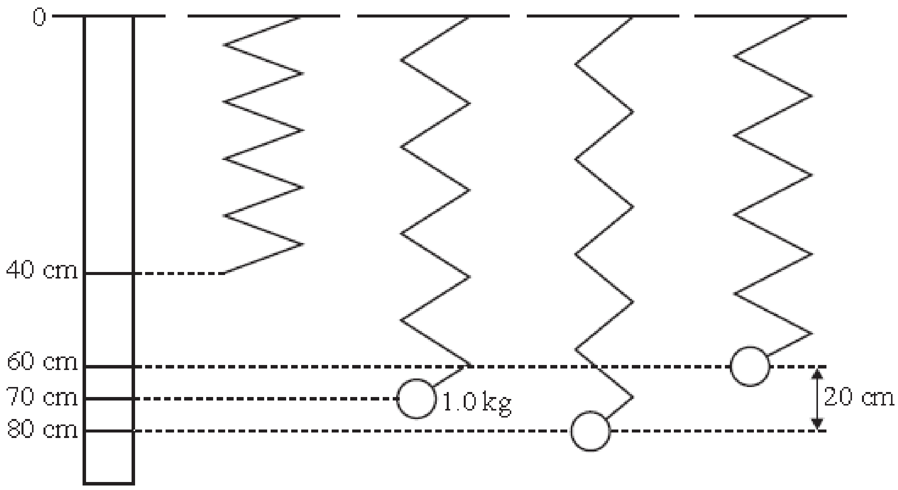
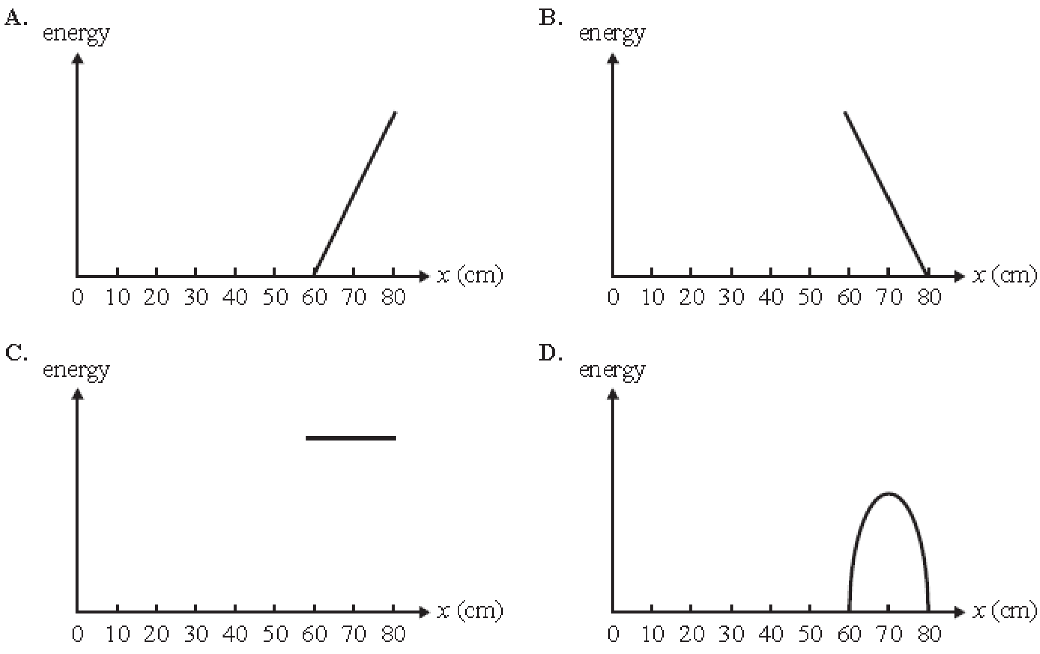
This question is straight from the 2011 mid-year exam. It is difficult and requires some thinking about the solution.

Physics students are conducting an experiment on a spring which is suspended from the ceiling. Ignore the mass of the spring.

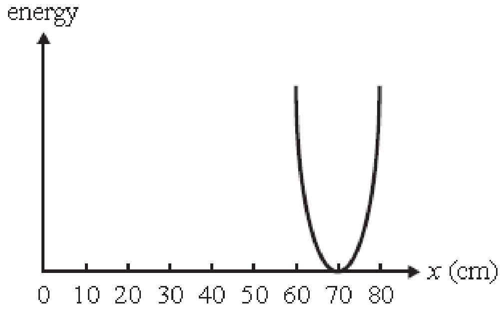


Without the mass attached, the spring has an unstretched length of 40 cm. A mass of 1.0 kg is then attached. When the 1.0 kg mass is attached, with the spring and mass stationary, the spring has a length of 70 cm.
The spring is now pulled down a further 10 cm from 70 cm to 80 cm and released so that it oscillates. Gravitational potential energy is measured from the point at which the spring is released (80 cm on previous figure).

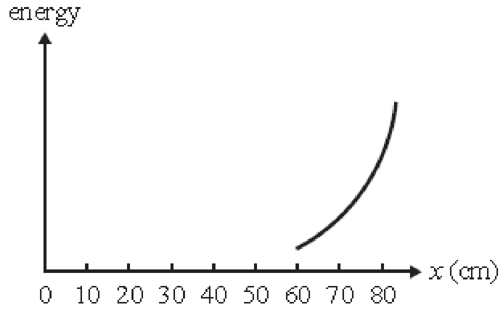
Use the following graphs (A–H) in answering Questions 17–20.



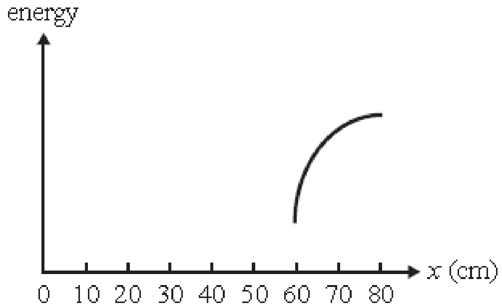
E.



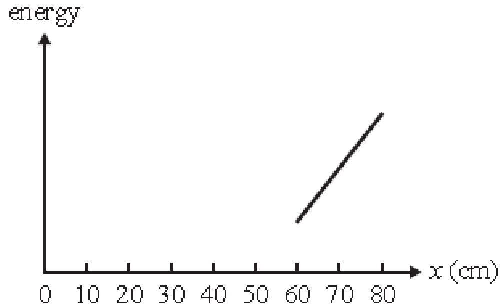
F.



G.



H.



Example 1 (2011 Question 17, 1 mark)

Which of the graphs (**A – H**) best shows the variation of the kinetic energy of the system plotted against the length of the stretched spring?

The kinetic energy of the system, is considered as the KE of the mass. At both extremes of the masses motion, it momentarily comes to rest, so the KE at these points is zero. The mass has its maximum speed in the middle of the motion, therefore the max KE occurs in the middle (at 70 cm)

Therefore graph D is best. (Average score 0.4/1)

Example 2 (2011 Question 18, 1 mark)

Which of the graphs (**A – H**) best shows the variation of the total energy of the system of spring and mass plotted against the length of the stretched spring?

The total energy of the system must remain unchanged because there are not any forces adding energy to the system by doing work.
Therefore the graph needs to be a straight horizontal line

Therefore graph C is best. (Average score 0.7/1)

Example 3 (2011 Question 19, 1 mark)

Which of the graphs (**A – H**) best shows the variation of the gravitational potential energy of the system of spring and mass (measured from the lowest point as zero energy) plotted against the length of the stretched spring?

Gravitational potential energy is given by mgh. This is a linear function, so the graph will be a straight line. It must have zero GPE at 80 cm.

Therefore graph B is best. (Average score 0.5/1)

Example 4 (2011 Question 20, 1 mark)

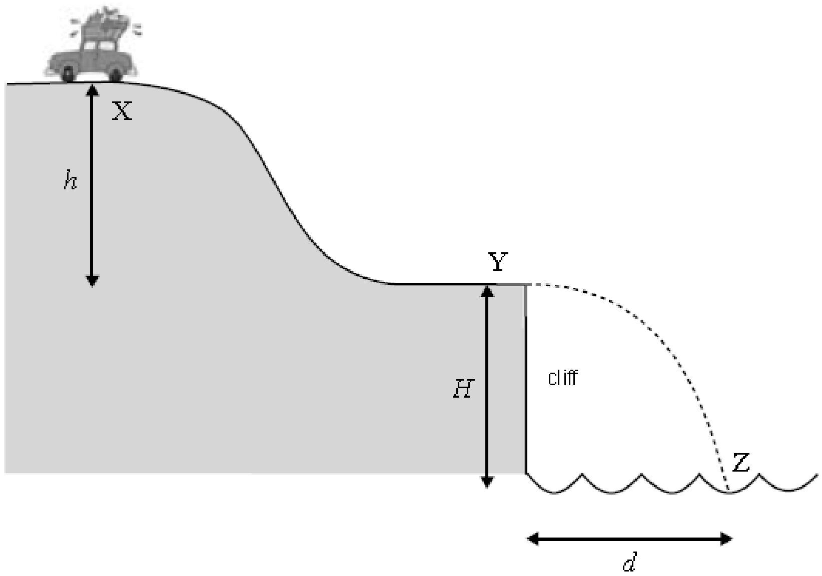
Which of the graphs (**A – H**) best shows the variation of the spring (strain) potential energy of the system of spring and mass plotted against the length of the stretched spring? Give reasons for choosing this answer for the spring (strain) potential energy.

Spring (strain) energy is given by ½ $k(\Delta x)^2$. The spring energy increases as the length of the spring changes from 60 cm to 80 cm, as Δx increases from 20 cm to 40 cm. The graph is not linear, (from E = ½ $k(\Delta x)^2$), hence the parabolic curve. The curve should tend to zero when $\Delta x \rightarrow 0$, i.e 40 cm length.

Therefore graph F is best. (Average score 0.8/3)

Multiple Choice Questions

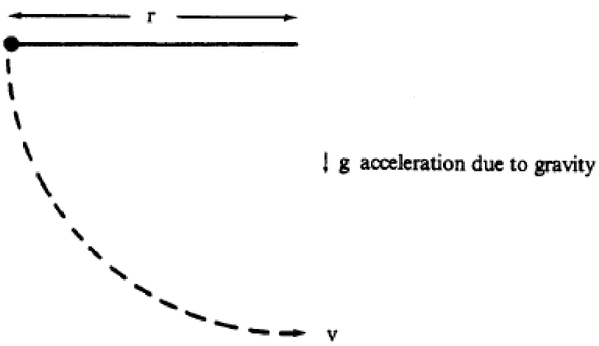
A car is on top of a hill at X, *h* metres above the top of a cliff. The top of the cliff is *H* metres above the water level. The brakes are released and the car begins to roll back down the hill. When the car reaches the cliff at Y it is projected horizontally and travels a horizontal distance, *d* metres, from the cliff edge. It enters the water at Z.
Take the acceleration due to gravity as *g* downwards. (For the following questions, ignore air resistance.)



