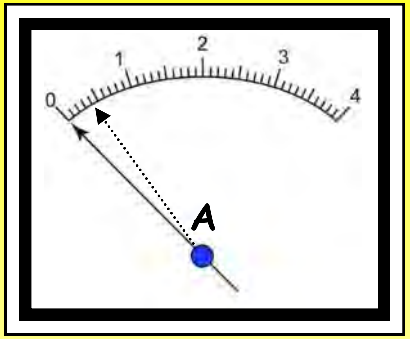
POINTER INSTRUMENTS

Analogue ammeter and voltmeters, have **CRITICAL DAMPING** so as to allow the needle pointer to reach its correct position on the scale after a single oscillation. If the damping were **LIGHT**, the pointer would oscillate about its actual reading for some time, making it difficult to read.



CAR FUEL GUAGES

These are given **HEAVY DAMPING** so that the pointer does not oscillate at all and so ignores small, transient changes in the fuel level in the tank.

SOUND LEVEL METERS

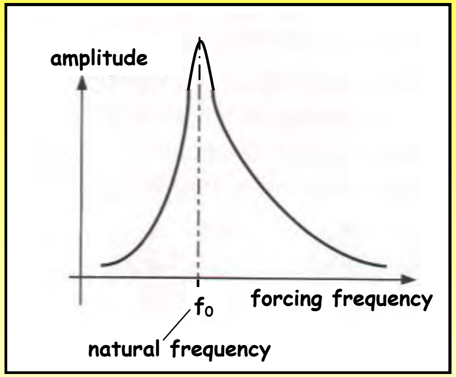
These are given **LIGHT DAMPING** so as to show rapid fluctuations in sound intensity.

FORCED OSCILLATIONS AND RESONANCE

When a periodic force is applied to an oscillating system, the system undergoes **FORCED OSCILLATIONS** and the response of the system depends on the frequency of the applied force and the **NATURAL FREQUENCY** of oscillation of the system.

The diagram opposite shows the response of an oscillating system as the **forcing frequency** is increased from zero.

If there is little or no damping, the **amplitude** of the oscillations becomes a **maximum** when :



frequency of the applied periodic force = natural frequency of the oscillating system

This condition is called **RESONANCE** and the Frequency at which it occurs is called the **RESONANT FREQUENCY**.

RESONANCE occurs when an oscillating system is forced to vibrate at a frequency close to its **natural frequency**; the **amplitude** of vibration increases rapidly and becomes a **maximum** when the **forcing frequency = the natural frequency of the system.**

EXAMPLES OF RESONANCE

Resonance can be a **problem [P]**, but there are situations where it can be **useful [U]**

- **When pushing a child on a swing**, we time our pushes so that the **periodic force frequency = natural frequency of oscillation of the swing-child system.** So a small push applied at the end of each oscillation of the swing produces increasing amplitude and so causing the child to swing higher and higher. **[U]**

> NOTE : If it were not for the damping due to friction and air resistance, the amplitude of oscillation would continue to increase and eventually the child would 'loop the loop'.

- **A high diver** times her bounces on The springboard so that the **frequency of her jumps = the natural frequency of vibration of the board.** In this way she Builds up a large amplitude oscillation and so gains substantial height when diving. **[U]**

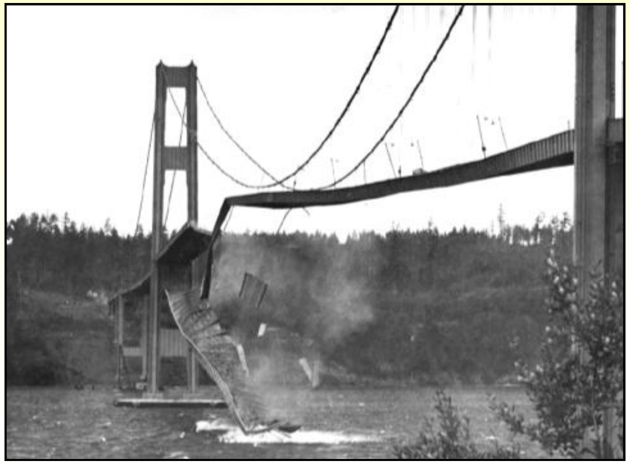
- In a microwave oven, the **microwave frequency matches the frequency of vibration of water molecules in the food being cooked.** This forces the molecules to vibrate with increased amplitude resulting in heating of the water and so cooking the food throughout its volume. **[U]**

