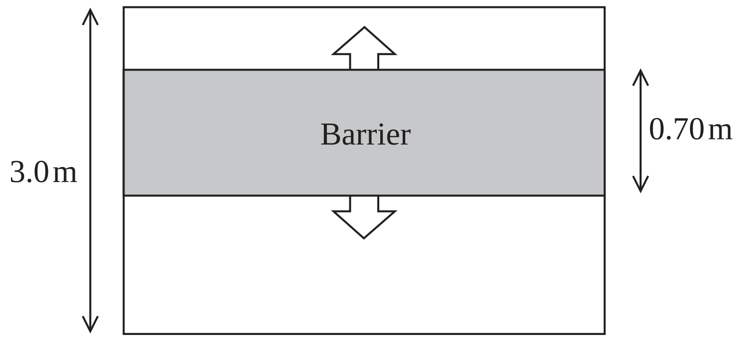
1 In a television game show contestants have to pass under a barrier. The barrier has a vertical height of 0.70 m and moves up and down with simple harmonic motion.



(a) State the conditions which must be met for an object to move with simple harmonic motion.

(2)

(b) The bottom edge of the barrier is initially in contact with the ground and moves up to a height of 2.3 m before returning back to its starting position. The bottom edge of the barrier touches the ground every 4.5 s.

A contestant requires a space at least 0.60 m high to get under the barrier.

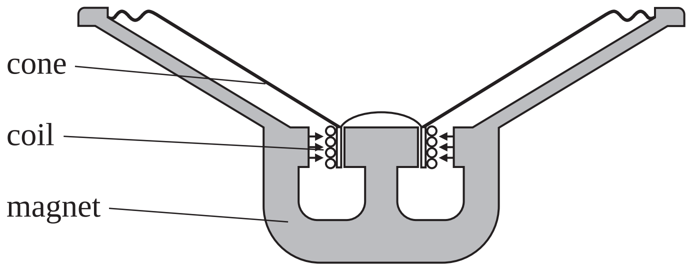
Calculate the maximum time this contestant has to get under the barrier.

(5)

Maximum time =

(Total for Question = 7 marks)

2 A simple loudspeaker consists of a cone, a coil of wire and a magnet. The cone and coil are attached to each other and are free to move. An alternating current in the coil causes the cone to oscillate.



*(a) Explain why an alternating current in the coil causes the cone to oscillate with the frequency of the alternating current.

(3)

(b) The loudspeaker cone undergoes simple harmonic motion.

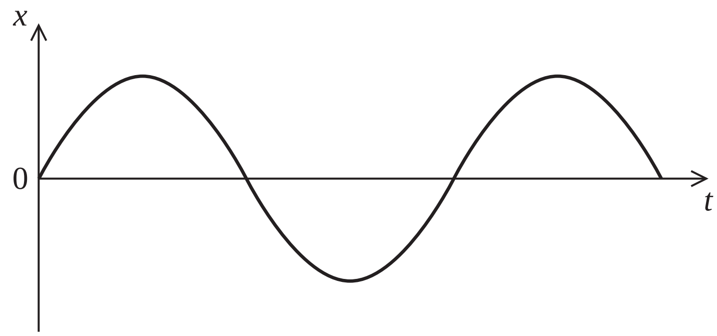
(i) State what is meant by simple harmonic motion.

(2)

(ii) The graph below shows how the displacement x of the cone varies with time t.

Add another line to the graph to show how the acceleration of the cone varies over the same time interval.

(1)



(c) Some sand is sprinkled onto the cone. The sand oscillates vertically with the frequency of the cone. Keeping the frequency constant, the current is increased. This increases the amplitude of oscillation of the cone.

At a particular amplitude of oscillation the sand begins to lose contact with the cone.

(i) By considering the forces acting on a grain of sand, explain why this happens.

(3)

(ii) At a particular frequency, when the amplitude of the cone is 0.25 mm, a grain of sand loses contact with the cone.

