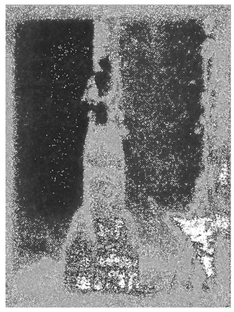
2.10 UNDERSTANDING WORK, ENERGY, POWER AND EFFICIENCY

Are you doing work when you are solving a physics problem?
Are you doing work when you pick up a pen that has fallen to the floor?
Photograph below shows that work is done.

A women is pushing the stroller

A fisherman is pushing the boat towards the beach.



The rocket engine produces an upward thrust.

WORK

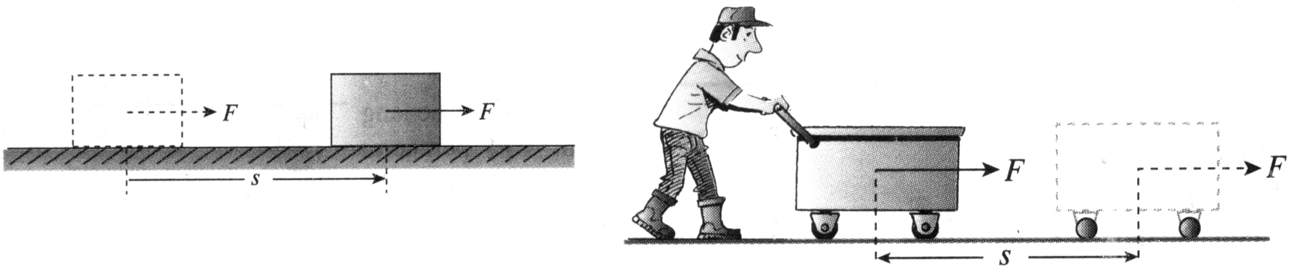


Figure 1

1. Work, W is defined as the ____ in the direction of the force (figure 1).

   Work, W = Force (F) x Distance (s) (in the direction of the force)
   W = F x s

   The SI unit for work is **Nm** or **Joule** (J).

2. Work is a _________________ quantity, that is, a quantity which has magnitude only but not direction.

3. If no distance is traversed or if there is no motion, then **no work has been done**.

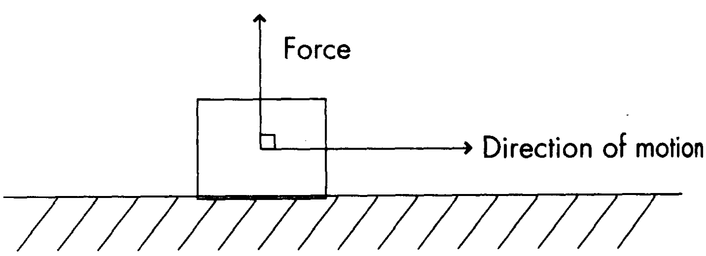


Figure 2

4. When the force and the direction of motion of an object are perpendicular as shown in figure 2, the work done is equal to **zero**.

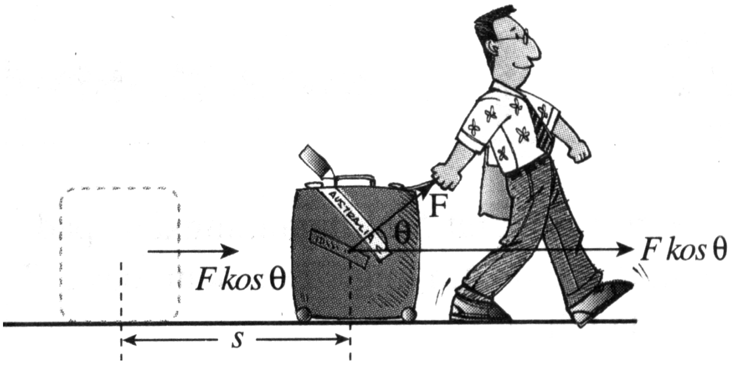
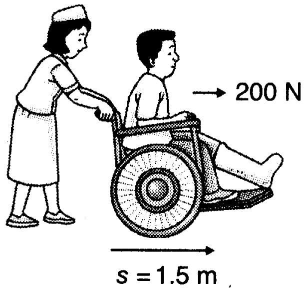


Figure 3

5. In such a case, the work can be determined by resolving the force along the direction of motion as shown in figure 3.

Work, W = F cos θ x s

Example 1



A nurse is pushing a patient in a wheelchair with a force of 200 N over a distance of 1.5 m. How much work is done by nurse?

