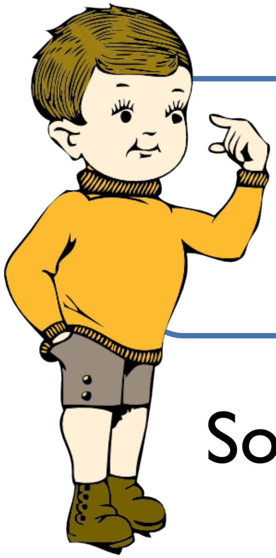
CHAPTER 6

- Work
- Energy
- Power

WORK

- Work
  - Concept of work
  - Positive & negative work
  - Work on slope with friction
  - Work by expanding gas

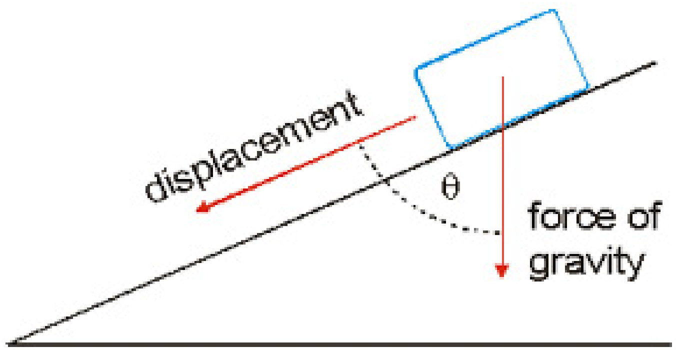
Concept of work



work

- Force applied (F) x distance moved (d) in the direction of the force

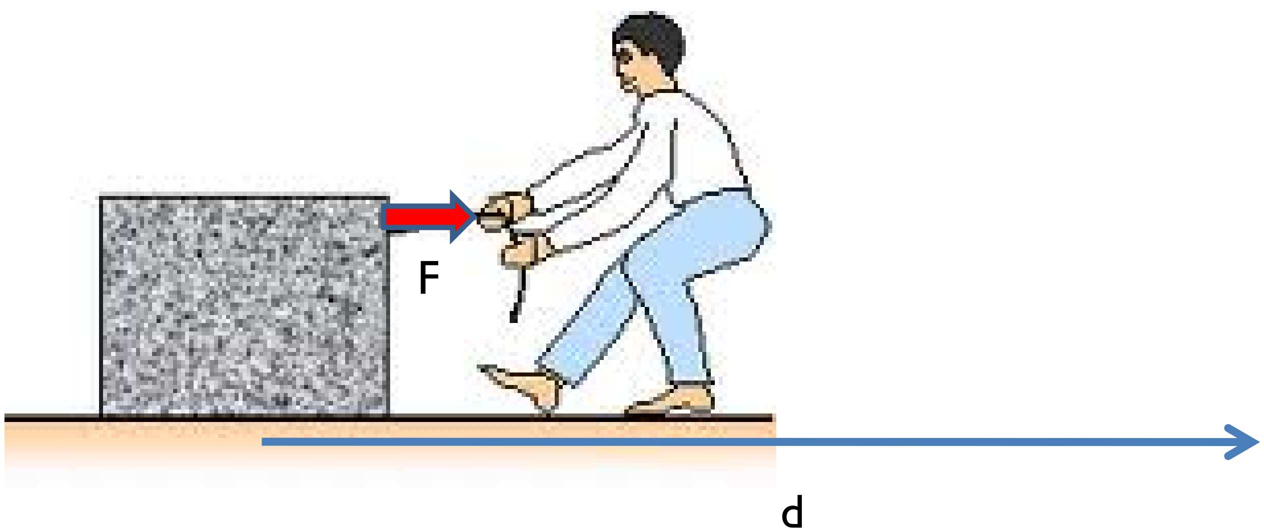
So, to do work, force must cause displacement



Work done = F cosθ x s

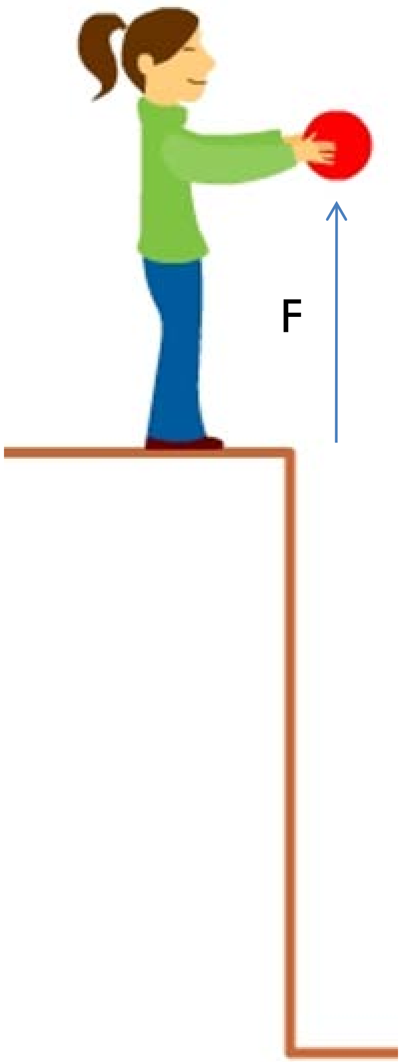
Concept of work

- When applied force is directly in the direction of the distance moved ($\theta = 0$)

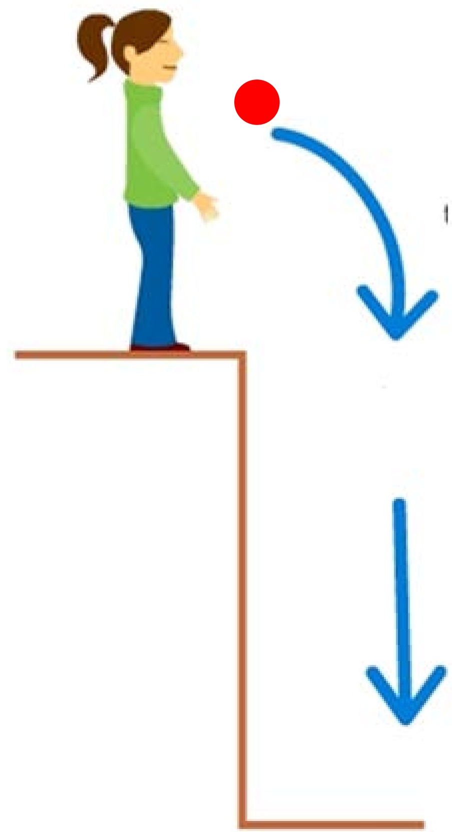


Work done = F x s

Concept of work



Work is done by the applied force on the object



Work is done by gravitational force on the object

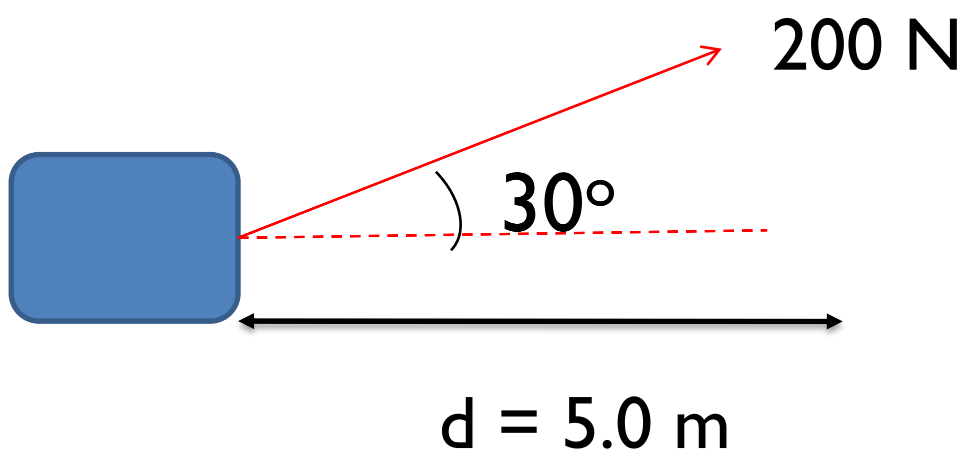
Question: Work Done

- Ben carries a 200-N suitcase up three flights of stairs (a height of 10.0 m) and then pushes it with a horizontal force of 50.0 N at a constant speed of 0.5 m/s for a horizontal distance of 35.0 meters. How much work does Ben do **on his suitcase** during this <u>entire</u> motion?

$$W = 3750 \text{ J}$$

Question: Work Done

- A man pulls a box along the horizontal frictionless floor using a rope. The force provided by the rope is 200 N at an angle of 30° to the horizontal. Calculate the work done if the box moves 5.0 m along the ground:



Ans: 865 J

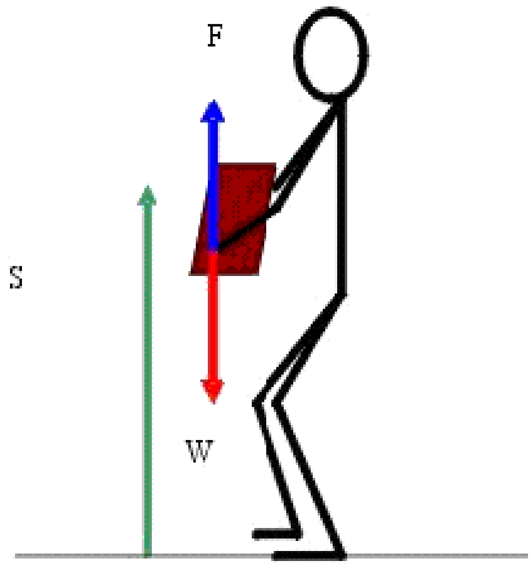
Positive work and negative work

- Form formula of work:

$$\textbf{Work done} = \mathbf{F \cos\theta \times s}$$

- When $0^o \leq \theta < 90^o$, work done is positive as $\cos \theta$ is positive
- Thus, work done by a force is positive if the applied force has a component in the direction of the displacement.
- Example:
  - When a body is falling down, the force of gravitation is acting in the downward direction. The displacement is also in the downward direction. Thus the <u>**work done by the gravitational force on the body is positive.**</u>

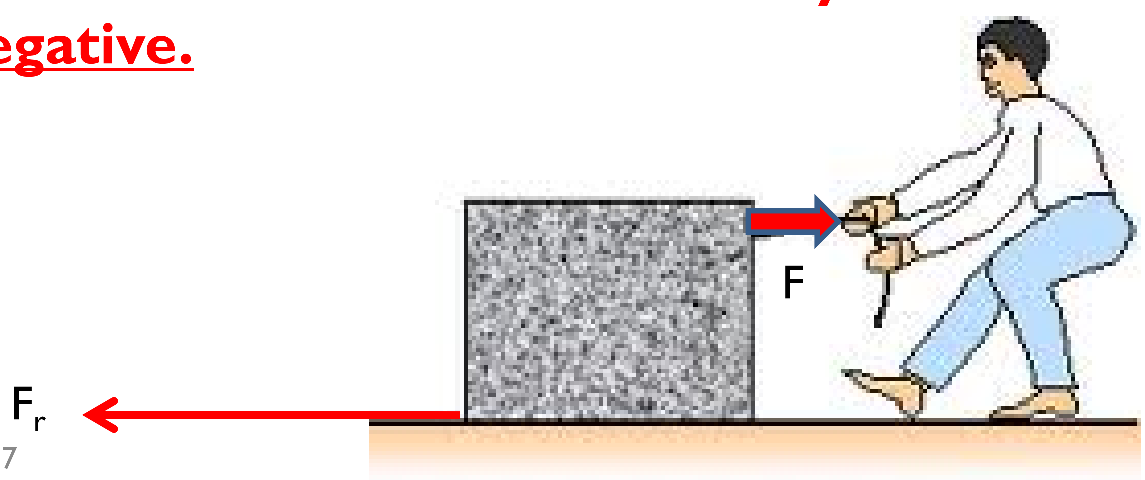
Positive work and negative work



- Consider the same body being lifted in the upward direction.
- In this case, the force of gravity is acting in the downward direction. But, the displacement of the body is in the upward direction.
- Since the angle between the gravitational force and displacement is 180°, the **work done by the gravitational force on the body (W) is negative.**
- But, in this case, the **work done by the applied force, F** which is lifting the body up **is positive** since the angle between the applied force and displacement is positive

