UNIT 4 FIRST LAW OF THERMODYNAMICS

Structure

4.1 INTRODUCTION

After being introduced to the concepts of work and heat, you are now ready to explore the relationship between them. The First Law of Thermodynamics provides the basis for considering them on equivalent terms, and establishes a quantitative relationship between them. It leads to the definition of a new property, Energy, which has many forms. While this law appears commonplace now, it has taken a long time to evolve, and has baffled many great scientists of the time.

Objectives

After studying this Unit, you should be able to

* understand the significance and implications of the empirical evidence for the relationship between heat and work,
* state and explain the significance of the First Law for a cyclic process,
* understand the implications of the First Law,
* define energy,
* prove that energy is a property,
* understand the concept of internal energy,
* state and understand the limitations of the Law of Conservation of Energy, and
* identify other forms of energy.

4.2 THE RELATIONSHIP BETWEEN HEAT AND WORK

There is no logical relationship between heat and work. If a relation does exist, it must be found in an experimental investigation. James Prescott Joule carried out such experiments between 1840 and 1849. His experiments were of two types :

4.2.1 Experiments Utilizing Heat and Work to Obtain Equivalent Effects:

Figure 4.1 (a) shows a process during which 1 kg of water is raised in temperature by a given amount as a result of thermal communication with a hot body at a higher temperature. A precisely similar change in the water can be accomplished without any heat transfer at all; figure 4.1 (b) shows the water being stirred by a paddle wheel inside a thermally insulated container, thereby raising its temperature.

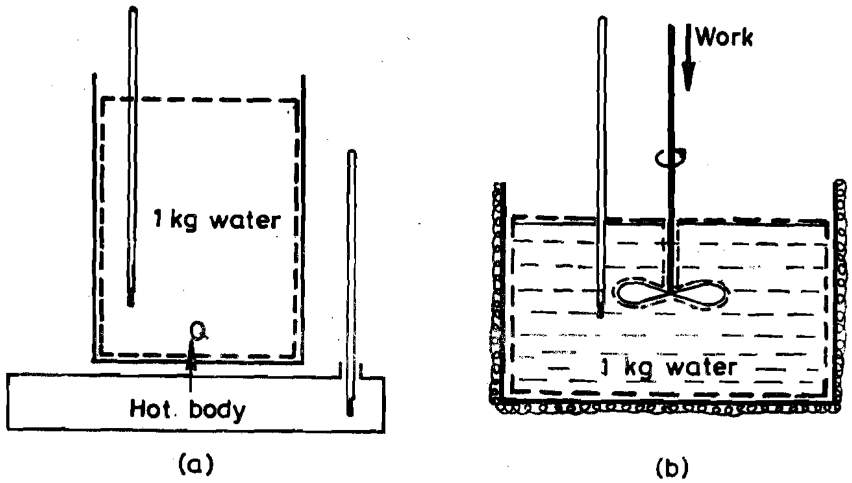

Figure 4.1 : Experiments in which the same effect is achieved (a) by Heat and (b) by Work

Thus heat and work can bring about equivalent effects. Joule carried out many experiments of this type with various systems and various types of work. He established that, within the limits of accuracy of his experiments, the number of units of work required to establish a given effect was proportional to the number of units of heat required to bring about the same effect. Symbolically, it meant that W/Q = a constant, where W and Q are the work and heat interactions which cause the same change of state in identical systems. The constant was referred to as the "Mechanical Equivalent of Heat", and was given the symbol J, with a value of 4.1868×10^3 N.m/kcal; in SI units, J = 1 newton metre per joule.

4.2.2 Experiments Involving Cyclic Processes

In the experiments discussed above, the initial and final states of the system were different. The results from these experiments are sufficient to form the basis for the First Law. The modern formulation, however, is better introduced by considering a second type of experiment, also carried out by Joule, in which heat and work are caused to undo each other's effects rather than to reproduce them. In this context, a cyclic process is defined as follows :

> "A process is cyclic if the initial and final states of the system executing the process are identical".

In a cyclic process, all system properties have the same values at the end of the process as at the beginning.