Example 2

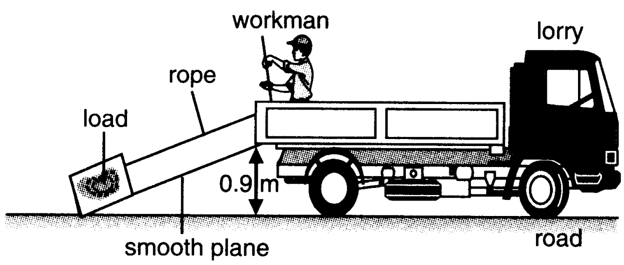
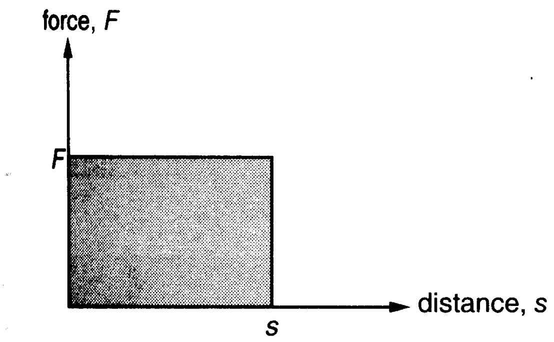
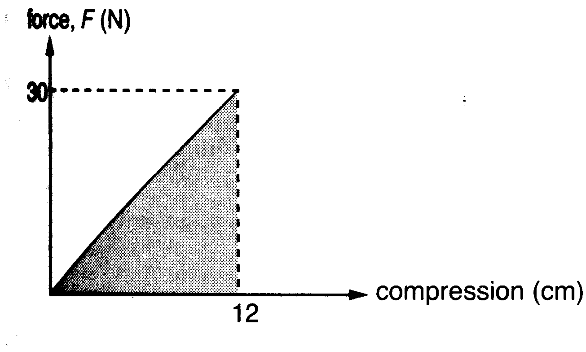


Diagram shows a workman pulling up a load onto a lorry using a smooth inclined plane. If the tension in the rope is 600 N and the inclined plane is 3 m in length, how much work is being done by the man?

6. If a graph of force versus (against) distance is drawn, then the work done is equal to the area under the graph.





ENERGY

1. When work is done, energy is consumed.

2. Energy is the ability to do work.

3. Mechanical energy is divided into potential energy and kinetic energy.

4. Energy is the product of the force, F and the distance, d.
   Energy = Work done
   = Force x Distance
   E = F x s

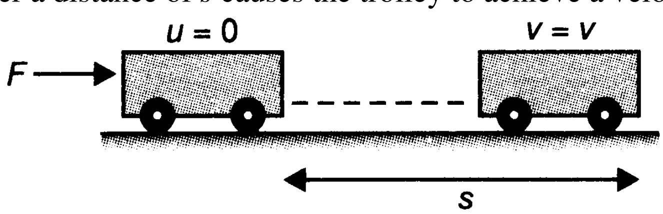
5. The SI unit for energy is the Nm or Joule (J).

6. Energy is a ________________ quantity

Kinetic Energy

1. Kinetic energy is the energy possessed by a moving object. Only moving objects possess kinetic energy.

2. Assume a force, F is acting on a stationery trolley of mass, m kg moving on a smooth surface. The force acting over a distance of *s* causes the trolley to achieve a velocity of v m s^{-1}.



3. The kinetic energy, E_k of an object of mass, m kg travelling at a velocity of v ms^{-1} is given as;

   Kinetic energy, $\mathbf{E_k = \frac{1}{2} mv^2}$

4. The factors that affect kinetic energy are:
   (a) mass of the object, m
   (b) velocity of the object, v

Example 1
A 0.6 kg trolley moves across the floor at a velocity of 0.5 m s^{-1}. What is the kinetic energy of the trolley?

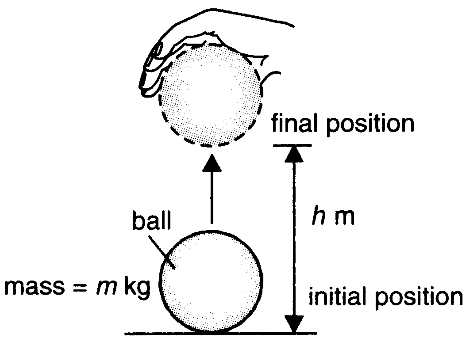
Example 2
A car of mass 950 kg accelerates from a velocity of 20 m s^{-1} to a velocity of 35 m s^{-1}. What is the work done for the car to accelerate?

Potential Energy

1. The potential energy of an object is the energy stored in the object because of its **position** or **state**.

2. There are two main types of potential energy.
   (a) Gravitational potential energy
   (b) Elastic potential energy

3. The gravitational potential energy of any object is the energy stored in the object because of **its height above the earth's surface**.



4. When an object of mass, m kg is raised to a height, h meters above the earth's surface, the object possesses gravitational potential.

