CSEC Physics Handout

Topic: Energy, Work, Power & Machines

Transformation & Conservation

SPECIFIC OBJECTIVE (5.1-5.4; 5.6)

Candidates should be able to:

1.1 identify the various forms of energy

1.2 define the joule

1.3 use the relationship work = force x displacement to calculate transferred energy

1.4 describe the energy transformation in a given situation

5.6 state the law of conservation of energy and apply it to the solution of problems

CONTENT

Forms of Energy

Energy exists in the following different forms:

Electrical, chemical, nuclear, magnetic, mechanical, heat, light, sound

The names of the various forms of energy give an indication of the situation in which they may be found. For example, chemical energy is released or stored when chemical changes occur, such as when fuel is burnt. Mechanical energy, on the other hand, is associated with the physical condition or state of bodies. It depends on whether or not a body is moving, disturbed or deformed in any way.

Work and Energy

Work is done when a force produces motion. The quantity or amount of work done by a force is given by the product of the force and the distance moved in the direction of the force. That is,

Work done = force x displacement

Or W = F x s

NB:

1. If a force acts on a moving object, then no work is done by the force, if the force acts at right angles to the direction of motion.
2. Work is a scalar quantity

When work is done on a body or a system, the body or system gains an amount of energy equal to the work done and this increases its capacity to do work. Conversely, when work is done by a body or a system, it loses an amount of energy equal to the work done and its capacity to do more work is decreased. As a result, the equation for work may be used to calculate energy transferred either to or from the body (or system) involved.

<u>The Joule</u>

The SI unit of work is the joule (J). it is defined as the work done when a force of 1 N moves its points of application 1m in the direction of the force.

i.e. 1 J = 1 Nm

<u>Energy Transformations</u>

A vast amount of the energy is present around us. However, it cannot always be used directly, but may first have to be changed into more convenient forms. Large quantities are stored as chemical energy in fossil fuels and batteries, as nuclear energy in radioactive atoms, as gravitational potential energy, and in many other forms. These can be converted into more readily usable forms, e.g. heat, light and electricity. The diagram, Figure 5.1 shows energy forms and their possible conversions. The arrows show the direction of conversion.

Some specific transformations are listed below:

1. In a dynamo: mechanical energy ➔ electrical energy
2. In an electric motor: electrical energy ➔ mechanical energy
3. In a motor car (petrol): chemical energy ➔ heat energy ➔ mechanical energy
4. In a power station: chemical energy ➔ heat energy ➔ mechanical energy ➔ electrical energy