Positive work and negative work

- ~~But, in this case, the **work done by the applied force, F** which is lifting the body up **is positive** since the angle between the applied force and displacement is positive.~~
- Similarly, frictional force is always opposing the relative motion of the body.
- When a body is dragged along a rough surface, the frictional force will be acting in the direction opposite to the displacement. The angle between the frictional force and the displacement of the body will be 180°. Thus, the **work done by the frictional force will be negative.**



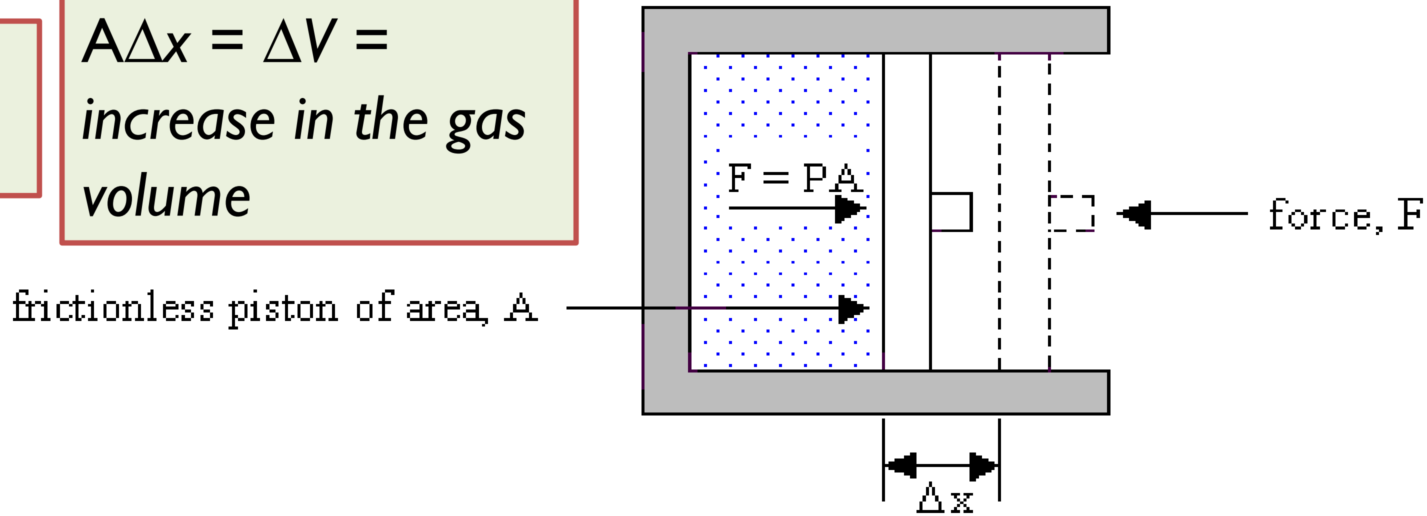
Example

- You are towing a car up a hill with constant velocity. The work done on the car by the gravitational force is :
  a) Positive
  b) Negative
  c) Zero

Work done by an expanding gas

Pressure (p)= force F)/area (A)

$A\Delta x = \Delta V$ = *increase in the gas volume*

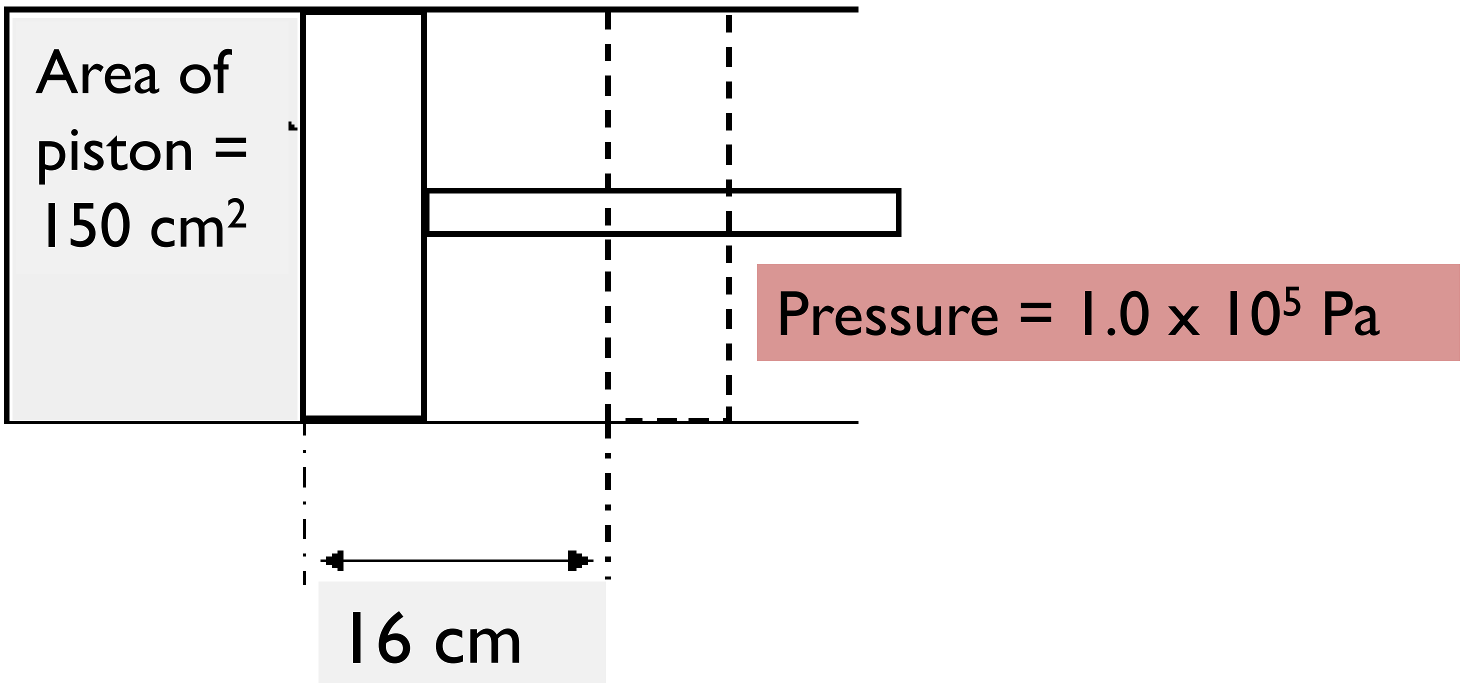


Work done by gas, W = force (PA) x distance moved **(Δx)**

= $P\Delta V$

***Pressure of gas is assumed to be constant throughout the gas expansion**

Question : work done by gas



When 300 J of energy is supplied to the gas, it expands and does work against a constant pressure of 1.0×10^5 Pa and pushes the piston 16 cm along the cylinder. Calculate:

(a) the work done by the gas 240 J

(b) the increase in internal energy of the gas. 60 J

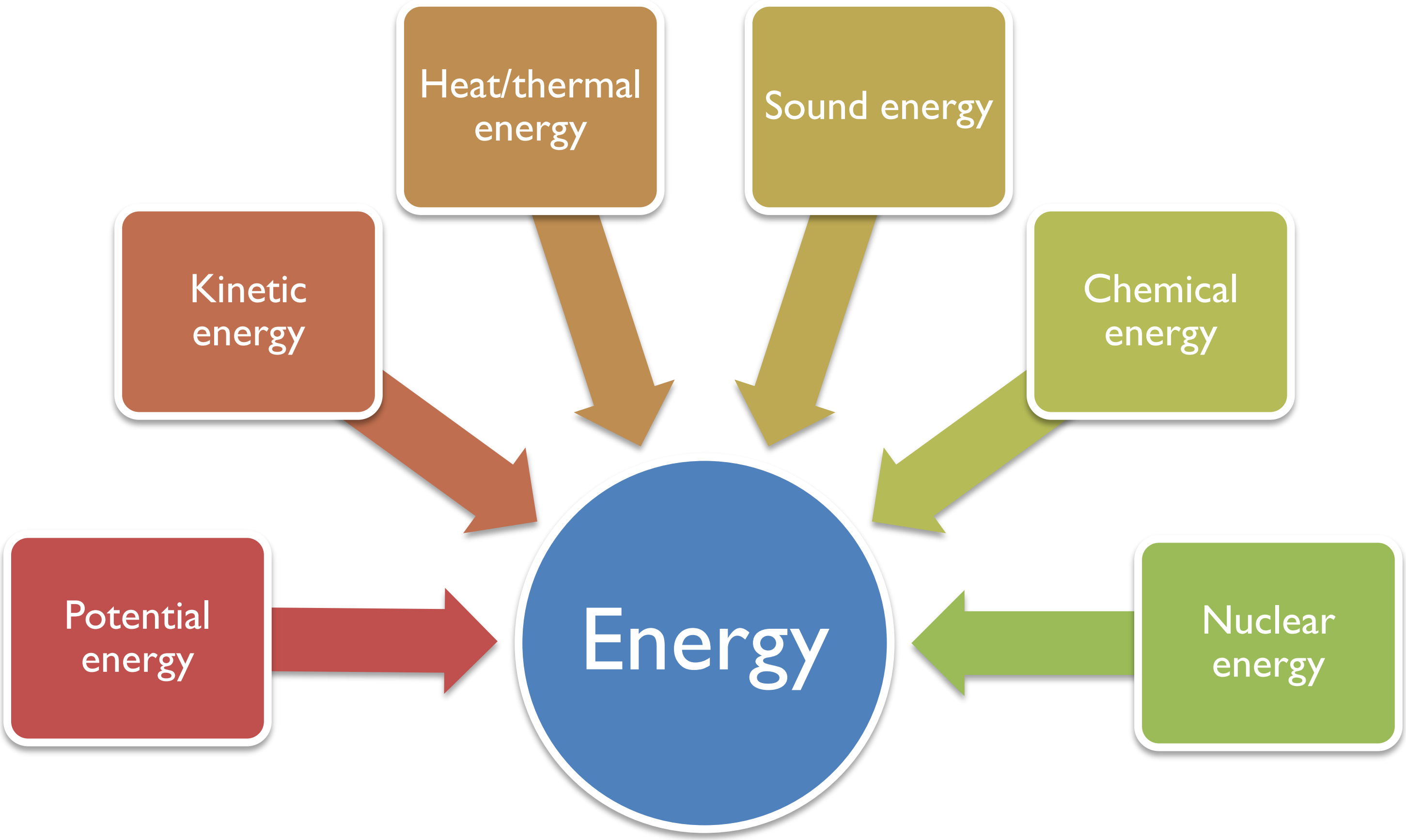
Question : Work done by gas

1. The volume of air in a tyre is 9.0×10^{-3} m^3. Atmospheric pressure is 1.0×10^5 Pa. Calculate the work done against the atmosphere by the air when the tyre burst and the air expands to a volume of 2.7×10^{-2} m^3 Ans: 800 J
2. High pressure gas in a spray can has a volume of 250 cm^3. The gas escapes into the atmosphere through a nozzle, so that its final volume is four times the volume of the can. Calculate the work done by the gas, given that atmospheric pressure is 1.0×10^5 PA Ans: 75 J

- Potential energy
  - G.P.E, Elastic potential energy, Electric potential energy
  - Derivation of G.P.E formula
- Kinetic energy
  - Derivation of kinetic energy formula
- Concept of Energy transfer
  - Principle of conservation of energy
  - Principle of conservation of mecahnical energy
- Internal energy of system