5. The gravitational potential energy is equal to the work done to raise an object to a particular height.

Work done, W = F x s

= mg x h

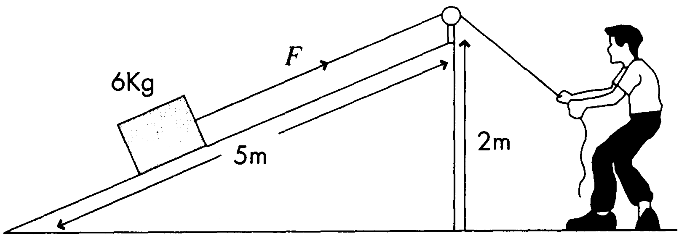
= **mgh**

Gravitional potential energy, $E_p = W$

$$E_p = mgh$$

6. Elastic Potential Energy of an object is the energy stored in the object as result of stretching or compressing it.

Example



The diagram above shows a mass of 6 kg being pulled by a force F up a smooth inclined plane. After the body has been pulled 5 m up the ramp/platform, it is found that the vertical height of the object is 2 m. Calculate the,

(a) gravitational potential energy at 5 m.

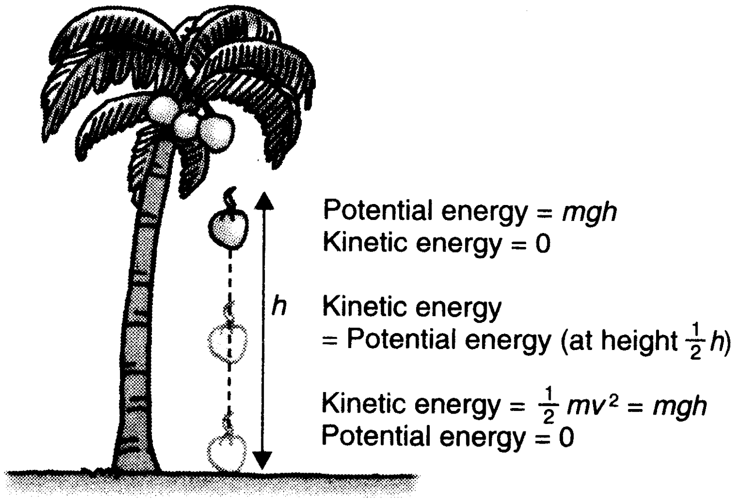
(b) work done to lift the body/mass up the smooth inclined ramp.

(c) value of F

Principle of Conservation of Energy

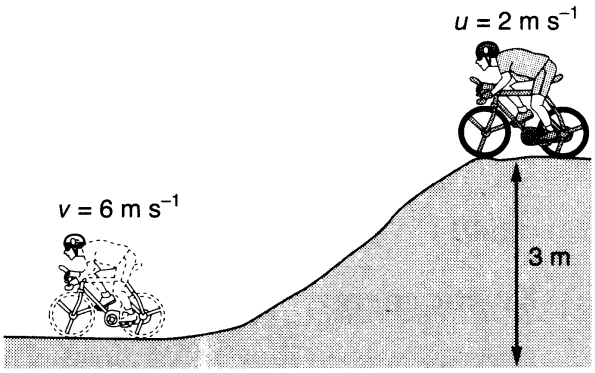
1. The principle of conservation of energy states ______________________________________
____

2. Energy cannot be destroyed but can be converted from one from to another.



3. When a coconut of mass, m kg falls from a height of h meters to the ground, it loses its **gravitational potential** energy which is changed into **kinetic energy** of motion.

Example



Lim rides his bicycle down the slope of a hill 3 m high at an initial velocity of 2 m s^{-1}, without pedalling. At the foot of the hill, the velocity is 6 m s^{-1}. Given that the mass of Lim with his bicycle is 75 kg. Find

(a) the initial kinetic energy of the bicycle.
(b) the initial potential energy of the bicycle
(c) the work done against friction along the slope.

POWER

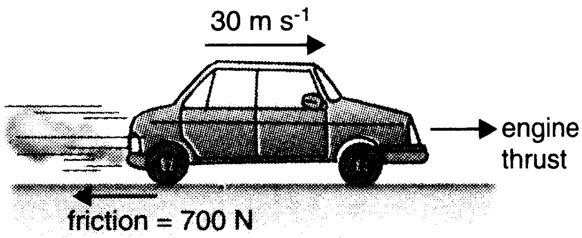
1. Power, P is the rate at which work is done or energy is changed or transferred.
2. Power is expressed as:

$$\textbf{\textit{Power, P}} = \frac{\text{workd done}}{\text{time taken}}$$

$$\mathbf{P} = \frac{W}{t}$$

3. The SI unit of power is J s^{-1} or watt (W).

Example



A car is moving at a constant velocity of 30 m s^{-1} . If the car has to overcome a frictional force of 700 N, what is the power of its engine?