- **Car body panels** as well as other parts can be set into resonant vibration as a result of transmitted engine vibrations at certain speeds.

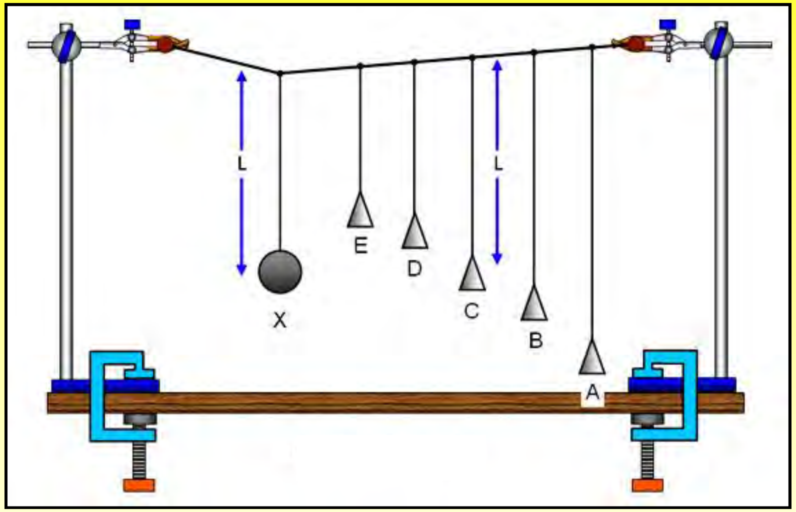
  This can also happen with some **washing machines when they are in the spin cycle.**

- **Tacoma Narrows bridge collapse**

  A cross-wind can cause a periodic force on a suspension bridge span. If the wind speed is such that **the frequency of the periodic force = the natural frequency of the bridge span,** large amplitude Resonant vibrations can be produced resulting in damage and possible destruction of the bridge.
  The dramatic collapse of the **TACOMA NARROWS BRIDGE** in the USA in 1940 was caused by such wind generated resonance.



RESONANCE DEMONSTRATION - BARTON'S PENDULUMS



Several pendulums of different lengths **(A,B,C,D and E)** hang from a supporting thread which is stretched between two fixed points as shown above. Each pendulum has its own natural frequency of oscillation.

When the driver pendulum **X** is set into oscillation, all the pendulums start to oscillate, but it is only pendulum C, whose length is equal to that of the driver (and so has **the same natural frequency**), which builds up a large amplitude. The response of the other pendulums depends on how close their length is to that of the driver **X**.

RESONANCE AND DAMPING

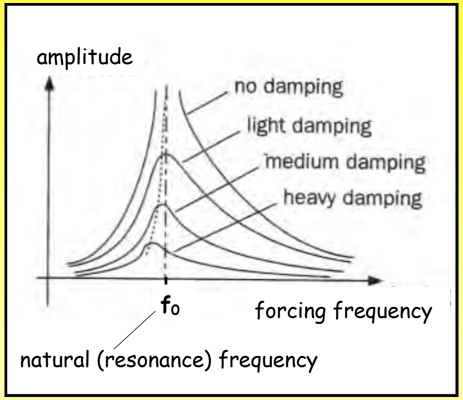
<u>WITHOUT DAMPING</u>

The amplitude (and hence energy) of a resonating system would increase continuously as shown in the diagram opposite.

In practice this can never happen because there is always some degree of damping.

<u>WITH DAMPING</u>

The amplitude (and energy) will increase until energy is being dissipated at the same rate as it is being supplied.