There are at least two reasons for studying cyclic processes in looking for significant relationships between temperature, work and heat :

* Cycles are common and important in energy conversion, and they operate continuously.
* Because the system returns to its initial state, in a cyclic process it is not necessary to consider the adjust spacing between 'the' and 'equations' equations of state of the working substances.

Referring back to the pair of processes performed by Joule, let the adiabatic stirring process of figure 4.1(b) be carried out first, resulting in a rise in water temperature. The stirring is then stopped, and the water in the container is brought into communication with another body which is chosen to be at a lower temperature than the water. The heat transfer in this case is from the water, not to it, as a result of which the temperature of the water falls. The thermal communication between the water in the container and the cold body is broken as soon as the water temperature has fallen to the original value prevailing at the commencement of the stirring process. Under these conditions, the water is in exactly the same state at the end as at the beginning of the process. Thus, the stirring and cooling of the water comprising the system together form a cyclic process.

Joule and other workers have carried out many such cyclic experiments. Both the nature of the system and the nature of the processes were varied. In each cyclic experiment, the sum of all the work interactions was proportional to the sum of all the heat interactions. The results of these experiments may be written symbolically as :

$$\sum_{cycle} W = J \sum_{cycle} Q \qquad ...(4.1)$$

where $\sum_{cycle}$ stands for 'sum of all the work or heat interactions during the cycle'. The proportionality constant J has the same value as in the first set of experiments.

4.3 STATEMENT OF THE FIRST LAW FOR CYCLIC PROCESSES

The results of the above two classes of experiments may be generalized to the following statement of the First Law :

"When a system executes a cyclic process, the net work is proportional to the net heat".

Equation 4.1 is applicable to processes in which the heat and work interactions occur in finite steps. When the interactions occur as a succession of infinite steps, the summation signs are replaced by integrals, yielding the following symbolic form of the law :

$$\oint \delta Q = J \oint \delta W \qquad ...(4.2)$$

Here δQ and δW represent infinitesimal elements of the heat and work interactions, and $\oint$ stands for "cyclic integral" or "integral around the cycle".

4.4 IMPLICATIONS OF THE FIRST LAW

- A consequence of the First Law is that in energy conversion processes involving heat to work conversion (or work to heat conversion) no more work (or heat) may be produced than 1 N.m/joule (or 1 joule/N.m). It will be seen later, after discussion of the second law, that there is a further constraint on the conversion of heat to work.
- The fixed rate of exchange between heat and work enables each to be expressed in the units of the other. Thus heat can be expressed in N.m, while work can be expressed in joules or kcal. This does not mean, of course, that heat and work are the same thing. We have taken great care in the preceding units to distinguish between work and heat. In the SI units, with J = 1 N.m/joule, the First Law of Thermodynamics for a cyclic process becomes

$$\oint \delta Q = \oint \delta W \qquad ...(4.3)$$

- We no longer need independent procedures for measuring work and heat. Rather than determining the value of J by careful experimentation, either the heat or the work standard may be abandoned, and J may be defined to have a definite value, viz., 4.1868×10^3 N.m/kcal or 1 N.m/joule.
- It can be seen that the First Law, as expressed by equations 4.2 and 4.3, relates the boundary interactions occurring when a system executes a cycle. There is no restriction on the nature of the system or its interactions with its surroundings; it is only necessary that the process must be cyclic.

Example 4.1 :

In a cyclic process the work transfers are +20J, -10J, -10J and + 30J. What is the net transfer for this cyclic process ?

Solution :

Let us apply the First Law as given by equation 4.3

$$\oint \delta Q = \oint \delta W = (+20 - 10 - 10 + 30)\ \text{J}$$

$$= +\ 30\ \text{J} \quad \text{ANSWER}$$

In thermodynamics, non-cyclic processes are more common than cyclic processes. It is therefore necessary to reformulate the First Law so that it can be applied to non-cyclic processes also. This reformulation has the effect of relating the interactions at the boundary to changes within the system. We will also encounter a new concept, and property, energy.

In order to show that the First Law implies the existence of a property, it is necessary to examine the characteristic features of properties, which we have defined in Unit 1.

4.5 PROPERTIES OF PROPERTIES

There are three logical consequences of the definition of the concept of "property" :

- The change in the value of a property of a system depends only on the end-states of the process, and not on the path of the process.
- If a characteristic or magnitude related to a system changes during a process by an amount that depends only on the end-states and not on the path of the process, that magnitude is a property of the system.
- In a cyclic process the net change in each property of a system is zero.

