Edexcel Physics A-level

Topic 13: Oscillations

Key Points

Simple Harmonic Motion

Simple harmonic motion (SHM) is a mechanical process that is characterised by the following conditions:

- The object **oscillates** either side of an **equilibrium** position
- A **restoring** force always acts **towards** this equilibrium position
- The **force** is **proportional** to the object's **displacement**
- Consequently the object has an **acceleration** proportional to its **displacement** and in the **opposite direction**

The **defining equation** for SHM is:

$$F = -kx$$

Where 'x' is displacement and 'k' is a constant.

Further Equations

You should understand the following terms in the context of SHM:

- The **frequency** is the number of full cycles that occur each second
- A full **cycle** is the motion from maximum positive displacement, to maximum negative displacement and then back to the maximum positive displacement again
- The **time period** is the length of time it takes to complete a cycle

Like in circular motion, SHM make use of ω, the **angular frequency**. You need to be able to apply the following equations when analysing SHM scenarios:

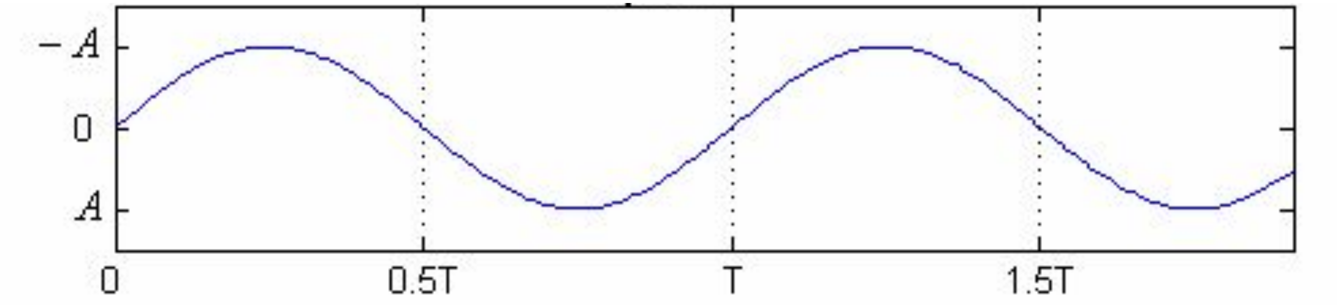
$$\omega = 2\pi f \qquad T = \frac{1}{f} = \frac{2\pi}{\omega}$$

$$a = -\omega^2 x \qquad x = A\cos\omega t \qquad v = -A\omega\sin\omega t \qquad a = -A\omega^2\cos\omega t$$

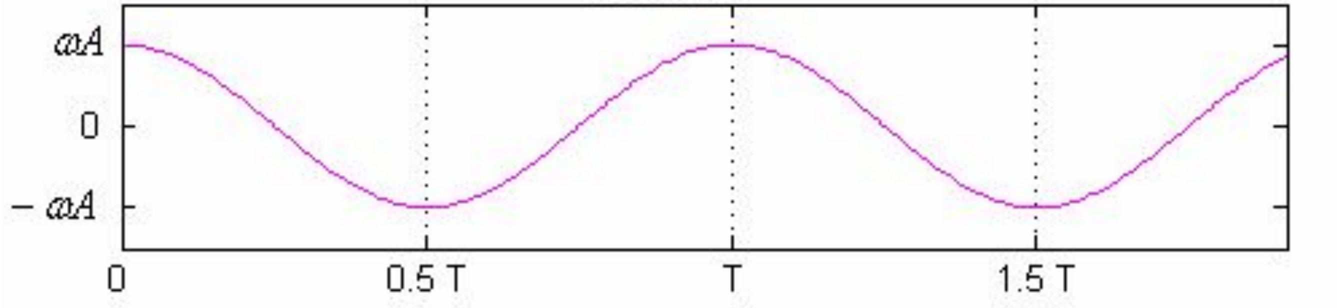
Make sure you are careful to substitute ‘a’ with **acceleration** and ‘A’ with **maximum displacement**.

SHM graphs

Below is a **displacement-time** graph for an object oscillating with SHM. The gradient at a given point on this graph gives the **velocity** that the object is moving at.



Below is a **velocity-time** graph for an object oscillating with SHM. The gradient at a given point on this graph gives the **acceleration** that the object is moving at.



Spring Oscillators

A **spring oscillator** consists of a **mass** on a spring which oscillates with **simple harmonic motion**.

The **time period** of oscillation for a spring oscillator is given by:

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

Note that the period isn't affected by the **gravitational field strength**. This means that the period will be the same on all planets.

It is also unaffected by the **magnitude of displacement**, meaning the period will be the same for all initial displacements.

Pendulum Oscillators

A **pendulum oscillator** consists of a **mass** on a string which oscillates with **simple harmonic motion**.

The **time period** of oscillation for a pendulum oscillator is given by:

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

Note that the period isn't affected by the **object's mass**. This means that the period will be the same regardless of how heavy the mass is.

It is also unaffected by the **magnitude of displacement**, meaning the period will be the same for all initial displacements.