DAMPING decreases :

- **The <u>AMPLITUDE</u> of resonant vibrations.**
- **The frequency at which the MAXIMUM response occurs (i.e. the <u>RESONANCE FREQUENCY</u>, f_0).**

DAMPING is useful when we want to reduce the unwanted effects of **RESONANCE.** For example, during earthquakes buildings are forced to vibrate by the vibrations of the Earth. Resonance can occur and cause the buildings to collapse. To avoid this, buildings can be constructed on foundations that absorb the energy of the shock waves. This damping prevents the amplitude of the vibrations from reaching dangerously high levels.

• **PRACTICE QUESTIONS (3) (For class discussion)**

1 **Explain** what is meant by : (a) **FREE** vibrations, (b) **FORCED** vibrations, (c) **DAMPING,** and (d) **CRITICAL** damping.

2 (a) What is the effect of **DAMPING** on the **AMPLITUDE** and **RESONANT FREQUENCY** of an oscillating system ?

(b) Briefly describe an example of a system in which damping is ;

(i) **Desirable,** (ii) **Undesirable.**

3 Sketch graphs (on the same axes) to show how each of the following quantities changes during a single complete oscillation of an undamped pendulum :

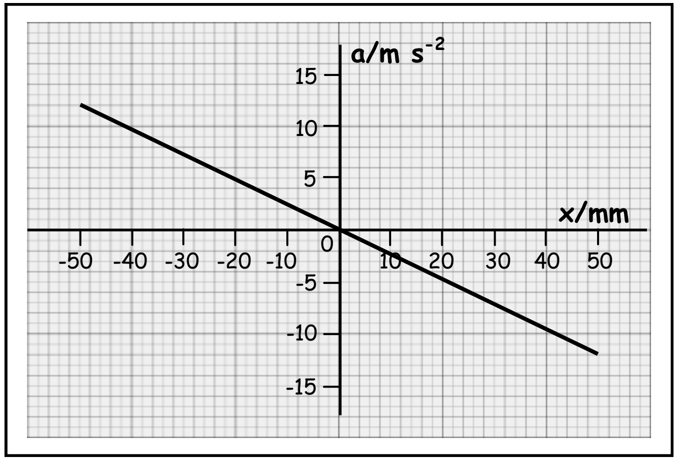
Kinetic energy **Potential energy** **Total energy**

4 State **two** examples of situations where resonance is a **PROBLEM,** and **two** others where resonance is **USEFUL.** In each case, say what the **oscillating system is** and **what forces it to resonate.**

5 The gear stick on an old car is found to vibrate with **large amplitude** when the car is at traffic lights and the engine is **idling** (i.e. running slowly at a low number of revolutions per second).

Explain why this only happens when the engine is **idling** and not at higher engine speeds.

1 A mass oscillates on the end of a spring in simple harmonic motion. The graph of the **acceleration (a)** of the mass against its **displacement (x)** from its equilibrium position is shown below.



(a) (i) **Define simple harmonic motion.**

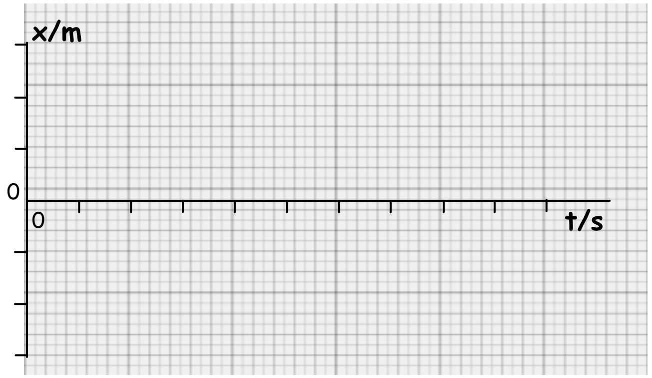
(ii) **Explain** how the graph shows that the mass is oscillating in simple harmonic motion.