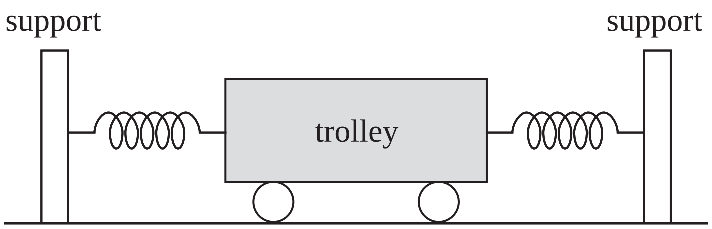
Calculate this frequency.

(3)

Frequency =

(Total for Question = 12 marks)

3 The diagram shows a mass-spring system that consists of a trolley held in equilibrium by springs attached to two fixed supports.



The trolley has a mass m and the spring arrangement has a force constant k.

(a) (i) The trolley is displaced towards one of the supports through a distance x and then released. Show that the initial acceleration of the trolley when it is released is given by $a = -\frac{kx}{m}$ and explain the significance of the minus sign.

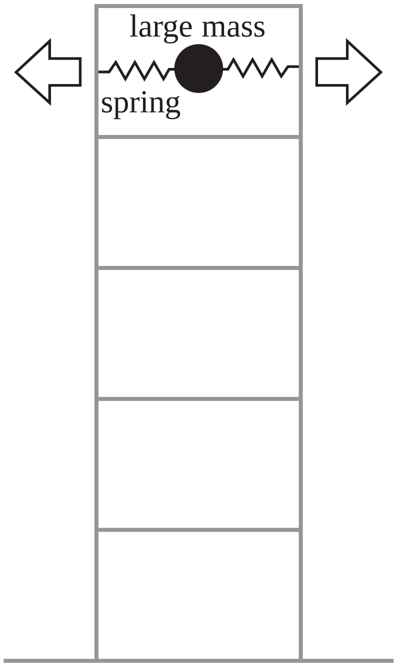
(2)

(ii) Use the expression in (i) to show that the trolley will oscillate with a time period T given by

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

(3)

(b) Mass-spring systems are sometimes used in tall buildings to reduce the oscillation of the building due to strong winds.



As the top of the building moves the mass is set into oscillation. The mass-spring system is designed to have a natural frequency equal to that of the building.

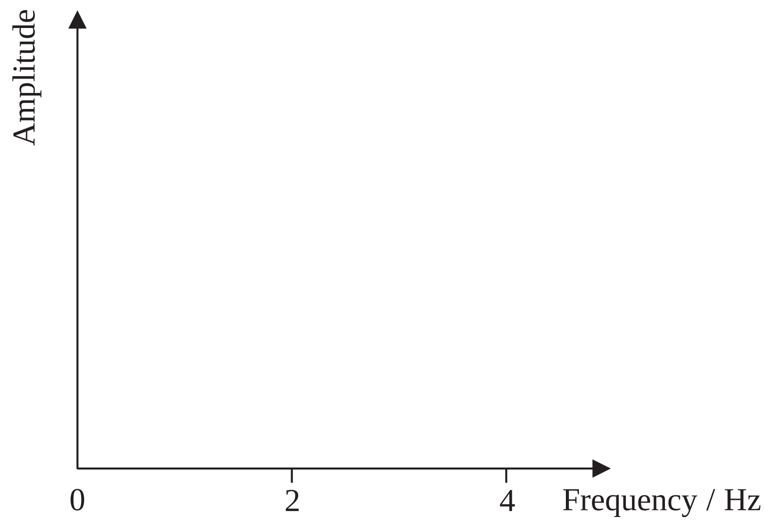
(i) In one building a mass-spring system has a mass of 3.5×10^5 kg and the spring arrangement has a force constant of 4.8×10^6 N m^{-1}.

Show that the natural frequency of the mass-spring system is about 0.6 Hz.

(3)

(ii) Sketch a graph to show how the amplitude of oscillation of the mass would vary with the frequency of movement of the building. Ignore the effects of damping.