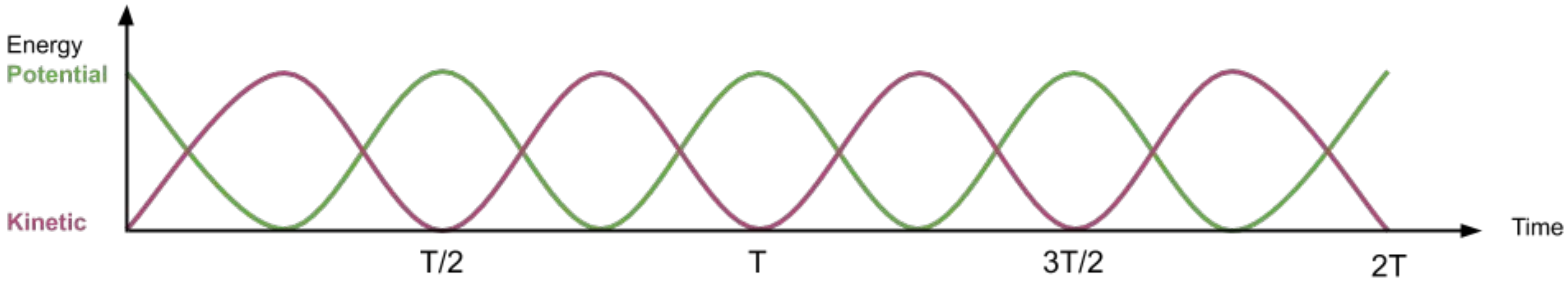
Energy of SHM

When an object oscillates with SHM, energy is **transferred** between kinetic and potential energies. These transfers are as follows:

- At maximum positive displacement, the potential energy is at a **maximum**
- As the object travels towards the equilibrium position, **potential energy** is transferred to **kinetic energy** as the object accelerates
- At the **equilibrium** position, the kinetic energy is at a **maximum** and the potential energy is at a minimum
- At maximum negative displacement, the **potential energy** is again at a maximum, while kinetic energy is at a minimum

SHM and Energy

The energy transfers that occur in SHM can be graphed:



Assuming **no damping** occurs:

$E_k + E_p$ = **total** energy and it is **constant** unless damping occurs.

There are **two** maximum points of E_k and E_p per **cycle**.

Damping

Damping of a SHM system occurs when **energy** is transferred **out** of the system. This results in the total energy no longer being **constant**. In reality **all** systems will experience some form of damping force, such as:

- Friction between components
- Air resistance

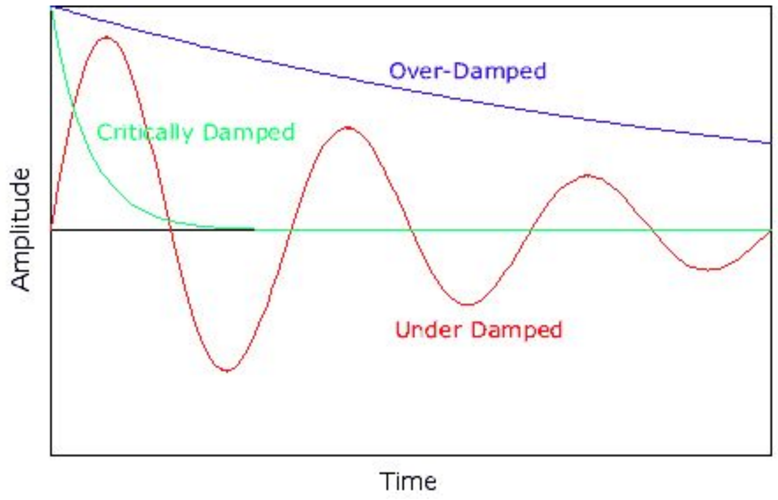
Systems are often also **deliberately** damped. Examples of this are:

- Car suspension systems
- Springed doors to prevent slamming
- Swings
- Speedometer dials

Types of Damping

There are **three** main types of damping that you need to be aware of:

1. **Light damping** is where the oscillations are reduced slowly, and is normally the type of damping caused by resistive forces such as air resistance and friction
2. **Critical damping** involves stopping the oscillations and returning to the equilibrium in the quickest time possible
3. **Overdamping** is caused when the damping force is greater than that for critical damping, and stops the oscillations, but takes longer to return to the equilibrium position



Vibrations

The vibrations that occur in SHM can be one of **two** types:

1. **Free vibrations:** The frequency a system tends to vibrate at in a free vibration is called the natural frequency.
2. **Forced vibrations:** A driving force causes the system to vibrate at a different frequency. For higher driving frequencies, the phase difference between the driver and the oscillations rises to π radians. For lower frequencies, the oscillations are in phase with the driving force. When **resonance** occurs, which is where energy is most efficiently transferred to the system, the phase difference will be π/2 radians.

Resonance

Resonance takes place when the driving frequency is **equal** to the natural frequency of the system. You should know that at resonance:

- The rate of **energy transfer** is at a **maximum**
- The driving force is **π/2** out of phase and **ahead** of the oscillations
- The **amplitude** of oscillation is at a **maximum**

In some situations resonance is **desirable** such as for **musical instruments**, however in other situations resonance is **undesirable**. Bridges and towers often have to be damped so that footfall or earthquakes don't produce oscillations at the structure's natural frequency. This is because the large amplitude oscillations caused by resonance could **damage** the structure.