EFFICIENCY

1. Work can be done by a machine when input energy is supplied.

2. If a machine does least work from the supplied energy, it is said to be non-efficient.

3. Efficiency of a machine is expressed as:

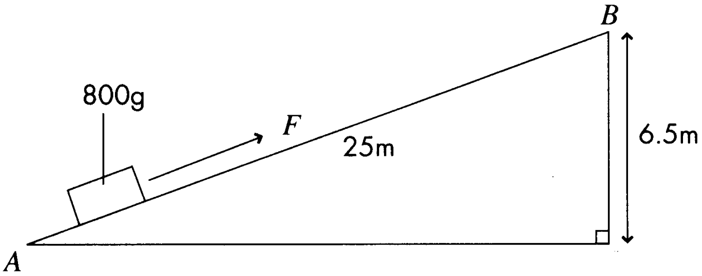
$$\textbf{Efficiency} = \frac{\text{Useful energy output}}{\text{Energy input}} \textbf{ x 100\%}$$

4. If a machine has the efficiency of 100% it is an excellent machine in which output work = input work.

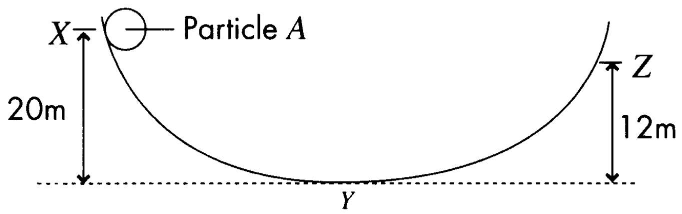
5. In general, the efficiency for all machines is less than 100% because of the work done against friction when operating a machine

   Example
   A 60 N load is lifted up to 0.30 m height with a machine which needs 25N of force and the load moves 0.90 m. Calculate
   (a) the work which is done by the force
   (b) the work which is done by the machine
   (c) the efficiency of the machine

Mastery Exercise



1. In the diagram above, a fixed force F acts on a box of mass 800 g such that it moves up from position A to position B. (Assume that the acceleration due to gravity, $g = 10\ ms^{-2}$)
   (a) What is the work done?
   (b) Calculate the potential energy attained by the box when it reaches position B.
   (c) The box is released when it reaches position B. If the ramp is smooth and there is no friction, what is the kinetic energy of the box when it slides back to position A?
   (d) What is the velocity of the box when it reaches position A?

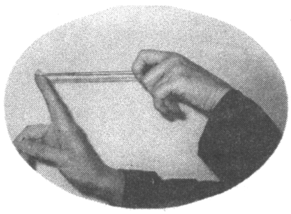


2. The above diagram shows a particle A of mass 3 kg being released from position X on curved ramp having a rough surface. (Assume that the acceleration due to gravity, $g = 10\ ms^{-2}$).
   (a) What is the energy possessed by A at the position X?
   (b) Give another position where the particle A possesses the same energy as found in the answer to (a) above.
   (c) Calculate the energy possessed by a particle A
      (i) at position X
      (ii) at position Z
   (d) Explain why there is difference in energy as the answers in (c)(i) and (c)(ii).
   (e) Explain the changes occurring to particle A along its journey from position X to Z.
   (f) If the surface of the ramp is smooth and friction can be neglected
      (i) what is the velocity of particle A at position Y?
      (ii) does particle A stop before, after, or at position Z? Why?

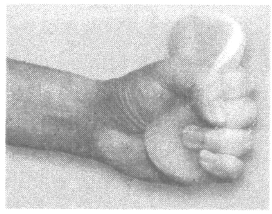
2.12 ELASTICITY

Understanding Elasticity

1. Some common devices like eraser and ruler will change its shape when an external force acting on it. When the external force is removed, the objects return to its original shape and dimensions.



A rubber band can be stretched due to its elasticity.



A sponge can be compressed easily due to its elasticity

2. The property of an object that enables it to return to its original shape and dimensions after an applied external force is removed is called **elasticity**.
3. The elasticity of solids is due to the strong intermolecular forces between the molecules of the solid. Stretching a solid causes the molecules to be slightly displaced away from one another. A strong attractive intermolecular force acts between the molecules to oppose the stretching as shown in figure 2.64.

***Figure 2.63** No external force applied. Molecules at their equilibrium separation. Intermolecular force = 0*

***Figure 2.64** Stretching a solid causes its molecules to be displaced away from each other. Attractive intermolecular force acts.*

***Figure 2.65** Compressing a solid causes its molecules to be displaced closer to each other. Repulsive intermolecular force acts.*

4. When the external stretching force is removed, this strong attractive intermolecular force brings the molecules back to their original positions. Therefore, the solid return to its original shape and size.
5. Compressing a solid causes the molecules in the solid to be closer to one another.
6. When a solid is compressed, the strong force of repulsion will push the atoms or molecules of the solid back to their original position as is shown in figure 2.65.

