A Level Physics Edexcel

13. Oscillations

CONTENTS

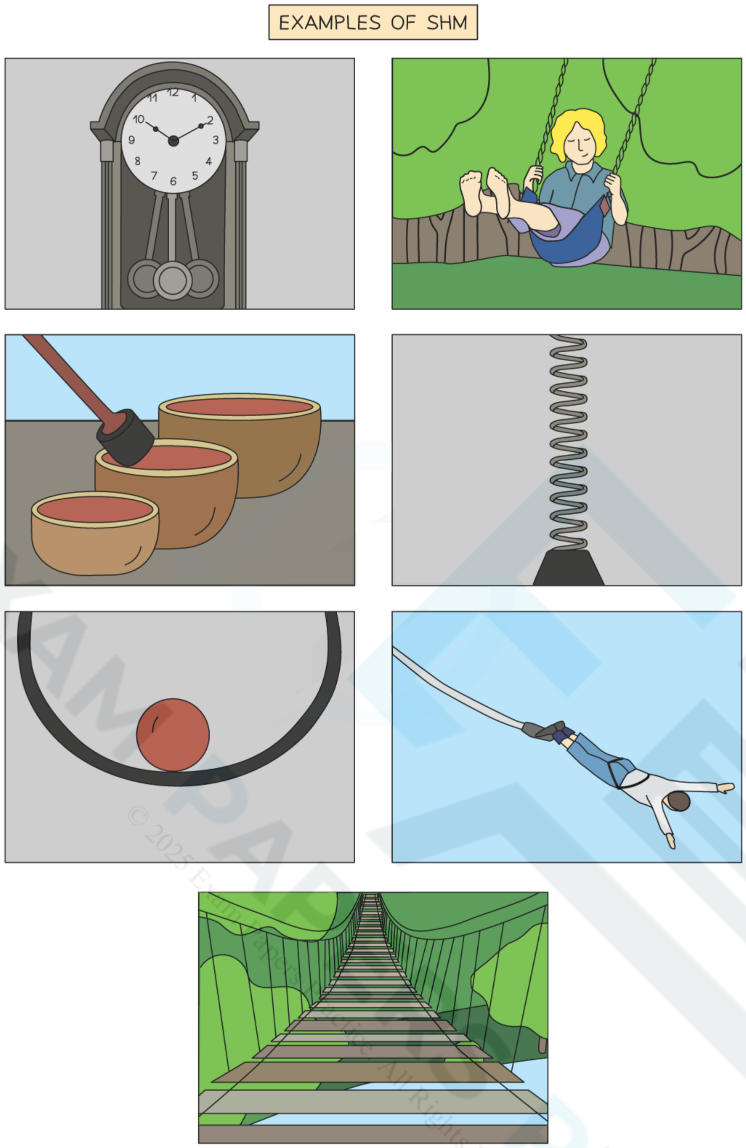
Simple Harmonic Motion

13.1 Conditions for Simple Harmonic Motion

Conditions for Simple Harmonic Motion

- **Simple harmonic motion (SHM)** is a specific type of oscillation
- An oscillation is said to be SHM when:
  - **The acceleration is proportional to the displacement**
  - **The acceleration is in the opposite direction to the displacement**

- Examples of oscillators that undergo SHM are:
  - The pendulum of a clock
  - A mass on a spring
  - Guitar strings
  - The electrons in alternating current flowing through a wire



- **Time period, *T*:**
  - The objects swings are periodic, meaning they are repeated in regular intervals according to their frequency or time period
  - If an object swings freely it always takes the same time to complete one swing

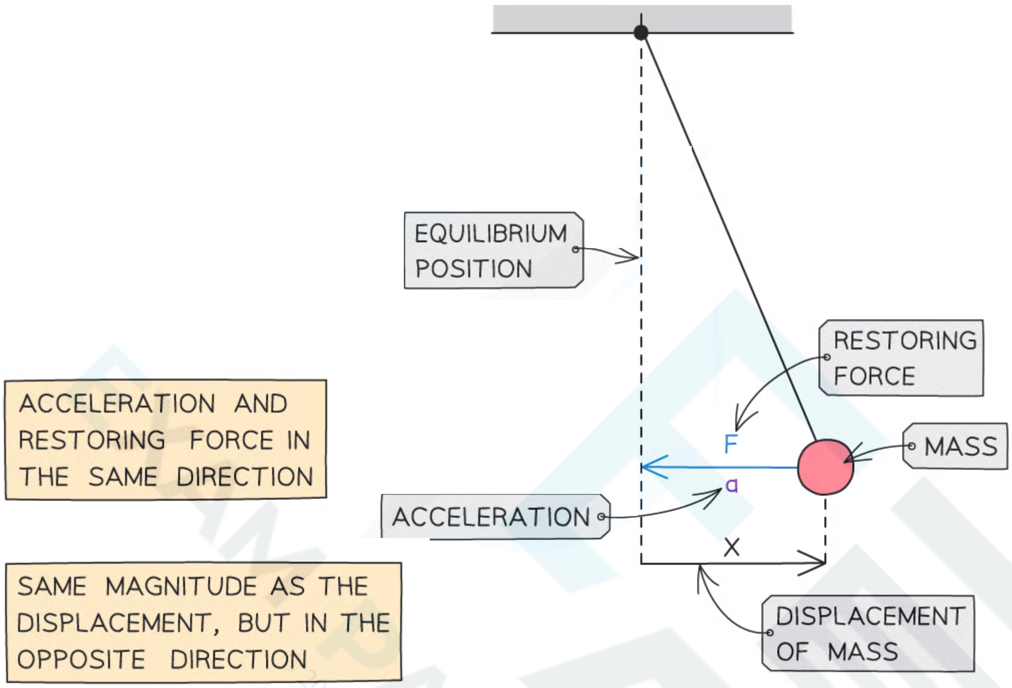
Restoring force

- When an object is moving in SHM a force, called the restoring force, F, is always trying to return the object back to its equilibrium position.
- The force is proportional to the displacement, x, from that equilibrium position

$$F = -kx$$

- Where:
  - F is the restoring force

- x is the displacement of the object from the equilibrium position
- k is a constant depending on the system
- the negative sign shows that the acceleration will always be towards the centre of oscillation



Force, acceleration and displacement of a pendulum in SHM

- This is why a person jumping on a trampoline is not an example of simple harmonic motion:
  - The restoring force on the person is **not** proportional to their distance from the equilibrium position
  - When the person is not in contact with the trampoline, the restoring force is equal to their weight, which is constant
  - This does not change, even if they jump higher

Worked Example

A 200g toy robot is attached to a pole by a spring, with a spring constant of 90 N m^{-1}, and made to oscillate horizontally.

(a) What force will act on the robot when it is at its amplitude position of 5 cm from equilibrium?

(b) How fast will the robot accelerate whilst at this amplitude position?

Part (a)

Step 1: Convert amplitude into m

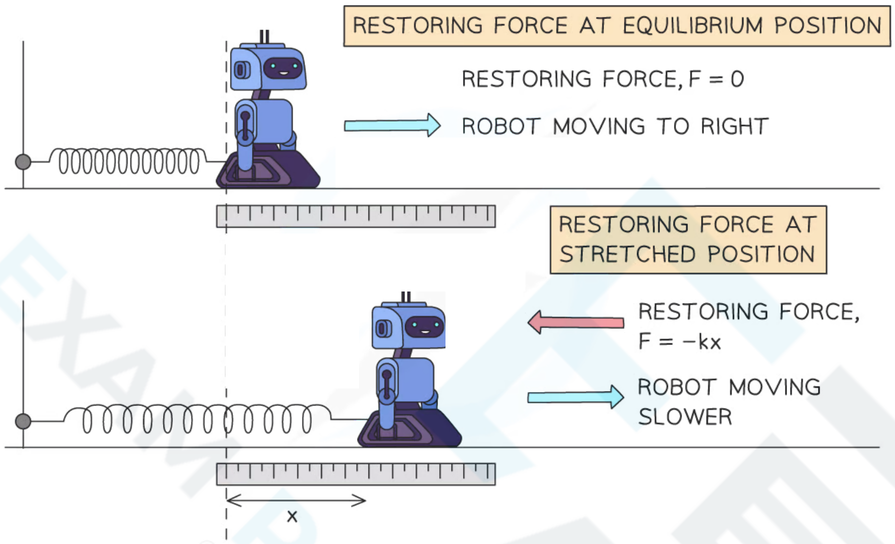
$$5 \text{ cm} = 0.05 \text{ m}$$

Step 2: Substitute values into the restoring force equation

$$F = -kx = -(90) \times (0.05) = -4.5 \text{ N}$$

Step 3: Explain the answer

A force of 4.5 newtons will act on the robot, trying to pull it back towards the equilibrium position.