Example 1 (2004 Question 12, 2 marks)

Which of the expressions (**A – D**) gives the speed of the car at point Y?

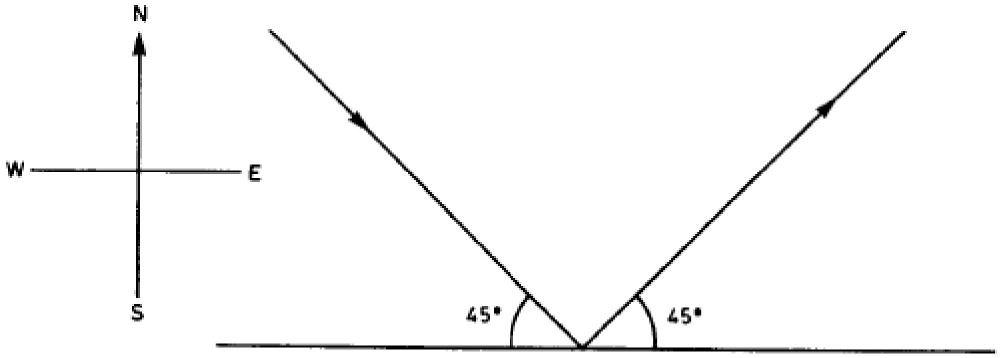
A. $\sqrt{2gh}$ **B.** $\sqrt{2gH}$ **C.** $\sqrt{2g(H+h)}$ **D.** $\sqrt{2g(H-h)}$



Example 2 (1981 Question 20, 1 mark)

A heavy ball on the end of a string of length *r* is raised to a horizontal position and then released. Its speed at the lowest point of its path will be equal to

A. gr **B.** $2gr$ **C.** $\sqrt{2gr}$ **D.** $\sqrt{\frac{\pi gr}{2}}$



A particle of mass *m*, travelling south-east at constant speed *v*, hits a wall and then travels north-east at the same speed *v*.

Example 3 (1980 Question 17, 1 mark)

The acceleration of the particle while it is in contact with the wall is

A. zero

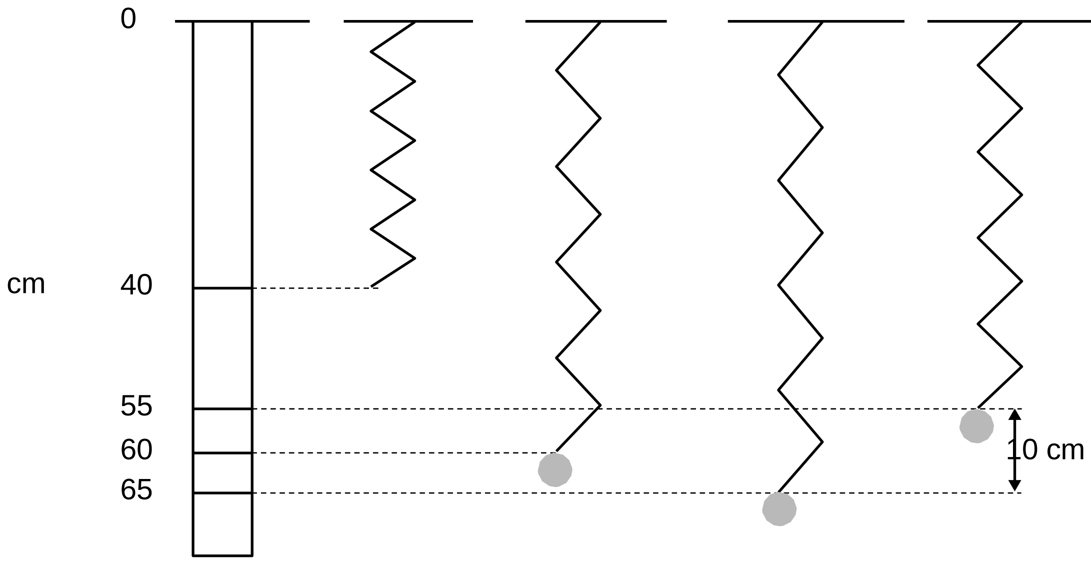
B. towards the east

C. towards the west

D. towards the north

E. changing from south-east to north-east

A novelty toy consists of a metal ball of mass 0.20 kg hanging from a spring of spring constant $k = 10\ N\ m^{-1}$. The spring is attached to the ceiling of a room as shown below. Ignore the mass of the spring.

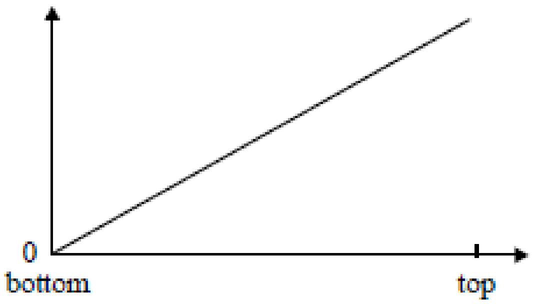


Without the ball attached, the spring has an unstretched length of 40 cm. When the ball is attached, but not oscillating, the spring stretches to 60 cm.

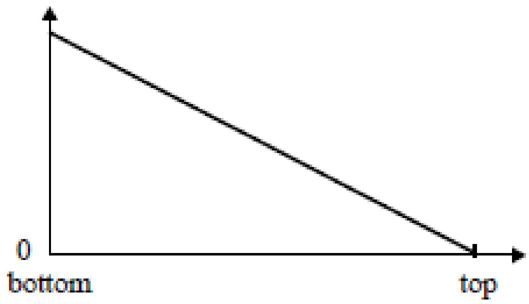
The ball is now pulled down a further 5 cm and released so that it oscillates vertically over a range of approximately 10 cm.
Gravitational potential energy is measured from the level at which the ball is released. Ignore air resistance.

Use Graphs A–E in answering Questions 13 and 14.

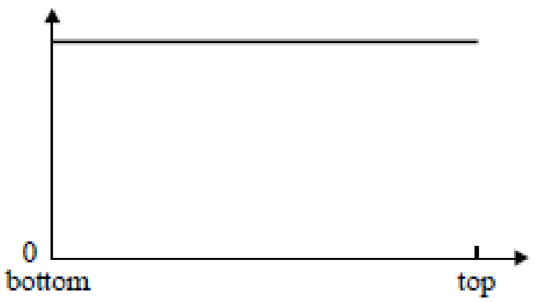
A.



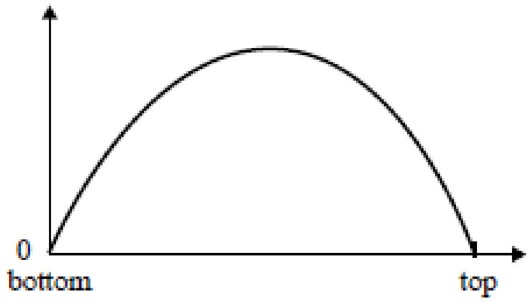
B.



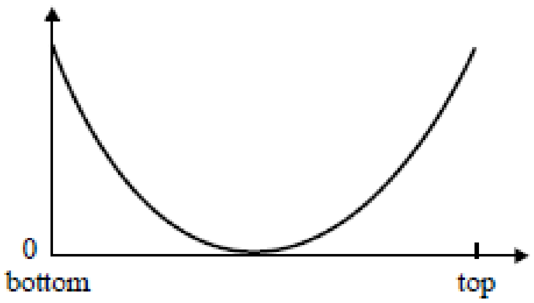
C.



D.



E.



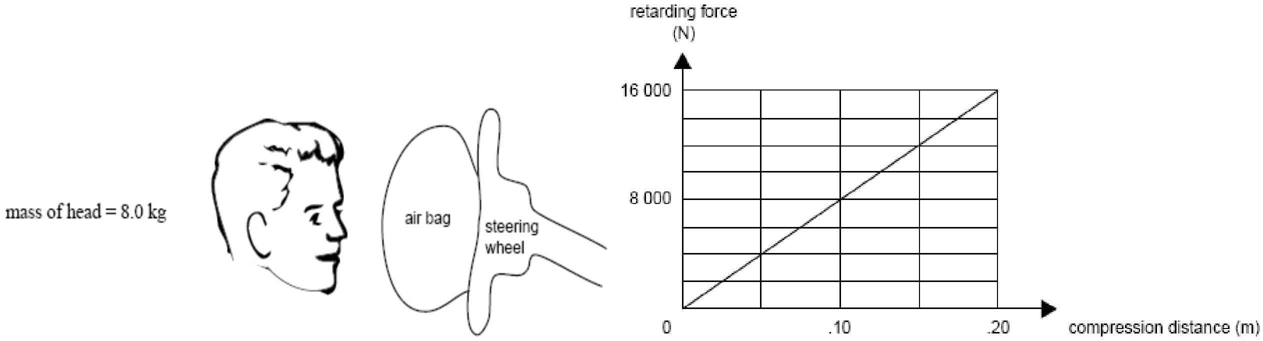
Example 4 (2008 Question 13, 2 marks)

Which of the graphs best represents the shape of the graph of **kinetic** energy of the system as a function of height?

Example 5 (2008 Question 14, 2 marks)

Which of the graphs best represents the **gravitational potential** energy of the system as a function of height?