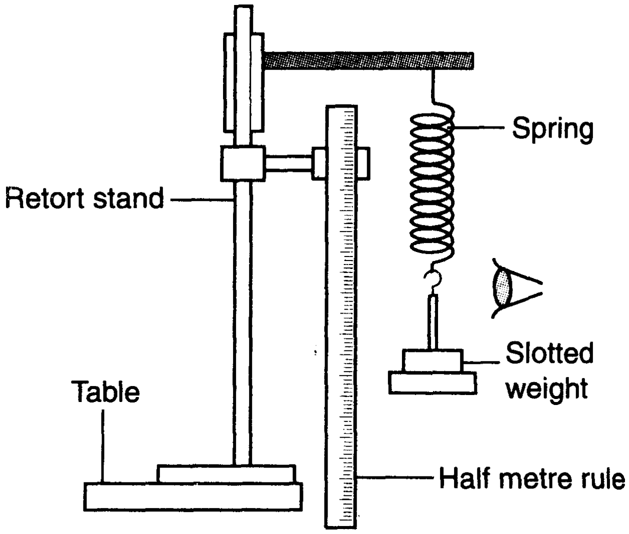
Relationship between force and extension of a spring

Title:
To investigate the relationship between force and the extension of a spring.

Hypothesis:
The tension of a spring is directly proportional to the applied force.

Variables:
Manipulated variable: Force
Responding variable: Extension of the spring

Materials and apparatus:
Steel spring, five 50 g slotted weight, half meter rule and retort stand with clamp.



Method
1. All the weights are removed from the spring. The original length of the spring is measured using a half meter rule.
2. A 50 g weight is hung from the end of the spring. The length of the spring is measured again and the extension is calculated.
3. Step 2 is repeated with 100 g, 150 g, 200 g, 250 g, and 300 g weights.
4. The graph of force against extension is plotted.

Result:

Mass of slotted weight, m/g	Force on the spring, (F=mg)/N	Length of spring, L/cm	Extension, x = (L-L_0)/cm
50			
100			
150			
200			
250			
300			

HOOKE'S LAW

1. Hooke's law states that the extension of a spring is directly proportional to the applied force provided that the elastic limit is not exceeded.

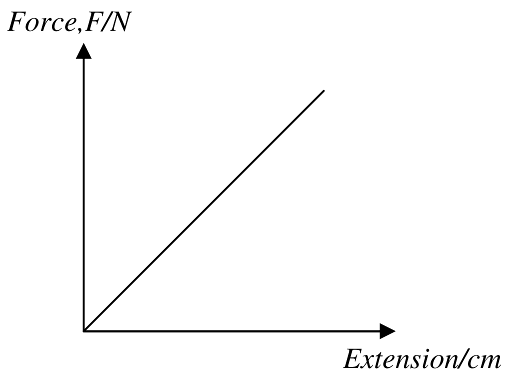


Figure 1

2. The elastic limit of a spring is defined as the maximum force that can be applied to a spring such that the spring will be able to be restored to its original length when the force is removed.
3. If the elastic limit is exceeded, the length of the spring is longer than the original length even though the force no longer acts on it / spring will not return to its original position.

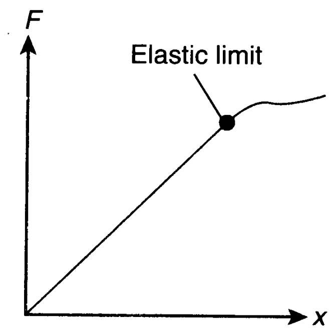


Figure 2

4. The results from experiment show that the graph is straight line passing through origin (figure 1) meaning that the extension of a spring is directly proportional to the applied force if the elastic limit is not exceeded.
5. The mathematical expression for Hooke's Law is,

   $F \alpha x$

   Therefore, F = kx ; k is constant of the spring/force constant

   $k = \frac{F}{x}$ with units N m^{-1}.
6. Spring constant is a measurement of the stiffness of the spring. A spring with a spring constant of 12 N m^{-1} requires a force of 12 N to produce an extension of 1 cm.
7. A spring with a large spring constant is harder to extend and is said to be stiffer.

