CHAPTER 9: ENERGY

9.0 INTRODUCTION

Energy is one of the most fundamental parts of our universe. We use energy every day. Energy lights our homes and powers our vehicles and planes. It warms our homes, cooks our food, plays our music, and gives us pictures on television.

Energy stored in plants is eaten by animals, giving them energy. And predator animals eat their prey, which gives the predator animal energy.

Everything we do is associated to energy in one form or another.

9.10 WORK DONE BY A CONSTANT FORCE

In Physics, the word "work" takes on a different meaning from the one commonly used. Work is defined as a force applied through a distance. Work done on an object by a constant force is the product of the object's displacement and the force acting parallel to the displacement.

$$W = F \times d$$

The SI unit for work is the **joule** (J). One joule is the product of one Newton and one meter, or a Joule is a one-Newton force applied through one meter, 1 J = 1 Nm.

Example 1

If a girl pushes a box with a 5.0 N force, and the box travels 2.0 m in the direction of her push, the amount of work done will be

$$W = F \times d$$

$$= 5.0 \text{ N} \times 2.0 \text{ m}$$

$$= 10 \text{ J}$$

Example 2

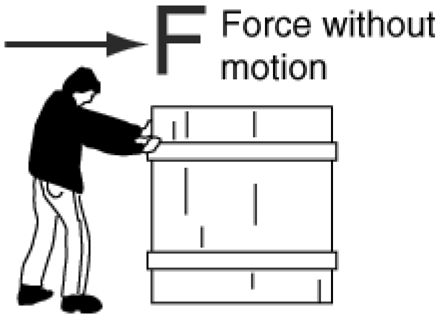
A 10 kg object experiences a horizontal force which causes it to accelerate at 5 m/s^2 , moving it a distance of 20 m, horizontally. How much work is done by the force?

The magnitude of the force is given by $F = ma$ = (10)(5) = 50 N. It acts over a distance of 20 m, in the same direction as the displacement of the object, implying that the total work done by the force is given by

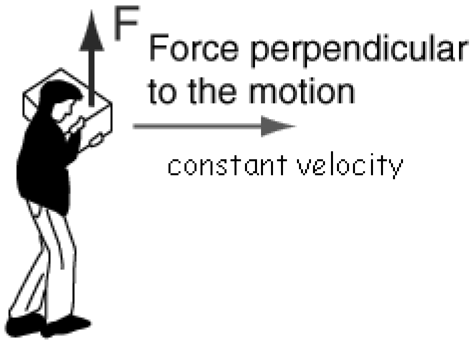
$$W = F \times d = (50)(20) = \underline{1000 \text{ J}}.$$

9.20 WHEN A FORCE DOES NO WORK

A force with no motion or a force perpendicular to the direction of motion does no work.



In the diagram above, no matter how hard or how long you have pushed, if the crate does not move, then you have done no work on the crate.



In the above diagram if the box is being carried at constant velocity, then no net force is necessary to keep it in motion. The force exerted by the person is an upward force equal to the weight of the box, and that force is perpendicular to the motion. When there is no motion in the direction of the force, then no work is done by that force.

Energy can be defined as the capacity for doing work. The simplest case of mechanical work is when an object is standing still and we force it to move. The energy of a moving object is called kinetic energy.

Note:

1. Energy is the ability to produce or create work. Work, on the other hand, is the ability to provide force and a change in distance to an object.

2. There are many types of energy such as solar energy, etc., but there is only one type of work.

3. Both work and energy are scalar units.

4. Both work and energy are measured in joules.

9.30 POWER

Power is the rate of work done in a unit of time. Power just shows us the time that the work requires. For example, same work is done by two different people with different time. Say one of them does the work in 5 seconds and the other does in 8 seconds. Thus, the man doing the same work in 5 seconds is more power full. The shorter the time the more power it has.

