A2 Level Physics

Chapter 13 – Oscillations

13.2.1 Damping

Notes

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Free and Forced Oscillations

When an object moves back and forth on either side of a fixed position (known as the equilibrium position), it is said to oscillate or vibrate.

We'll discuss two types of oscillations in this pack.

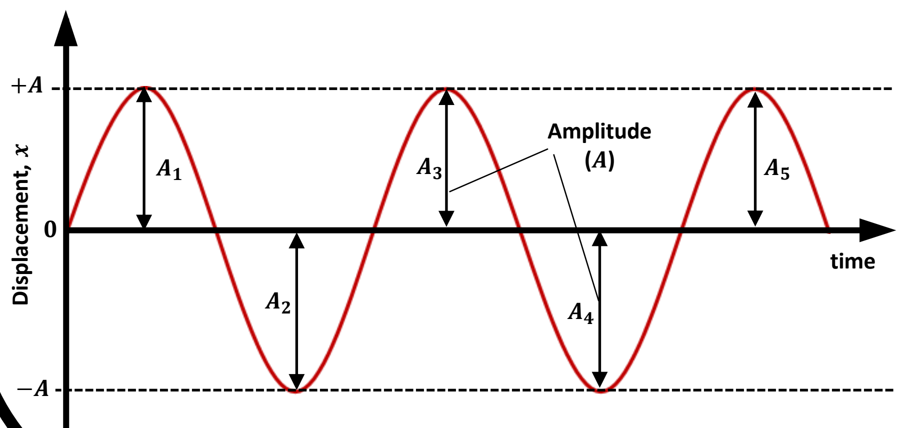
1) Free Oscillation

Free oscillation is achieved by releasing a pendulum or a mass-spring system from its maximum amplitude and allowing it to swing freely (ideally in a vacuum).

There is no energy transfer to or from the environment in free oscillations. As a result, pulling and releasing a pendulum or stretching and releasing a mass on a spring causes it to oscillate at its resonant frequency (or natural frequency).

All oscillating system have a natural frequency, which is the frequency at which it oscillates without being disturbed after the initial disturbance.

If no energy's transferred to or from the surroundings, the object will continue to oscillate with the same amplitude forever. This never happens in practise, but a spring vibrating in air is known as a free oscillation.



$r_1 = r_2 = r_3 \ldots\ldots\ldots etc$

Resonance

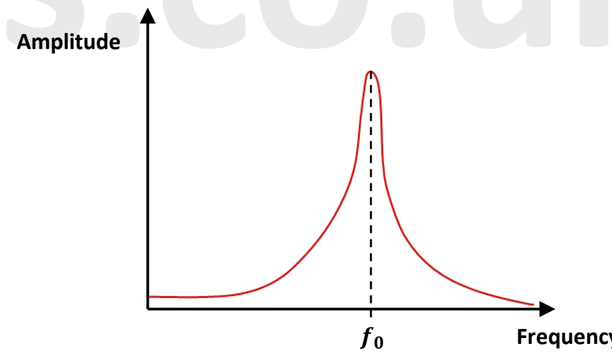
2) Forced Oscillation

However, when an external driving force is applied, oscillators can be forced to oscillate.

If you pushed a pendulum in the other direction as it swung one way, it would swing back the other way. You may get the pendulum to oscillate at a different frequency by repeatedly applying forces in different directions with your hand. This would be a forced oscillation instead of SHM. The frequency at which you were causing it to swing at would be your driving frequency.

A good example of forced oscillations is when engine vibrations are felt in the steering wheel and gear stick of a car. Forced oscillations of these objects are caused by engine vibrations.

When a system or object is forced to vibrate at its natural frequency (f_0), it absorbs more and more energy, resulting in oscillations with very large amplitudes.



Resonance occurs when the **forcing frequency is equal to the natural frequency** of the system and the **maximum amplitude** is achieved. The frequency at which it occurs is called the resonant frequency.

Useful examples of resonance

High Diver

When a diver is jumping on a diving board, she is attempting to match the frequency of her jumps to the diving board's natural frequency. This will allow the diver to achieve a large amplitude where they are at an appropriate height to dive.

Child on a swing

A child on a swing is another example. We try to time our pushes such that our driving frequency is the same as the swing's natural oscillation frequency. As a result, slight pushes at the end of each oscillation of the swing cause the amplitude to increase, causing the child to swing higher and higher.