In mathematical terms, a property is defined by a point function, which has a definite value when the finite number of variables forming its argument are specified.

4.6 DEFINITION OF ENERGY

The increase of energy of a system during a change of state is numerically equal to the net heat minus the net work during the process.

In symbols,

$$E_2 - E_1 = Q - W \qquad \text{...(4.4)}$$

where E_2 and E_1 are the energies of the system in the final state 2 and the initial state 1, respectively.

4.6.1 Remarks on the Definition of Energy

- It may be seen that only changes of energy have been defined. This means that energy has to be measured with respect to some arbitrary base or datum.
- The energy of a system of unit mass is called the specific energy, and is given the lower-case symbol e.
- Till now, it has been presumed that the path of the entire process between states 1 and 2 is specified. It will be shown presently that only the end states 1 and 2 need be specified, so that E is a property.

4.7 PROOF THAT ENERGY IS A PROPERTY

Figure 4.2 shows a diagram with arbitrary properties of a system x and y as abscissa and ordinate. The points 1 and 2 represent two states of the system.

Let us consider a cyclic process executed by the system. Starting from state 1, the process proceeds to state 2 along the path marked A, and returns to state 1 along the path C. From the First Law we can write :

$$\oint (\delta Q - \delta W) = \int_{1_A}^{2} (\delta Q - \delta W) + \int_{1_C}^{2} (\delta Q - \delta W) = 0 \qquad \text{...(4.5)}$$

in which the summation around the cyclic process has been split into its component parts.

Let us now consider a second cyclic process, which differs from the first in that the outward path is now B rather than A. Applying the First Law to this process, we obtain :

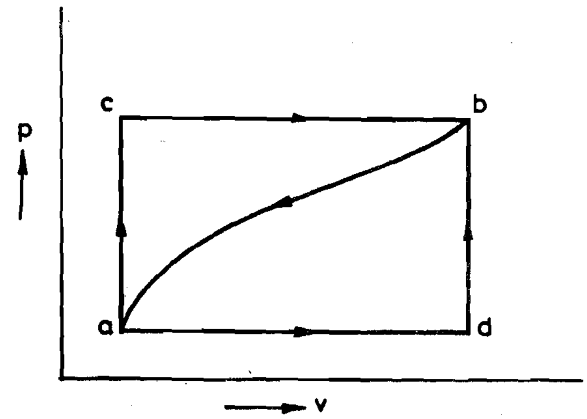

Figure 4.2 : Path of two cyclic processes passing through two common state points

$$\int_{1_B}^{2} (\delta Q - \delta W) + \int_{2_C}^{1} (\delta Q - \delta W) = 0 \qquad \text{...(4.6)}$$

From an inspection of equations 4.5 and 4.6, we see that

$$\int_{1_A}^{2} (\delta Q - \delta W) = \int_{1_B}^{2} (\delta Q - \delta W) \qquad \text{...(4.7)}$$

This shows that the integral of $(\delta Q - \delta W)$ from state 1 to state 2 is the same for paths A and B. Since these have been arbitrarily chosen, we can say that the integral has the same value for any path between 1 and 2.

Denoting $\int \delta Q$ by Q, the net heat transfer during the process from 1 to 2, and $\int \delta W$ by W, the net work during the same change of state, we can say that $(Q - W)$ has the same value for any path between 1 and 2. From the definition of energy, equation 4.4, $Q - W = E_2 - E_1$, so that it is seen that $(E_2 - E_1)$ has the same value for any path between 1 and 2. This implies that the value of $(E_2 - E_1)$ depends only on the end states. From our earlier discussion on properties of properties, it follows that energy E is a property.

4.8 STATEMENT OF THE FIRST LAW FOR NON-CYCUC PROCESSES

The statement of the First Law for a non-cyclic process is as follows :

$$Q - W = \Delta E \qquad \text{...(4.8)}$$

where the symbol ΔE denotes the increase in the magnitude of energy E during the process, i.e. its final value minus its initial value. It implies that E is a property. (Δ can not be applied to Q or W, which are not properties).