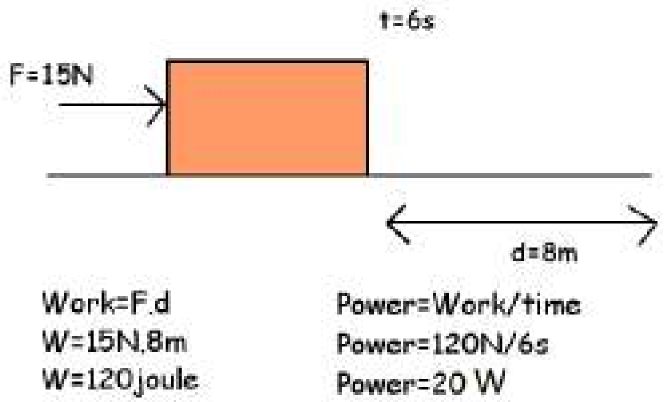
$$\text{Power} = \frac{\text{Workdone}}{\text{Time taken}}$$

The unit of power is, J/s, however, we generally use watts (W).

1 J/s = 1 W

Example

Find the power of the man who pushes a box 8 m with a force of 15 N in 6 seconds.



The power of the man is 20 W. In other words he does 20 Joule of work in 6 seconds.

Note: Amount of power does not show the amount of work done. It just gives the time that work requires.

9.40 FORMS OF ENERGY

There are many forms of energy: like solar, wind, wave and thermal to name a few, but we will look at 5 only.

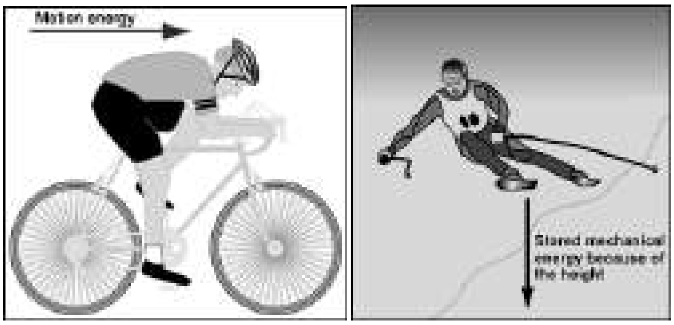
1. *Mechanical energy:*

Mechanical energy is the sum of potential energy and kinetic energy present in the components of a mechanical system. It is the energy associated with the motion or position of an object. For instance, if a man is pushing a car, he transfers chemical energy from him to the car and the car therefore attains mechanical energy. There are two types; energy of motion (kinetic energy) or stored energy of position (potential energy).

- Motion energy: This is the energy something has because it is moving (eg a speeding cricket ball). You can feel the effect of this energy if the cricket ball hits you. Motion energy is also called kinetic energy.

- Stored mechanical energy: This is energy something has stored in it because of its height above the ground or because it is stretched or bent or squeezed (eg in a stretched rubber band). You can feel it when the band is released.

Stored mechanical energy is also called potential energy.



Source: http://www1.curriculum.edu.au/sciencepd/energy/mech_activity.htm

We will look at this in more detail later.

2. *Nuclear energy*

Nuclear power stations work in pretty much the same way as fossil fuel-burning stations, except that a "chain reaction" inside a nuclear reactor makes the heat instead.

The reactor uses Uranium rods as fuel, and the heat is generated by nuclear fission: neutrons smash into the nucleus of the uranium atoms, which split roughly in half and release energy in the form of heat.

Carbon dioxide gas or water is pumped through the reactor to take the heat away, this then heats water to make steam. The steam drives turbines which drive generators and produces electricity.

3. *Radiant energy*

Radiant energy is the energy of electromagnetic waves. Radiant energy is sometimes used to refer to the electromagnetic waves themselves, rather than their energy (a property of the waves), Because electromagnetic (EM) radiation can be considered to be a stream of photons, radiant energy can be viewed as the energy carried by these photons. The sun provides radiant energy.