Part (b)

Step 1: Convert mass of robot into kg

$$200 \text{ g} = 0.2 \text{ kg}$$

Step 2: Substitute values into Newton's second law equation:

$$F = ma$$

$$\text{So, } a = \frac{F}{m} = \frac{-4.5}{0.2} = -22.5 \text{ m s}^{-2}$$

Step 3: Explain the answer

The train will decelerate at a rate of 22.5 m s^{-2} when at this amplitude position

Exam Tip

Even with this topic you must make sure you convert all quantities into standard SI units

Equations for Simple Harmonic Motion

Acceleration and SHM

- Acceleration *a* and displacement *x* can be represented by the defining equation of SHM:

$$a \propto -x$$

- The acceleration of an object oscillating in simple harmonic motion is:

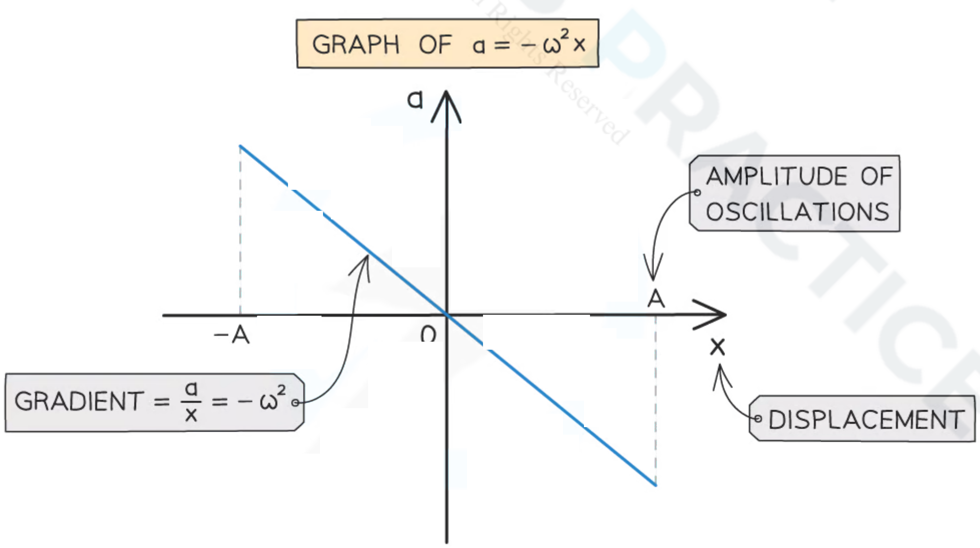
$$a = -\omega^2 x$$

- Where:
  - a = acceleration (m s^{-2})
  - ω = angular frequency (rad s^{-1})
  - x = displacement (m)

- This is used to find the acceleration of an object with a particular angular frequency ω at a specific displacement *x*
- The equation demonstrates:
  - The acceleration reaches its **maximum** value when the displacement is at a **maximum** i.e.. x = A (amplitude)
  - The **minus** sign shows that when the object is displaced to the **right**, the direction of the acceleration is to the **left** and vice versa (*a* and *x* are always in opposite directions to each other)

Displacement and SHM

- The graph of acceleration against displacement is a straight line through the origin sloping downwards (similar to y = –x)



The acceleration of an object in SHM is directly proportional to the negative displacement

- The key features of the graph are:
  - The gradient is equal to $-\omega^2$
  - The maximum and minimum displacement x values are the amplitudes $-A$ and $+A$
- A solution to the SHM acceleration equation is the displacement equation:

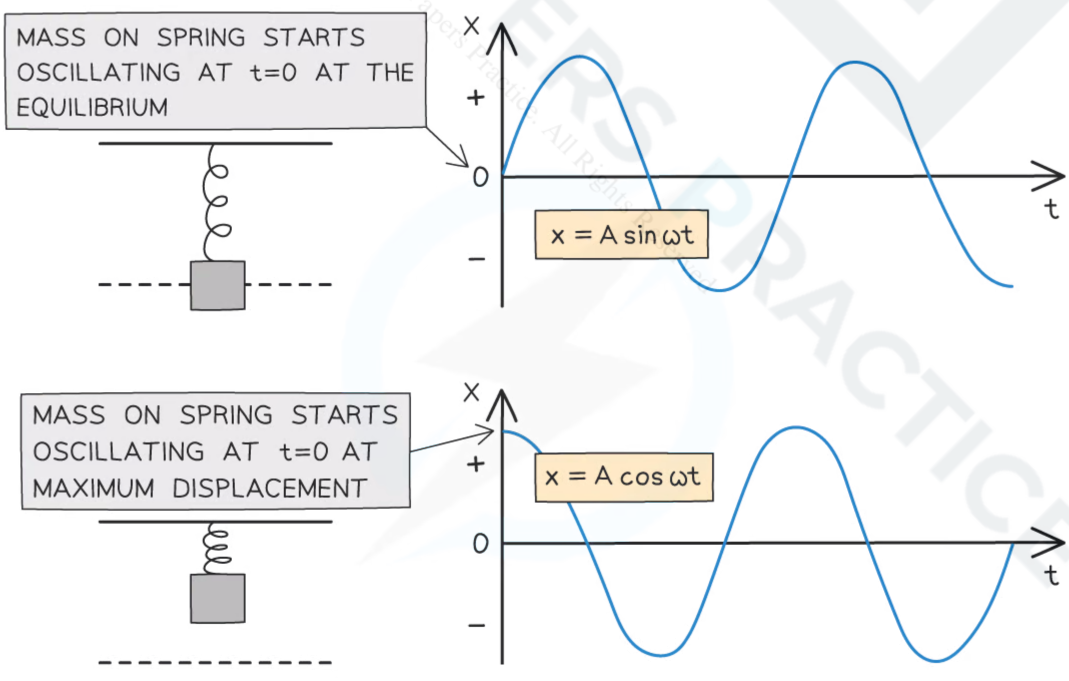
$$x = A\cos(\omega t)$$

- Where:
  - A = amplitude (m)
  - t = time (s)

- This occurs when:
  - An object is oscillating from its amplitude position ($x = A$ or $x = -A$ at $t = 0$)
  - The displacement will be at its maximum when $\cos(\omega t)$ equals 1 or –1, when $x = A$
- This equation can be used to find the position of an object in SHM with a particular angular frequency and amplitude at a moment in time
- If an object is oscillating from its equilibrium position ($x = 0$ at $t = 0$) then the displacement equation will be:

$$x = A\sin(\omega t)$$

- The displacement will be at its maximum when $\sin(\omega t)$ equals 1 or –1, when $x = A$
- This is because the sine graph starts at 0, whereas the cosine graph starts at a maximum



These two graphs represent the same SHM. The difference is the starting position

Worked Example

A mass of 55 g is suspended from a fixed point by means of a spring.

The stationary mass is pulled vertically downwards through a distance of 4.3 cm and then released at t = 0.

The mass is observed to perform simple harmonic motion with a period of 0.8 s.

Calculate the displacement x, in cm, of the mass at time t = 0.3 s.