8. A spring with a smaller force constant is easier to extend and is said to be less stiff or softer.

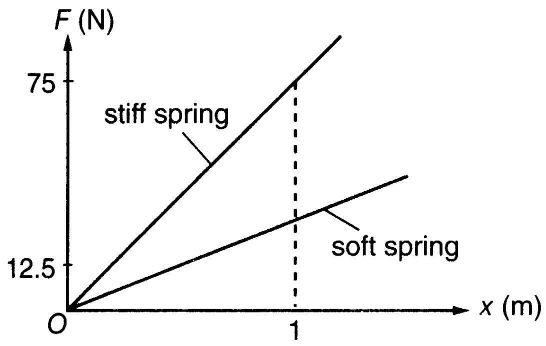


Figure 3

- spring constant k = gradient of graph
- a larger value of k indicates a stiffer spring
- a steeper graph indicates a stiffer spring

Example

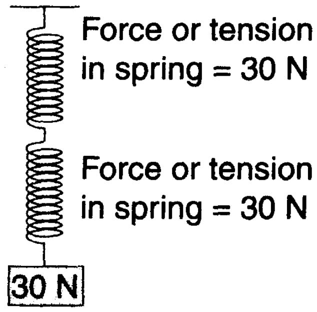
The length of a spring is increased from 23.0 cm to 28.0 cm when a mass of 4 kg was hung from the end of a spring.

(a) What the load on the spring in newtons?

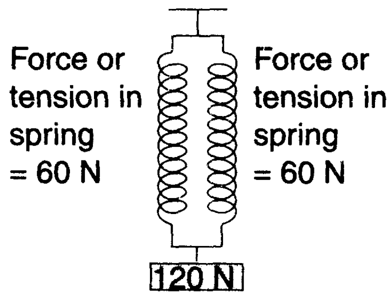
(b) What is the extension of the spring?

(c) Calculate the force constant of the spring
(Assume g = 10 Nkg^{-1})

SYSTEM OF SPRING



1. Two springs can be connected in series or in parallel.
2. When two springs are connected in series, the applied force acts on each spring. The force due to the 30 N load acts along the system such that each spring experience a force or tension of 30 N.



3. When two springs are connected in parallel, the applied force is shared equally among the springs. The force due to the 120 N load is shared by the springs. Therefore, the tension in each spring is 60 N.

Example 2:

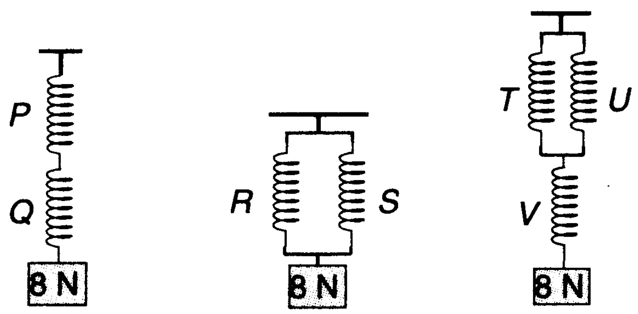


Figure above shows a spring extends by 1 cm when an 8 N force is applied on it. Similar springs used to set up three systems.

Calculate the total extension in each system.

Example 3:

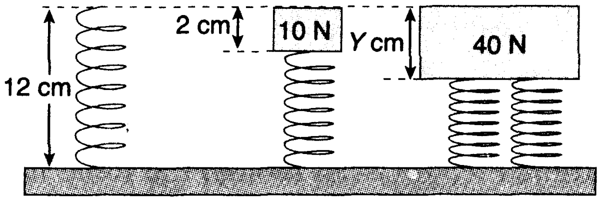


Figure 3 shows identical springs. What is the value of Y?

ELASTIC POTENTIAL ENERGY

1. Elastic potential energy is the energy stored in a spring when it is extended or compressed.
2. When a force extends a spring, work is done. The work done on the spring is the energy transferred to the spring and stored as elastic potential energy.
3. Consider a force, F that produces an extension, x in a spring. The work done on the spring,

   W = average force x extension

   $$= \left(\frac{F}{2}\right)x$$

   $$= \frac{1}{2}Fx$$

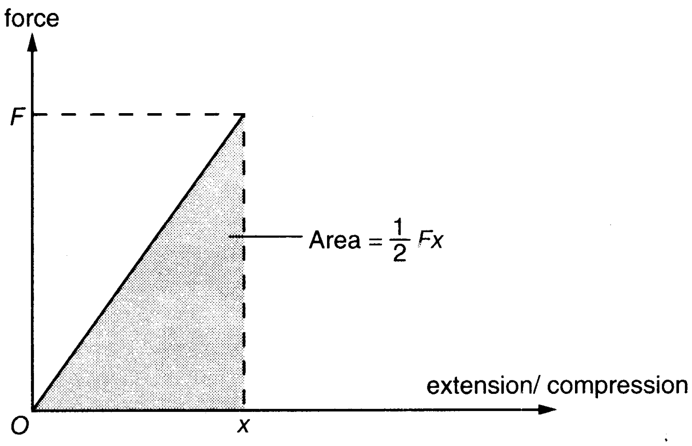
   From Hooke's law, F = kx

   Therefore, $W = \frac{1}{2}(kx)\,x$

   $= \frac{1}{2}kx^2$

   Hence, the elastic potential energy stored in a stretched spring is given by,

   $E_p = \frac{1}{2}kx^2$



Area under the graph represents elastic potential energy

Example 4
A 2 kg load is hung form the end of a spring with a force constant of 160 Nm^{-1}.
(a) What is the tension in the spring?
(b) What is the extension of the spring?
(c) Calculate the elastic potential energy stored in the spring.
[Assume g = 10 N kg^{-1}]

FACTORS WHICH INFLUENCE THE ELASTICITY OF A SPRING

1. Factors which influence the elasticity of a spring are as follows;

(a) type of spring material
- a spring made from a hard material requires a larger force to stretch it. Hence, the spring constant, k is greater. For example; steel spring is harder than the copper spring.