4. *Electrical energy*

Electrical energy is energy stored in a charged particle within an electric field. Electric fields are areas surrounding a charged particle that exert a force on another charged particle within the field. Electrical energy is a type of potential energy, or energy stored in an object due to the position of the object. In the case of electrical energy, the object is the charged particle, and the position is within the electric field.

Another way of looking at electrical energy is electrical potential, which is measured in volts. Electrical energy is used to move charges through wires to create current, or electricity. Electricity is used to do work in our homes.

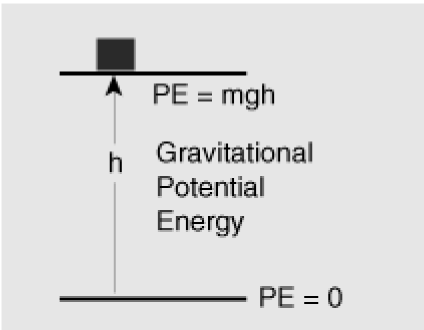
Lightning involves the transformation of electrical energy into thermal energy and light energy.

5. *Chemical energy*

Chemical energy is energy that has been stored in chemical form, such as in fuels or sugars or as energy stored in car batteries. Gasoline is a chemical that combines with oxygen and a little heat to release the great amount of thermal energy stored in the chemical structure of the gasoline. Other such chemicals include sucrose, methane, ethanol, and methanol.

9.50 POTENTIAL AND KINETIC ENERGY

9.51 Potential Energy



Gravitational potential energy is the energy stored in an object as the result of its vertical position or height. The energy is stored as the result of the gravitational attraction of the Earth for the object. The gravitational potential energy dependent on two variables. They are the mass of the object and the height to which it is raised. There is a direct relation between gravitational potential energy and the mass of an object. More massive objects have greater gravitational potential energy. There is also a direct relation between gravitational potential energy and the height of the object. The higher the object is elevated, the greater the gravitational potential energy it have. These relationships are expressed by the following equation:

PE_{grav} = mass x pull of gravity (g) x height

(gravitational field g = 10 N/kg on the Earth).

Examples
1. What is the potential energy of a 6 kg mass 4 m above the ground?
Potential energy = 6 x 10 x 4 = 240 J

2. A 45 kg girl jumps from a 0.4 m high stool onto the ground. How much potential energy does she lose?
Potential energy lost = 45 x 10 x 0.4 = 180 J

3. A man slides a 25 kg box up a ramp onto the back of a lorry. If the ramp is 2 m long and the back of the lorry is 0.8 m above the ground how much potential energy does the box gain?
All that matters is the VERTICAL height moved and not the length of the ramp. So:
Potential energy gained = 25 x 10 x 0.8 = 200 J

9.52 Kinetic Energy

Kinetic energy is energy of motion or because it is moving. The kinetic energy of a mass *m* is given by

$$E_k = \frac{1}{2}mv^2$$

where E_k is the kinetic energy

m = mass of object

v = speed of object

Kinetic energy is a scalar quantity; it does not have a direction. Unlike velocity, acceleration, force, and momentum, the kinetic energy of an object is completely described by magnitude alone. Like work and potential energy, the standard metric unit of measurement for kinetic energy is the Joule. As might be implied by the above equation, 1 Joule is equivalent to 1 kgm^2/s^2.

Examples
1. What is the kinetic energy of a 500 kg horse running at 15 m/s?
Kinetic energy = ½ x 500 x 15^2 = 56 250 J

2. What is the kinetic energy of a one milligram raindrop falling at 0.5 mm/s.
Kinetic energy = ½ x 0.000001 x 0.0005^2 = 0.000 000 000 000 125 J = 1.25 x 10^{-13} J
Notice here that the mass must be in kg and the velocity in m/s.