Microwave Ovens

Microwave ovens use microwave frequency that matches the natural frequency of water particles in food to heat it up.

Examples of Problems caused by Resonance

Bridges

A cross-wind can cause a periodic force on a bridge span because eddy currents created by the wind along the bridge span. Resonance occurs when the periodic frequency caused by the wind speed is equal to the natural frequency of the bridge span. It may come to a point where the bridge collapses.

Earthquakes

When the periodic frequency caused by earthquakes match the natural frequencies of the surrounding building they will start to resonant. The building will eventually collapse as a result of this.

Damping Oscillations

We know that there is no energy loss to the surroundings in free oscillations, thus the object's amplitude will remain constant.

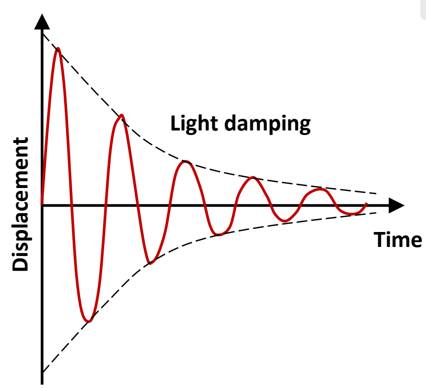
However, all oscillating systems, lose energy to its surroundings in practice. Frictional forces such as air resistance are commonly the cause. Because of these frictional forces, a system's energy is dissipated as thermal energy (heat) into the surroundings.

This simply means that if I had a pendulum that was left to swing freely, its amplitude would decrease with each swing.

This effect is known as damping.

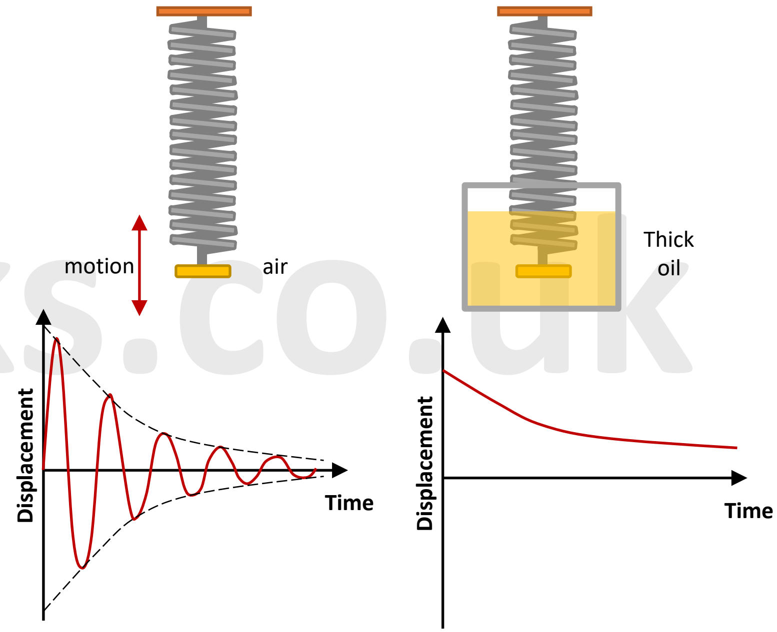
The motion of an oscillating object is DAMPED in the presence of dissipative forces.

In a lightly or moderately damped oscillating system, the amplitude of the oscillations steadily decrease with time, as seen in the diagram below. It's worth noting that the time period remains constant as the amplitude lowers.



Damping Oscillations

The degree of damping can vary, affecting the rate at which the amplitude is reduced. For example, in a mass-spring system oscillating in air the amplitude decreases gradually because the damping is light. In thick oil, the same oscillating system is heavily damped. As a result, the dissipative forces are much greater in thick oil than they are in air, and the amplitude decreases much faster.



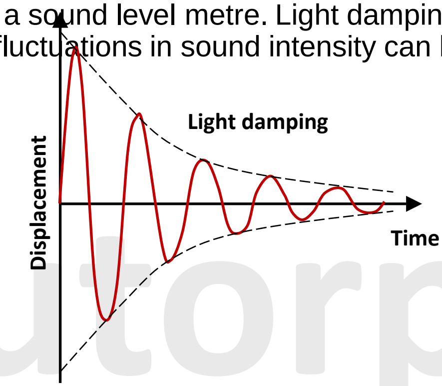
Degree of Damping

Lightly Damping

Lightly damped systems take a long time to stop oscillating, and the amplitude of their oscillations only decreases a small amount each period.