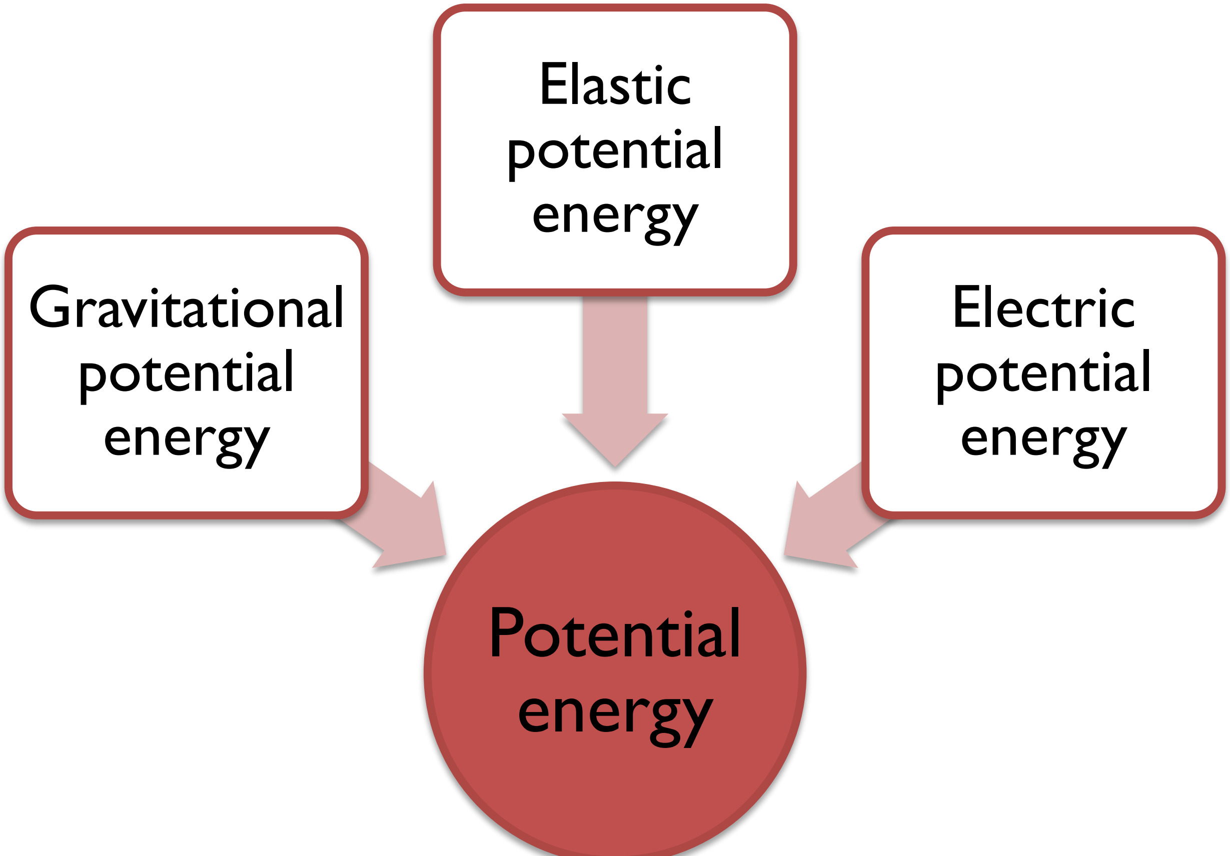
ENERGY

Various forms of energy



Energy is an ability to do work

Potential energy



Ability of an object to do work as a result of its position or shape

1

Gravitational potential energy

What ?

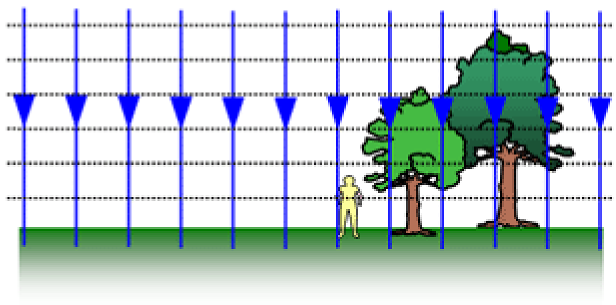
- Energy an object possesses because of its position in a gravitational field

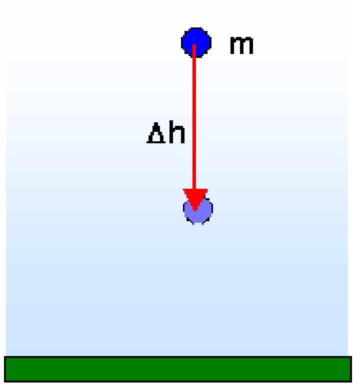
Formula G.P.E

- mass (m) x g x height (h) = mgh

Formula ΔG.P.E

- mass (m) x g x change in height (Δh)
- Δh is measured parallel to the field





Derive formula for G.P.E

There is uniform gravitational field near the surface of earth.

Thus, all object are accelerated towards earth by the same gravitational field strength which is equal to 9.81 N/kg or 9.81 ms^{-2}

As F = ma, it means all objects experience force of F_g which is

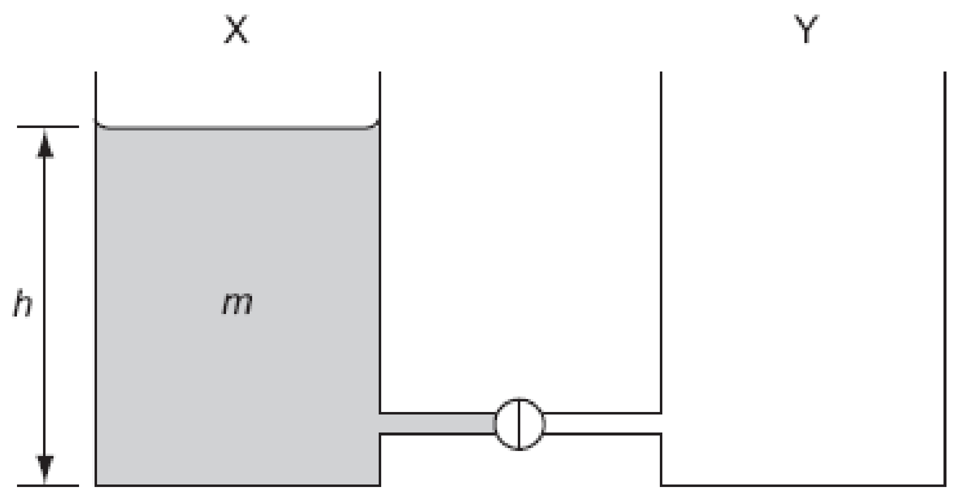
- mass x acceleration of free fall,
- $F_g = mg$

Work done = F x s,

- So, work done by gravitational force in bringing a mass to a height h = G.P.E
- mgh

Question: Gravitational Potential Energy

The diagram shows two identical vessels X and Y connected by a short pipe with a tap.



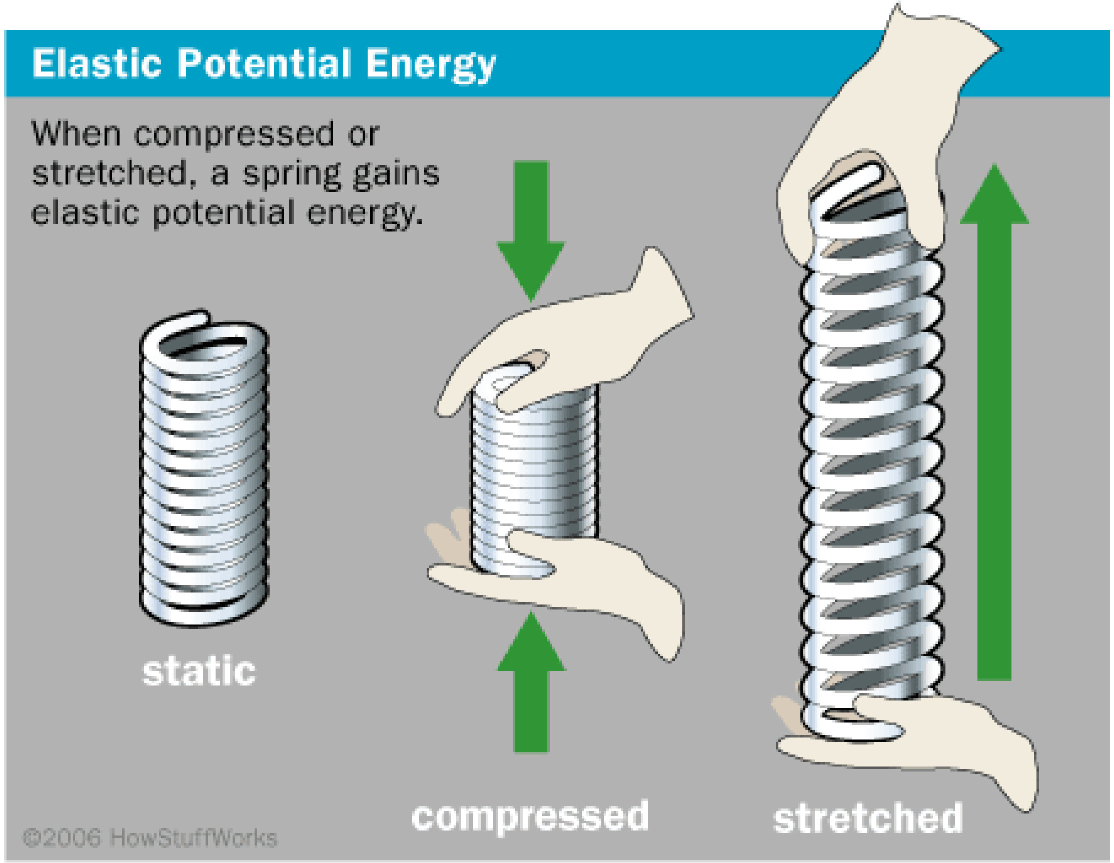
Ans:

mgh/4

Initially, X is filled with water of mass m to a depth h, and Y is empty. When the tap is opened, water flows from X to Y until the depths of water in both vessels are equal.

How much potential energy is lost by the water during this process? (g = acceleration of free fall)

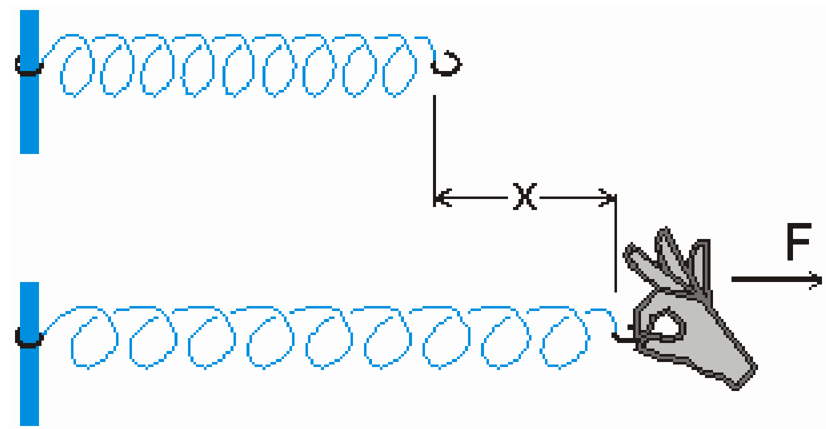
Elastic Potential Energy, E_p



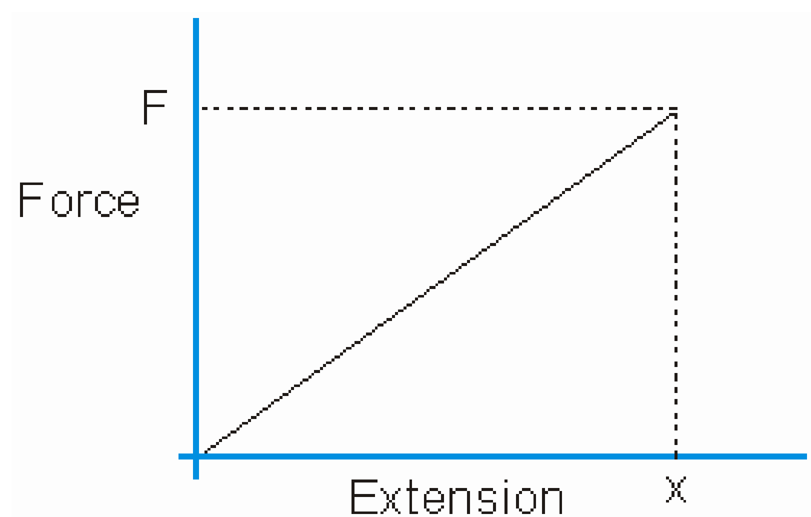
Energy stored due to the deformation of an elastic object