9.60 HOOKE'S LAW

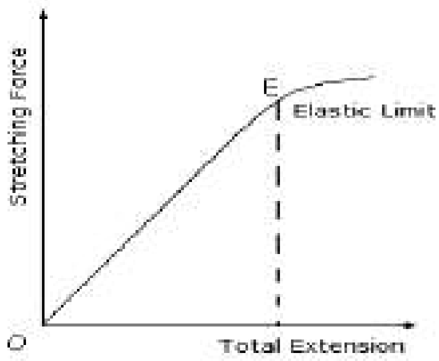
Elasticity is the ability of a material to return to its original shape/length when the stretching force or the compressing force is no longer acting on it. Hooke's law states that the force applied is proportional to the extension of spring provided the elastic limit is not exceeded.

This means that doubling the force doubles the extension, trebling the force trebles the extension and so on. Using the sign for proportionality we can write **Hooke's Law** as

$$F = -kx$$

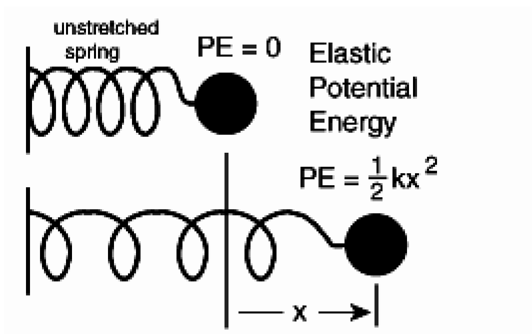
where F = Force applied on spring (N)
x = Extension on the spring (m)
k = spring constant (N/m)

The graph of the figure on the right is for a spring stretched beyond its elastic limit. OE is the straight line passing through the origin O and its graphical proof that Hooke's Law holds over this range.



Elastic Potential energy is given as the area under the graph in the extension *x*.

E_p (elastic) = $\frac{1}{2}kx^2$



Examples
Question 1: A spring is stretched by 50 cm and has force constant of 2 N/m. Calculate the Force applied?

Solution: Given: Force constant $k = 2$ N/m

Extension $x = 0.5$ m.

The force applied is given by $F = - kx$

$= - 2\text{N/m} \times 0.5$ m

$= - 1$ N.

Question 2: A force of 100 N is stretching a spring by 0.2 m. Calculate the force constant?

Solution: Given: Force F = 100 N,

Extension $x = 0.2$ m.

The force constant is given by $k = - F/x$

$= - 100/0.2$ m

$= - 500$ N/m.

9.70 SOURCES OF ENERGY

Energy can be generally classified as non-renewable and renewable. Most of the energy used in the world is from non-renewable supplies. Most countries are dependent on ***non-renewable*** energy sources such as fossil fuels (coal and oil) and nuclear power. These sources are called non-renewable because they cannot be renewed or regenerated quickly enough to keep pace with their use. Some sources of energy are renewable or potentially renewable. Examples of renewable energy sources are: solar, geothermal, hydroelectric, biomass, and wind.

9.71 Non- Renewable Sources of Energy

1. Fossil Fuels

1. Coal

Coal is the most abundant fossil fuel in the world. Coal formed slowly over millions of years from the buried remains of ancient swamp plants. During the formation of coal, carbonaceous matter was first compressed into a spongy material called "peat," which is about 90% water. As the peat became more deeply buried, the increased pressure and temperature turned it into coal.

2. Oil

Crude oil or liquid petroleum is a fossil fuel that is refined into many different energy products (e.g., gasoline, diesel fuel, jet fuel, heating oil). Oil forms underground in rock such as *shale*, which is rich in organic materials. After the oil forms, it migrates upward into porous reservoir rock such as sandstone or limestone, where it can become trapped by an overlying impermeable cap rock. Wells are drilled into these oil reservoirs

to remove the gas and oil. Over 70 percent of oil fields are found near tectonic plate boundaries, because the conditions there are conducive to oil formation.

Despite its limited supply, oil is a relatively inexpensive fuel source for most developed countries. It is a preferred fuel source over coal. An equivalent amount of oil produces more kilowatts of energy than coal. It also burns cleaner, producing about 50 percent less sulfur dioxide. However, for Fiji oil is a very expensive fuel.