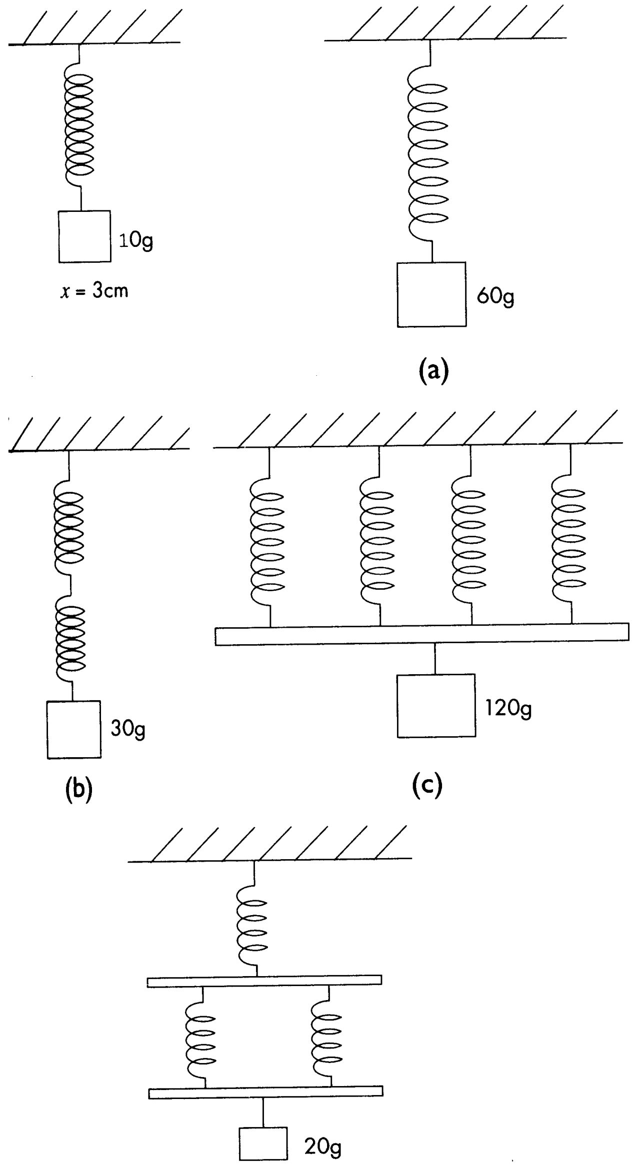
(b) diameter of the coil of spring
- a spring made of a larger diameter coil is 'softer'.

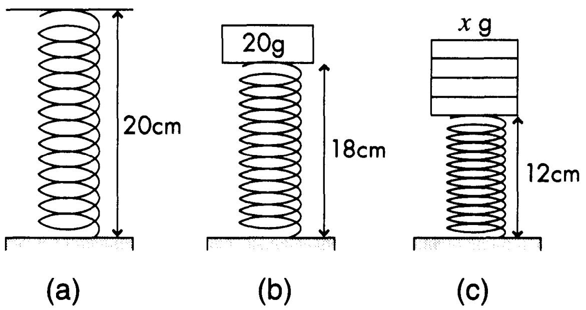
(c) diameter of the wire of the spring
- a spring coil of spring made from thicker wire is more difficult to stretch than a coil of spring made from wire that is thinner.

(d) arrangement of the spring
- a longer spring is easier to stretch compared to a shorter spring.
- springs arranged in series are easier to stretch when compared to springs arranged in parallel.

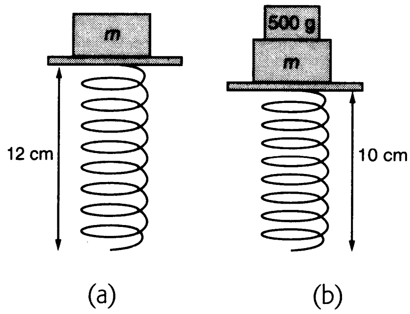
Mastery Exercise

1. A spring extends by 3 cm when it is hung with a 10g weight. Find the total extension in each of the spring systems shown in the diagram.