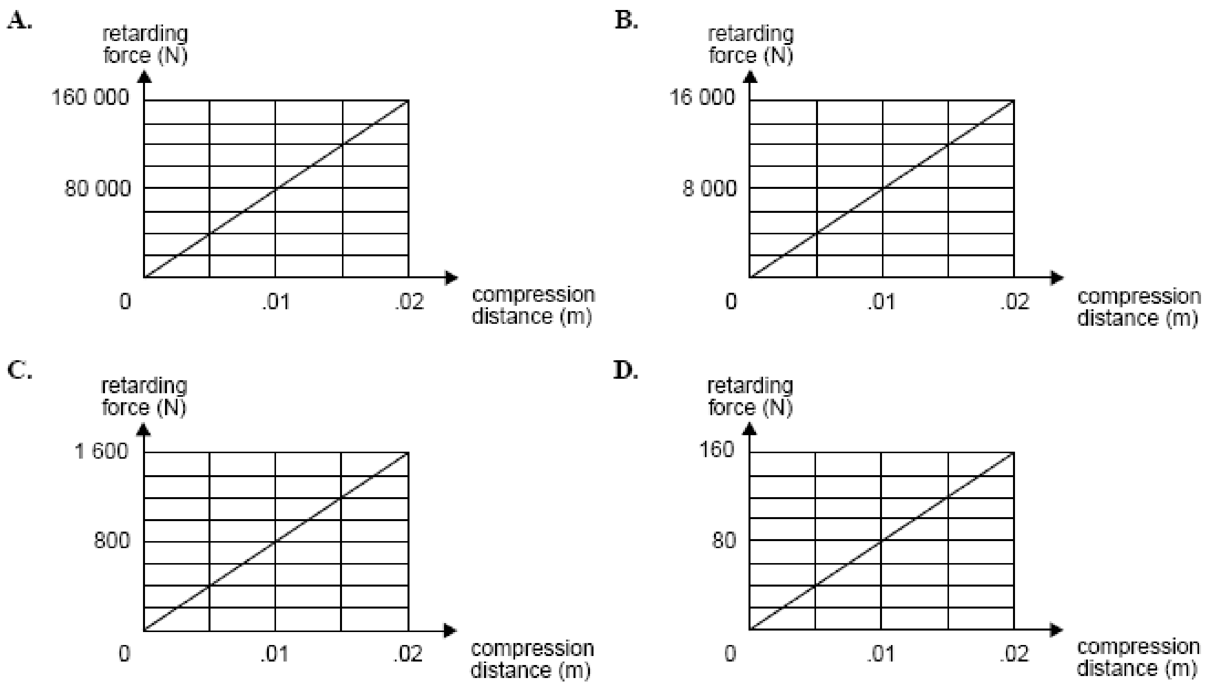
A car, equipped with a driver's air bag, hits a large tree while travelling horizontally at 54 km h^{-1} (15 m s^{-1}). The air bag is designed to protect the driver's head in a collision.
For Questions **8 – 9**, model this as a collision involving the driver's head (mass 8.0 kg).



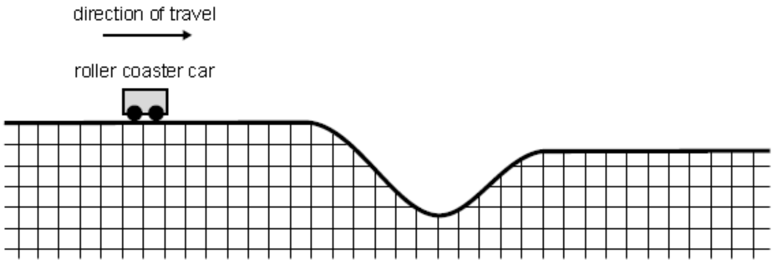
Tests show that the graph of retarding force on the driver's head versus compression distance of the air bag is as shown.

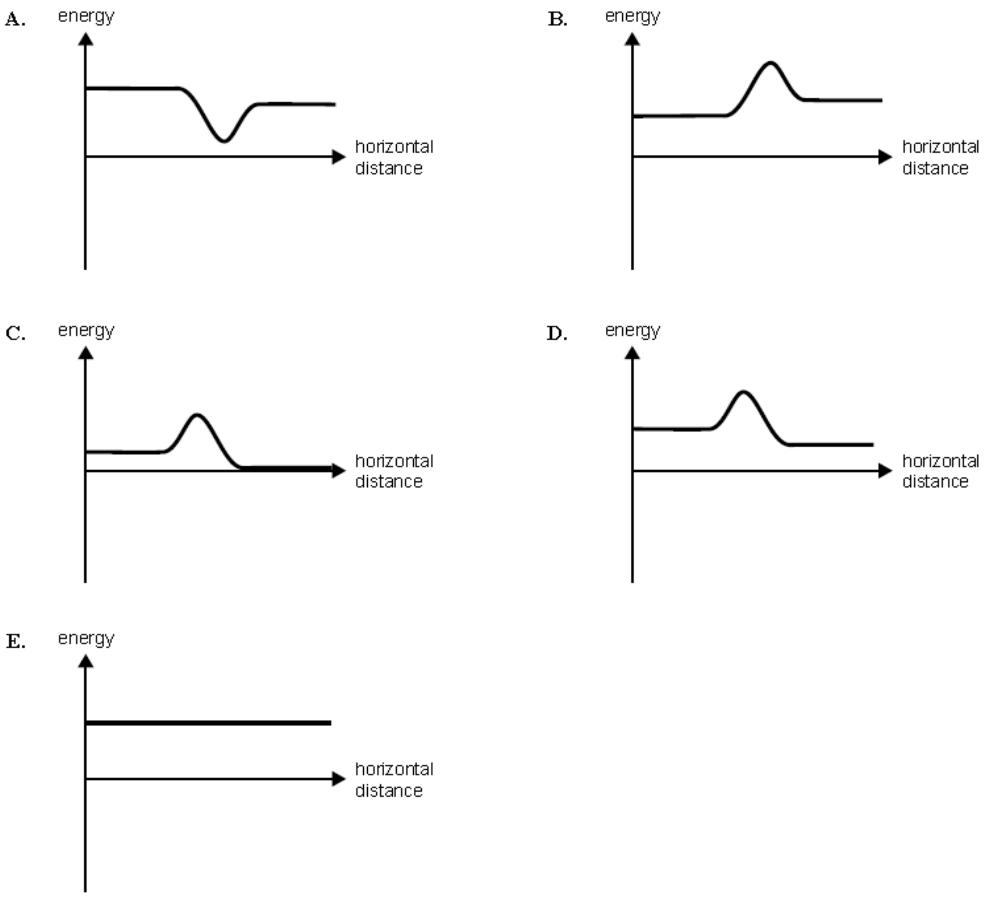
Example 6 (2000 Question 8, 2 marks)

Which **one** of the graphs (**A**–**D**) best represents the retarding force versus compression distance if the collision was with the hard surface of the steering wheel rather than the air bag?



The diagram below shows a section of a roller coaster track. The roller coaster car is travelling at constant speed towards the right.





Example 7 (2001 Question 7, 2 marks)

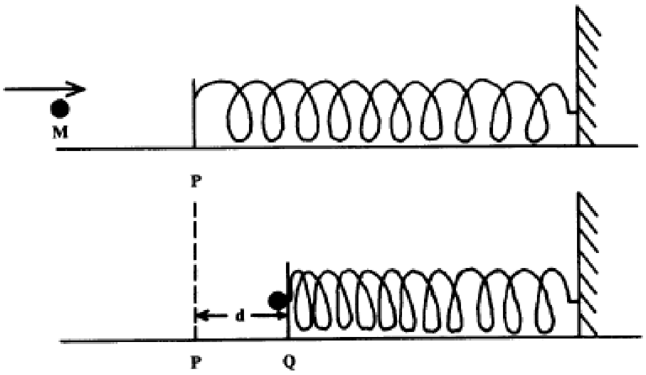
Which of the graphs (**A** – **E**) best shows the gravitational potential energy of the roller coaster car against the horizontal distance from the start of the track?

Example 8 (2001 Question 8, 2 marks)

Which of the graphs (**A** – **E**) best shows the kinetic energy of the roller coaster car against the horizontal distance from the start of the track? (Neglect frictional effects.)

Example 9 (2001 Question 9, 1 mark)

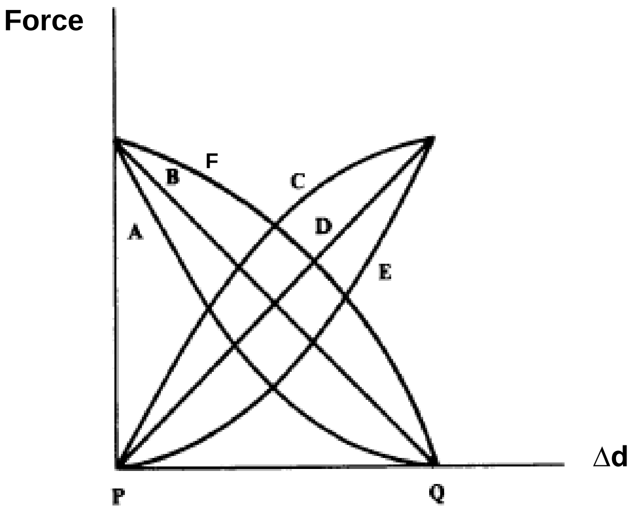
Which of the graphs (**A – E**) best shows the total energy of the roller coaster car against the horizontal distance from the start of the track? (Neglect frictional effects.)



A moving mass M, strikes and sticks to the end of a light spring of spring constant *k*, which is lying on a smooth surface as shown above. As a result of this impact the spring is compressed by an amount *d* from *P* before it comes momentarily to rest at *Q*.

Example 10 (1982 Question 29, 1 mark)

Which of the graphs (A – F) below best shows the variations with distance, of the force exerted on the spring by the mass *M*?



Example 11 (1982 Question 31, 1 mark)

Which of the expressions below is correct for the velocity of the mass when it first contacted the end of the spring?

A. $\frac{1}{2}kd^2$

B. kd

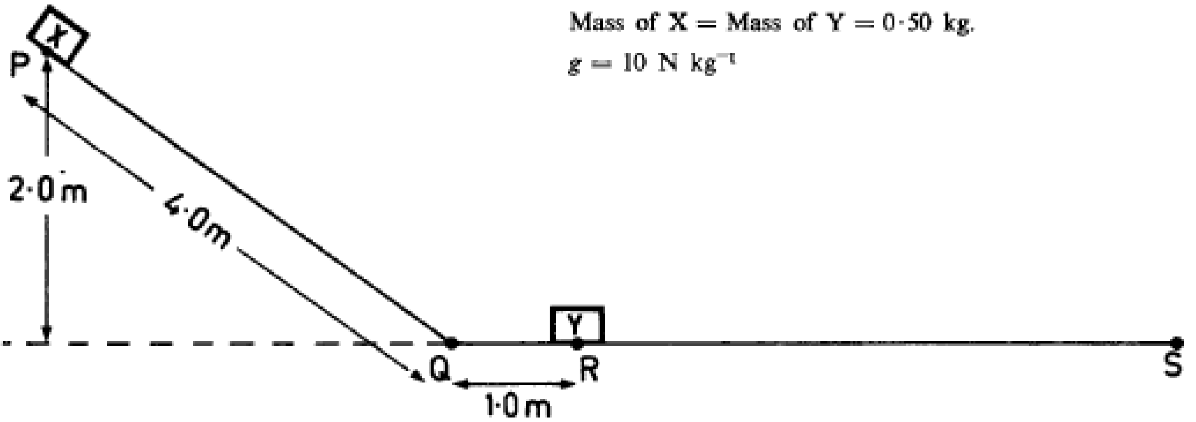
C. $\sqrt{\frac{k}{m}}d$

D $\frac{1}{2\pi}\sqrt{\frac{k}{m}}$

Example 12 (1982 Question 32, 1 mark)

Which of the graphs (**A – E**) best shows the variation of the kinetic energy of the mass as it moves from *P* to *Q*

Two blocks, X and Y, are at points P and R as shown in the diagram, *which is not to scale.*



X and Y are initially at rest at the positions shown in the diagram.