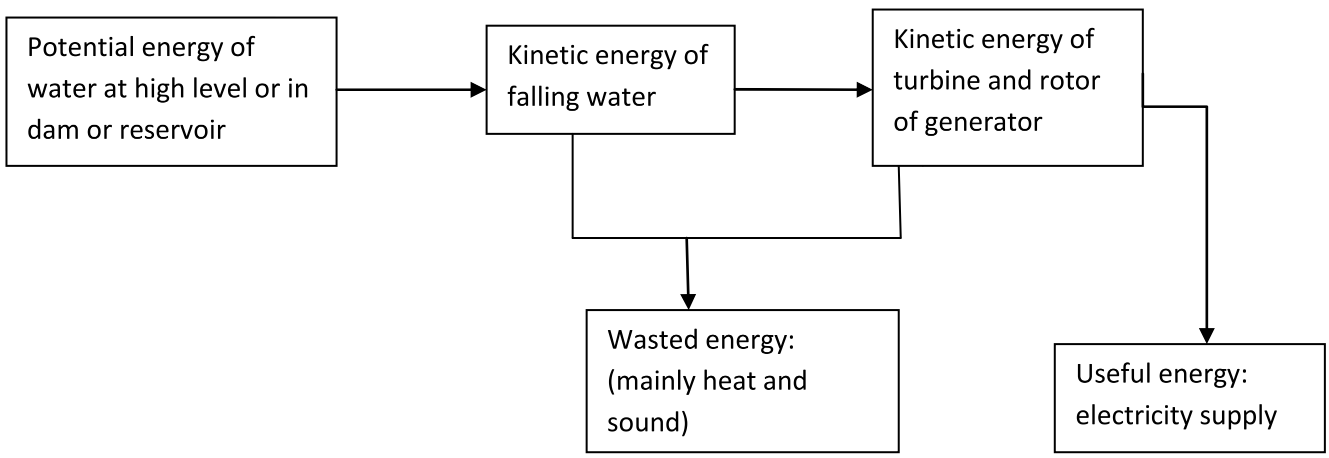
Laws of Conservation of Energy

The law of conservation of energy states that the total amount of energy in the universe is constant; energy is neither created nor destroyed, merely changed from one form to another. This principle or law is very important and fundamental in Physics, since energy may be required in any one of its various forms. It can also be used to solve problems. The equation below is useful when solving problems or writing down energy changes:

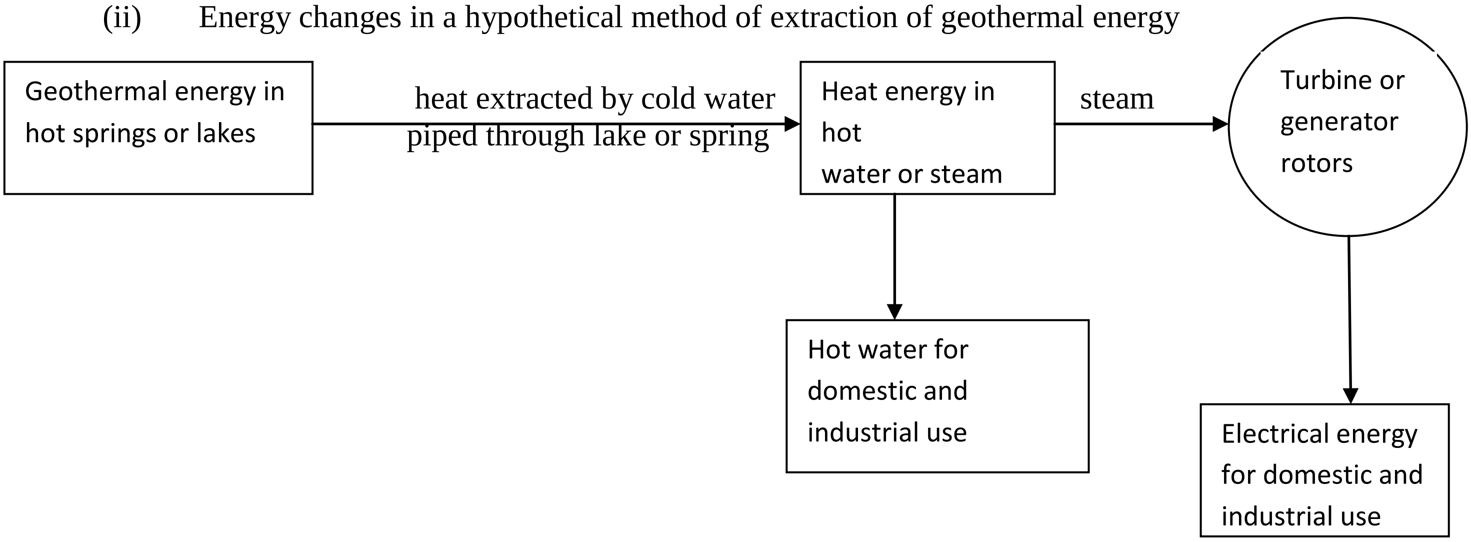
Energy input = useful energy output + wasted energy

Some specific examples energy of transformations obeying the conservation principle are shown below. In every case, the wasted energy output must be accounted for:

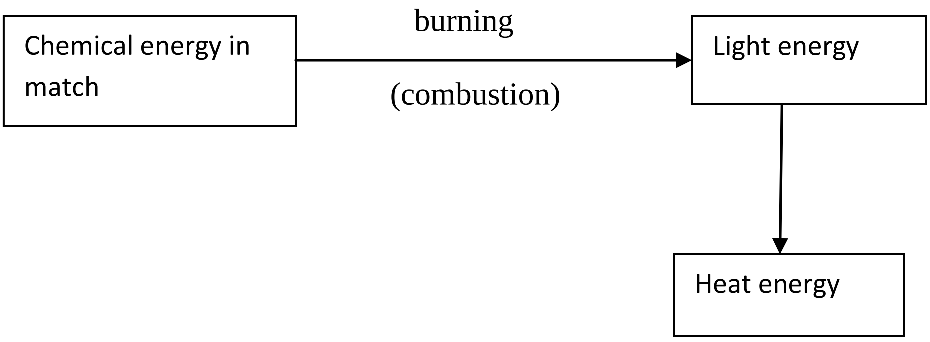
(i) Energy changes in a hydro-electric power station



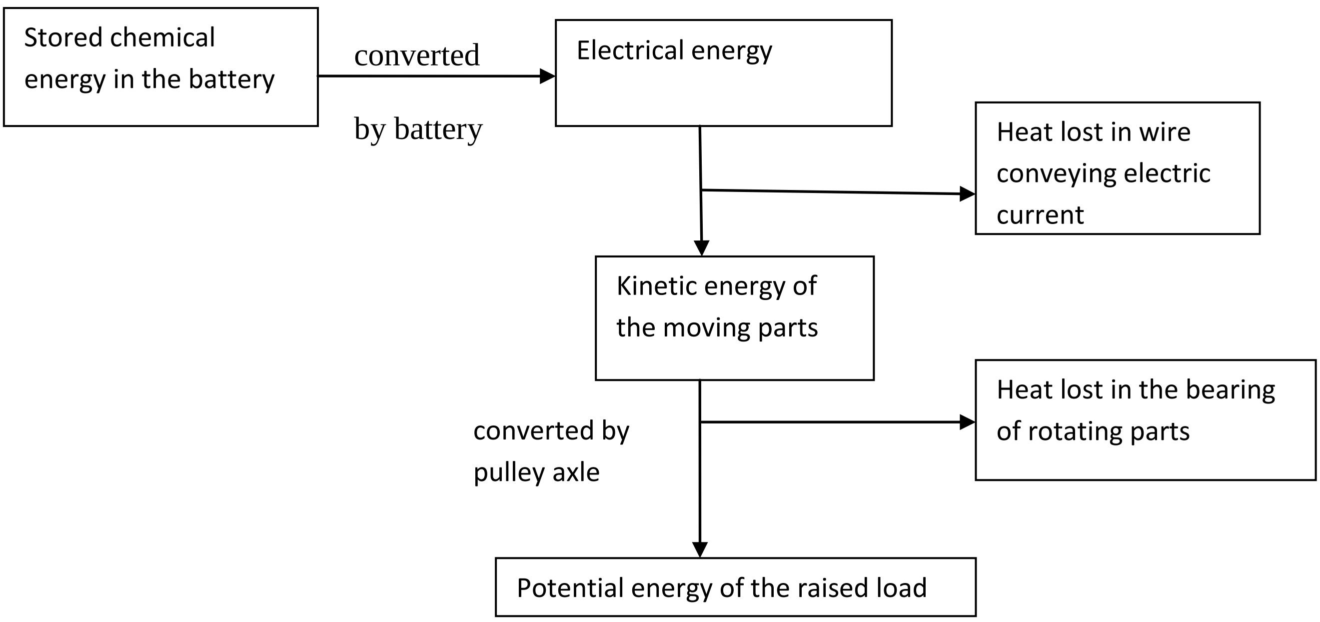
(ii) Energy changes in a hypothetical method of extraction of geothermal energy



(iii) Energy changes in a lighted match



(iv) Energy changes when an electrical motor (powered by a battery) raises a load



POTENTIAL AND KINETIC ENERGY

<u>*SPECIFIC OBJECTIVE (5.7-5.10)*</u>

Candidates should be able to:

<u>Potential Energy E_p</u>

5.7 express potential energy as the energy stored by an object by virtue of its position or state

5.8 calculate the change in gravitational potential energy using $\Delta E_p = mg\Delta h$

<u>Kinetic Energy E_k</u>

5.9 express kinetic energy as the energy possessed by a body by virtue of its motion

5.10 perform calculations involving $E_k = ½ mv^2$

<u>CONTENT</u>

<u>Potential Energy</u>

Potential Energy is defined as the energy stored by a body, or system of bodies, by virtue of its position or state.