A pendulum is an example of a lightly damped system; air resistance causes the pendulum to just slightly slow down each period.

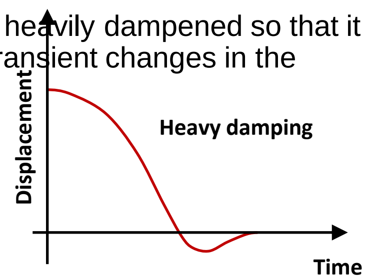
Another example is a sound level metre. Light damping is applied to these so that rapid fluctuations in sound intensity can be seen.



Heavy Damping

In heavy damping, the amplitude of oscillation rapidly decreases to zero. When released, the oscillating system barely overshoots the equilibrium position before coming to rest.

Example: Car fuel gauges. The pointer is heavily dampened so that it does not oscillate and so ignores slight, transient changes in the tank's fuel level.



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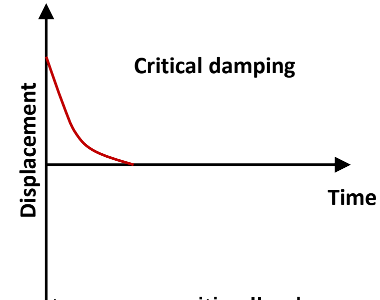
Degree of Damping

Critical damping

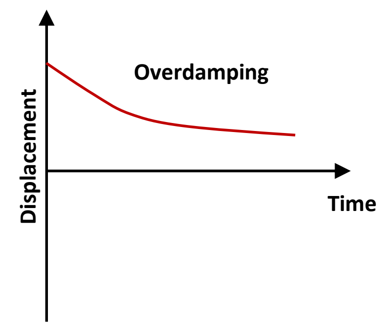
In critical damping, the amplitude of the oscillation decreases to zero in the shortest possible time and does not overshoot the equilibrium position.



Example: Car suspension systems are critically damped to prevent oscillation and return to equilibrium as quickly as possible.

Overdamping

In an overdamped system, the return to the equilibrium position is very slow.



Example: some heavy doors are overdamped so that they don't slam shut too quickly and instead close gently, allowing people to go through them.

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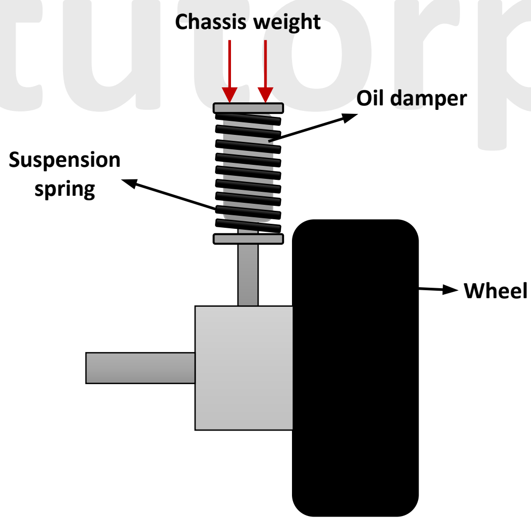
Example of Damping

Car Suspension System

A car's suspension system consists of a coiled spring between the wheel axle and the chassis near each wheel. The spring smooths out the force of the jolts when the wheel is rocked, such as on a bumpy road. Each spring contains an oil damper that keeps the chassis from bouncing up and down too much.

The dampers provide critical damping, allowing the car to return to its equilibrium position with little or no oscillation in the shortest possible time after a jolt. In this way the wheels follow an uneven surface, while the car itself follows a nearly horizontal path.

Note: If the damping was Heavy, the passengers would feel the impact of each bump, whereas if it was Light, the car and passengers would bounce around for a while after each bump.



Example of Damping

Millennium Bridge

If there is insufficient damping, a steady trail of people walking in step across a footbridge can cause resonant oscillations of the bridge span.

The Millennium Bridge in London had to be closed and installed with an appropriate dampening system shortly after it was opened because it swayed in resonance when people first walked across it. People walking on the bridge generated a driving frequency, which, if it matched the bridge's natural frequency, it would have caused the bridge to oscillate and eventually break.

A network of dampers has been installed under the Millennium Bridge, which has lowered oscillation amplitudes by altering the resonant frequencies. Using viscous dampers, this offers critical damping.

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