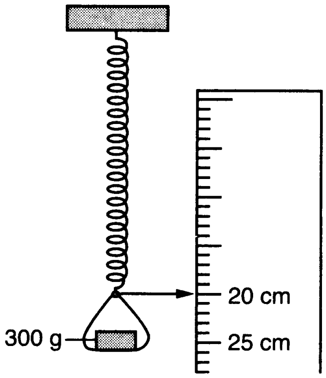




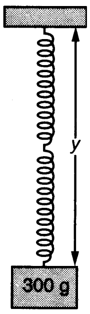
2. Diagram (a) shows a spring whose original length is 20 cm. When a weight of 20 g is placed atop the spring as in diagram (b), the spring is stretched by 2 cm. If a weight of x g is placed atop the same spring as in diagram (c), it is found that the spring is stretched by 8 cm. What is the value of x?



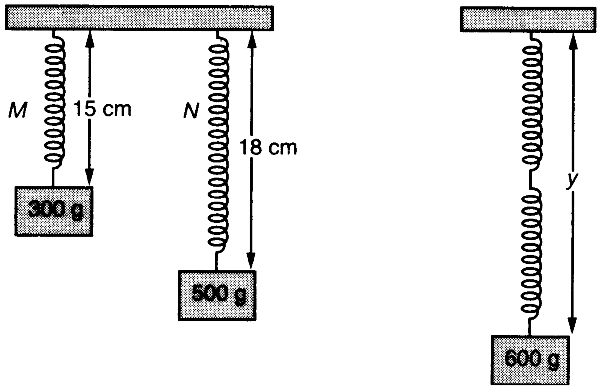
3. The above figure shows a spring which is compressed. Calculate the value of m if the original length of the spring is 15 cm.



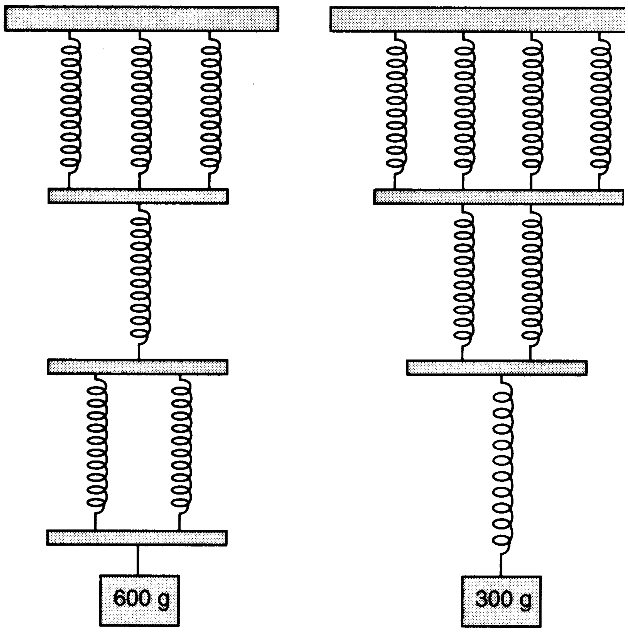
4. The figure shows the pointer reading of a spring. When an additional load of 200 g is placed in the pan, the pointer reading is 25 cm. What is the reading of the pointer when the total load is removed?



5. The above figure shows a system of two identical springs. Initially each spring is of length 12 cm and becomes 15 cm when it is loaded with a mass of 600 g. What is the value of y?

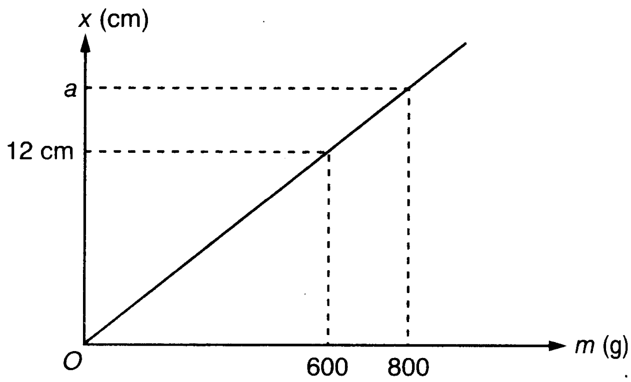


6. M and N are two non-identical springs each measuring 12 cm. When subjected to loading, their respective lengths are as shown in the above figure. What is the length y of the spring system if M and N are arranged in series and the applied load is 600 g?



(a) (b)

7. The above figure shows a spring system comprised of identical springs. Each springs is of length 18 cm and extends to 22 cm when subjected to a load of 200 g. What is the length of the spring system in figures (a) and (b).



8. The above figure is a graph of extension, x versus load, m for a spring.
   (a) what is the value of the spring constant, k?
   (b) what is the value of a?
   (c) what is the potential energy stored when the spring is extended by *a* cm?