Thus a wound up clock spring or a stretched electric band has potential energy of state, while a raised object has potential energy due to its position above the ground.

The most common form of potential energy encountered at this level is gravitational potential energy. This is the amount of potential energy which a body gains/has owing to the work done in moving it against the gravitational attraction of the Earth. Over small distances at the Earth's surface, for example, the change in this energy is approximately proportional to the distance moved by the body in a vertical direction (i.e. its change of height)

Recall that:

Work done by a force = force x distance moved in the direction of the force

⇨ work = applied force x vertical distance

= weight x vertical distance (numerically)

= change in potential energy

Hence, if a mass m is moved vertically, so that its height change by an amount Δh, then the change in gravitational potential energy is given by the equation

$\Delta E_p = m\,g\,\Delta h$

Note carefully also that for movement in the direction of the gravitational force the system does work and E_p of the system (i.e. Earth and body) decreases. For movements against the gravitational pull some external agent does work and the system (Earth and body) gains E_p, i.e. ΔE_p is positive.

Kinetic Energy

Kinetic energy is defined as the energy possessed by a body by virtue of its motion.

Examples of objects possessing kinetic energy include:

(i) a falling stone

(ii) a rotating disc

(iii) a bullet in motion

(iv) a bowled cricket ball

(v) moving water or wind or molecules

If a body of mass m is moving with a velocity v, its kinetic energy E_k is given by the formula

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

regardless of how the body may have acquired its motion.

Thus the kinetic energy of a moving body depends on its mass and on the SQUARE of its speed.

A stationary body has no kinetic energy.

POWER

SPECIFIC OBJECTIVE (5.11-5.13)

Candidates should be able to:

5.11 recall power as energy converted per unit time and use the relationship to solve problems

5.12 define the watt

5.13 describe experiments to measure power

The total quantity of energy of all forms in the universe may be vast but it is finite. Energy available to man on Earth is also finite but is only a tiny fraction of what is present in the universe. In addition, many reserves of energy on earth are "non-renewable', so there must be concern not only for the absolute quantities of energy which we use but also for how fast we use energy from presently available sources.

The rate, at which energy is used, converted from one form to another or supplied for one purpose or another, is called "power". There are both long-term and short-term implications of how fast energy is used or consumed by machines and man. Apart from the possibility of exceeding rates of renewal of some forms of energy and of exhausting reserves of non-renewable sources of energy, one must be concerned about the rate of consuming energy because excessively high rates of using energy can give rise to problems related to supply, distribution and safety.

Power, P, may be defined as the rate of working or the rate at which any machine or system delivers, transforms, "consume" or uses energy.

Its defining equation is:

$$\text{Power} = \frac{\text{Energy converted or consumed}}{\text{time taken}}$$ or symbolically

$$P = \frac{E}{t}$$ or

$$\text{Power} = \frac{\text{Work done}}{\text{time taken}} = \frac{W}{t}$$

From its defining equation, its SI unit is the Js^{-1} which is called the "watt" (W). one watt is a power of 1 joule per second.

Thus, $1\ W = 1\ Js^{-1}$

Systems which have both large and small powers are met with in everyday life and the concept of power is an important and relevant part of the all physical science.

MACHINES AND EFFICEINCY

SPECIFIC OBJECTIVE (5.16-5.19)

Candidates should be able to:

5.16 identify a machine as a force or distance multiplier and assess its suitability for performing a given task

5.17 explain the term efficiency and recall the factors which affects its value

5.18 calculate efficiency

5.19 describe experiments to measure efficiency

Machines

A machine is a device which enables a force (the effort) acting at a point to overcome another force (the load) acting at some other point.

A machine may be identified as a force or distance multiplier; it is a force multiplier, if the load is greater than the effort (e.g. a spanner), or a distance multiplier, if the distance moved by the load is greater than the distance the effort moves (e.g. bicycle).

