time taken

Light damping	Wider range of driving frequencies responded to
Heavy damping	Much wider range of driving frequencies responded to

C.5 The Doppler Effect

1) The phenomenon by which the **frequency** of waves is altered if there is a **relati** **source** of a wave and any **observer** was first explained by Christian Johann **Do**

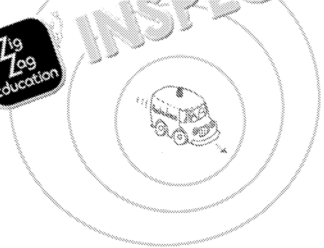
It applies to all types of travelling waves, though we often give two examples: and **sound waves** is also acceptable)

2) The source and the observer are moving relative to each other.

3) a)

The drawing needs to show that there will be compression of the wave fro

b)



The drawing needs to show the stretching of the wave fronts as the ambu

4) **(Additional HL)**

Using $f^1 = f\left(\frac{v}{v - u}\right)$, f = 900 Hz, v = 346 m/s and u = 27 m/s

f^1 = 900 × (346/319)

= 976.18 Hz

5) a) The observer is moving

b) The source is moving

c) The effect of the reflection is that the car is ... an observer and a sou

in frequency perceived. The additi... of ... in the equation corrects th

d) $\Delta f = \frac{2fv}{c}$ so rearranging gives ... $\frac{fc}{2f}$

Δf ... $c = 3 \times 10^8$, $f = 400 \times 10^9$

So ... m/s, therefore the car is exceeding the speed limit

6)

Example	What waves	Mechanism
Blood flow in medical investigations	Ultrasound	The incident frequency is know the speed and direction of the blood cells can be calculated b the reflected frequency
Weather forecasting	Radar	Radar pulses reflecting off clou systems are analysed for change in speed, phase or Doppler shift the remaining pulse. Distance, motion and constituti can be determined.

7) a) $v = \frac{\Delta\lambda c}{\lambda}$, and λ = 430 m, $\Delta\lambda$ = 432 m

$$v = \frac{(432 - 430) \times 3 \times 10^8}{430}$$

= ... km/s

b) Th... erse appears to be expanding and most parts are moving away

But as we are not observing from the centre of expansion, some objects

8) Hubble's law states that the recessional velocities of galaxies are proportion

$v/c \approx \frac{\Delta f}{f} = \frac{\Delta\lambda}{\lambda}$ would confirm that the furthest away, and hence fastest-mov

greater Doppler shift.