(b) Use data from the graph :

(i) To find the **amplitude** of the motion.

(ii) To show that the **period** of oscillation is **0.4 s.**

(c) (i) The mass is released at **t = 0** at displacement **x = 0.050 m.** Draw a graph on the axes below of the displacement of the mass until **t = 1.0 s. Add scales to both axes.**



(ii) State a **displacement** and **time** at which the system has **maximum kinetic energy**.

(OCR A2 Physics - Module 2824 - January 2005)

2 The external wing mirror of a large vehicle is often connected to the body of the vehicle by a long metal arm as shown in **fig. 1** The wing mirror assembly sometimes behaves like a mass on a spring, with the mirror oscillating up and down in **simple harmonic motion** about its equilibrium position. The graph of **fig.2** shows a typical oscillation.

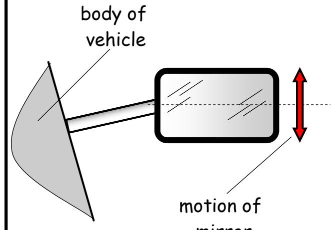
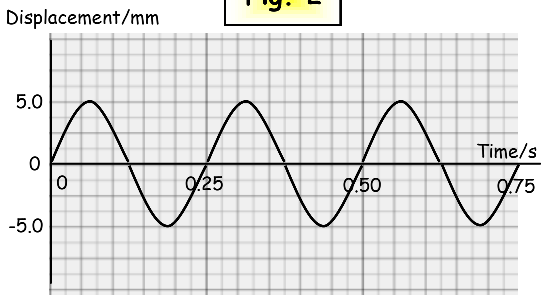


Fig. 1

Fig. 2



(a) (i) **Define simple harmonic motion.**

(ii) Calculate the **frequency** of oscillation of the wing mirror.

(iii) Calculate the **maximum acceleration** of the wing mirror.

(b) With the vehicle at rest and the engine running slowly at a particular number of revolutions per second, the wing mirror oscillates significantly, whereas at other engine speeds the mirror hardly moves.

(i) **Explain** how this phenomenon is an example of **resonance.**

(ii) Suggest, **giving a reason, one** change to the motion of the mirror :

1. For a mirror of **greater mass.**
2. For a metal arm of **greater stiffness.**

(OCR A2 Physics - Module 2824 - June 2006)

3 This question is about a **mass-spring system**. **Fig. 1** shows a mass attached to two springs. The mass moves along a horizontal tube with one spring stretched and the other compressed. An arrow marked on the mass indicates its position on the scale. **Fig.1** shows the situation when the mass is displaced through a distance **x** from its equilibrium position. The mass is experiencing an **acceleration a** in the direction shown. Fig.2 shows a graph of the **magnitude** of the **acceleration a** against the **displacement x.**