Example 13 (1978 Question 32, 1 mark)

The kinetic energy of the two blocks at the end of their motions is zero, i.e. it is less than the initial potential energy of block X. Which of the following statements provides the best explanation for this?

A. Energy is not conserved in this situation.

B. The potential energy of block X has been transformed into forms of energy other than kinetic energy of the blocks.

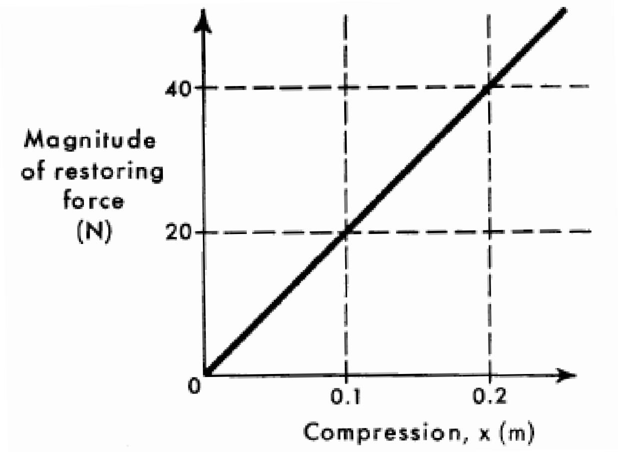
C. Potential energy is never conserved.

D. Potential energy has been lost because the collision between X and Y was elastic.

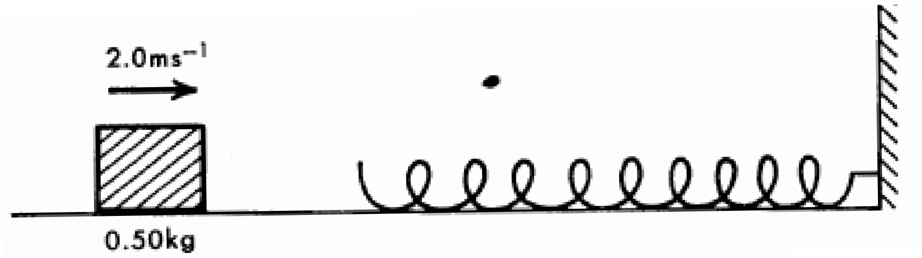
A spring behaves so that the restoring force it exerts is related to the compression by the relationship

$F = 200\,x$

Where F is the magnitude of the restoring force (in N) and x is the compression (in m).



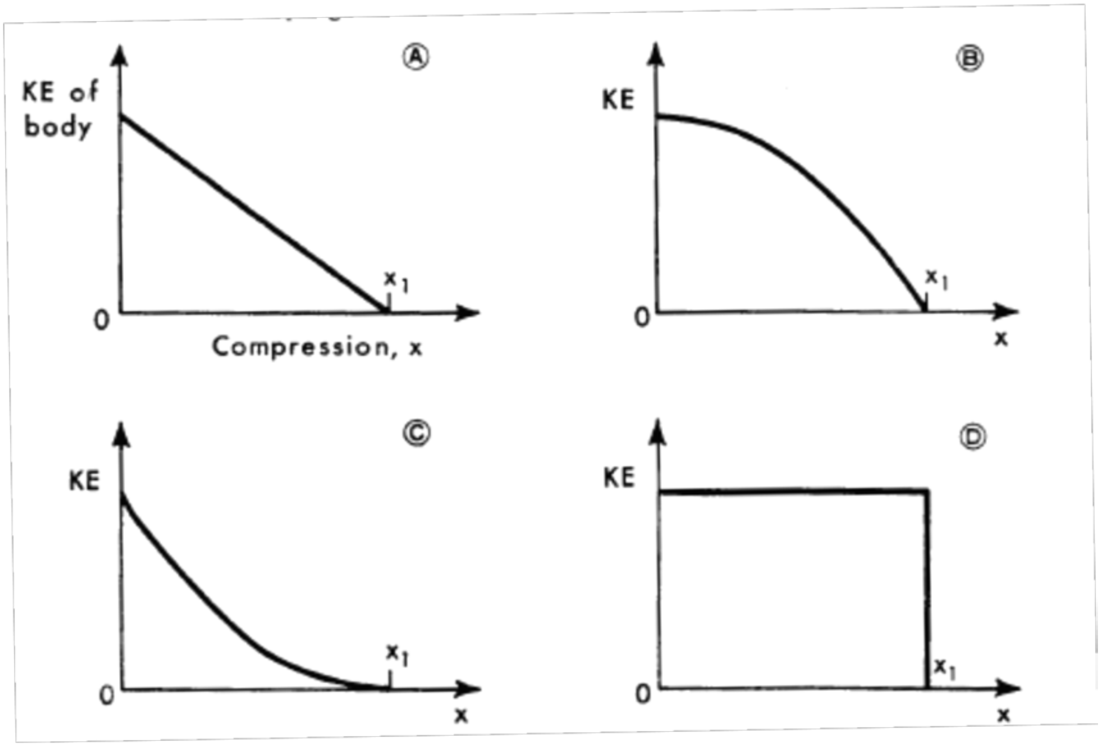
A body of mass 0.50 kg travelling at 2.0 m s^{-1} approaches the spring which is fixed to a wall as shown below. Friction can be neglected.



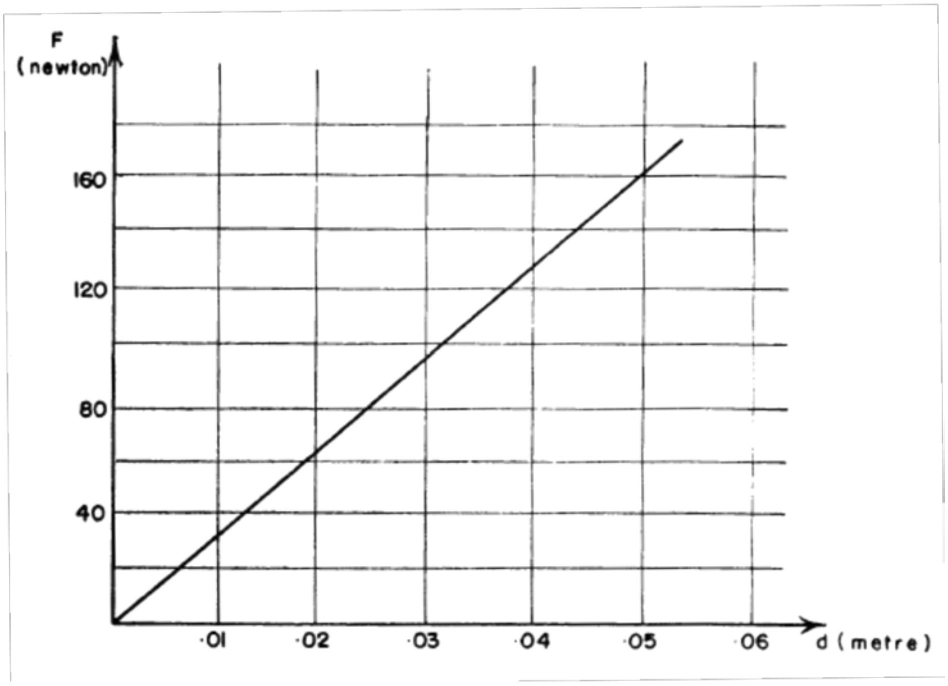
The body comes to rest instantaneously at a time t_1, when the spring is compressed by a total amount x_1. It then rebounds.

Example 14 (1977 Question 22, 1 mark)

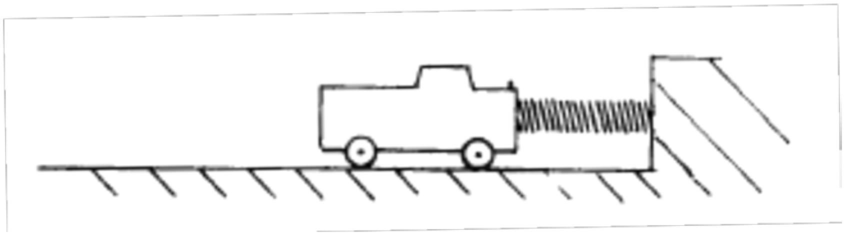
Which of the graphs below best represents the kinetic energy of the body as a function of the compression, x_1 of the spring?



The graph below shows the relation between force applied and compression for a steel spring.

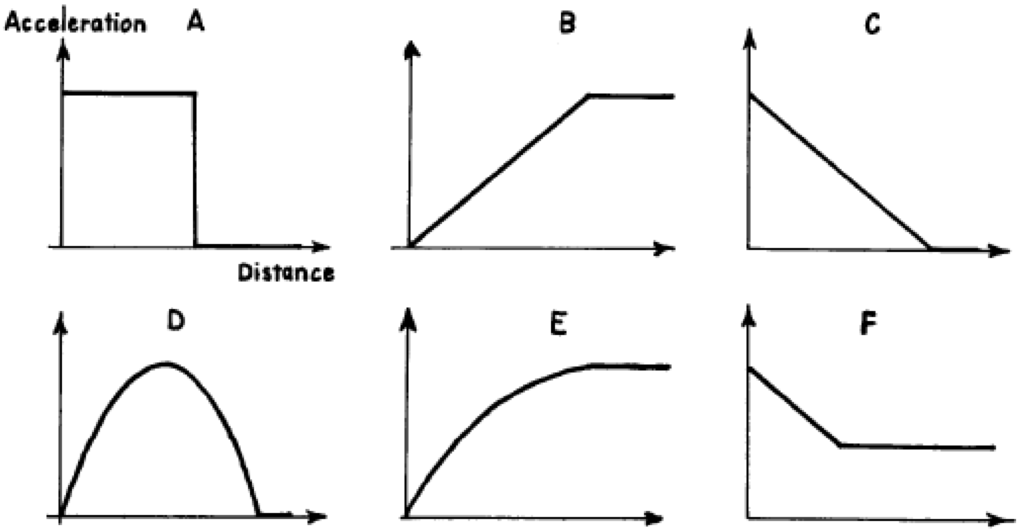


The spring is now compressed by 0.01 m and placed between a fixed support and a toy car of mass 20 kg.