Examples of simple machines:

- levers: scissors, bottle opener, spanner
- pulley system
- bicycle
- forearm of humans

Efficiency

The principle of conservation of energy implies that the total energy output of a machine must be equal to the total energy input. However, the work done by the machine on a load is usually less than the energy input. This is because some of the input energy is usually wasted, (converted into heat energy or noise) when work is done against dissipate forces such as friction.

The work done by a machine on the load is described as the “useful work” done or the useful energy output. Hence we may write the energy equation as:

Energy input = useful energy output + wasted energy

The efficiency, η, of a machine is a measure of the useful energy output of the machine compared with the energy input. It is defined as the ration of useful energy output to the energy input (usually expressed as a percentage)

$$\text{Efficiency} = \frac{\text{useful energy output}}{\text{energy input}} \times 100\ \%$$

$$= \frac{\text{work done on load}}{\text{work done by effort}} \times 100\%$$

$$= \frac{\text{useful power output}}{\text{Power input}} \times 100\%$$

FRICTION

SPECIFIC OBJECTIVE (5.14-5.15)

Candidates should be able to:

5.14 use the fact that friction opposes the relative motion of surfaces in contact and of bodies through fluids

5.15 recall that thermal energy is produced when work is done against friction

When two surfaces in contact move or tend to move relative to each other, frictional force comes into effect. The nature of the surfaces may be the same or different. They may be two solid surfaces, or a solid and a fluid surface. Friction always opposes relative motion; therefore it is a resistive force. When two surfaces in contact move relative to each other, a force acts to overcome the resistive frictional force; this force does work which appears as thermal energy.

Friction is due mainly to irregularities which act as obstructions to motion of the surfaces in contact, and to a lesser extent, to attraction between the molecules in the surfaces when they come into contact. The frictional force between two surfaces depends on how hard they are pressed together.

If one of the surfaces is "smooth", then the frictional force which the surfaces mutually exert on one is considered to be zero. Friction can be reduced by lubrication. Lubricants prevent the two surfaces from sticking together.

Machines are moved on rollers and wheels to reduce friction by replacing sliding friction with the ground by sliding or rolling friction between lubricated surfaces. Those which move through fluids such as water and air are made streamline to reduce frictional (viscous) drag.

Friction may be useful in some situations but is a nuisance in others.

"Advantages" of Friction

i) friction prevents slipping and sliding since it opposes motion

ii) When a vehicle is being driven, friction exists between the tyre and the road. It is the force ultimately, that causes the vehicle to move forward.

iii) When the brakes on a bicycle are applied it is the friction between the brake and the wheel rim which is transforming the bicycle's kinetic energy into heat energy (which is lost to the atmosphere) so that the cycle will come to a stop

iv) A parachutist relies on the frictional forces of the air.

"Disadvantages" of Friction

i) When a force is applied to cause a body to slide, the net force acting on the body is usually less than the applied force since a part of it is opposed by friction

ii) In a machine, friction reduces the efficiency. Part of the energy input is used to overcome friction so less is available to do useful work. The energy is overcoming friction is usually wasted as heat which can also cause overheating if not dissipated quickly enough. Overheating in machines where there are fast moving parts can result in complete failure of the machine.

CONSERVING ENERGY

SPECIFIC OBJECTIVE (5.5-5.20)

Candidates should be able to:

1.5 discuss the use of energy from alternative sources in the Caribbean

5.20 suggest ways in which energy/fuel may be used more efficiently and economically in the Caribbean

CONTENT

Energy Use in the Caribbean: The need for Alternative Sources

Most of the energy used in the Caribbean today comes from the oil and natural gas. Of all the Caribbean territories only Trinidad and Tobago, and to a much smaller extent Barbados, produce these fuels. As a consequence, the Caribbean imports most of its energy, and this result in loss of foreign exchange. Therefore, some attempts to harness alternate energy sources in the region are essential.

Of the alternative sources of energy available regionally most obvious one is solar energy. Other sources include wind and wave energy, geothermal energy, biogas energy, hydroelectric energy and tidal energy. Solar energy is already in use in several Caribbean countries where solar water heaters are quite popular. Research work at the University of the West Indies is focusing on the use of solar energy to dry crops. The Caribbean Development Bank has a “Technology and energy Unit” involved in promoting research in alternative energy sources. Historically, wind energy was harnesses by windmills for use in grinding sugar cane. Many small windmills for pumping water are still in evidence but most are in need of renovation. Many of countries in the region are undertaking research to determine alternative forms of energy that are most beneficial to them.