Step 1: Write down the SHM displacement equation

Since the mass is released at t = 0 at its maximum displacement, the displacement equation will be with the cosine function:

$$x = A\cos(\omega t)$$

Step 2: Calculate angular frequency

$$\omega = \frac{2\pi}{T} = \frac{2\pi}{0.8} = 7.85 \ rad \ s^{-1}$$

Remember to use the value of the time period given, not the time passed

Step 3: Substitute values into the displacement equation

x = 4.3cos (7.85 × 0.3) = −3.0369... = −3.0 cm (2 s.f)

Make sure the calculator is in **radians mode**

The negative value means the mass is 3.0 cm on the opposite side of the equilibrium position to where it started (3.0 cm above it)

Speed and SHM

- The speed of an object in simple harmonic motion varies as it oscillates back and forth
  - Its speed is the magnitude of its velocity
- The greatest speed of an oscillator is at the equilibrium position ie. when its displacement x = 0
- How the speed v changes with the oscillator's displacement x in SHM is defined by:

$$v = \pm\omega\sqrt{(A^2 - x^2)}$$

- Where:
  - v = speed (m s^{-1})
  - A = amplitude (m)
  - ± = 'plus or minus'. The value can be negative or positive
  - ω = angular frequency (rad s^{-1})
  - x = displacement (m)

- This equation shows that when an oscillator has a greater amplitude A, it has to travel a greater distance in the same time and hence has greater speed v
- Although the symbol v is commonly used to represent velocity, not speed, exam questions focus more on the magnitude of the velocity than its direction in SHM

Worked Example

A simple pendulum oscillates with simple harmonic motion with an amplitude of 15 cm.

The frequency of the oscillations is 6.7 Hz.

Calculate the speed of the pendulum at a position of 12 cm from the equilibrium position.

Step 1: Write out the known quantities

- Amplitude of oscillations, ***A* = 15 cm = 0.15 m**
- Displacement at which the speed is to be found, ***x* = 12 cm = 0.12 m**
- Frequency, **f = 6.7 Hz**

Step 2: Oscillator speed with displacement equation

$$v = \pm \omega \sqrt{(A^2 - x^2)}$$

- Since the speed is being calculated, the ± sign can be removed as direction does not matter in this case

Step 3: Write an expression for the angular frequency

- Equation relating angular frequency and normal frequency:

$$\omega = 2\pi f = 2\pi \times 6.7 = 42.097...$$

Step 4: Substitute in values and calculate

$$v = (2\pi \times 6 \cdot 7) \times \sqrt{(0 \cdot 15)^2 - (0 \cdot 12)^2}$$

v = 3.789 = 3.8 m s^{-1} (2 s.f)

Exam Tip

Since displacement is a vector quantity, remember to keep the minus sign in your solutions if they are negative, you could lose a mark if not! Also, remember that your calculator must be in **radians** mode when using the cosine and sine functions. This is because the angular frequency ω is calculated in rad s^{-1}, **not** degrees. You often have to convert between time period T, frequency f and angular frequency ω for many exam questions – so make sure you revise the equations relating to these.

Period of a simple pendulum

- A simple pendulum is:
  - An object moving from side to side
  - Attached to a fixed point above
- The time period of a simple pendulum can also be calculated using this equation:

$$T = 2\pi\sqrt{\frac{l}{g}}$$

- Where:
  - l is the length of the pendulum swing
  - g is the strength of gravity on the planet on which the pendulum is set up

Worked Example

A child is sitting on a swing that is 200 cm long. What is the period of oscillation?

Step 1: Convert length to meters

$$200 \text{ cm} = 2 \text{ m}$$

Step 2: Substitute the correct values

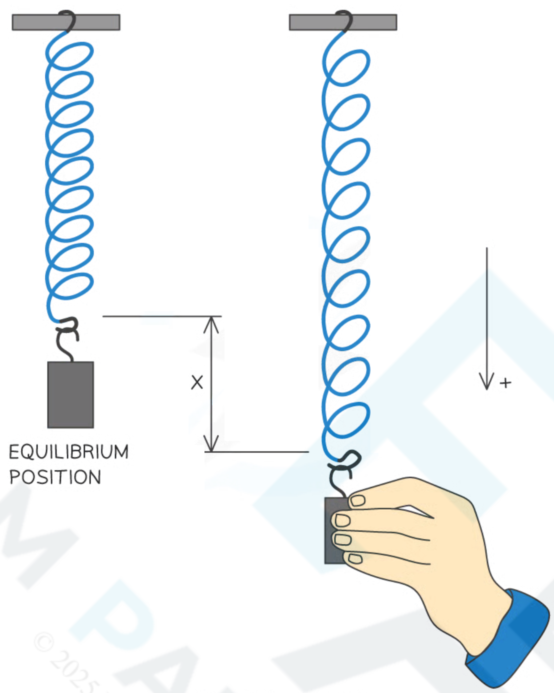
$$T = 2\pi\sqrt{\frac{l}{g}} = 2\pi\sqrt{\frac{2}{9.81}} = 2.84 \text{ s}$$

Step 3: Confirm the answer

The time period of 1 oscillation of the swing is 2.84 s

Period of a Mass-Spring System

- A mass-spring system means:
  - An object moving up and down
  - On the end of a spring



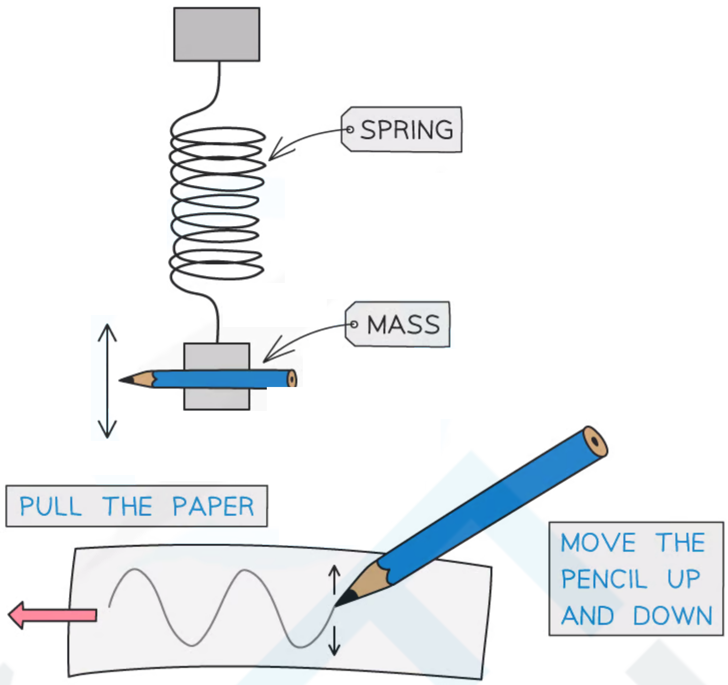
- The equation for the restoring force in SHM ***F* = – *kx***
  - is the same as the equation for **Hooke's Law**
- The **time period, *T*** can be calculated using the equation:

$$T = 2\pi\sqrt{\frac{m}{k}}$$

- Where:
  - *m* is the mass of the object on the end of the pendulum
  - *k* is the spring constant of the material the pendulum is made from

Observing the Motion of a Mass-Spring System

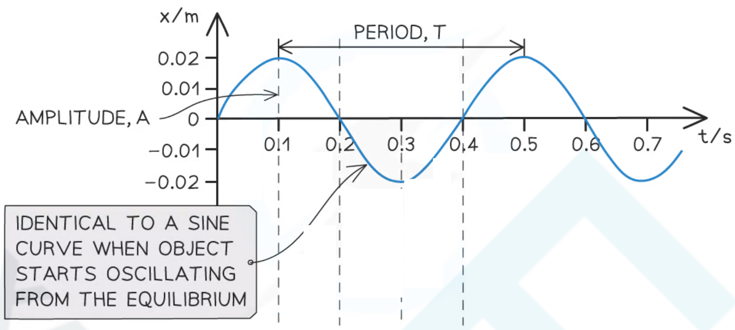
- An experimental and graphical method can be used to observe the motion of a simple mass-spring system
  - Tie a pencil together with the mass and set the mass in free oscillations by displacing it downwards slightly
- The oscillations will move the pencil up and down
  - On a piece of graph paper, allow the pencil to trace the path of the oscillations by pulling the paper sideways as the mass-spring system oscillates up and down
- The oscillations will produce a curved, periodic graph
  - This will decrease in amplitude as the mass-spring system slows down



The motion of oscillator can be observed through a simple mass and spring system

Displacement-Time graph for an oscillator

- The displacement of an object in simple harmonic motion can be represented by a graph of displacement against time
- All undamped SHM graphs are represented by **periodic functions**
    - This means they can all be described by sine and cosine curves