3. Gas

Natural gas production is often a by-product of oil recovery, as the two commonly share underground reservoirs. Natural gas is a mixture of gases, the most common being *methane* (CH_4). It also contains some *ethane* (C_2H_5), *propane* (C_3H_8), and *butane* (C_4H_{10}). Natural gas is usually not contaminated with sulfur and is therefore the cleanest burning fossil fuel. After recovery, propane and butane are removed from the natural gas and made into *liquefied petroleum gas* (*LPG*).

2. Nuclear Power

Nuclear energy originates from the splitting of uranium atoms in a process called fission. At the power plant, the fission process is used to generate heat for producing steam, which is used by a turbine to generate electricity.

9.72 Renewable Sources of Energy

1. Solar Energy

The solar cells also called photovoltaic (PV) cells, which as the name implies (photo meaning "light" and voltaic meaning "electricity"), convert sunlight directly into electricity. A module is a group of cells connected electrically and packaged into a frame (more commonly known as a solar panel), which can then be grouped into larger solar arrays.

Photovoltaic cells are made of special materials called semiconductors such as silicon, which is currently used most commonly. Basically, when light strikes the cell, a certain portion of it is absorbed within the semiconductor material. This means that the energy of the absorbed light is transferred to the semiconductor. The energy knocks electrons loose, allowing them to flow freely.

PV cells also all have one or more electric field that acts to force electrons freed by light absorption to flow in a certain direction. This flow of electrons is a current, and by placing metal contacts on the top and bottom of the PV cell, we can draw that current off for external use. This current, together with the cell's

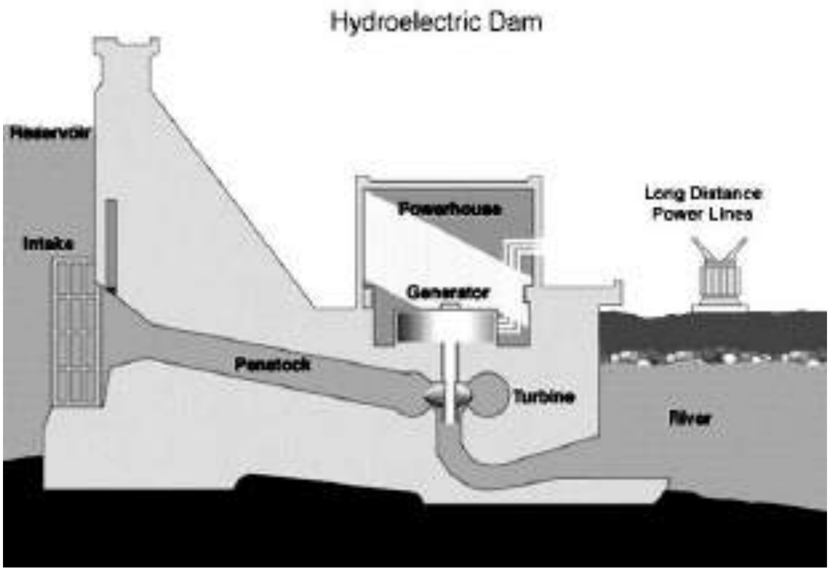
voltage (which is a result of its built-in electric field or fields), defines the power (or wattage) that the solar cell can produce.

Energy Transformation: Sunlight hits the PV panel and the panel transforms the light energy into electrical energy. The electrical energy (electricity) passes through the wire circuit to light up the bulb.

2. Hydropower

The dam stores lots of water behind it in the reservoir. Near the bottom of the dam wall there is the water intake. Gravity causes it to fall through the penstock inside the dam. At the end of the penstock there is a turbine propeller, which is turned by the moving water. The shaft from the turbine goes up into the generator, which produces the power. Power lines are connected to the generator that carries electricity to your home and mine. The water continues past the propeller through the tailrace into the river past the dam.