Solar Energy

Less than one part in $10^9$of the Sun’s radiant energy reaches the earth but still amounts to more than 5 kWh per square meter per day in the Caribbean. The Caribbean (not being heavily industrialized) consumes relatively small quantities of energy. Since we have an abundance of sunshine we should look at this source as a suitable supply for our needs.

Utilizing of Solar Energy

Solar energy can be extracted by means of:

i) Solar collectors: These are used mainly to heat water in homes and in hotels. In the Caribbean, where there are very few sunless days, they are very cost expensive.

ii) Solar Air Conditioning: Solar energy is used to operate heat pumps that extract energy from the space to be cooled.

iii) Solar Cells: Solar cells convert sunlight into electrical energy. Only about 5 % of the radiant energy is converted into electrical energy and so many solar cells covering a large area would be required to generate a substantial amount of electrical energy. A solar cell has applications ranging from calculators and watches to space satellites.

Geothermal Energy

This is the energy that is available from the earth itself. The center of the earth is very much hotter (4000 ^{0}C) than its surface. Thermal energy flows towards the surface by conduction through the rocks in the earth's crust and by convection in hot lakes, springs in Soufriere in St Lucia to generate electricity. The project was abandoned before its completion but the idea is still a good one.

Tidal Energy

This is a form of gravitational potential energy. Gravitational attraction between the moon and earth causes the level of water in the ocean to rise and fall about twice daily. The oscillation of the water surface is being utilized to generate power in certain places.

Biogas

This is an indirect source of solar energy. The chlorophyll in plants captures approximately 4×10^{13} Js^{-1} or 0.02 per cent of the energy the Earth receives from the Sun.

"Biomass", is used to describe plant and animal organic matter from which the energy may be obtained. This includes wood, agricultural and domestic wastes and both land and aquatic plants. The most promising and abundant source of biomass material in the region is wood, although overharvesting will lead to consequence.

Wood is burnt directly as a cooking fuel, or used to produce charcoal which is similarly burnt.

Biomass can also be used to manufacture more efficient fuels such as methane and alcohol. Biogas (60-65%methane and carbon dioxide), produced by the decay of biomass or organic material is another example.

Wind Energy

Moving air can extent a very large force. The energy of moving air is used by sailing ships and windmills. Wind energy is presently being seriously investigated as a source of power for generating electricity. The future of this technology is enhanced with the revival of simple water pumping and mechanical operations and the development of high speed megawatt turbines.

Hydro-electricity

The power of moving water has been a source of energy for many years. Historically, this energy has been used to drive water wheels, and is now used in hydro-electric systems where the kinetic energy of fulling water drives a turbine which in turn drives a generator. The energy initially came from the sun when water in the sea and lakes was evaporated and then fell as rain. Hydro-electric power is very clean and dependable and may be a feasible proposition in countries such as Guyana.

Nuclear Energy

The nuclei of (certain) atoms constitute another alternative source of energy. In fact, the estimated reserves of nuclear energy are so vast that this form of energy may justifiably be considered to be almost "inexhaustible"

There is much misformation and unfounded fear in the public domain about the harnessing and use of nuclear energy but Caribbean country may wisely consider the possibility of using this form of energy for generation of electricity. Because of its many advantages.

It should be noted that the technology for generating electricity from nuclear energy is no longer new, even if it is not in widespread use. As with other large scale operations, there are associated risks but these are primarily related to possible natural disasters, tragic accidents and/ or effectively similar circumstances. However, safety standards in technologically-advanced atomic power plants are exceedingly high because of our currently greater knowledge and better understanding of the physical principles involved.

The use of atomic energy for meeting the future energy needs of Caribbean peoples is a feasible option.

Efficient and Economical Use of Energy/Fuel

We need energy to carry out all our activities so it is vital that we use energy wisely. Saving and conserving energy are all the more important when we consider that most of the energy presently used is obtained from "non-renewable" sources.