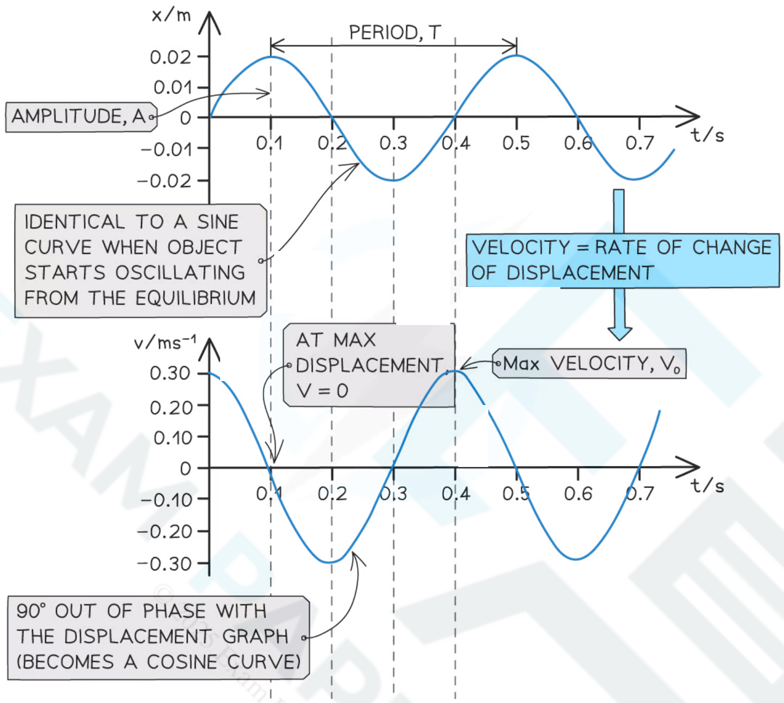
- **Key features of the displacement-time graph:**
    - The amplitude of oscillations A can be found from the maximum value of x
    - The time period of oscillations T can be found from reading the time taken for one full cycle
    - The graph might not always start at 0
    - If the oscillations starts at the positive or negative amplitude, the displacement will be at its maximum

Exam Tip

This graph might not look identical to what is in your textbook, depending on where the object starts oscillating from at t = 0 (on either side of the equilibrium, or at the equilibrium). However, if there is no damping, they will all always be a general sine or cosine curve.

Velocity-time graph for an oscillator

- The velocity of an object in simple harmonic motion can be represented by a graph of velocity against time



- **Key features of the velocity-time graph:**
  - It is 90° out of phase with the displacement-time graph
  - Velocity is equal to the rate of change of displacement
  - So, the velocity of an oscillator at any time can be determined from the **gradient of the displacement-time graph:**

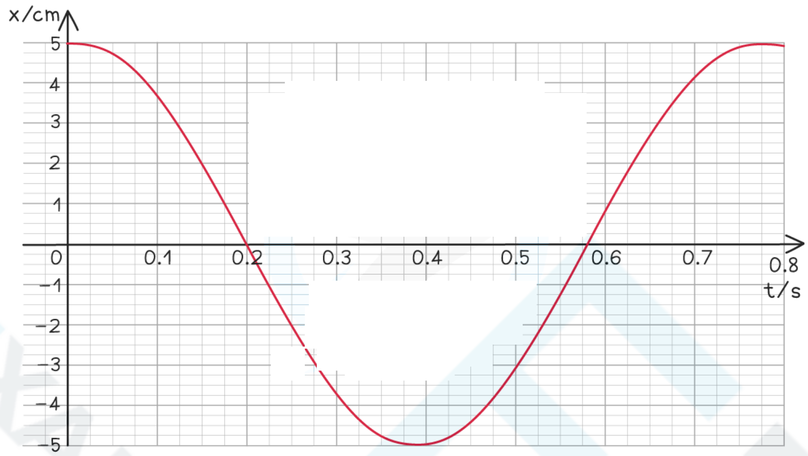
$$v = \frac{\Delta x}{\Delta t}$$

- An oscillator moves the fastest at its equilibrium position
  - Therefore, the velocity is at its **maximum** when the **displacement is zero**

Worked Example

A swing is pulled 5 cm and then released.

The variation of the horizontal displacement *x* of the swing with time t is shown on the graph below.

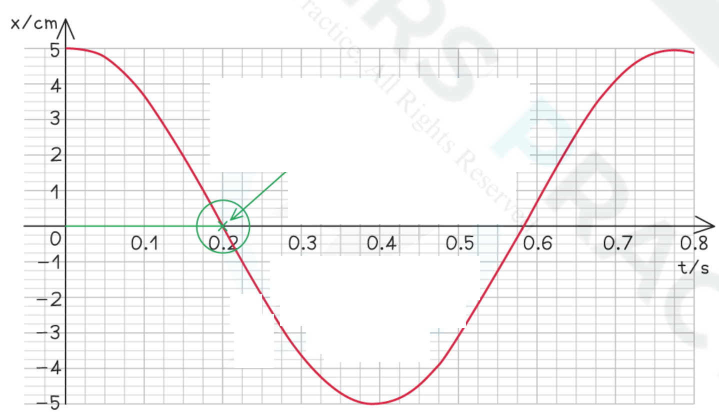


The swing exhibits simple harmonic motion.

Use data from the graph to determine at what time the velocity of the swing is first at its maximum.

Step 1: The velocity is at its maximum when the displacement x = 0

Step 2: Reading value of time when x = 0



From the graph this is equal to 0.2 s

Exam Tip

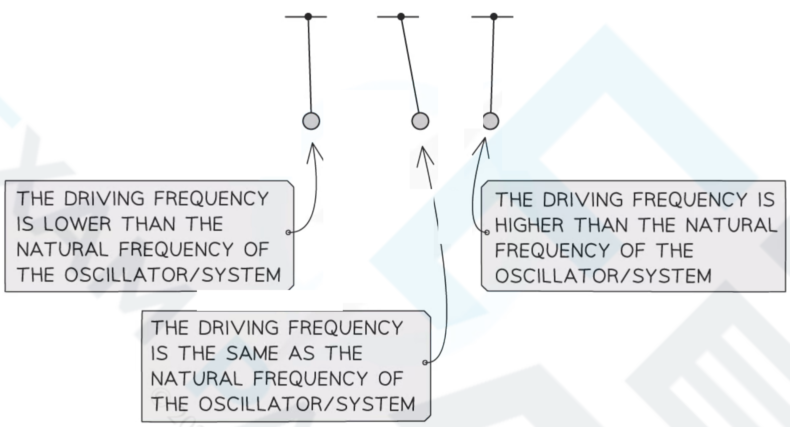
These graphs might not look identical to what is in your textbook, depending on where the object starts oscillating from at t = 0 (on either side of the equilibrium, or at the equilibrium). However, if there is no damping, they will all always be a general sine or cosine curves.

Resonance

13.6 Resonance

Resonance

- The frequency of forced oscillations is referred to as the **driving frequency**, f, or the frequency of the applied force
- All oscillating systems have a **natural frequency**, f_0, this is defined as the frequency of an oscillation when the oscillating system is allowed to oscillate freely
    - Oscillating systems can exhibit a property known as resonance



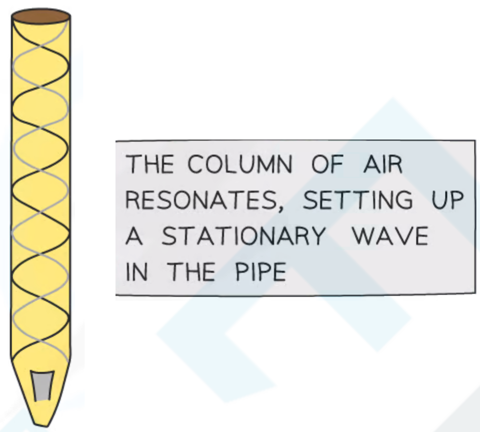
- When the **driving frequency** approaches the **natural frequency** of an oscillator, the system gains more energy from the driving force
    - Eventually, when they are equal, the oscillator vibrates with its maximum amplitude, this is **resonance**
- Resonance is defined as:

    When the frequency of the applied force to an oscillating system is equal to its natural frequency, the amplitude of the resulting oscillations increases significantly