Elastic Potential Energy, E_p

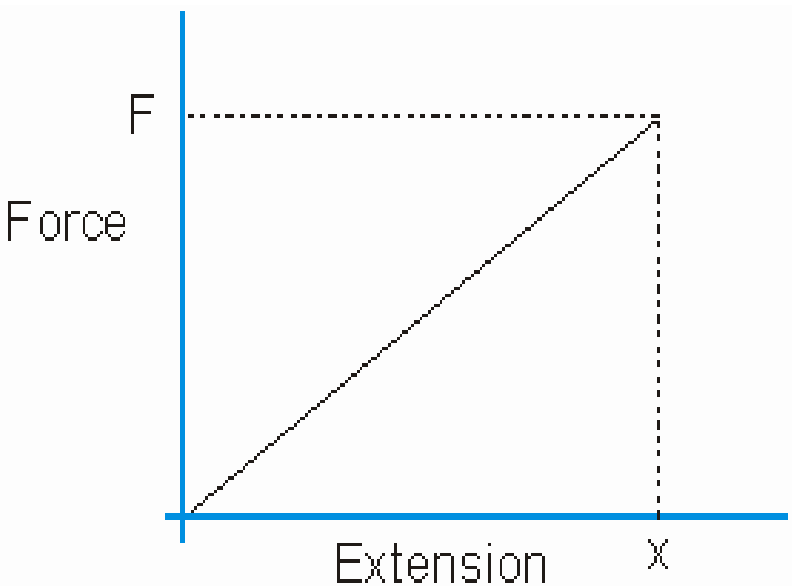
- Consider a spring being extended by a *steadily increasing* force. When the force has a magnitude F, the extension is x.



- A graph of force against extension would be a straight line passing through the origin, as long as the **elastic limit** of the spring has not been exceeded (**Hooke's law**).



Elastic Potential Energy, E_p



Work done to stretch the spring = the energy gained by the spring.

Work done on spring is

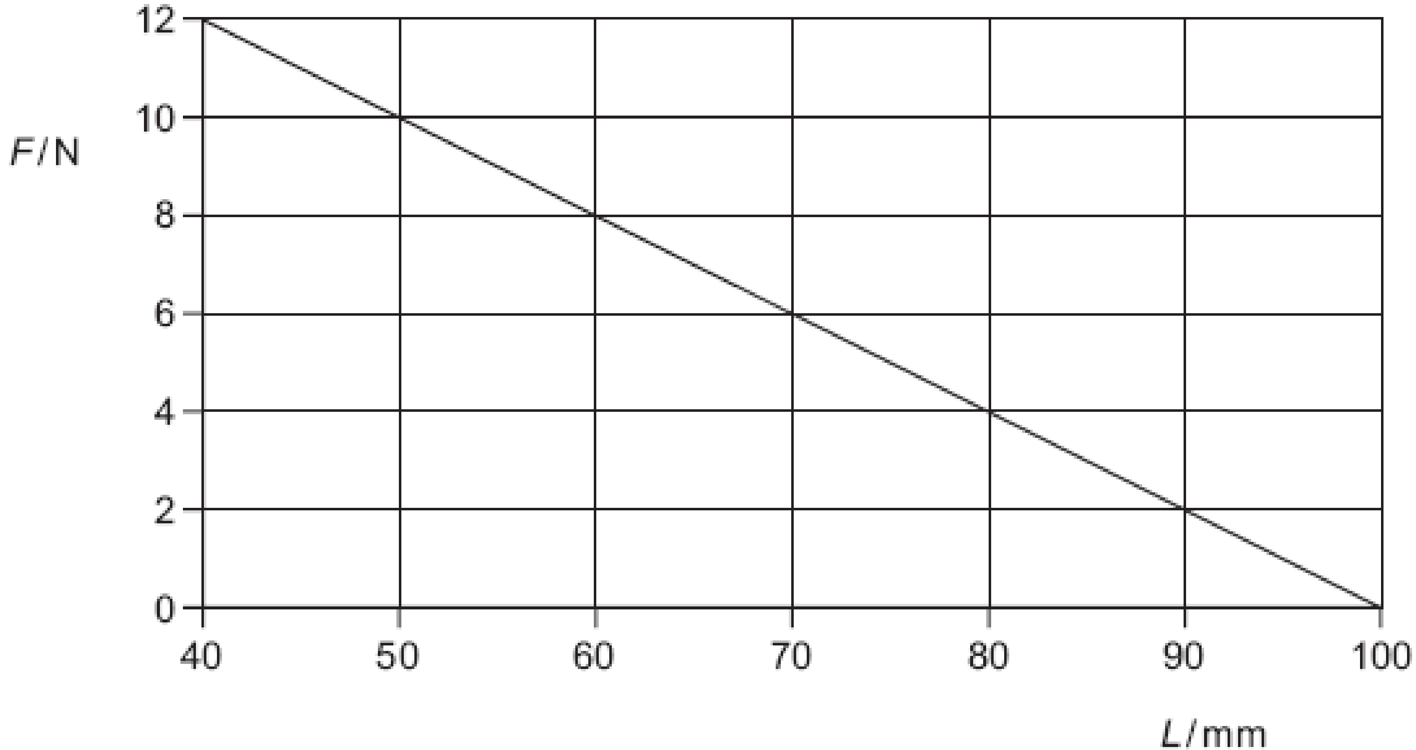
average force x distance moved

<u>This equal to area under graph</u>

So, E_p of spring is

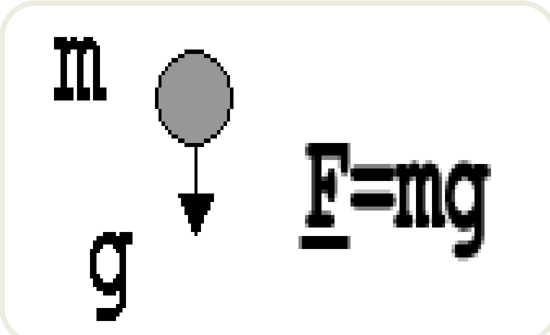
$$\mathbf{E_p = \tfrac{1}{2} Fx}$$

Question: Elastic potential energy



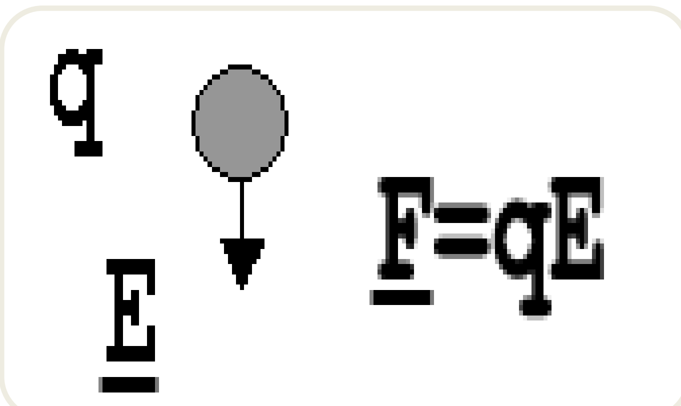
A spring of original length 100 mm is compressed by a force. The graph shows the variation of the length L of the spring with the compressing force F. *What is the energy stored in the spring when the length is 70 mm?* 0.090 J

Electric and gravitational potential energy



Particle with mass, m in gravitational field, g

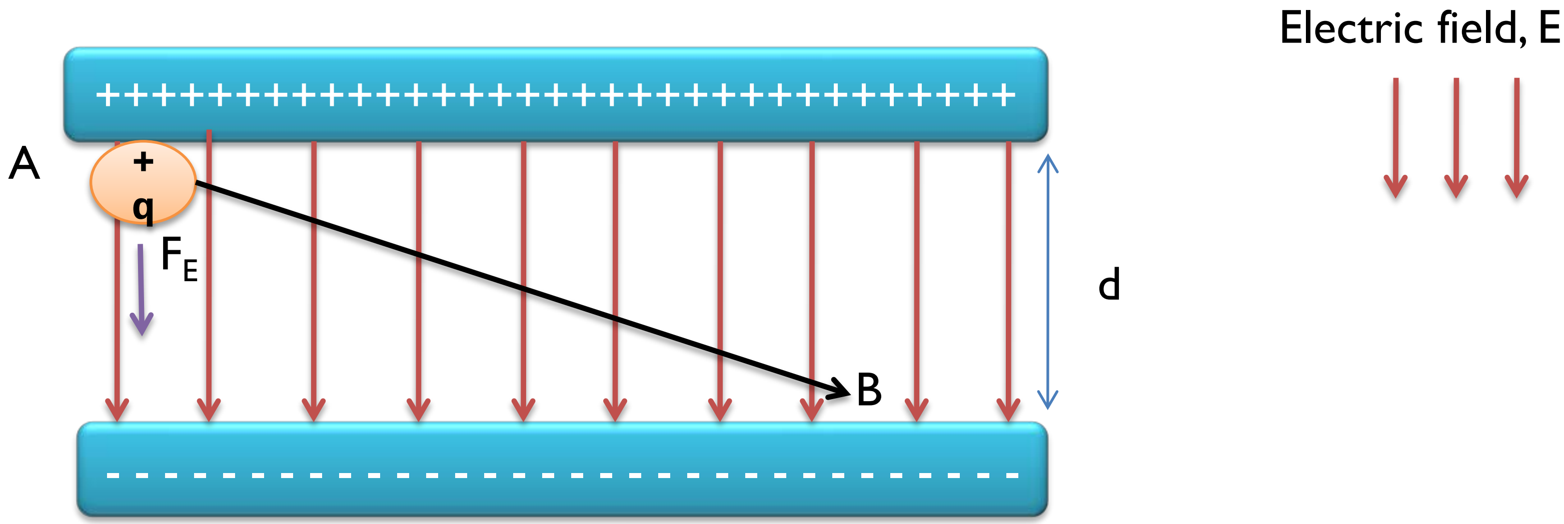
- Experience a force , F_g
- $F_g = mg$



Charged particle with charge, +q in an electric field, E

- Experience a force, F_E
  $F_E = qE$

Electric potential energy



- A positive charge experiences a force F_E when placed at point A in a uniform electric field.
- The charge is then moved from point A to point B
- **From A to B, the charge lost its potential energy equal to work done by force F_E**