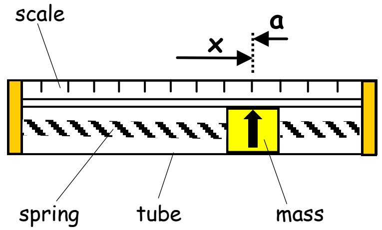


Fig.1

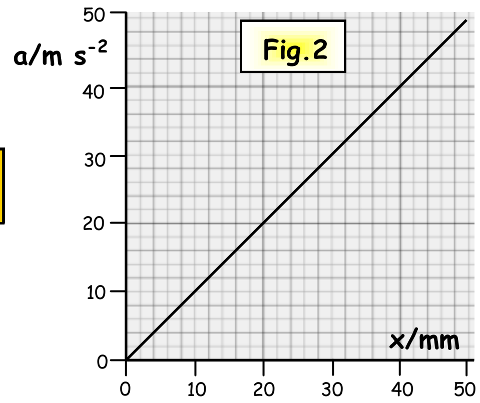


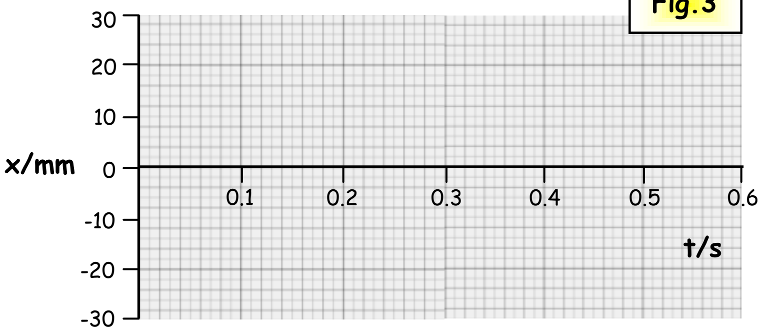
Fig.2

(a) (i) State **one feature** from each of **Fig.1** and **Fig.2** which shows that the mass performs **simple harmonic motion** when released.

(ii) Use data from **Fig.2** to show that the frequency of simple harmonic oscillations of the mass is about **5 Hz**.

(iii) The mass oscillates in damped harmonic motion before coming to rest. On the axes of **Fig.3**, sketch a graph of damped harmonic oscillation of the mass, from an initial displacement of **25.0 mm**.

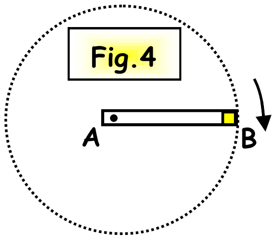
Fig.3



(b) The mass-spring system of **Fig.1** can be used as a device to measure acceleration, called an accelerometer. It is mounted on a rotating test rig, used to simulate large g-forces for astronauts. **Fig.4** shows the plan view of a long beam rotating about axis **A** with the astronaut seated at end **B**, facing towards **A**. The accelerometer is parallel to the beam and is fixed under the seat, **10 m** from **A**.

(i) When the astronaut is rotating at a constant speed, the arrow marked on the mass has a constant deflection. **Why ?**

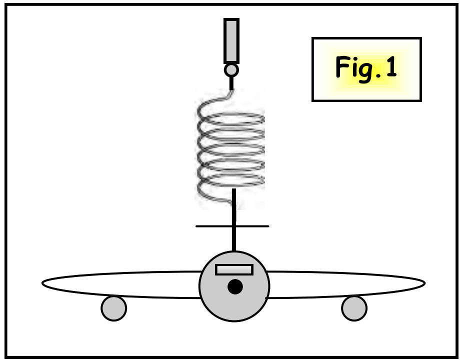
Fig.4



(ii) Calculate the **speed v** of rotation of the astronaut when the deflection is **50 mm**. *(OCR A2 Physics - Module 2824 - Jan 2006)*

4 (a) **Fig.1** shows a toy consisting of a light plastic aeroplane suspended from a long spring *16*

Fig.1



(i) The aeroplane is pulled down **0.040 m** and released. It undergoes a vertical **harmonic oscillation** with a period of **1.0 s**. The oscillations are **lightly damped**.

Sketch on the axes of **Fig.2** below, the **displacement y** of the aeroplane against **time t** from the moment of release.