(3)



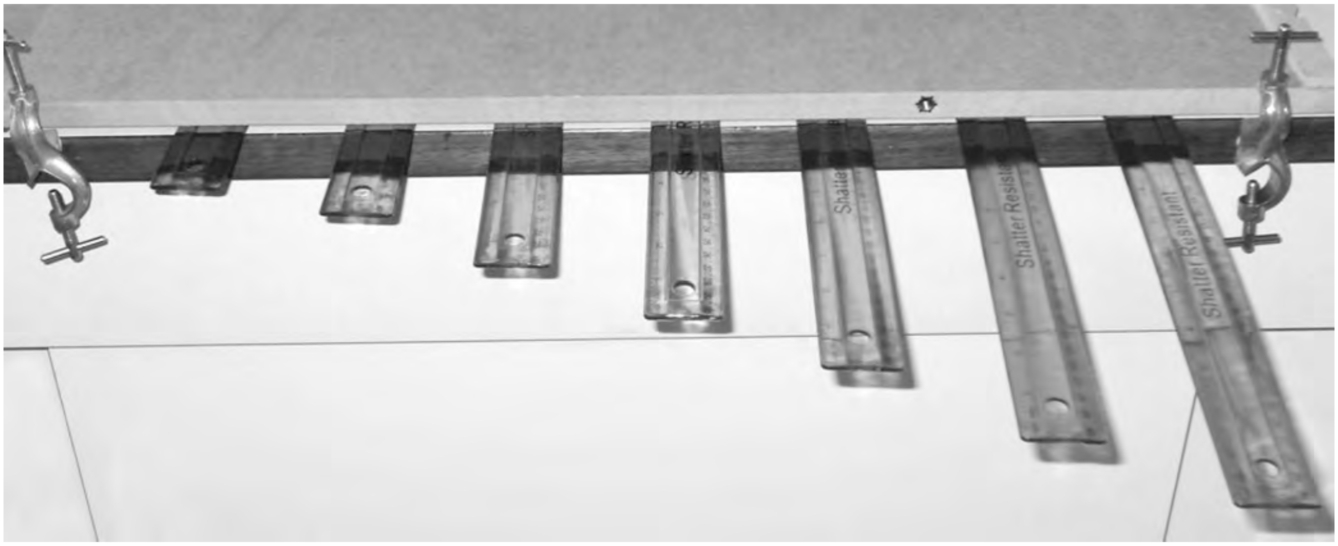
(iii) In order to be effective the mass-spring system needs to be damped.

Explain what is meant by damping in this context and suggest why damping is a desirable feature of the mass-spring system in a tall building.

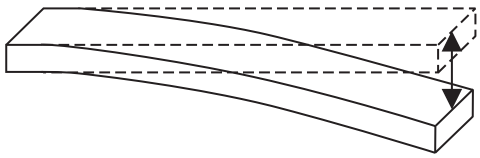
(3)

(Total for Question = 14 marks)

4 A student makes the “ruler piano” shown in the photograph.



One end of each ruler is held flat on the desk whilst the other end is set into oscillation. Each ruler oscillates at a different frequency. Some of the rulers produce an audible sound.



(a) State the condition for an oscillation to be simple harmonic.

(2)

(b) The end of one ruler moves through 5.0 cm from one extreme position to the other, and makes 10 complete oscillations in 4.5 s.

Calculate the maximum velocity of this end.

(3)

Maximum velocity =

(c) A standing wave is set up on each oscillating ruler.

Explain why each length of ruler oscillates at a different frequency.

(3)

(Total for Question = 8 marks)

5 A toy for cats consists of a plastic mouse of mass m attached to a spring. When the mouse is on a low-friction horizontal surface, with the spring attached to a rigid support as shown, it performs simple harmonic motion when given a small displacement x from its equilibrium position and released.

(a) Show that the acceleration of the mouse, a, is given by $a = -\left(\frac{k}{m}\right)x$, where k is the stiffness of the spring.

(2)

(b) The mouse has a mass m = 0.15 kg and the spring extends by 20 cm when the mouse is supported vertically by the spring.

Calculate the frequency of oscillation of the mouse if it is set into oscillation on a low friction horizontal surface.

(5)

Frequency =

(Total for Question = 7 marks)