$$\Delta P_E = F_E \times d$$

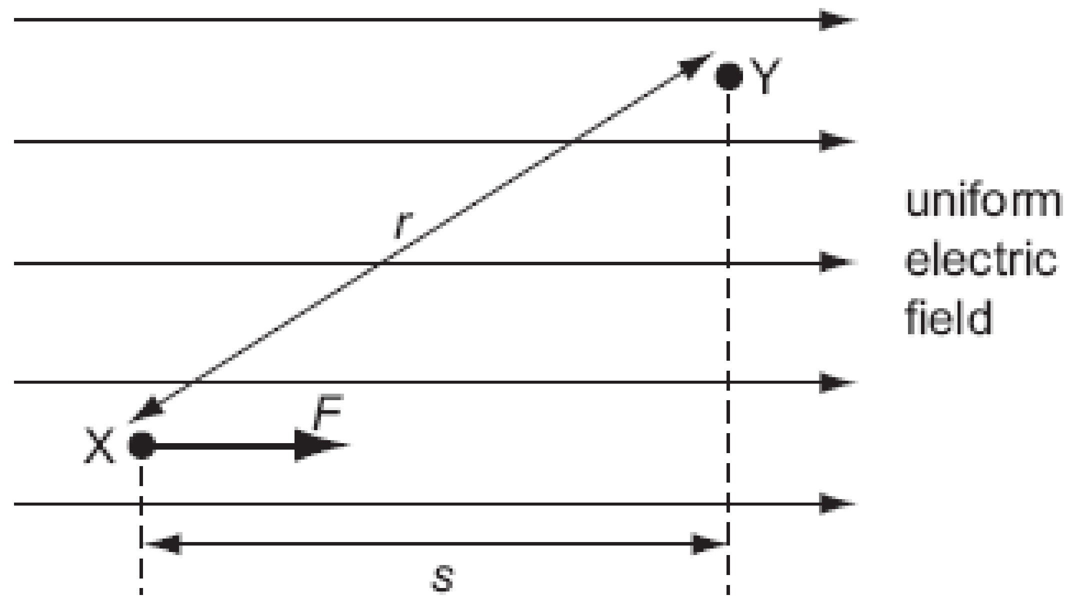
Question : electric potential energy

A decreases by Fs

B increases by Fs

C decreases by Fr

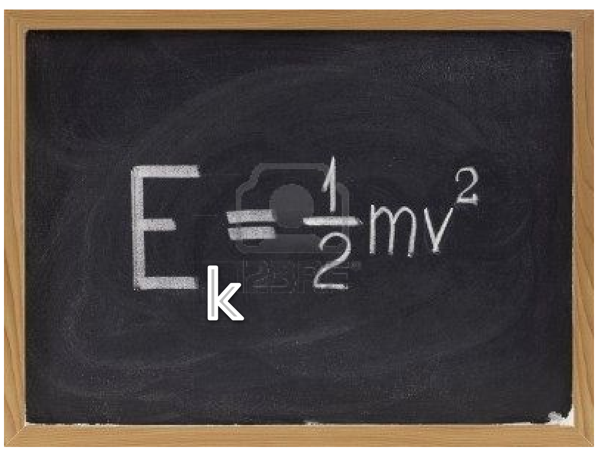
D increases by Fr



- A positive charge experiences a force F when placed at point X in a uniform electric field. The charge is then moved from point X to point Y.
- ***What is the change in the potential energy of the charge?***

Kinetic energy

- The *kinetic energy* of an object is the energy it possesses because of its motion
- For object of mass m travelling at speed v, we have, its kinetic energy E_k as



E = kinetic energy
m = mass of the object
v = speed of the object

Derive kinetic energy formula

An object accelerated uniformly from rest (u = o) to velocity, v for a distance s because

It was pushed by a force F which enable it to accelerate, *a* for that distance s.

From $v^2 = u^2 + 2as$, we obtained

$\mathbf{v^2 = 2as}$

Multiplying both side by ½ m, we get

$\mathbf{\frac{1}{2} mv^2 = mas}$; (but, ma = F)

Thus, $\mathbf{Fs = \frac{1}{2} mv^2}$

Fs = Work done by force F = energy transferred to the car (kinetic energy)

Energy transfer

A boy eat rice

- Boy gain chemical energy

The boy lift a ball

- Chemical energy converted to gravitational potential energy

The ball falling down

- Gravitational potential energy into kinetic energy

Ball on the ground

- Kinetic energy into chemical energy

Principle of conservation of energy

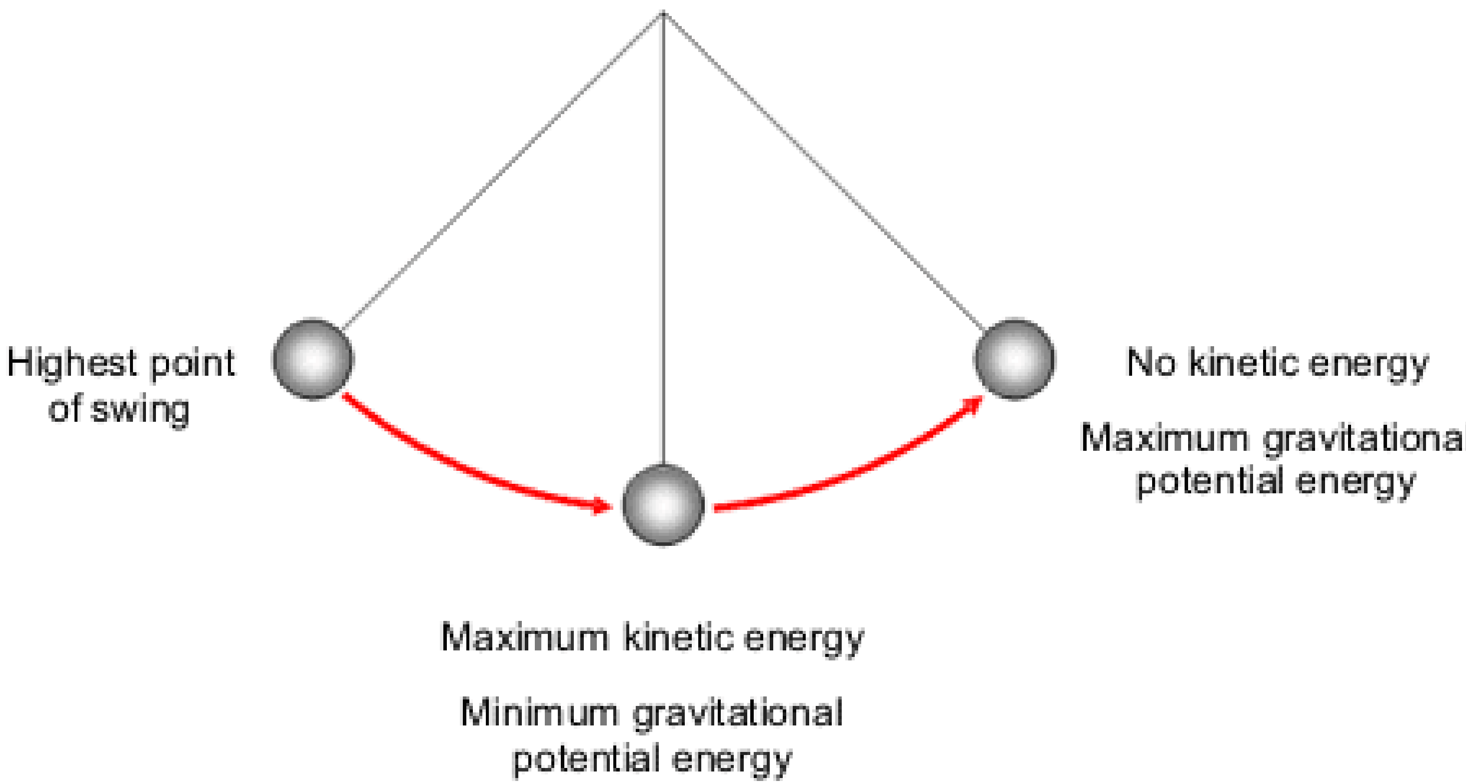
Energy cannot be created or destroyed but can change from one form to another,

Energy is measured in the same units as work :joules (J)	Amount of energy transferred = Amount of work done

Example: Principle of conservation of energy

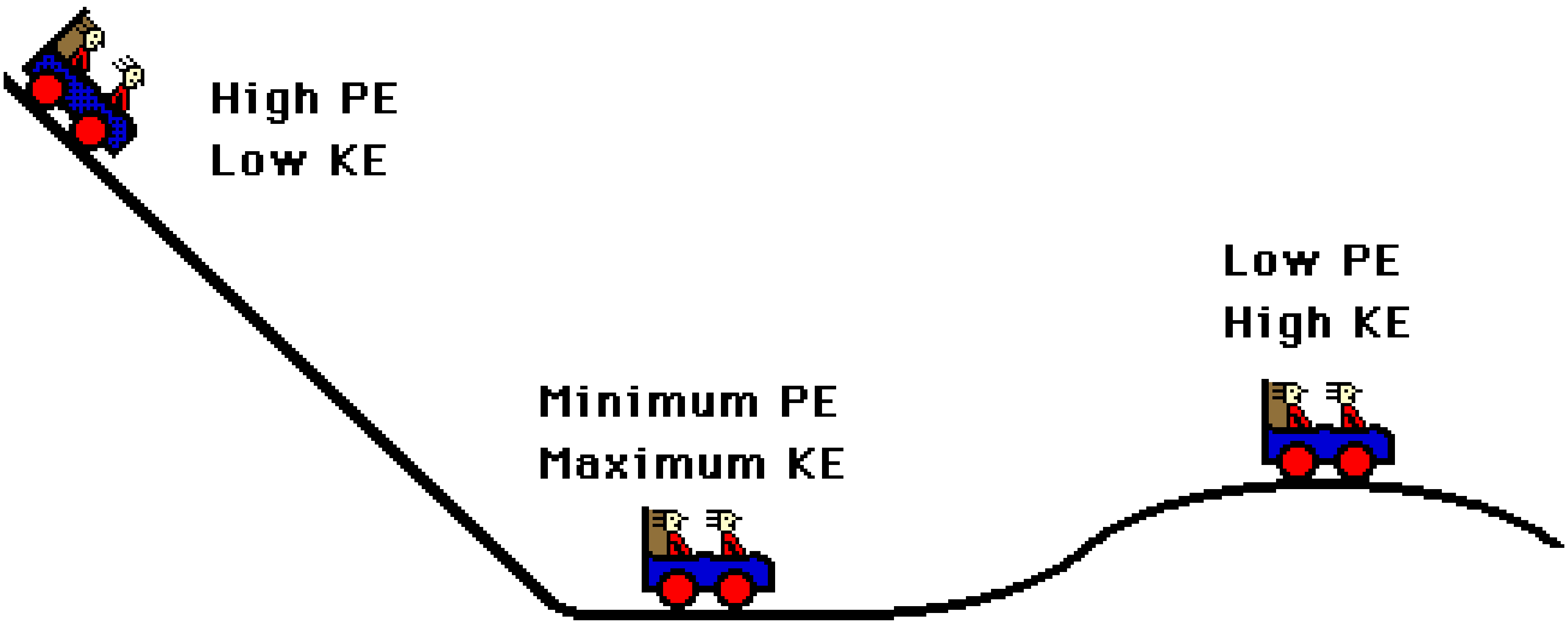
Potential energy = Kinetic energy + heat energy

Example: Principle of conservation of energy



Highest speed

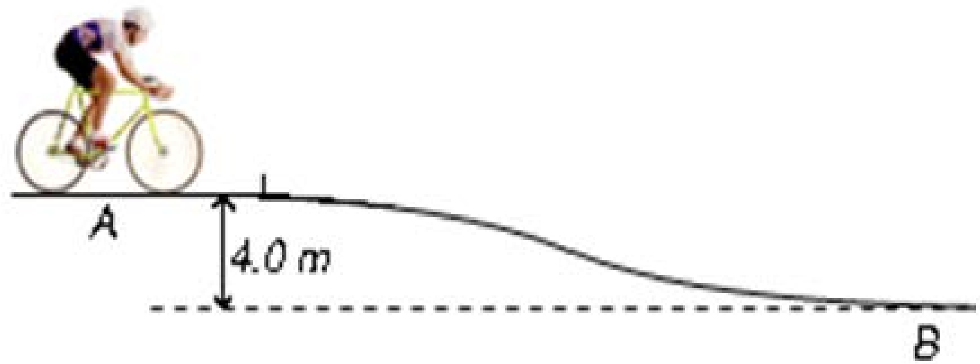
Example: Principle of conservation of energy



As a coaster car loses height, it gains speed; PE is transformed into KE. As a coaster car gains height it loses speed; KE is transformed into PE. The sum of the KE and PE is a constant.