- For example, when a child is pushed on a swing:
    - The swing plus the child has a fixed natural frequency
    - A small push after each cycle increases the amplitude of the oscillations to swing the child higher. This frequency at which this push happens is the driving frequency
    - When the driving frequency is exactly equal to the natural frequency of the swing oscillations, resonance occurs
    - If the driving frequency does not quite match the natural frequency, the amplitude will increase but not to the same extent as when resonance is achieved
- This is because, at resonance, energy is transferred from the driver to the oscillating system **most efficiently**
    - Therefore, at resonance, the system will be transferring the maximum kinetic energy possible

Resonance Effects

- Resonance occurs for any forced oscillation where the frequency of the driving force is equal to the natural frequency of the oscillator
- Examples include:
    - An organ pipe, where air resonates down an air column setting up a stationary wave in the pipe
    - Glass smashing from a high pitched sound wave at the right frequency
    - A radio tuned so that the electric circuit resonates at the same frequency as the specific broadcast



Standing waves forming inside an organ pipe from resonance

Core Practical 16: Investigating Resonance

Aim of the Experiment

- Determine the value of an unknown mass by a graphical method by using the resonant frequencies of the oscillation of known masses

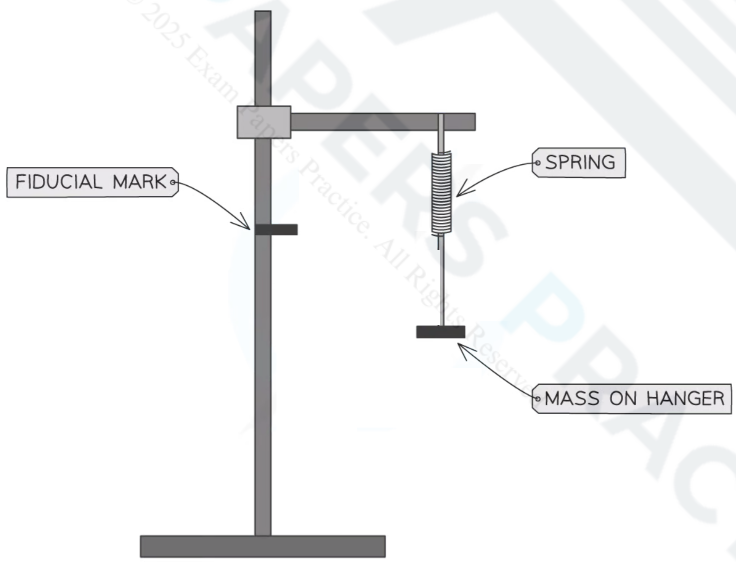
Variables

- Independent variable = mass (kg)
- Dependent variable = time period (s)
- Control variables:
  - The spring / oscillator

Equipment

- Spring (standard 20–25 mm spring)
- Slotted 100g masses and hanger
- Retort stand and clamp
- Digital timer
- Unknown test mass
- Digital scales

Method

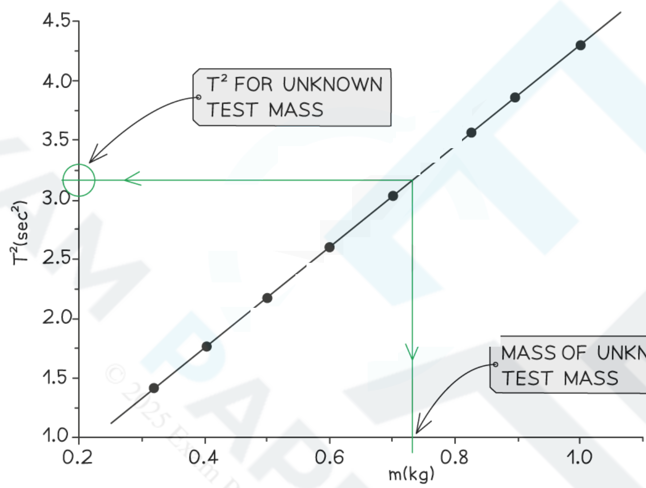


1. Set up the spring with 100 g mass attached
2. On the stand make a clear fiducial mark about 5 cm below the bottom of the spring
3. Extend the spring so that the bottom is level with the fiducial marker, release and start timing
4. Measure time for 10 oscillations
5. Repeat with the same mass two more times
6. Find the average time period of one oscillation

7. Add 100 g and adjust the fiducial mark downwards so that it is 5 cm below the new level of the spring
8. Repeat steps 3–7 until the total mass is 500 g
9. Plot a graph of T^2 on the y-axis against m on the x-axis

Testing the unknown mass

- Follow steps 2 - 6 for the test mass
- Find the value of the time period, T and square it to find T^2
- On the graph mark a horizontal from T^2 to the graph line and where they intersect, take the arrow vertically down to meet the x-axis
- The value of m which this line coincides with is the mass of the test mass
- Check the result using digital scales



Analysis

- Analysis for this graph is based on three equations related to simple harmonic motion;
  - Angular velocity, $\omega = \sqrt{\frac{k}{m}}$ **(equation 1)**
  - Where k = spring constant (N kg^{-1}) and m = mass (kg)
  - Angular velocity, $\omega = 2\pi f$ **(equation 2)**
  - Where f = frequency of oscillations (Hz)
  - Frequency, $f = \frac{1}{T}$ **(equation 3)**
  - Where T = time period for one oscillation (s)
- Substitute **equations 2** into **equation 1**;

$$2\pi f = \sqrt{\frac{k}{m}}$$

- Substitute **equation 3** into **equation 2**

$$\frac{2\pi}{T} = \sqrt{\frac{k}{m}}$$

- Square both sides

$$\frac{4\pi^2}{T^2} = \frac{k}{m}$$

- Make T^2 the subject

$$T^2 = m\left(\frac{4\pi^2}{k}\right)$$

- Plot a graph of T^2 on the y-axis against m on the x-axis to get a straight line through the origin with;

$$\text{gradient} = \left(\frac{4\pi^2}{k}\right)$$

Safety Considerations

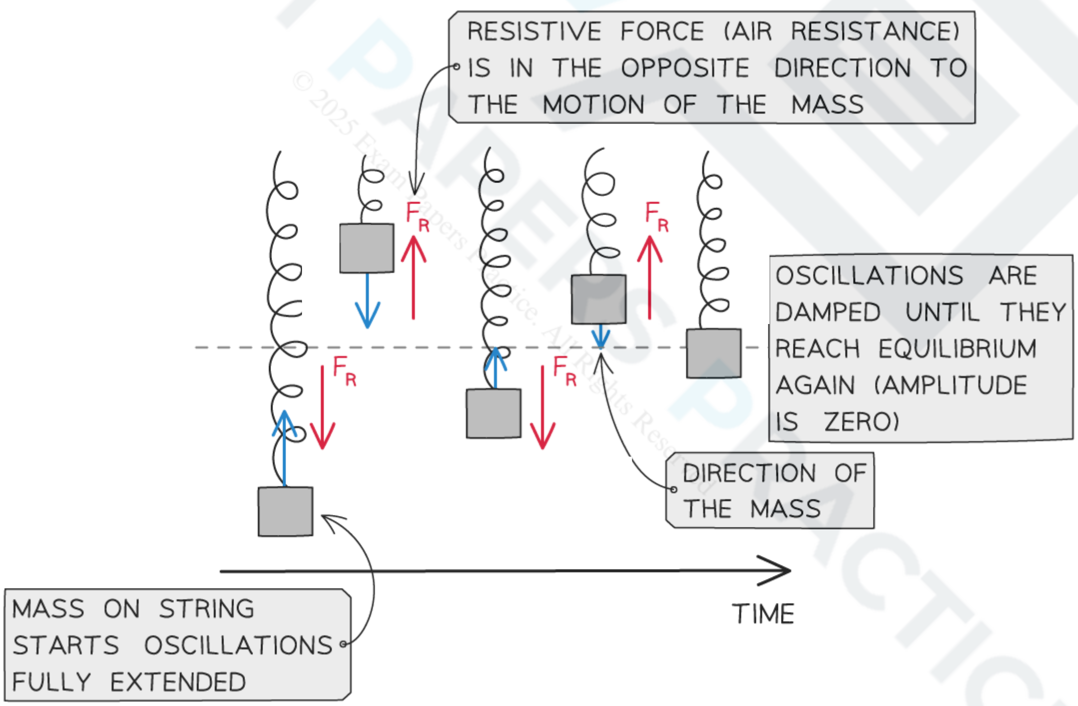
- Clamp stand to the desk for stability
- Wear safety glasses in case the spring flies off or snaps
- Place a cushion or catch-mat in case of falling masses