Example 15 (1974 Question 23, 1 mark)

Which of the following graphs best represents the relationship between the acceleration of the toy car and the distance travelled by the toy car?



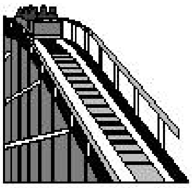
Extended Questions

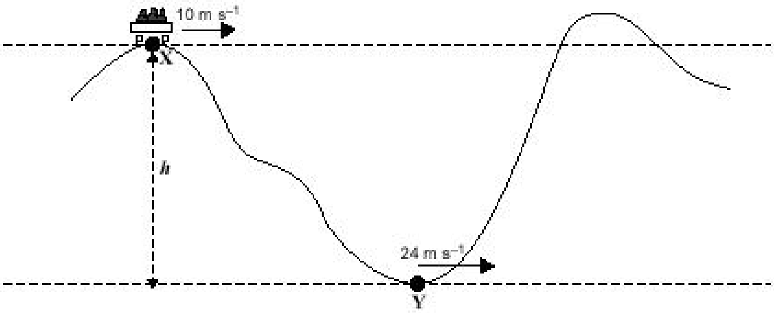
A delivery van of mass 1200 kg, travelling south at 20 m s^{-1}, collides head-on with a power pole. The impact crushes the crumple zone of the van by 0.60 m bringing the van to rest against the pole.

Example 16 2004 Question 4 (3 marks)

Calculate the average force that the pole exerts on the van.

Jo is riding on a roller-coaster at a fun fair. Part of the structure is shown below





When Jo is at **X** her velocity is 10 m s^{-1} in a horizontal direction, and at **Y** it is 24 m s^{-1} in a horizontal direction.

Example 17 (2000 Question 14, 3 marks)

What is the height difference (*h*) between points **X** and **Y**? Assume that friction and air resistance are negligible.

A car – truck crash can be modelled as a ‘head-on’ collision between a truck of mass 4000 kg travelling at 15 m s^{-1} and a stationary car of mass 1000 kg.
After the collision the truck continues moving forward at 10 m s^{-1}.

Example 18 (1998 Question 4, 3 marks)

Calculate the speed of the car immediately after the collision.

Example 19 (1998 Question 5, 2 marks)

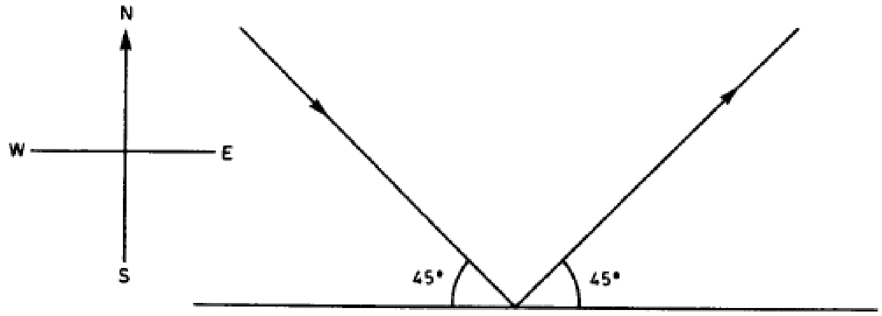
Calculate the combined total kinetic energy of the **truck** and **car** immediately **before** the collision.

Example 20 (1998 Question 6, 2 marks)

Calculate the combined total kinetic energy of the **truck** and **car** immediately **after** the collision.

Example 21 (1998 Question 7, 3 marks)

Compare the magnitudes of the **total** kinetic energies before and after the collision as calculated in Questions 5 and 6. Explain any differences that you observe.

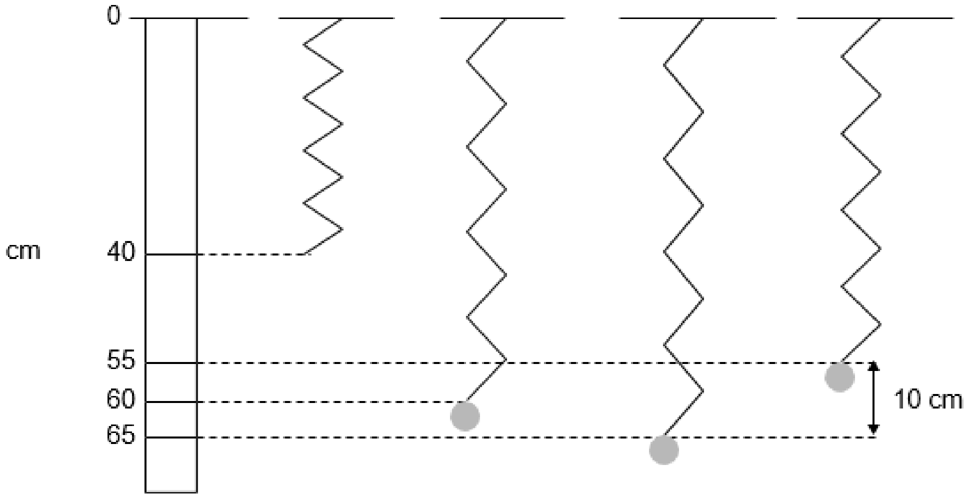


A particle of mass *m*, travelling south-east at constant speed *v*, hits a wall and then travels north-east at the same speed *v*.

Example 22 (1980 Question 16, 1 mark)

How much work has been done on the particle by the wall?

A novelty toy consists of a metal ball of mass 0.20 kg hanging from a spring of spring constant $k = 10\ N\ m^{-1}$. The spring is attached to the ceiling of a room as shown below. Ignore the mass of the spring.

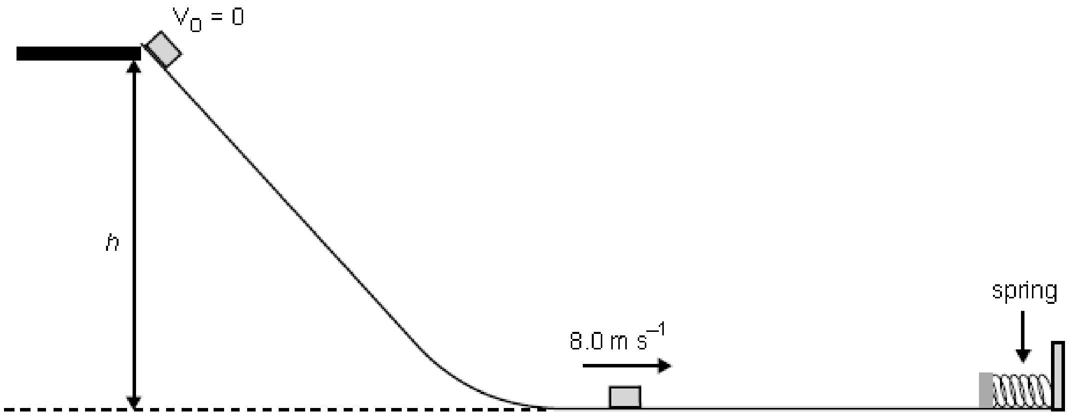


Without the ball attached, the spring has an unstretched length of 40 cm. When the ball is attached, but not oscillating, the spring stretches to 60 cm.

Example 23 (2008 Question 12, 2 marks)

How much energy is stored in the spring when the ball is hanging stationary on it? You must show your working.

In a storeroom a small box of mass 30.0 kg is loaded onto a slide from the second floor, and slides from rest to the ground floor below, as shown below. The slide has a **linear length of 6.0 m**, and is designed to **provide a constant friction force** of 50 N on the box. The box reaches the end of the slide with a speed of 8.0 m s^{-1}.



Example 24 (2004 Pilot Question 14, 4 marks)

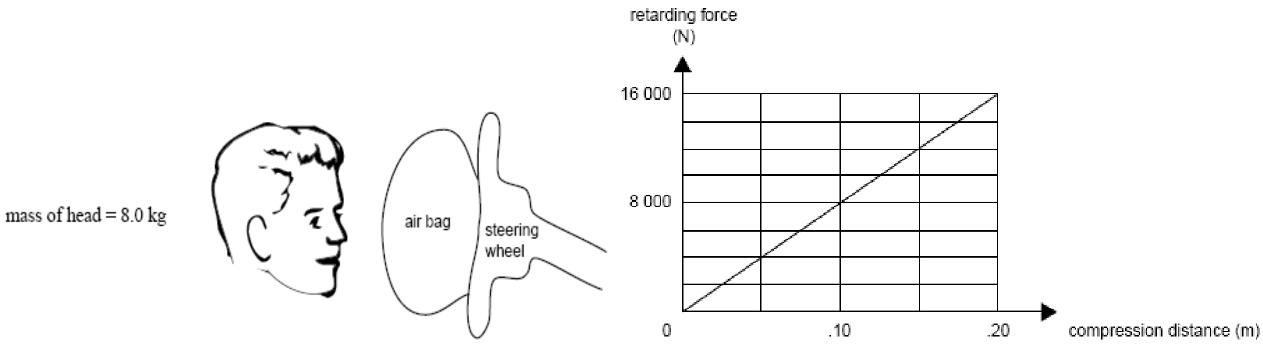
What is the height, *h*, between the floors?

The box then slides along the **frictionless floor**, and is momentarily stopped by a spring of stiffness 30 000 N m^{-1}.

Example 25 (2004 Pilot Question 15, 3 marks)

How far has the spring compressed when the box has come to rest?

A car, equipped with a driver's air bag, hits a large tree while travelling horizontally at 54 km h^{-1} (15 m s^{-1}). The air bag is designed to protect the driver's head in a collision.
For Questions **7 – 9**, model this as a collision involving the driver's head (mass 8.0 kg).