Question : principle of conservation of energy

- A cyclist, together with his bicycle, has a total mass of 90 kg and is travelling with a constant speed of 15 ms^{-1} on a flat road at A, as illustrated in the figure below. He then slide down a small slope to B so descending 4.0m.



- Calculate
  (i) the kinetic energy at A,
  (ii) the loss of potential energy between A and B
  (iii) the speed at B, assuming there is no friction occur

1.01×10^4 J

3.53×10^3 J

17.4 ms^{-1}

Internal forces & external forces

- The importance of categorizing a force as being either internal or external is related to the ability of that type of force to **change an object's total mechanical energy** (kinetic energy +potential energy) when it does work upon an object.

Internal forces	External forces
$\mathbf{F_{grav}}$	F applied
$\mathbf{F_{spring}}$	Friction
	Air
	Normal

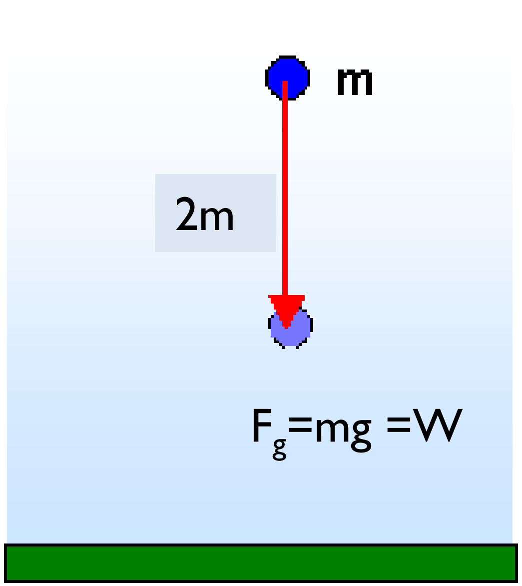
Principle of conservation of mechanical energy

- In a system in which the only forces acting are associated with potential energy (gravitational and elastic forces) the sum of the kinetic and potential energy is constant)

  KE + PE = constant

- It means, if only internal forces are doing work (no work done by external forces), there is no change in total mechanical energy; the total mechanical energy is said to be *conserved.*
- But, whenever work is done upon an object by an external force, there will be a change in the total mechanical energy of the object.

Work done by internal forces



- If **only internal force** doing net work on an object the total mechanical energy (KE + PE) of that object remains constant. form.

$$\mathbf{(KE_i + PE_i) = (KE_f + PE_f)}$$

- Example:
  - A ball falls from a height of 2 meters **in the absence of air resistance.**
  - Here, only gravitational force act on the object, W(internal force). Air resistance is not present, so, it did not do any work, so, it did not change mechanical energy of the object
  - The ball is losing height (falling) and gaining speed. Thus, the internal force (gravity) transforms the energy from PE (height) to KE (speed). Total mechanical energy is conserved

KE = kinetic energy
PE = potential energy
i = initial
f = final

Work and mechanical energy relation

$$\boxed{PE_i + KE_i + W_{ext} = PE_f + KE_f}$$

- From equation above, if only **<u>internal forces</u>** are doing work (work done by external forces = 0), there is no change in total mechanical energy; the *<u>total mechanical energy is said to be conserved.</u>*

$$\boxed{PE_i + KE_i = PE_f + KE_f}$$

- But, whenever work is done upon an object by an **<u>external force</u>**, there will be **a change in the total mechanical energy of the object**.

$$\boxed{PE_i + KE_i + W_{ext} = PE_f + KE_f}$$

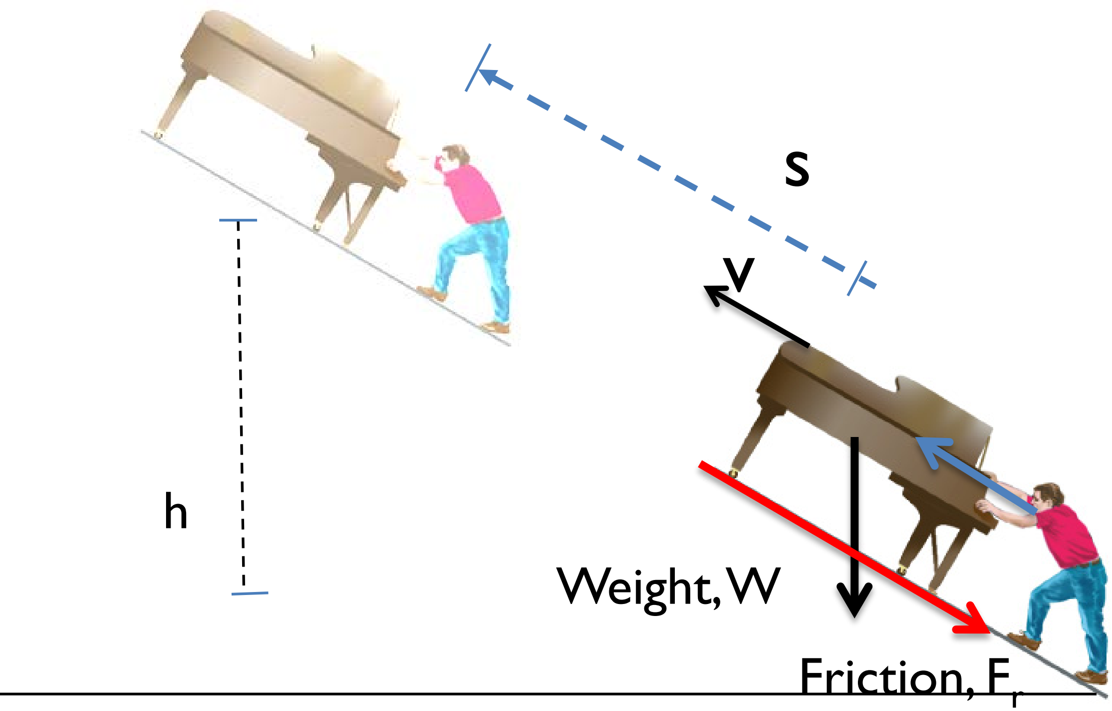
Work and mechanical energy relation

- Work done by external forces on an object can be positive or negative. (Refer to positive and negative work notes).
- So, work done by an external forces on an object can cause decrease or decrease in the total mechanical energy of the object.
- However, we can always sure that **work done by friction force** is always negative

$$\boxed{PE_i + KE_i + W_{ext} = PE_f + KE_f}$$

Pushing up an object on slope

Case 1: with friction and at constant velocity



v = steady speed

- The man push the object towards h height with constant velocity v.
- There is friction force F_r that oppose the object's motion. Find the total work done by the man, W_{man} on the object.

• Here, there are two external forces involved;

  - Applied force by the man on the object
  - Friction force on the object

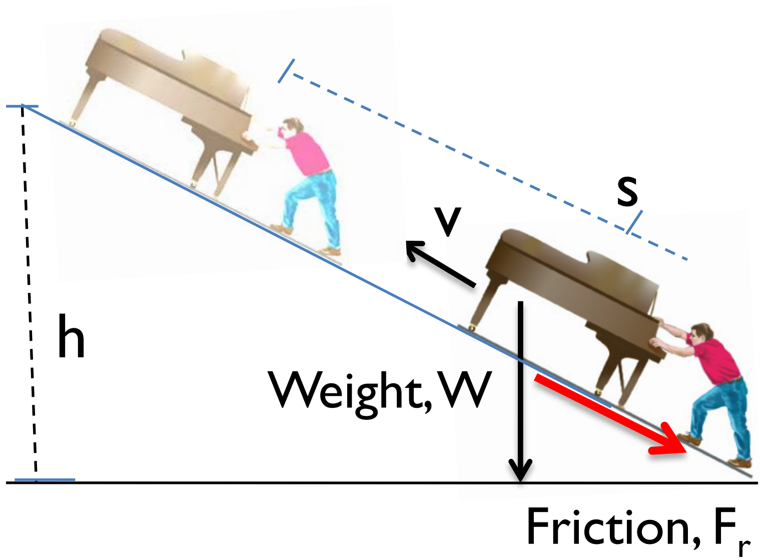
Pushing up an object on slope

$$\boxed{PE_i + KE_i + W_{ext} = PE_f + KE_f}$$

- $PE_i = 0$, $KE_i = 0$, $PE_f = Wh$, $KE_f = 0$
- W_{ext}
  - Work done by friction on object = $F_r \cos 180 \times s$
    - (-ve)(because **θ is 180°)**
  - Work done by man on object = W_{man}
- Equation becomes
- $-F_r s + W_{man} = Wh$
- So, work done by the man, Wman = $F_r s + Wh$

Work done overcome friction　Work done against gravity

Pushing up an object on slope



a) Work to overcome friction

- What's the friction force we've got to overcome? **F**
- What's the work done against friction?**F x s**

b) Work to overcome gravity

- What's the weight we've got to lift?**W**
- What's the distance moved to overcome W? **h**
- What's the work done against gravity? **W x h**

So, total work done, W_T by the man

= (a) + (b)

= (F_r x s)+ (W x h)

Pushing up a slope with friction

- So, we have calculated the **work done by the man** is

  $F_r s$ + Wh.

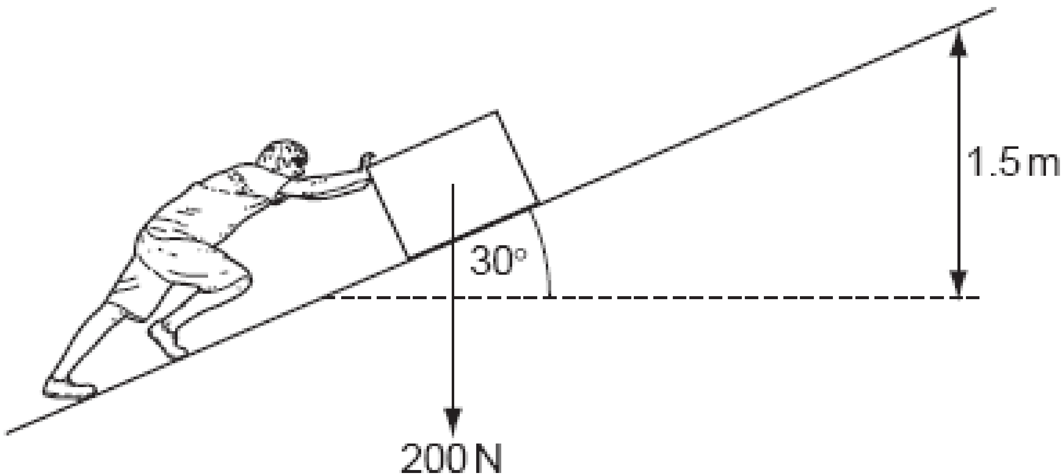
- This also equals to
  - work done against friction + work done against gravity
- So, for an object to move at constant velocity up a slope, total work done on it also equal to

work done against friction
+
work done against gravity

- However, we need to understand that this equation comes from conservation of mechanical energy equation

Question

Case 1: Pushing up at a slope with friction with constant velocity



- A box of weight 200 N is pushed so that it moves at a steady speed along a ramp, through a height of 1.5 m. The ramp makes an angle of 30° with the ground. The frictional force on the box is 150 N while the box is moving. What is the work done by the person?

750 J

Question

- Case 2: Pushing up at a slope with friction with uniform acceleration
- A car of mass 1.0×10^3 kg increases its speed from 10 ms^{-1} to 20 ms^{-1} whilst moving 500 m up a road inclined at an angle a to the horizontal where $\sin \alpha = 1/20$. There is a constant resistance to motion of 300 N. Find the driving force exerted by the engine assuming that it is constant.