Damped & Undamped Oscillating Systems

- In practice, all oscillators eventually stop oscillating
  - Their amplitudes decrease rapidly, or gradually
- This happens due to **resistive forces**, such friction or air resistance, which act in the opposite direction to the motion of an oscillator
- Resistive forces acting on an oscillating simple harmonic system cause **damping**
  - These are known as **damped** oscillations
- Damping is defined as:

  The reduction in energy and amplitude of oscillations due to resistive forces on the oscillating system

- Damping continues until the oscillator comes to rest at the equilibrium position
- A key feature of simple harmonic motion is that the **frequency** of damped oscillations **does not change** as the amplitude decreases
  - For example, a child on a swing can oscillate back and forth once every second, but this time remains the same regardless of the amplitude



Damping on a mass on a spring is caused by a resistive force acting in the opposite direction to the motion. This continues until the amplitude of the oscillations reaches zero

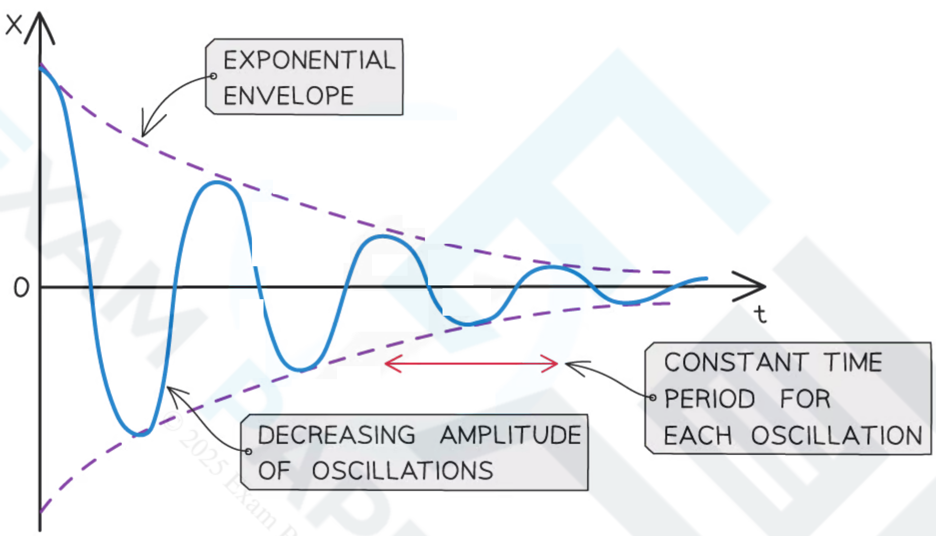
Types of Damping

- There are three degrees of damping depending on how quickly the amplitude of the oscillations decrease:

- Light damping
- Critical damping
- Heavy damping

Light Damping

- When oscillations are lightly damped, the amplitude does not decrease linearly
  - It decays exponentially with time
- When a lightly damped oscillator is displaced from the equilibrium, it will oscillate with gradually decreasing amplitude
  - For example, a swinging pendulum decreasing in amplitude until it comes to a stop

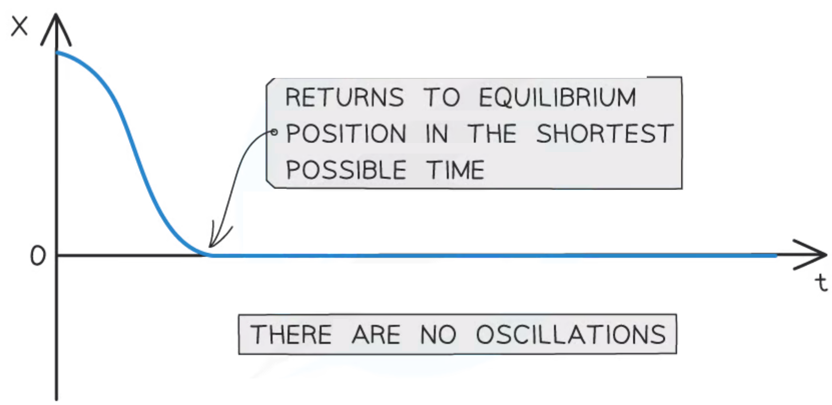


A graph for a lightly damped system consists of oscillations decreasing exponentially

- **Key features of a displacement-time graph for a lightly damped system:**
  - There are many oscillations represented by a sine or cosine curve with gradually decreasing amplitude over time
  - This is shown by the height of the curve decreasing in both the positive and negative displacement values
  - The amplitude decreases exponentially
  - The frequency of the oscillations remain constant, this means the time period of oscillations must stay the same and each peak and trough is equally spaced

Critical Damping

- When a critically damped oscillator is displaced from the equilibrium, it will return to rest at its equilibrium position in the shortest possible time **without** oscillating
  - For example, car suspension systems prevent the car from oscillating after travelling over a bump in the road

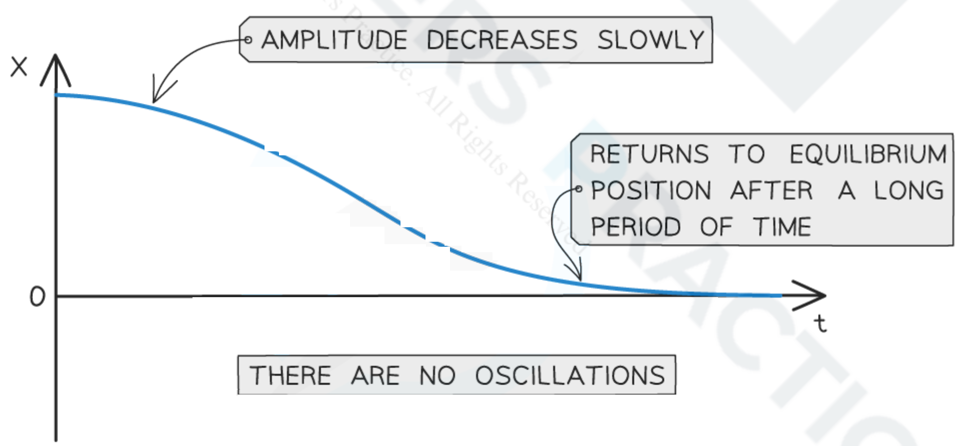


The graph for a critically damped system shows no oscillations and the displacement returns to zero in the quickest possible time

- **Key features of a displacement-time graph for a critically damped system:**
  - This system does **not** oscillate, meaning the displacement falls to 0 straight away
  - The graph has a fast decreasing gradient when the oscillator is first displaced until it reaches the x axis
  - When the oscillator reaches the equilibrium position (x = 0), the graph is a horizontal line at x = 0 for the remaining time

Heavy Damping

- When a heavily damped oscillator is displaced from the equilibrium, it will take a long time to return to its equilibrium position **without** oscillating
- The system returns to equilibrium more slowly than the critical damping case
  - For example, door dampers to prevent them from slamming shut



A heavy damping curve has no oscillations and the displacement returns to zero after a long period of time

- **Key features of a displacement-time graph for a heavily damped system:**
  - There are no oscillations. This means the displacement does not pass 0
  - The graph has a slow decreasing gradient from when the oscillator is first displaced until it reaches the x axis

- The oscillator reaches the equilibrium position ($x = 0$) after a long period of time, after which the graph remains a horizontal line for the remaining time

Worked Example

A mechanical weighing scale consists of a needle which moves to a position on a numerical scale depending on the weight applied. Sometimes, the needle moves to the equilibrium position after oscillating slightly, making it difficult to read the number on the scale to which it is pointing to. Suggest, with a reason, whether light, critical or heavy damping should be applied to the mechanical weighing scale to read the scale more easily.