Example 4.2

With reference to figure 4.3, when a system is taken from A to B along ACB, 100 kJ of heat is transferred to the system which performs 30 kJ of work.

(a) What is the heat transfer to the system along the path ADB if the work done is 10 kJ.

(b) When the system is returned from B to A along the curved path, 20 kJ of work is done on the system. Determine the magnitude and sign of the corresponding heat transfer.

(c) If $E_A = 0$ and $E_D = 40$ kJ, determine the heat transfers during the processes AD and DB.

Solution

Refer to figure 4.3

For the path ACB, according to the I Law,

$Q - W = \Delta E$; $100 - 30 = \Delta E$

Hence $E_B - E_A = 70$ kJ

(a) For the path ADB, according to the I Law,

$Q - 10 = E_B - E_A = 70$

Hence $Q = 80$ kJ ANSWER

(b) For the curved path BA, according to the I Law

$Q - (-20) = E_A - E_B = -70$

Hence $Q = -90$ kJ ANSWER

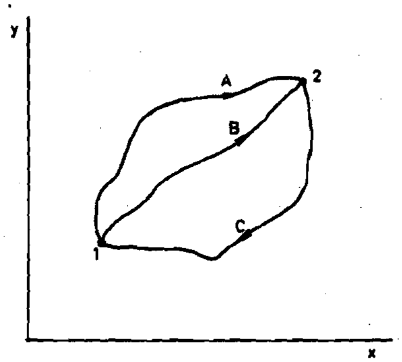

Figure 4.3 : For Illustrative Example 4.2

(c) $E_A = 0$; $E_D = 40$ jK

For the process AD, $\Delta E = E_D - E_A = 40$ kJ.

W = Work done during ADB, since the work done during the constant volume process DB is zero.

= 10 kJ

From the I Law, $Q - 10 = 40$,

so that $Q = 50$ kJ ANSWER

For the process DB, $W = 0$ (Constant volume process)

$\Delta E = E_B - E_D = (E_B - E_A) - (E_D - E_A)$

$= 70 - 40 = 30$ kJ

From the I Law, $Q - 0 = 30$ so that $Q = 30$ kJ ANSWER.

4.9 COMPARISON OF THE MECHANICS AND THERMODYNAMIC CONCEPTS OF ENERGY

We have discussed earlier the comparison of the mechanics and thermodynamic concepts of work. We now look at the difference in their perspective as regards energy. In mechanics, energy is defined as "the capacity for doing work". This actually represents "mechanical energy". It is not the same thing as the more comprehensive energy of thermodynamics, although the two concepts have many features in common. In advanced texts of thermodynamics, the capacity-for-doing-work feature is associated with the "quality" of energy. The following example illustrates the similarities and differences between the two concepts.

Figure 4.4 shows a system comprising a hemispherical bowl and a steel ball. The ball is initially at rest at the lowest position of the bowl. It is then lifted by an external force until it is at rest near the rim. For example, the ball could be lifted by hand and placed at the higher position; or a magnet may be employed to move the steel ball to the higher position. The work done by the system is negative in this process, since the surroundings have done work on the system. Heat transfer is absent, and hence $(E_2 - E_1)$ is positive; the energy of the system has increased. The "mechanical energy" has also increased, and by the same amount; the ball has a higher potential energy.

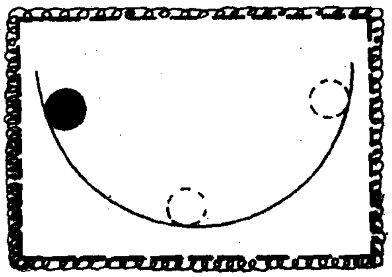

Figure 4.4 : Hemispherical Bowl containing a steel ball

The ball is now released so that it rolls backwards and forwards within the bowl. There are neither heat nor work interactions at the system boundary during the oscillations, so that the energy of the system remains unchanged. If friction is absent, this is also true of the "mechanical energy". During the oscillations, the decrease of gravitational potential energy which the ball experiences in reaching the bottom of the bowl is exactly balanced by an increase in kinetic energy; the sum of the two energy terms remains constant.