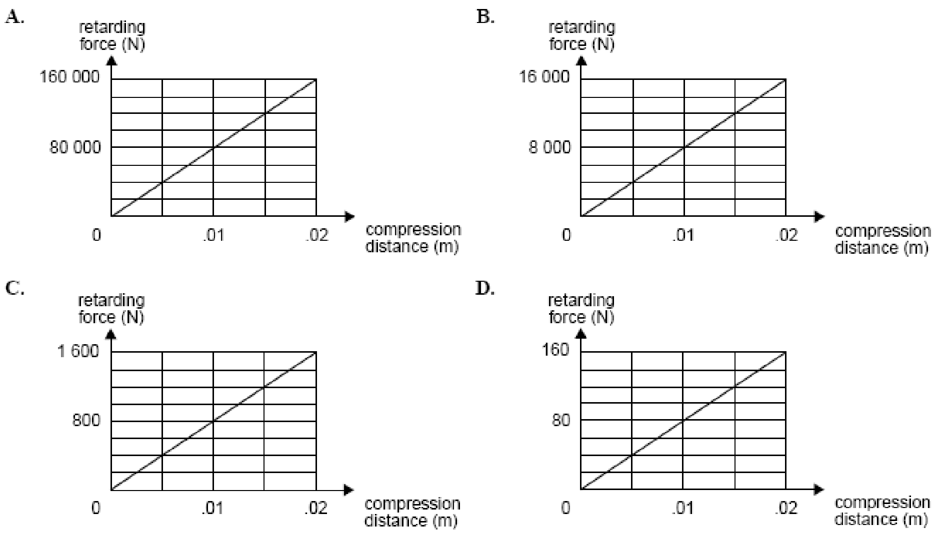


Tests show that the graph of retarding force on the driver's head versus compression distance of the air bag is as shown.

Example 26 (2000 Question 7, 4 marks)

Calculate the maximum compression distance of the air bag in this collision.

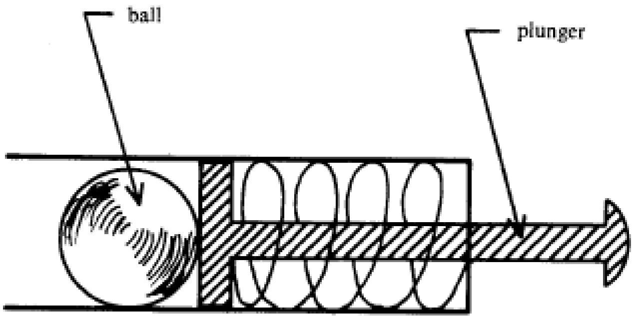
Which **one** of the graphs (**A**–**D**) best represents the retarding force versus compression distance if the collision was with the hard surface of the steering wheel rather than the air bag?



Example 27 (2000 Question 9, 3 marks)

Explain your answer to Question 8, giving specific reasons for choosing the graph that you selected as the best answer.

In a horizontal pinball machine, a 0.10 kg ball rests against a plunger of mass 0.10 kg which can be pulled back against a light spring as shown.
The spring constant is 250 N m^{-1}.



Example 28 (1983 Question 27, 1 mark)

What force must the player exert on the plunger to compress the spring by 0.040 m?

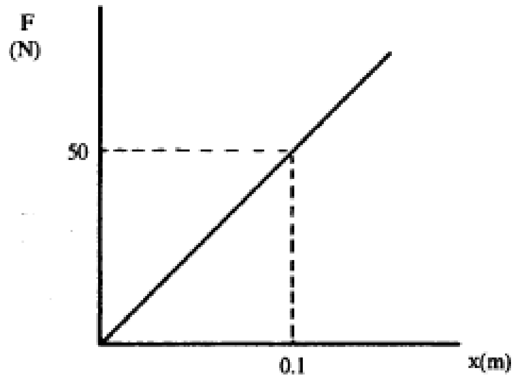
Example 29 (1983 Question 28, 1 mark)

In compressing the spring, how much work has been done?

Example 30 (1983 Question 29, 1 mark)

When the player releases the handle, with what velocity will the ball leave the plunger?

The spring constant (k) of a spring can be defined as the force per unit distance required to extend the spring. Thus a strong spring will have a large value of k, while a weak spring will have a small value. The force-extension curve of a spring is shown. Take g = 10 m s^{-2}



Example 31 (1981 Question 21, 1 mark)

What is the value of *k*, the spring constant? (Give both magnitude and unit)

Example 32 (1981 Question 22, 1 mark)

A 10 kg mass hangs at rest from the spring. How much energy is stored in the spring?

Jane, an adventurous tourist from New Zealand (and mate of Tarzan), decides to try the new sport of falling off a bridge with a 'bungee' attached to her ankles. The 'bungee' is a stretchy rope which can be considered as an ideal spring with a spring constant of 17 N m^{-1}.
Jane has a mass of 50 kg, and in jumping from the bridge, her centre of mass falls through a distance of 13 m before the 'bungee' starts to exert a force on her. Take g= 10 m s^{-2}.

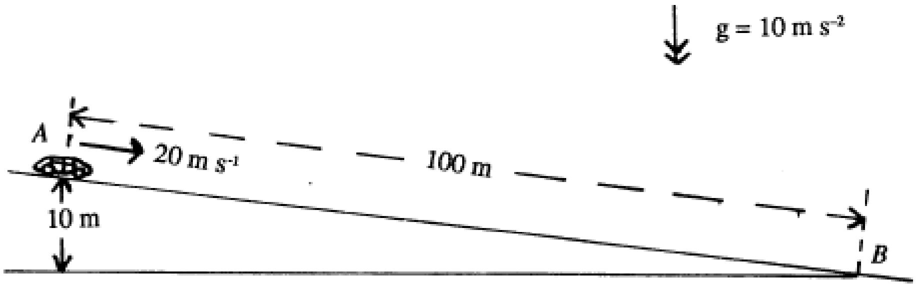
Example 33 (1990 Question 25, 1 mark)

Assuming air resistance is negligible, what is Jane's speed when the 'bungee' first exerts an upward force on her?

Example 34 (1990 Question 26, 1 mark)

How much energy is stored in the 'bungee' when she has fallen a further 4 m?

In a braking test a car of mass 1000 kg was travelling down a hill on a straight road which has a constant slope of 1 in 10 as shown in the diagram.
The car was travelling at 20 m s^{-1} at *A* where a constant braking force was applied so that the car came to a stop at *B*, 100 m from *A*.



Example 35 (1988 Question 6, 1 mark)

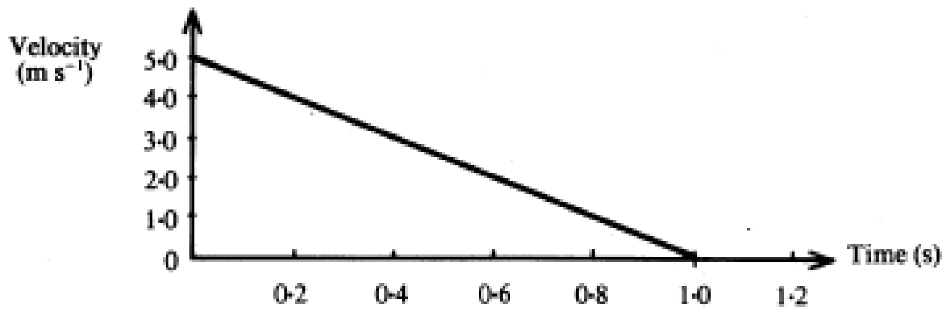
What is the kinetic energy of the car at *A*?

Example 36 (1988 Question 7, 1 mark)

What is the change in gravitational potential energy of the car in going from *A* to *B*?

Example 37 (1988 Question 8, 1 mark)

What is the magnitude of the constant braking force acting on the car as it moved from *A* to *B*?



The graph above gives the velocity-time relationship for a block of mass 4.0 kg which slides across a rough, horizontal floor, coming to rest after 1.0 sec.

Example 38 (1986 Question 3, 1 mark)

What distance did the block travel in the 1.0 s time interval?

Example 39 (1986 Question 4, 1 mark)

What was the work done on the block by the floor?

A bow used in archery consists of a curved section, often made of wood, with a string fastened between its ends as shown in figure 1. To load the bow, an arrow is held against the string and pulled back to its full extent as shown in figure 2. The arrow is then released to fly towards its target.

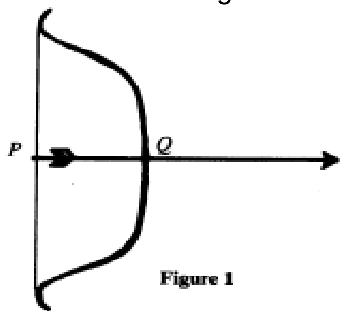


Figure 1

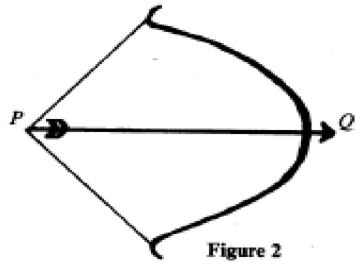
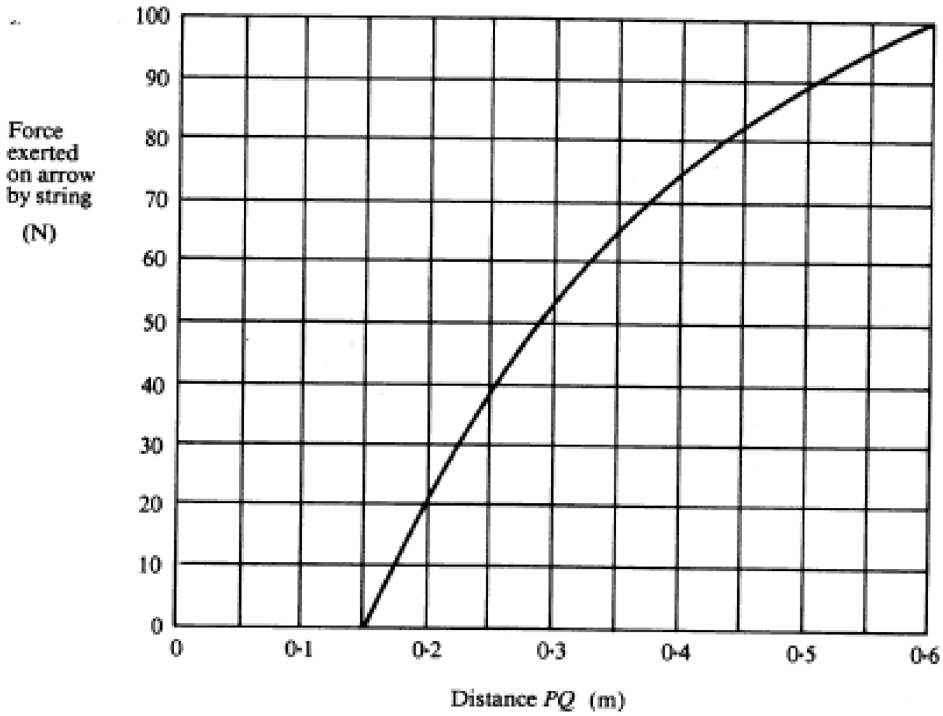


Figure 2

As the distance *PQ* in Figure 2 is increased, an increasing force is exerted on the arrow by the string. Figure 3 shows the force exerted on the arrow versus *PQ* as *PQ* is increased from 0.15 m to 0.60 m.