The cost of energy to many countries in the Caribbean is very high and accounts for a large percentage of the import bill of these countries. The importance of energy conservation, in the Caribbean, therefore cannot be overemphasized.

Energy conservation is a good way to save money and measures should be implemented to bring about these savings in many areas, namely, in the home, the commercial and industrial sectors and in transportation. Energy is generally consumed directly as fuel or as electricity and can and should be conserved greatly in the following activities:

- Cooking/baking
- Water usage
- Lighting
- Cooling/refrigeration
- Heating
- Transportation by automobiles

Wherever possible, the use of solar energy is recommended. Not only is this source renewable, but the cost of accessing it may be greatly reduced.

Some ways in which energy may be used more economically and efficiently are described below:

Cooking, Baking

(i) Make sure pots are tightly covered-the contents of a covered pot can be brought to a boil faster and saves (time and) energy

(ii) Turn off the stove approximately 3 minutes before the food is finished and keep the lid tightly closed-the residual heat completes the cooking of the food.

(iii) Pressure cookers and double-boilers are recommended- they save time and energy and are less destructive of nutrients and vitamins

(iv) Cook in large quantities whenever possible-it takes less energy to reheat.

(v) Open the oven door only when necessary-energy is lost each time the door is opened.

Water Usage

The following practices can help to cut cost of energy required for distribution of water and so reduce the cost, to the consumer and the country, of water and energy.

(i) Check all taps and paper to ensure that there are no leaks.

(ii) Attach water saving device to taps (e.g. a shower-head can be used to reduce the water flow while soaping)

(iii) Take showers instead of baths.

(iv) Select the appropriate setting on washing machines according to the size and type of load.

(v) Use a drip system for watering plants and vegetables.

Lighting

(i) Use natural lighting wherever possible.

(ii) Use bulbs with adequate rather than excessive power rating in all areas and use localized lighting for close work such as reading and sewing.

(iii) Turn off lights that are not needed.

(iv) Consider the use of florescent lamps instead of incandescent where appropriate-they are more efficient and have longer lifetimes. (note however, that these lamps are more expensive)

(v) Clean light fixtures regularly especially in industrial plants where dust can reduce the light output by as much as 40%.

(vi) Do not have all lights in a large room (e.g. general office) activated by one switch; independently controlled lighting allows light to be switched off near windows during the day or in areas where no one is working.

(vii) Use light color finishes on wall to reflect light in a room.

Cooling/ Refrigeration

(i) The size and type of the refrigerator and the method of defrosting (manual or automatic) determine the cost and the amount of electricity used. Purchase a refrigerator wisely.

(ii) Set the temperature selector only as cold as necessary.

(iii) Do not place the refrigerator near the stove or in direct sunlight.

(iv) Allow hot food to cool before placing in the refrigerator.

(v) Defrost regularly- thick ice reduces the cooling capability of the refrigerator as ice acts as unwanted insulation

(vi) Avoid excessive opening of the door of the refrigerator.

Air Conditioning

(i) Use natural ventilation instead, wherever this is possible.

(ii) Do not set the thermostat switch as a temperature lower than that which is needed.

(iii) Keep all doors and windows closed when the air conditioner is working

(iv) Close drapes especially at windows which are in direct sunlight or use windows with reflective or absorptive films attached.

(v) Cover the roof with reflective roof coating to reduce heat entering from above.

(vi) Clean filters, fans, vents, cooling ducts regularly to minimize energy lost.

Heat

(i) Use solar water heating instead of gas or electric heating for processes that require hot water.

(ii) Repair leaking pipes carrying hot water or stream to prevent hast lost and save energy.

(iii) Hot water pipes and tanks should be lagged with insulating material to prevent heat lost by radiation.

(iv) Clean heating elements regularly-scale build up reduces the rate efficiency of heat transfer.

Automobiles

(i) Keep vehicles in good working condition by having regular servicing.

(ii) Try to avoid rapid acceleration since this consumes more fuel and increase maintenance cost.

(iii) Anticipate stops- braking hard and too frequently wastes fuel and wears out the brakes.