Tips:
Use work – mechanical energy relation
$(KE_i + Pe_i + W_{ext}) = (KE_f + PE_f)$

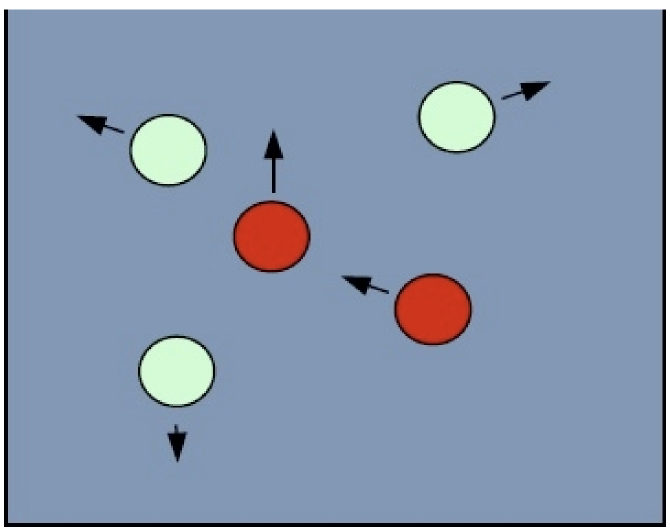
Answ: 1.1×10^3 N

Internal energy of a system

- A room temperature glass of water sitting on the floor has no apparent energy, either potential or kinetic .
- But **on the microscopic scale**, there are high speed molecules traveling at hundreds of meters per second.
- Internal energy of a system is the energy of the atoms of the system possess.
- This energy mostly comes from the motion of the molecules, rotation and vibration within molecules

Internal energy of a system

The sum of the kinetic and potential energy of the particles in the system.



Kinetic energy: from the motion of particles
Potential energy: from the interactions between the particles

POWER

- Definition
- Derivation of power equation= force x velocity
- Efficiency

Power

Unit = Watt (W) =1 W = 1 J/s

unit

$$Power = \frac{work\ done}{time\ taken}$$

definition

Power

= force x velocity

formula

POWER

Deriving Power Equation

Power is defined as = work done / time taken

Power = (force x distance) / time taken

Power = force x velocity

Question : power

- A 950 kg sack of cement is lifted to the top of a building 50 m high by an electric motor.

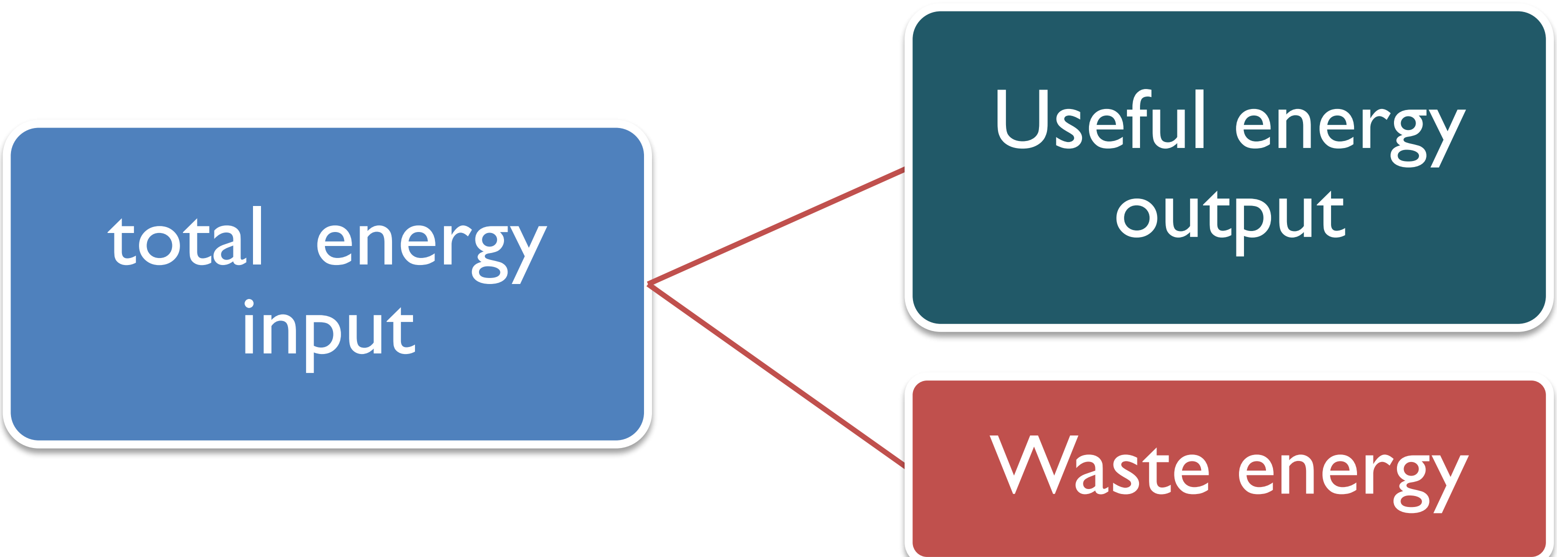
a) Calculate the increase in the gravitational potential energy of the sack of cement **<u>4. 66 x 10^5</u>J**
b) The output power of the motor is 4.0 kW. Calculate how long it took to raise the sack to the top of the building. **<u>117 s</u>**
c) The electrical power transferred /produced by the motor is 6.9 kW. In raising the sack to the top of the building, how much energy is wasted in the motor as heat **<u>3.4 x 10^5 J</u>**

Efficiency, η

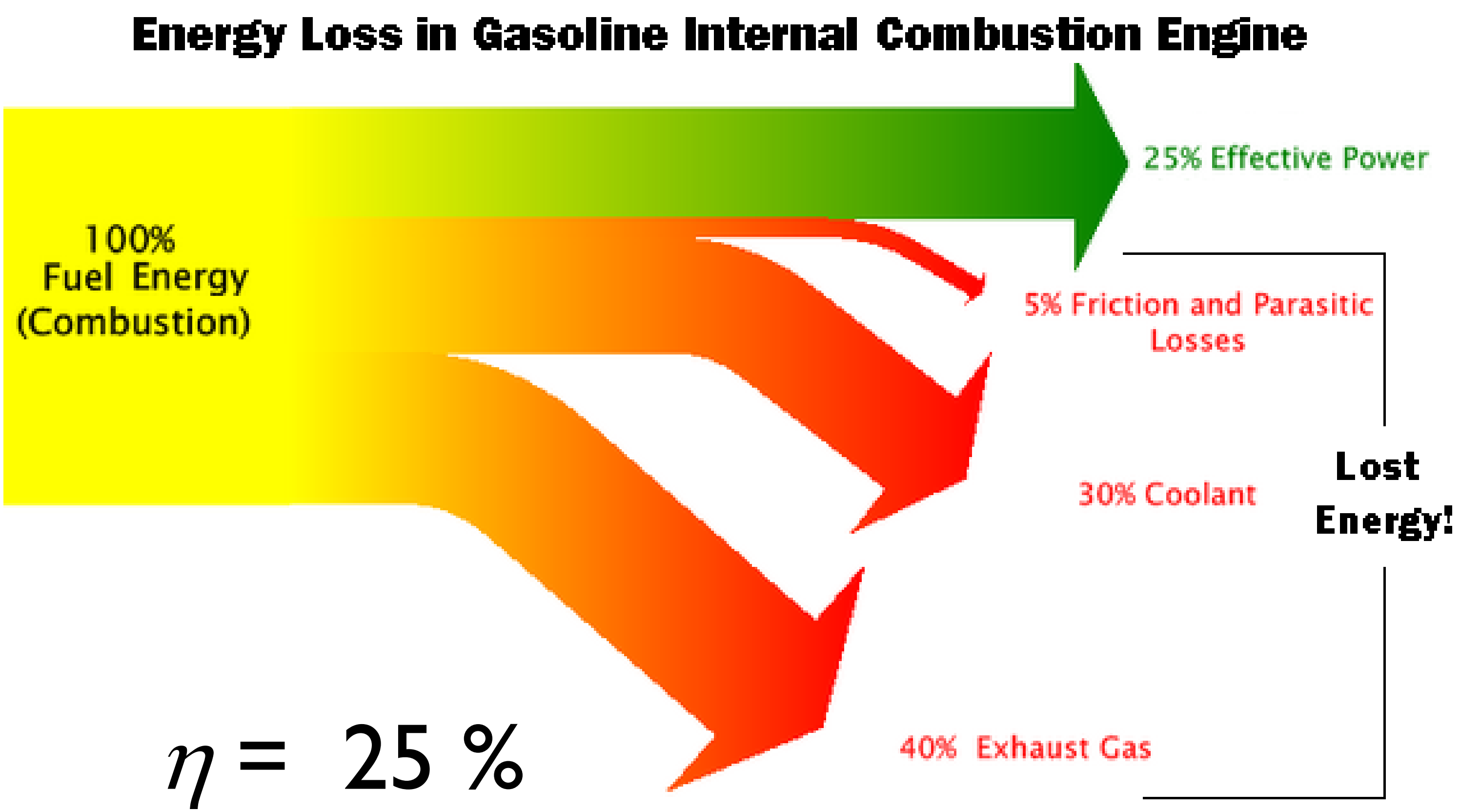
- When a work is done on an object, it means energy is transferred to the object.
- However, not all energy transfer is efficient.
- Means, only part of energy transfer goes to where it is wanted
- The rest is wasted in some form that is not wanted

Efficiency, η

$$\eta = \frac{\textbf{useful output energy}}{\textbf{total energy input}} x100\%$$