Example 40 (1986 Question 19, 1 mark)

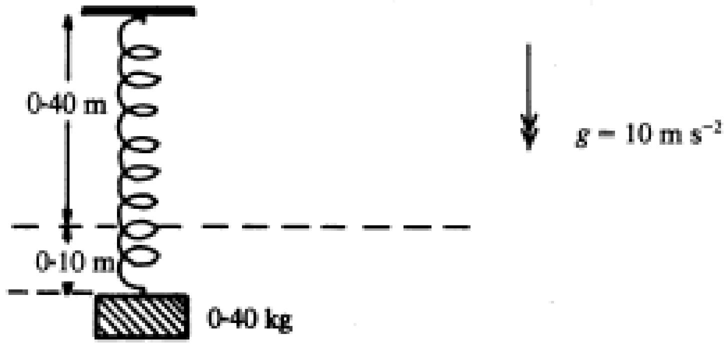
Find the amount of work required to increase *PQ* from 0.15 m to 0.60 m.

Assume that all the energy stored in the bow when *PQ* is 0.60 m is transferred to the arrow when it is released. The mass of the arrow is 0.60 kg.

Example 41 (1986 Question 20, 1 mark)

Calculate the speed of the arrow when it leaves the string.

A light spring of natural length. 0.40 m, hangs from a fixed support. When a mass of 0.40 kg is hung from the spring the spring, the spring is stretched by 0.10 m, as shown in the figure.



Example 42 (1986 Question 27, 1 mark)

What is the spring constant of the spring?

Example 43 (1986 Question 28, 1 mark)

What work is done on the spring by the 0.40 kg mass in extending it from its natural length by 0.10 m?

A block of mass 1.0 kg is connected to a light spring, of natural length 0.50 m, and placed on a frictionless surface as shown in Figure 2.
The block is at rest in Figure 2. The characteristics of the spring are shown in Figure 1.

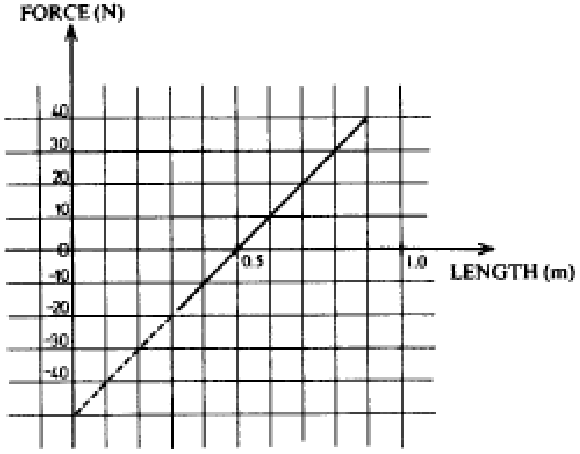


Figure 1

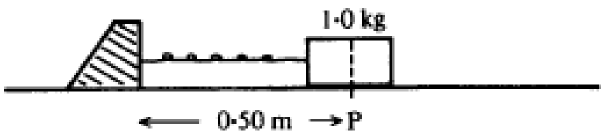


Figure 2

A girl moves the block 0.10 m to the right as shown in Figure 3 and holds the block in this position.

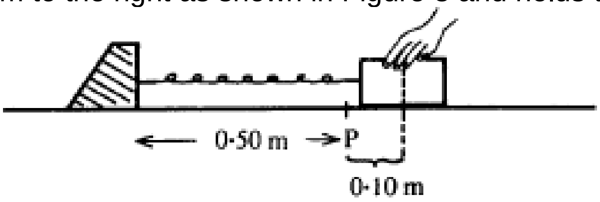


Figure 3

Example 44 (1985 Question 22, 1 mark)

What is the magnitude of the horizontal force the girl must apply to the block to hold it at the position shown in figure 3?

The girl now releases the block.

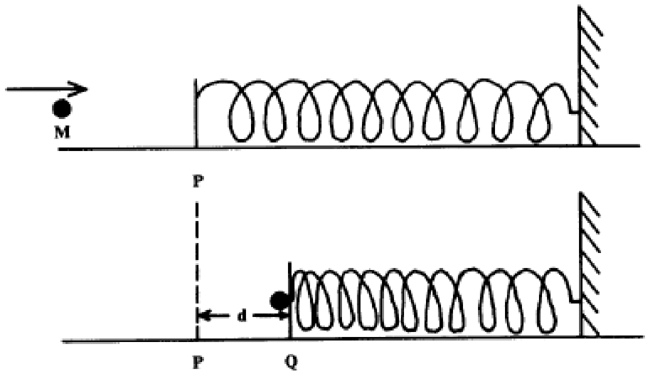
Example 45 (1985 Question 23, 1 mark)

What is the kinetic energy of the block when the spring returns to a length of 0.50 m?

The girl now replaces the block with a 3.0 kg block and holds it at the position shown in figure 3. The girl releases the 3.0 kg block

Example 46 (1985 Question 24, 1 mark)

What is the kinetic energy of the block when the spring returns to a length of 0.50 m?



A moving mass M, strikes and sticks to the end of a light spring of spring constant *k*, which is lying on a smooth surface as shown above. As a result of this impact the spring is compressed by an amount *d* from *P* before it comes momentarily to rest at *Q*.

Between the two situations shown in the first diagram, the potential energy stored in the spring changed by ΔV.

Example 47 (1982 Question 30, 1 mark)

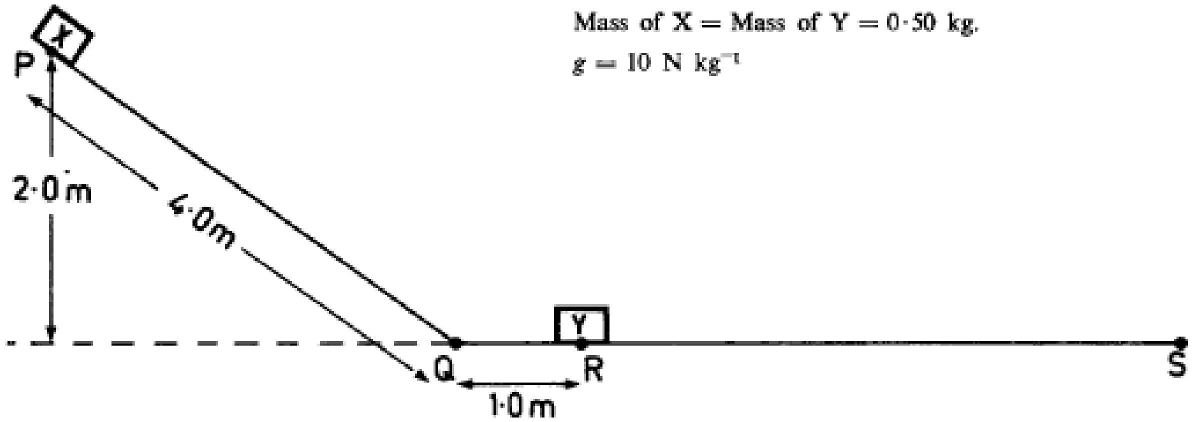
Write an expression for ΔV in terms of the symbols defined above.

A box of mass 20 kg is pulled 3.0 m along a rough floor with a force of 100 N. The friction force acting on the box is a constant 30 N.

Example 48 (1981 Question 11, 1 mark)

What is the change in kinetic energy of the box?

Two blocks, X and Y, are at points P and R as shown in the diagram, *which is not to scale.*



X and Y are initially at rest at the positions shown in the diagram.

Example 49 (1978 Question 27, 1 mark)

What is the difference between the potential energy of block X and the potential energy of block Y, when they are in their initial positions?

X is released and slides down the slope to PQ
Throughout the surface PQRS, a constant friction force of 1.0 N acts on X and Y when they are moving.

Example 50 (1978 Question 28, 1 mark)

How much work is done against friction as block X slides down PQ?

Example 51 (1978 Question 29, 1 mark)

What is the kinetic energy of block X as it reaches point R?

Example 52 (1978 Question 30, 1 mark)

If the collision between X and Y is elastic, what is the kinetic energy of block Y as it leaves point R?

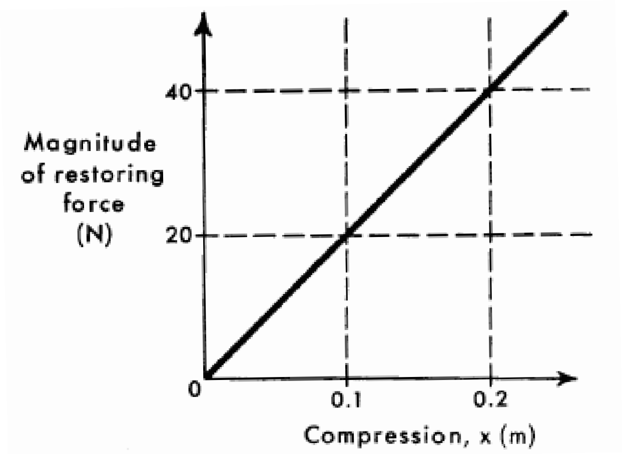
Example 53 (1978 Question 31, 1 mark)

If S is the point at which block Y comes to rest, what is the distance RS?

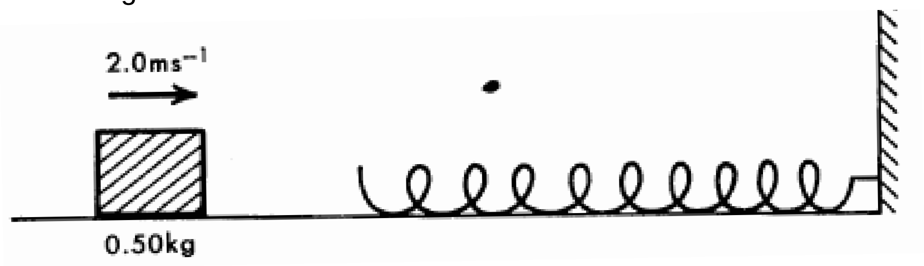
A spring behaves so that the restoring force it exerts is related to the compression by the relationship

$$F = 200\,x$$

Where F is the magnitude of the restoring force (in N) and x is the compression (in m).



A body of mass 0.50 kg travelling at 2.0 m s^{-1} approaches the spring which is fixed to a wall as shown below. Friction can be neglected.



The body comes to rest instantaneously at a time t_1, when the spring is compressed by a total amount x_1. It then rebounds.