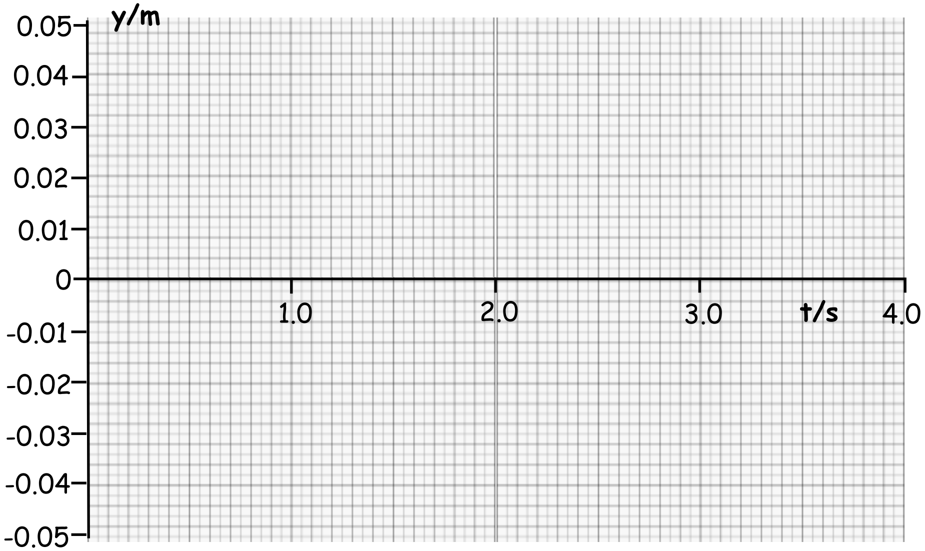


Fig.2

(ii) The aeroplane is replaced by a **heavier** model made of the **same plastic** having the **same fuselage**, but **larger wings**.

State and **explain TWO** changes which this substitution will make to the displacement against time graph that you have drawn on **Fig.2.**

(b) The top end of the spring in **Fig.1** is then vibrated vertically with a small constant amplitude. The motion of the aeroplane changes as the frequency of oscillation of the top end of the spring is increased slowly from **zero through resonance to 2.0 Hz.**

Explain the conditions for resonance to occur and **describe** the changes in the motion of the aeroplane as the frequency changes from zero to 2.0 Hz.

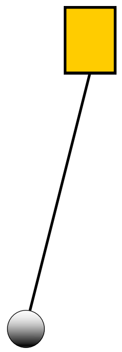
(OCR A2 Physics - Module 2824 - June 2005)

5 (a) **Define simple harmonic motion.**

(b) **Fig.1** shows a simple pendulum with the bob at the amplitude of its swing.

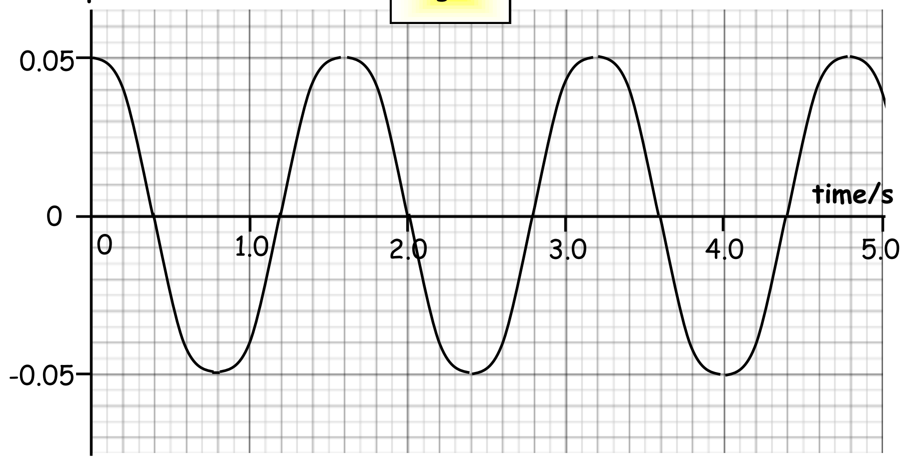
On **Fig.1, draw** and **label** arrows to represent the forces acting on the bob.

Fig.1



(c) **Fig.2** shows the graph of displacement of the bob against time.

Fig.2



(i) Use **Fig.2** to determine the **frequency** of oscillation of the pendulum. Give a suitable unit for your answer.

(ii) Use **Fig.2 or otherwise** to determine the **maximum speed** of the bob. Show your method clearly.

(d) The bob is now made to oscillate with **twice** its previous amplitude. The pendulum is still moving in simple harmonic motion.

State with a reason, the change, if any, in :

(i) The **period.**

(ii) The **maximum speed** of the bob.

(OCR A2 Physics - Module 2824 - June 2004)