ANSWER:

- Ideally, the needle should not oscillate before settling
  - This means the scale should have either **critical** or **heavy damping**
- Since the scale is read straight away after a weight is applied, ideally the needle should settle as quickly as possible
- Heavy damping would mean the needle will take some time to settle on the scale
- Therefore, **critical damping** should be applied to the weighing scale so the **needle can settle as quickly as possible** to read from the scale

Exam Tip

Make sure not to confuse **resistive** force and **restoring** force:

- Resistive force is what **opposes the motion** of the oscillator and causes damping
- Restoring force is what brings the oscillator **back to the equilibrium position**

Free & Forced Oscillations

Free Oscillations

- Free oscillations occur when there is no transfer of energy to or from the surroundings
  - This happens when an oscillating system is displaced and then left to oscillate
- In practice, this only happens in a vacuum. However, anything vibrating in air is still considered a free vibration as long as there are **no external forces** acting upon it
- Therefore, a **free oscillation** is defined as:

An oscillation where there are only internal forces (and no external forces) acting and there is no energy input

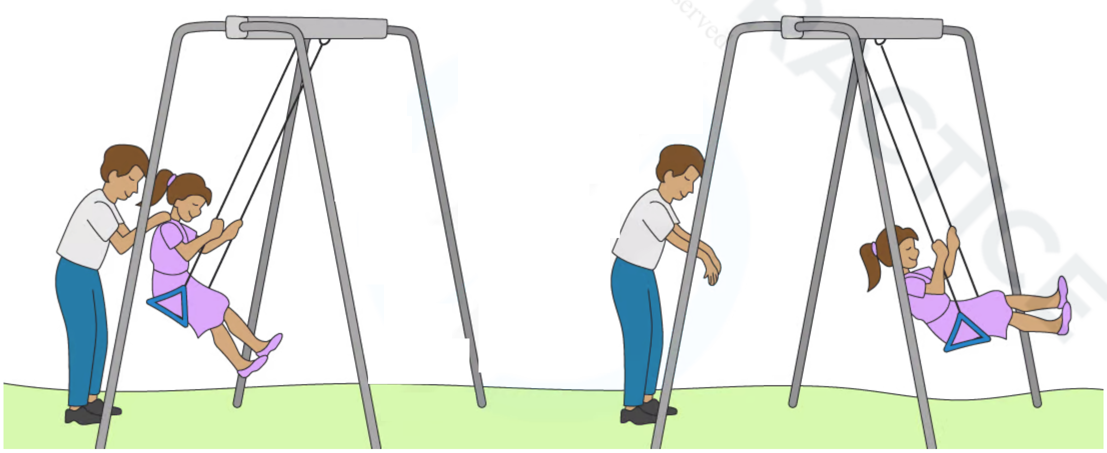
- A free vibration always oscillates at its **resonant frequency**

Forced Oscillations

- In order to sustain oscillations in a simple harmonic system, a periodic force must be applied to replace the energy lost in damping
  - This periodic force **does work** on the resistive force decreasing the oscillations
  - It is sometimes known as an external **driving** force
- These are known as **forced oscillations** (or vibrations), and are defined as:

Oscillations acted on by a periodic external force where energy is given in order to sustain oscillations

- Forced oscillations are made to oscillate at the same frequency as the oscillator creating the external, periodic driving force
- For example, when a child is on a swing, they will be pushed at one end after each cycle in order to keep swinging and prevent air resistance from damping the oscillations
  - These extra pushes are the forced oscillations, without them, the child will eventually come to a stop



Worked Example

State whether the following are free or forced oscillations:

(i) Striking a tuning fork

(ii) Breaking a glass from a high pitched sound

(iii) The interior of a car vibrating when travelling at a high speed

(iv) Playing the clarinet

(i) Striking a tuning fork

This is a free vibration. When a tuning fork is struck, it will vibrate at its natural frequency and there are no other external forces

(ii) Breaking a glass from a high pitched sound

This is a forced vibration. The glass is forced to vibrate at the same frequency as the sound until it breaks. The frequency of the high-pitched sound is the external driving frequency

(iii) The interior of a car vibrating when travelling at a particular speed

This is a forced vibration. The interior of the car vibrates at the same frequency as the wheels travelling over a rough surface at a high speed

(iv) Playing the clarinet

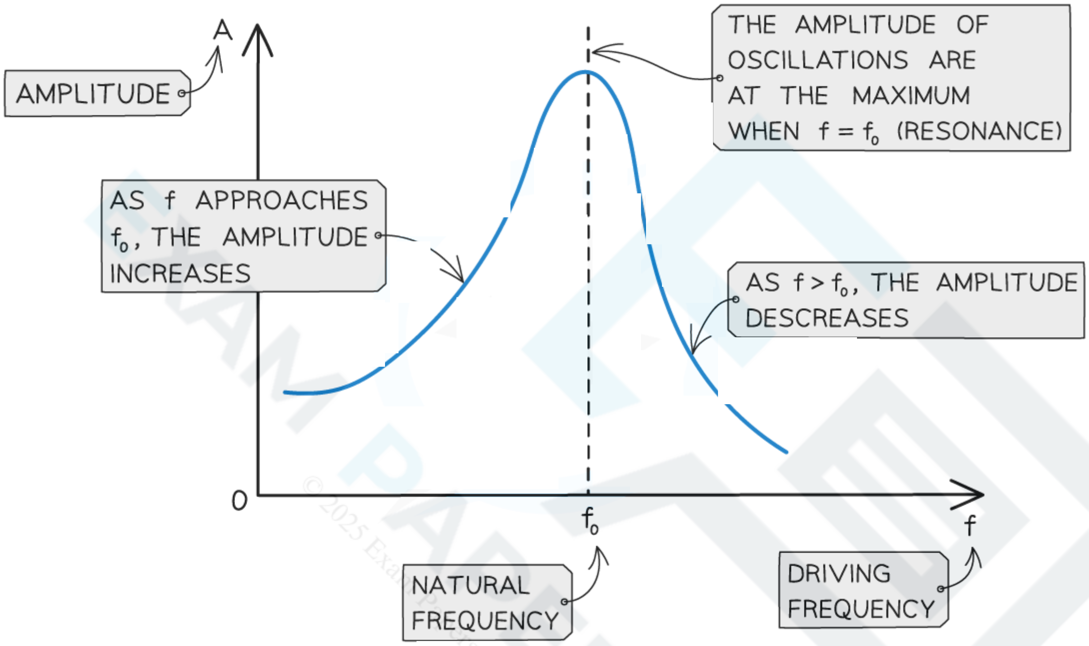
This is a forced vibration. The air from the player's lungs is used to sustain the vibration in the air column in a clarinet to create and hold a sound. The air column inside the clarinet mimics the vibrations at the same frequency as the air forced into the mouthpiece of the clarinet (the reed).

Exam Tip

Avoid writing 'a free oscillation is not forced to oscillate'. Mark schemes are mainly looking for a reference to internal and external forces and energy transfers

Resonance Graphs

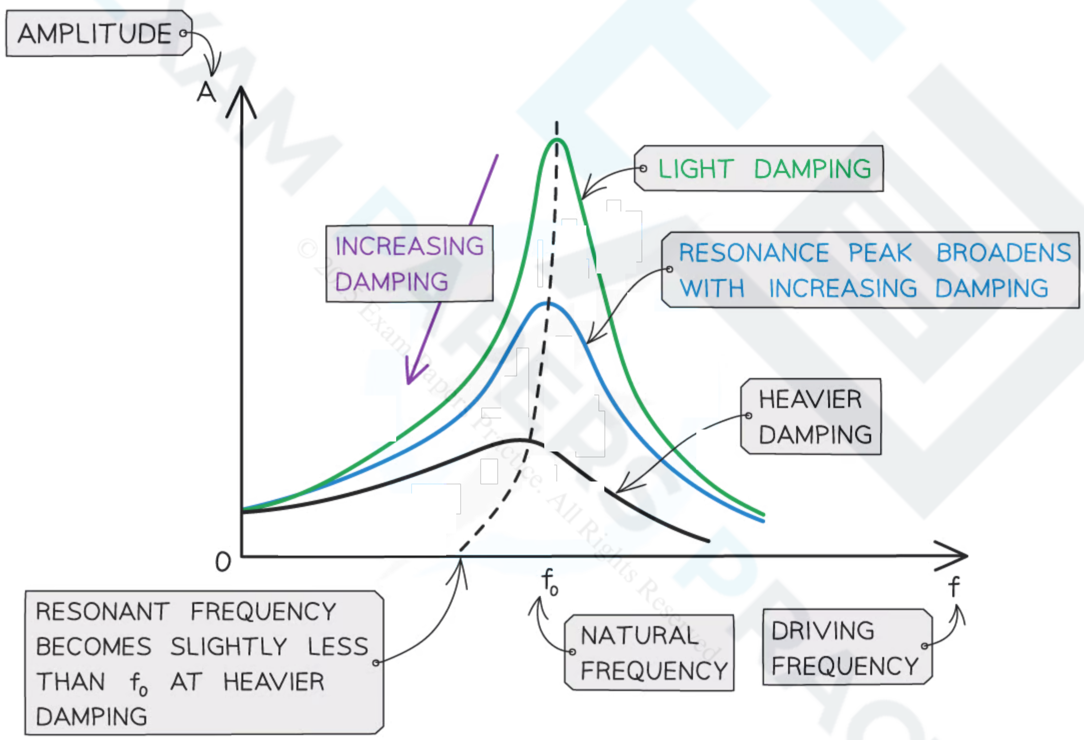
- A graph of driving frequency *f* against amplitude *A* of oscillations is called a **resonance curve**. It has the following key features:
  - When $f < f_0$, the amplitude of oscillations increases
  - At the peak where $f = f_0$, the amplitude is at its maximum. This is **resonance**
  - When $f > f_0$, the amplitude of oscillations starts to decrease