Example 54 (1977 Question 21, 1 mark)

Calculate the value of x_1.

A 100 kg man slides down a vertical rope with a constant acceleration of 8.0 m s^{-2}.
(Take g = 10 m s^{-2})

Example 55 (1975 Question 10, 1 mark)

What is the magnitude of the frictional force exerted on the man by the rope?

Example 56 (1975 Question 11, 1 mark)

What is the tension in the rope?

The man slides a distance of 10 m.

Example 57 (1975 Question 12, 1 mark)

How much work is done on the man by the gravitational field?

Example 58 (1975 Question 13, 1 mark)

How much mechanical energy is lost in travelling this distance?

A piece of elastic 0.200 metre long is extended by 0.040 metre when a mass of 0.050 kg is hung on it. Take g= 10 N kg^{-1}

Example 59 (1975 Question 33, 1 mark)

What force does the mass exert on the elastic? (State magnitude and unit)

Example 60 (1975 Question 34, 1 mark)

How much work is done extending the elastic? (State magnitude and unit)

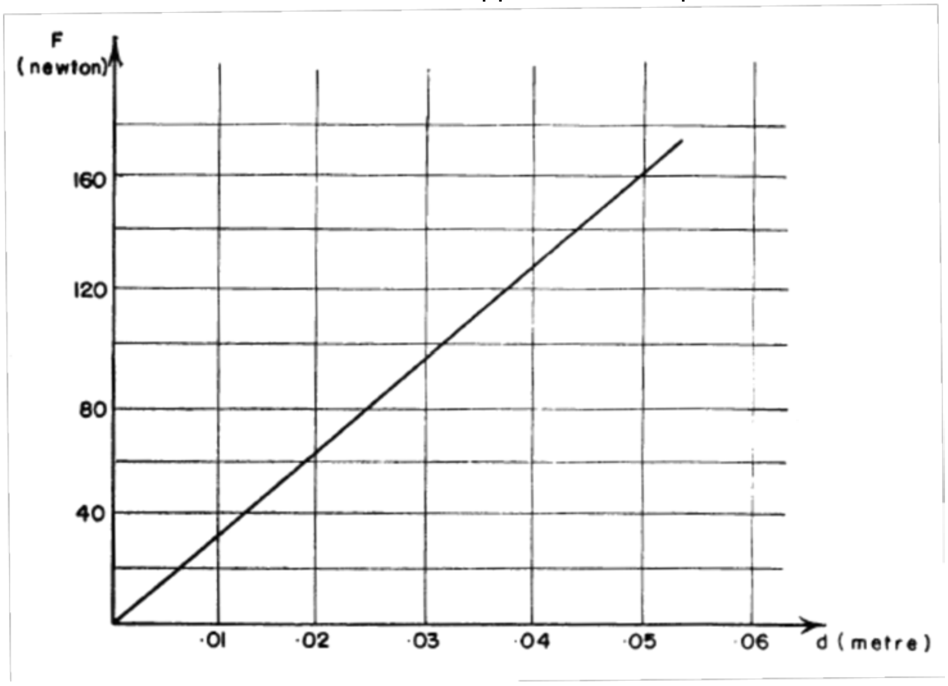
Example 61 (1975 Question 35, 1 mark)

A student pulls the mass downwards through a further 0.040 metre. How much work does the student do? (State magnitude and unit)

Example 62 (1975 Question 36, 1 mark)

A piece of the same elastic 0.400 metre long has the same mass hung on it. By how much will it be extended? (State magnitude and unit)

The graph below shows the relation between force applied and compression for a steel spring.



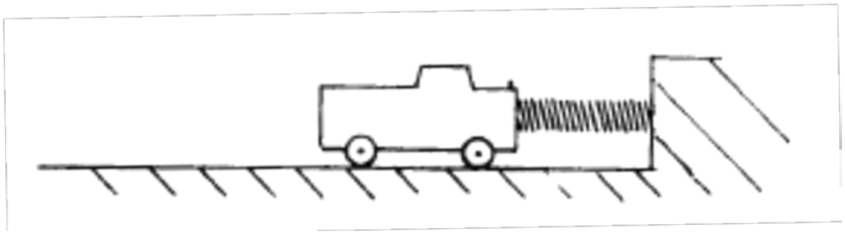
Example 63 (1974 Question 20, 1 mark)

What is the spring constant of the spring?

Example 64 (1974 Question 21, 1 mark)

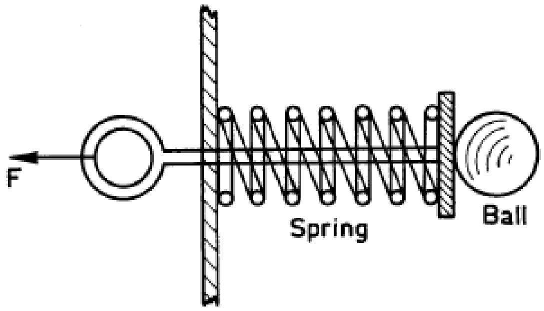
How much energy is stored in the spring when it is compressed by 0.05 m?

The spring is now compressed by 0.01 m and placed between a fixed support and a toy car of mass 20 kg.

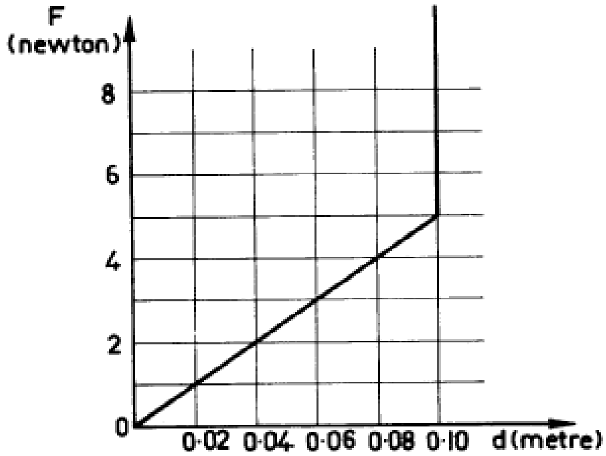


Example 65 (1974 Question 22, 1 mark)

What is the maximum acceleration of the toy car after the spring is released?



In a pinball machine the plunger is pulled to compress the spring.
When it is released, the spring projects the steel ball.
Experiments performed on the mechanism yield the graph of spring displacement *d* against the compressing force *F*.



Example 66 (1973 Question 35, 1 mark)

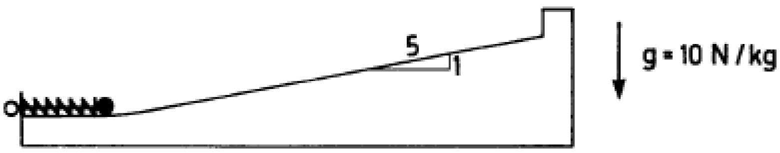
What is the spring constant of the spring before it is fully compressed?

Example 67 (1973 Question 36, 1 mark)

How much work is done in compressing the spring to a point where the force is 5.0 Newton?

Example 68 (1973 Question 37, 1 mark)

How much additional work is done in increasing the force to 8.0 Newton?



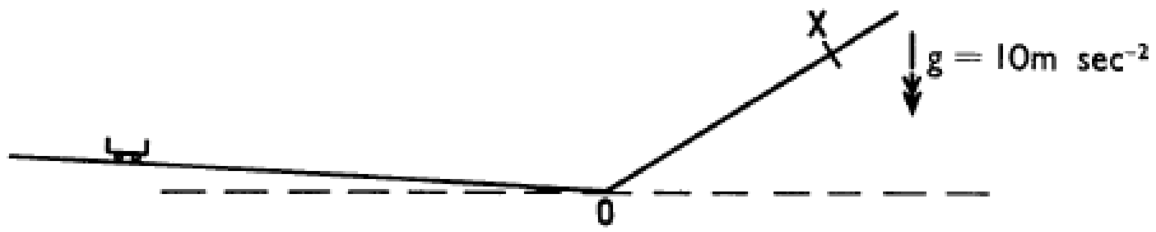
The above arrangement is used on the pinball table as shown.

Example 69 (1973 Question 38, 1 mark)

A ball of mass 0.250 kg is placed on the plunger. The spring is fully compressed and then released. Assuming that the plunger and the spring have negligible mass, what is the velocity, *v*, of the ball when it leaves the plunger?

Example 70 (1973 Question 39, 1 mark)

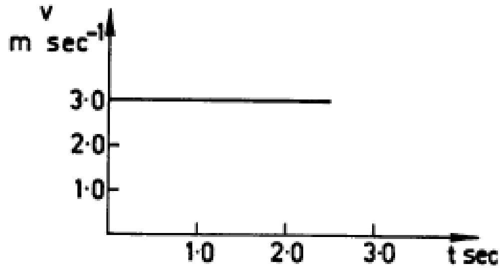
The table has a slope of 1 in 5. How far along the surface of the table could the ball travel?
(answer in terms of *v*)



A trolley of mass 2.2 kg is placed on a track which has a slight downhill gradient. A small frictional force acts on the trolley.

The trolley is given an initial push and after 2.5 sec reaches O. Here it encounters a steep uphill track, and come to rest momentarily, at X.

The speed time relation for the trolley over the first 2.5 sec is shown below.



Example 71 (1972 Question 1, 1 mark)

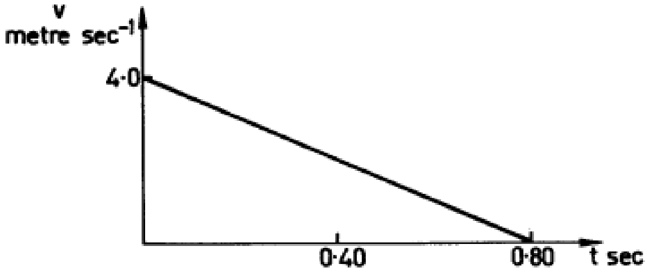
What is the net force acting on the trolley during the first 2.5 sec?

Example 72 (1972 Question 2, 1 mark)

How much work was done by the trolley over the distance OX?

Example 73 (1972 Question 3, 1 mark)

Friction over the distance OX is negligible. What is the vertical height of X above O?



The graph represents the velocity-time relation for a block of mass 0.20 kg. The block was given an initial push (at time t = 0), slid across the floor and came to rest.

Example 74 (1971 Question 1, 1 mark)

How much work was done in bringing the block to rest?

Example 75 (1971 Question 2, 1 mark)

What was the frictional force of the floor on the block?

Example 76 (1971 Question 3, 1 mark)

What distance did the block travel in the 0.80 sec time interval?