Energy Transformation: The potential energy in the head of water is converted into kinetic energy in the turbine which converts the kinetic energy into electrical energy.



Source: http://www.alternative-energy-news.info/technology/hydro/

3. Wind Energy

Wind power is produced by using wind generators to harness the kinetic energy of wind. Wind turbines operate on a simple principle. The energy in the wind turns two or three propeller-like blades around a rotor. The rotor is connected to the main shaft, which spins a generator to create electricity.

Wind turbines are mounted on a tower to capture the most energy. At 30 meters or more above ground, they can take advantage of faster and less turbulent wind.

Wind turbines can be used to produce electricity for a single home or building, or they can be connected to an electricity grid for more widespread electricity distribution.

Energy Transformation: Windmills convert the kinetic energy of wind movement into mechanical power that moves the parts of a windmill, for example, to pump water, a generator is part of the machine that converts mechanical energy into electrical energy.

Source: http://www.alternative-energy-news.info/south-korea-off-shore-wind-farm/

4. Biomass

Biomass is any organic matter like trees, plants, or animal waste that can be used as an energy source. Energy comes from the sun through a process called photosynthesis, and is released when biomass is burned or decomposes.

Source: http://www.greenmountain.com/resources/enviro-kids/renewable-energy-101/biomass-energy

Leftover wood and crop waste from factories and farms can be burned to produce electricity.

1. Wood scraps, sawdust and crop waste are collected from farms or manufacturing plants
2. The waste is burned to heat water and create steam
3. Steam is sent to a turbine, which spins to power a generator
4. Generator creates electricity and sends to transmission lines

5. Ocean Power

One way to harness the kinetic energy of all that moving ocean water involves building a dam, known as a barrage, on a smaller arm of the bay. Sluice gates along the barrage open when the tides produce an adequate difference in the level of the water on opposite sides of the dam. This allows water to flow across turbines that look just like those used in a traditional hydroelectric power plant. The turbines turn a generator, which produces electricity.

Another way to take advantage of ocean tides is to tap into tidal currents, which run close to the shore at water depths of about 20 to 30 meters. To do this, power companies use turbines resembling those seen on terrestrial wind farms, except they are oriented so that the rotors are underwater. The rotors, each about 20 meters in diameter, are also spaced more closely than those on wind farms. As tidal currents surge past the turbines, the rotors spin, turning a generator.

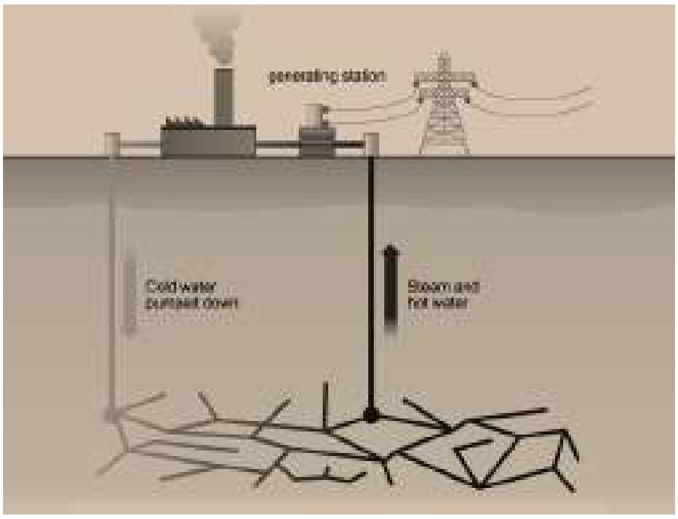
Source:http://energyinformative.org/wave-energy/

This device looks like a sea snake in the water. It consists of a series of joints that generate power as the waves move them up and down through hydraulic rams and a generator. An underwater cable moves the electricity to the shore.

6. Geothermal

Deep inside the Earth lies hot water and steam that can be used to heat our homes and businesses and generate electricity cleanly and efficiently.