The maximum amplitude of the oscillations occurs when the driving frequency is equal to the natural frequency of the oscillator

Damping & Resonance

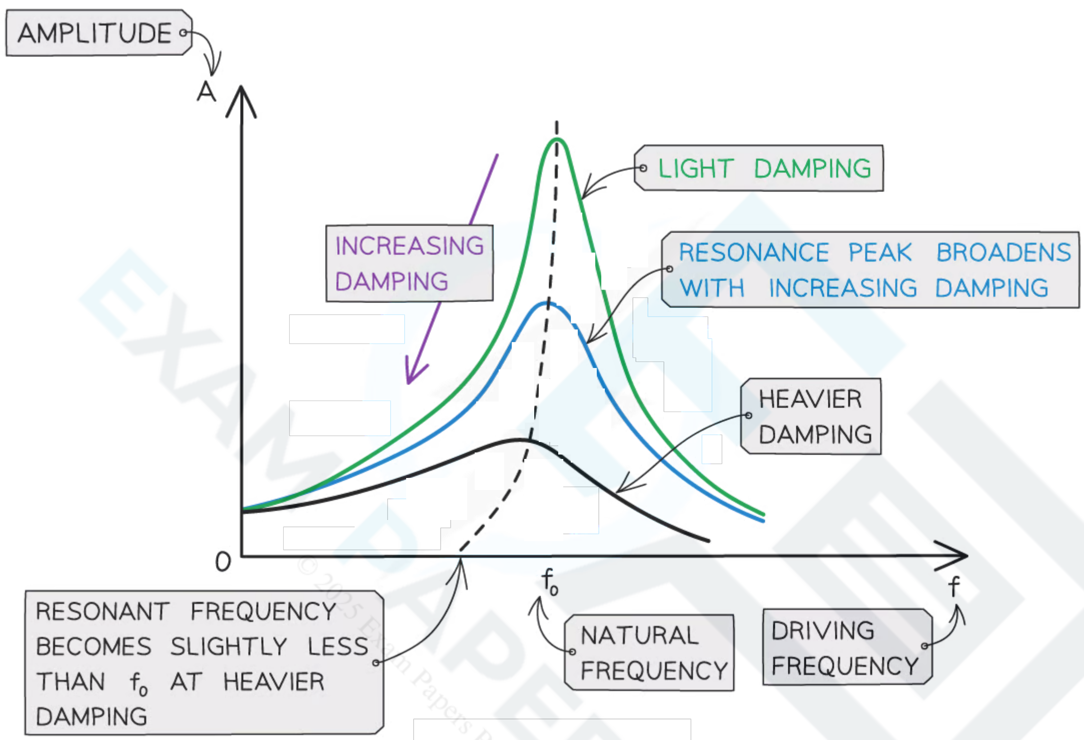
- Damping **reduces** the amplitude of resonance vibrations
- The height and shape of the resonance curve will therefore change slightly depending on the degree of damping
  - **Note:** the natural frequency f_0 of the oscillator will remain the same
- As the degree of damping is increased, the resonance graph is altered in the following ways:
  - The amplitude of resonance vibrations **decrease**, meaning the peak of the curve lowers
  - The resonance peak **broadens**
  - The resonance peak moves slightly to the **left** of the natural frequency when heavily damped
- Therefore, damping reduced the sharpness of resonance and reduces the amplitude at resonant frequency



As damping is increased, resonance peak lowers, the curve broadens and moves slightly to the left

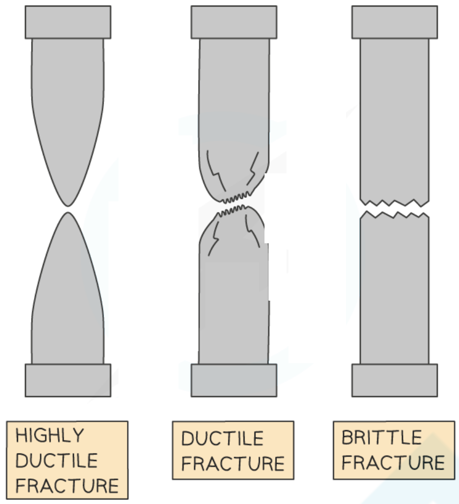
Damping & Plastic Deformation

- **Damping** an oscillator affects its **amplitude** of oscillation:
  - When **damping** is **increased** the **amplitude decreased**
  - **damping** and **amplitude** are **inversely proportional** to each other

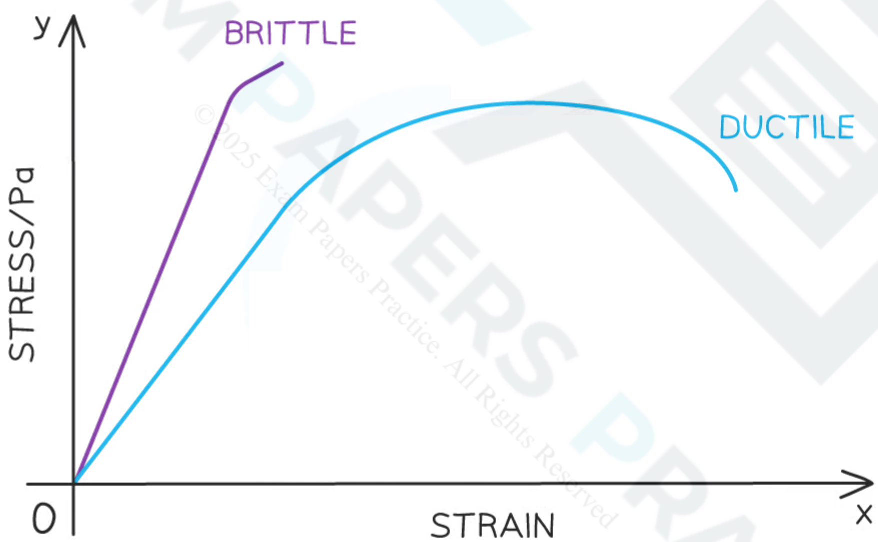


As damping is increased, resonance peak lowers, the curve broadens and moves slightly to the left

- A **Ductile** material can be stretched for a long time before it snaps
  - We can say it undergoes a large amount of **plastic deformation** before it is **permanently deformed**



- Examples of ductile materials include:
  - Most metals (particularly copper, gold and silver)
  - Non-metals are generally not ductile



Brittle and ductile materials on a stress-strain graph. These are the same on a force-extension graph too

- The **amplitude of oscillations** can be reduced due to the **plastic deformation** of a **ductile material**
- This happens because energy from the oscillations is used to deform the material
  - The kinetic energy of the oscillator is reduced and transferred into the deformation of the material
- A climbing rope is different from a rescue rope or a bungee cord:
  - A climbing rope is designed to extend when loaded suddenly

- The rope stretches to reduce the amplitude of the oscillation when a climber falls onto it
- It provides critical damping by immediately stopping the climber from bouncing

A climber uses a dynamic rope that stretches when she falls onto it. This reduces the amplitude of her oscillation and the force she experiences reducing injury.