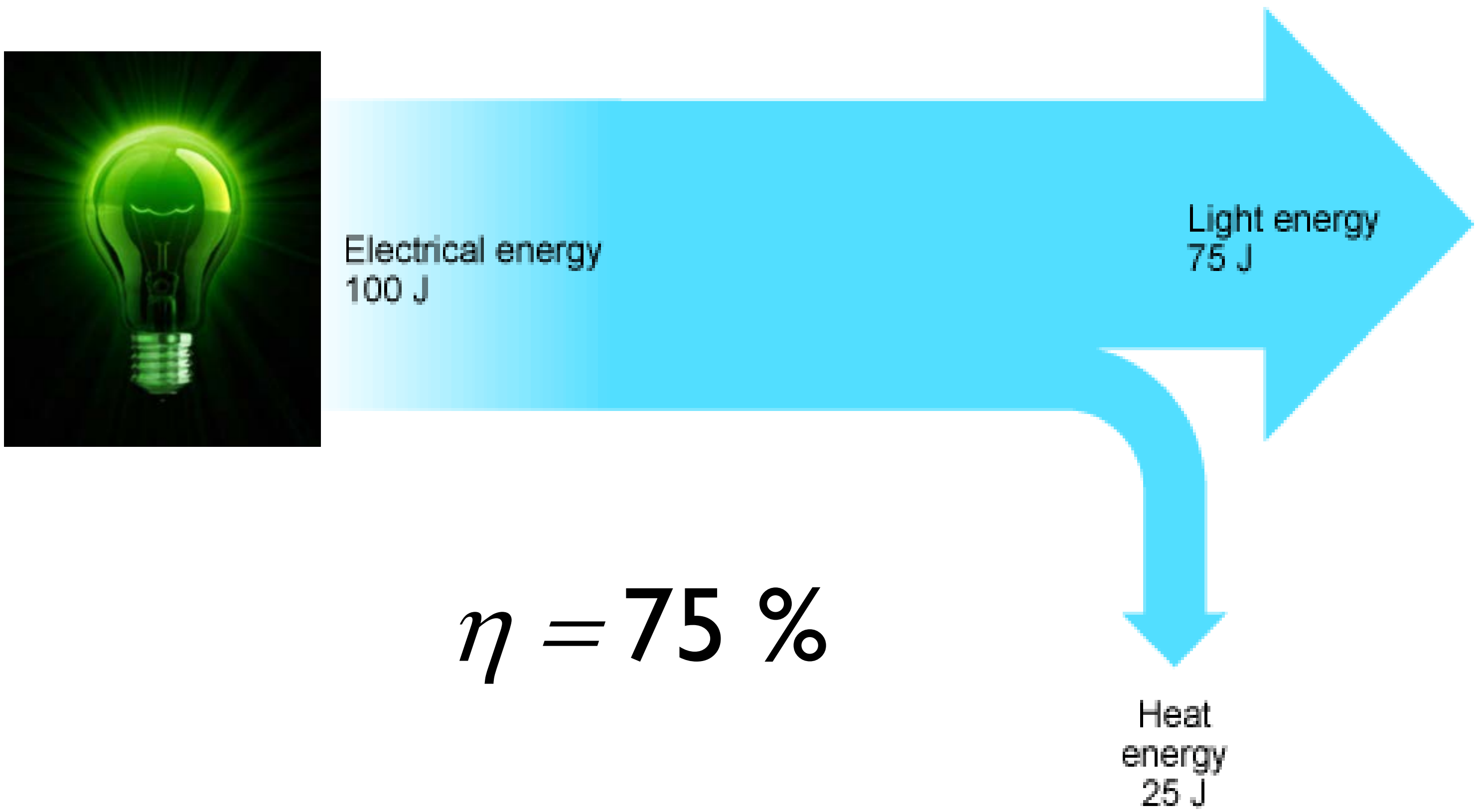
Question: Efficiency, η



$$\eta = 25\ \%$$

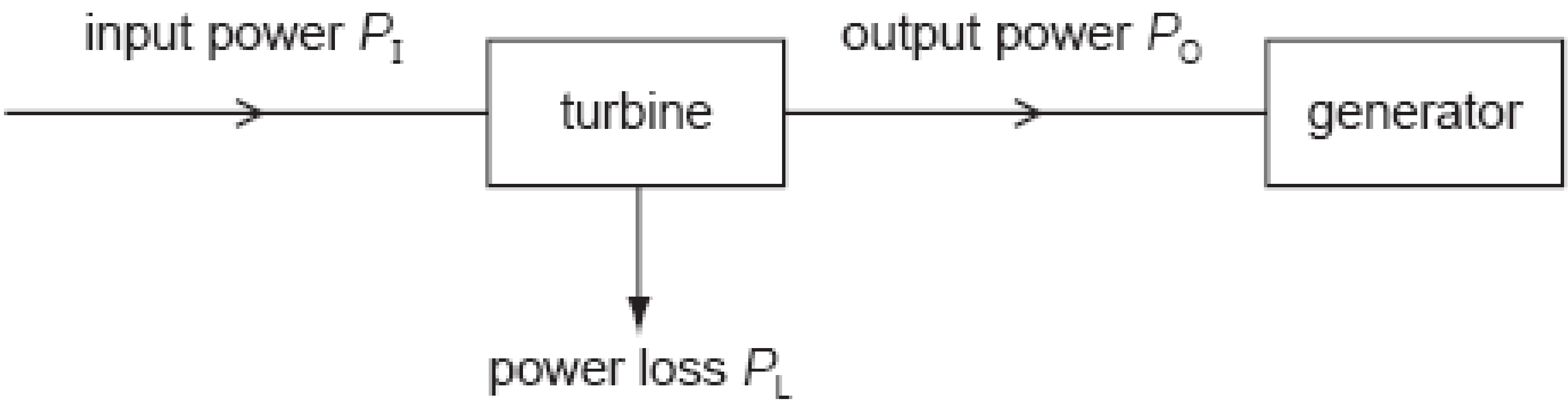
Question : Efficiency, η

Calculate efficiency of the lamp



$$\eta = 75\ \%$$

Question : Efficiency, η



- A steam turbine is used to drive a generator.
- What is the efficiency of the turbine?

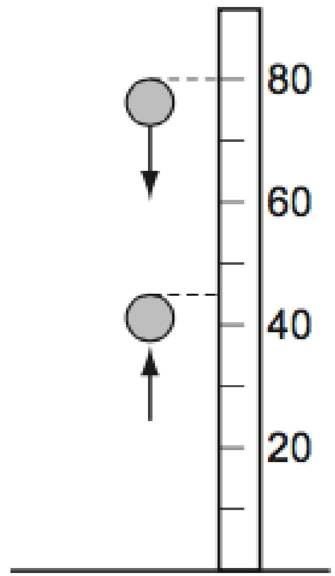
$$\frac{P_O}{P_I}$$

The END

Tutorials

S13 QP11

17 A solid rubber ball has a diameter of 8.0 cm. It is released from rest with the top of the ball 80 cm above a horizontal surface. It falls vertically and then bounces back up so that the maximum height reached by the top of the ball is 45 cm, as shown.



If the kinetic energy of the ball is 0.75 J just before it strikes the surface, what is its kinetic energy just after it leaves the surface?

A 0.36 J **B** 0.39 J **C** 0.40 J **D** 0.42 J

S13 QP12

15 A ball is thrown vertically upwards.

Neglecting air resistance, which statement is correct?

A The kinetic energy of the ball is greatest at the greatest height attained.

B By the principle of conservation of energy, the total energy of the ball is constant throughout its motion.

C By the principle of conservation of momentum, the momentum of the ball is constant throughout its motion.

D The potential energy of the ball increases uniformly with time during its ascent.

16 A bow of mass 400 g shoots an arrow of mass 120 g vertically upwards. The potential energy stored in the bow just before release is 80 J. The system has an efficiency of 28%.

What is the height reached by the arrow when air resistance is neglected?

A 4 m **B** 19 m **C** 187 m **D** 243 m

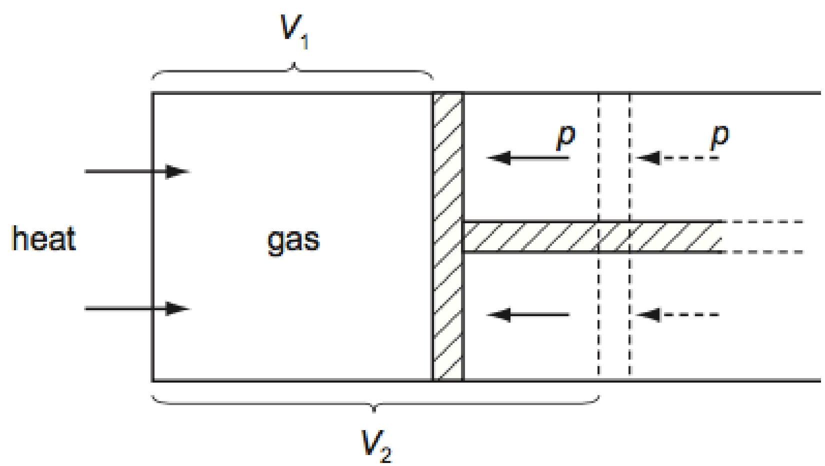
S13 QP12

17 A train on a mountain railway is carrying 200 people of average mass 70 kg up a slope at an angle of 30° to the horizontal and at a speed of $6.0\,m\,s^{-1}$. The train itself has a mass of 80 000 kg. The percentage of the power from the engine which is used to raise the passengers and the train is 40 %.

What is the power of the engine?

A 1.1 MW **B** 2.8 MW **C** 6.9 MW **D** 14 MW

18 A gas is enclosed inside a cylinder which is fitted with a frictionless piston.

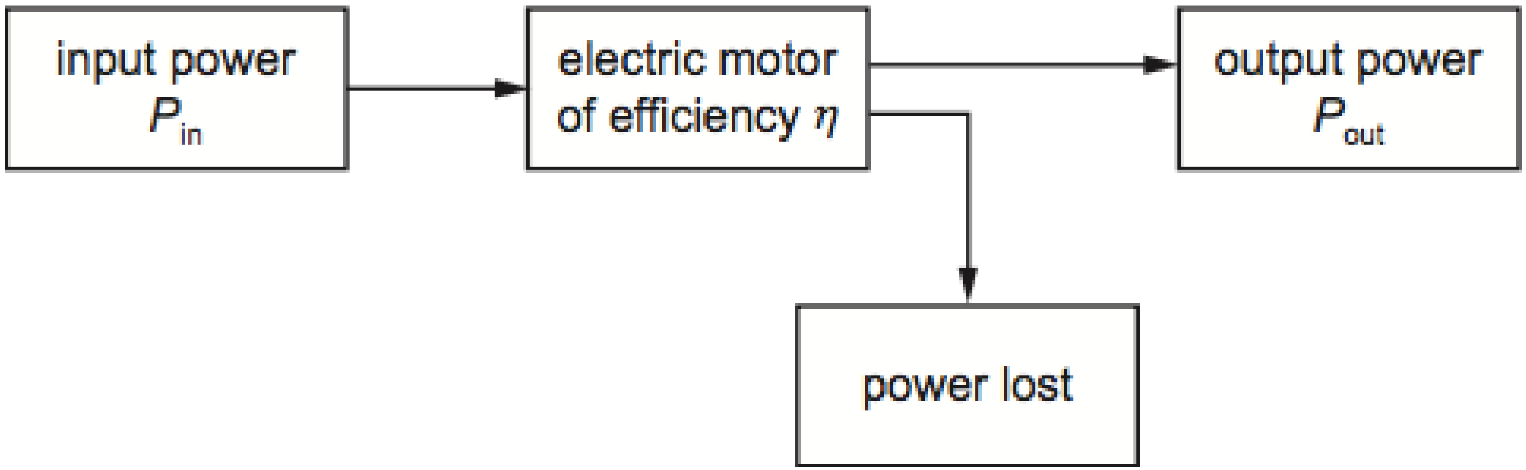


Initially, the gas has a volume V_1 and is in equilibrium with an external pressure p. The gas is then heated slowly so that it expands, pushing the piston back until the volume of the gas has increased to V_2.

How much work is done by the gas during this expansion?

A $p(V_2 - V_1)$ **B** $\frac{1}{2}p(V_2 - V_1)$ **C** $p(V_2 + V_1)$ **D** $\frac{1}{2}p(V_2 + V_1)$

16 An electric motor has an input power P_{in}, useful output power P_{out} and efficiency η.



How much power is lost by the motor?

A ηP_{in}

B $\left(\dfrac{1}{\eta} - 1\right) P_{in}$

C ηP_{out}

D $\left(\dfrac{1}{\eta} - 1\right) P_{out}$

9 An object of mass 4.0 kg moving with a speed of 3.0 m s^{-1} strikes a stationary object in an inelastic collision.

Which statement is correct?

A After collision, the total kinetic energy is 18 J.

B After collision, the total kinetic energy is less than 18 J.

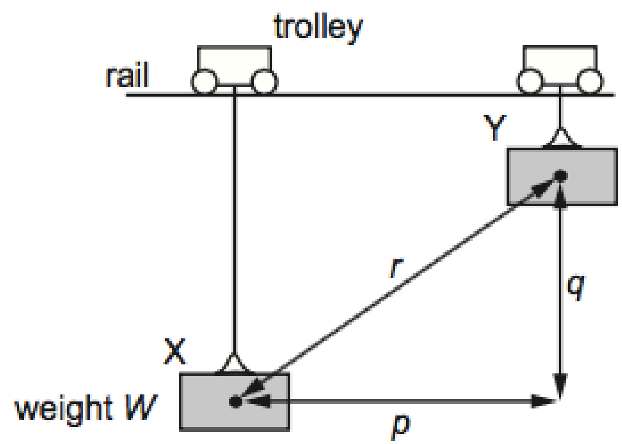
C Before collision, the total kinetic energy is 12 J.

D Before collision, the total kinetic energy is less than 12 J.

14 What is the average power output of a laser that can deliver 0.20 J of energy in 10 ns?

A 2 nW **B** 20 mW **C** 200 kW **D** 20 MW

15 A weight W hangs from a trolley that runs along a rail. The trolley moves horizontally through a distance p and simultaneously raises the weight through a height q.



As a result, the weight moves through a distance r from X to Y. It starts and finishes at rest.

How much work is done on the weight during this process?

A Wp **B** $W(p + q)$ **C** Wq **D** Wr

16 The engine of a car exerts a force of 600 N in moving the car 1.0 km in 150 seconds.

What is the average output power of the engine?

A 4.0 W **B** 4.0 kW **C** 90 kW **D** 90 MW