The heat inside the Earth is intense enough to melt rocks. Those molten rocks are known as magma. Because magma is less dense than the rocks surrounding it, it rises to the surface. Sometimes magma escapes through cracks in the Earth's crust, erupting out of volcanoes as part of lava. But most of the time magma stays beneath the surface, heating surrounding rocks and the water that has become trapped within those rocks. Sometimes that water escapes through cracks in the Earth to form pools of hot water (hot springs) or bursts of hot water and steam (geysers). The rest of the heated water remains in pools under the Earth's surface, called geothermal reservoirs.



Source: http://www.electrical-res.com/geothermal-energy-electricity/

9.80 EXERCISES

1. The work done in moving a block across a rough surface and the heat energy gained by the block can both be measured in

   A. Watts B. Newtons

   C. degrees D. Joules

2. Which of the following has the greatest gravitational energy with respect to the floor?

   A. 6 kg mass placed 5 m above the floor.

   B. 10 kg mass placed 2 m above the floor.

   C. 2 kg mass placed 10 m above the floor.

   D. 1000 kg mass resting on the floor

3. A man lifts a 10 kg parcel to a height of 80cm above the ground at a constant speed of 1 m/s.

   (a) The work he does on the parcel is

   A. 800 J B. 80 J C. 8000 J D. 0 J

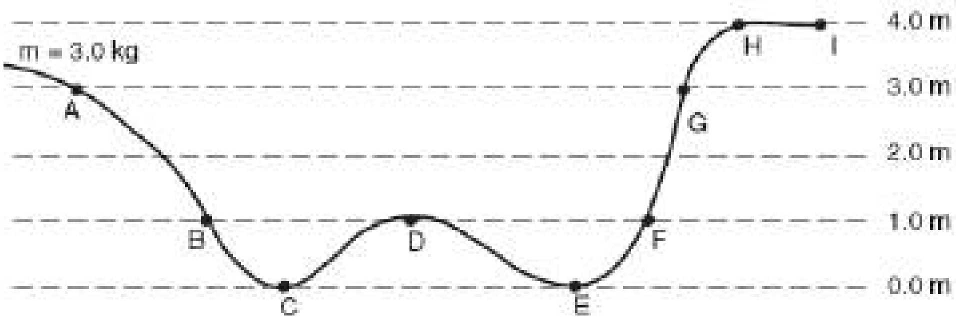
   (b) The man now holds the parcel at the same height above the ground. The work he does now on the parcel is

   A. 800 J B 80 J C. 8000 J D. 0 J

4. A ball has a mass of 2 kg. It is dropped from a cliff and strikes the ground below at 10 m/s.

    i. What is the kinetic energy as it is about to strike the ground?
    ii. What was its potential energy before it was dropped?
    iii. Determine the height from which it was dropped.

5. A 3.0 kg object is placed on a frictionless track at point *A* and released from rest.



    i. Calculate the gravitational potential energy of the object at point *A*.
    ii. Calculate the kinetic energy of the object at point *B*.
    iii. Which letter represents the farthest point on the track that the object will reach?

6. A spring which has a natural length of 20 cm. When a 6 N weight is hung on it, the spring stretches to 32 cm.

(a) The spring constant is:

A. 0.5 N/m   B. 5 N/m   C. 50 N/m   D. 250 N/m

(b) If the 6 N weight is replaced by a 5 N weight, what is the new length?

A. 10 cm   B. 24 cm   C. 28 cm   D. 30 cm

7. A spring of length 10cm stretches to 22 cm when a force of 4 N is applied to it. If it obeys Hooke's law, its total length when a force of 6 N is applied is

A. 28 cm   B. 42 cm   C. 50 cm   D. 56 cm

9. A spring is compressed a distance of 14 cm if a force of 35 N acts on it. Calculate:

    i) the spring constant in (N/m).
    ii) the energy stored in the spring if it is compressed to 14cm.