If friction is present, however, the situation is very different. The height reached by the ball during each successive oscillation is reduced, and the maximum velocity attained at the bottom of the bowl is also lower during each successive oscillation. Finally the ball comes to rest again at the bottom of the bowl. Again, since no heat or work interactions are present at the system boundary, the energy of the system has the same value as immediately after the ball was first raised (E_2). The "mechanical energy", on the other hand, has decreased to the value prevailing before the ball was raised (E_1).

In mechanics, it is explained that "the energy has been dissipated". Alternatively, it is said that "the energy has been converted into heat". These phrases are not in accordance with the thermodynamic usage of the word "heat". Even though the ball and the bowl are at a higher temperature than in the beginning, this has not occurred as a result of any heat transfer between the system and the surroundings.

The explanation, according to thermodynamics, is that "the mechanical energy has been transformed into another mode of energy, termed internal energy" (to be discussed presently). Thus the energy of thermodynamics includes the energy which is defined in mechanics, but is much more general, including other forms of energy.

4.10 INTERNAL ENERGY

"Internal" energy is so named because it is intimately related to the internal structure of the substances, in terms of the internal microscopic energy modes. This includes the translational, rotational and vibrational energies of the molecules. It is convenient to separate the macroscopically measurable mechanical energy (represented by potential and kinetic energy of the system) from the energy in these "hidden microscopic modes", which is the internal energy. It can not be measured directly, but must be determined by inference. Evaluation of the internal energy as a function of the state of the system is one of the central problems in thermodynamics.

Internal energy represents the particular mode of energy which can be directly influenced by heat interaction. For constant specific heat, temperature rise is a measure of the increase in internal energy, and temperature rise can be effected through heat transfer.

4.11 THE LAW OF CONSERVATION OF ENERGY

The following statement is given in many texts as an alternative formulation of the First Law :

"The energy of a system remains constant if the system is isolated from its surroundings as regards heat and work".

In other words, the energy of an isolated system, such as our universe, remains constant. This leads to other statements such as : "Energy can neither be created nor destroyed".

It will be seen that the Law of Conservation of Energy is less general than the First Law. Equation 4.8 shows that when $Q = 0$ and $W = 0$, $\Delta E = 0$, which is embodied in the Law of

Conservation of Energy ; thi., however, does not state how the energy changes when Q and W are not zero.

4.12 OTHER MODES OF ENERGY

We have encountered three modes of energy till now :

* gravitational potential energy
* kinetic energy
* internal energy

There are other modes of energy; some examples are discussed here.

4.12.1 Chemical Energy

During a chemical reaction, reactants are converted into products; as, for example, when petrol vapour and air burn to form carbon dioxide, water vapour and other combustion products in a petrol engine. This may be accompanied by heat and work interactions, and changes in properties such as temperature and pressure. In particular, if the reaction vessel is rigid and insulated, so that the energy is constant, the temperature of the products will experience a considerable rise in this "exothermic" reaction. In such a case, we may say that the chemical energy is transformed into internal energy.

4.12.2 Strain Energy

A compressed spring or elastic structure has part of its energy in the form of strain energy. A related form of energy is that associated with capillarity or surface tension; systems exhibiting this phenomenon are said to have part of their energy in the form of "surface energy".

4.12.3 Electrical Energy

A system comprising electrically charged elements is said to have part of its energy in the form of "electrical energy".

4.12.4 Magnetic Energy

A system comprising magnetic poles has part of its energy in the form of "magnetic energy".

If both magnetic and electrical effects are simultaneously present, their interactions also produce a contribution to the total energy of the system.

In summary, the First Law embodies two distinct assertions :

* A system can interact with its surroundings in only two ways, namely, work and heat.
* There is a property called energy whose change measures the net effect of these interactions.

Energy has two characteristics :

* It is conserved for any process undergone by an isolated system.
* It is additive; i.e. it is an 'extensive' property.

Example 4.3 :

(a) Figure 4.5 shows a rough inclined plane with a rectangular block resting on the sloping face. The block is a poor conductor of heat while the plane is a good conductor. The block slides slowly down the plane, which rises in temperature. State whether the heat, work and increase in energy are positive, negative, or zero, for (a) the block, (b) the plane, and (c) the block and the plane.

Solution :

(a) Refer to Figure 4.5

In this case, the block is a poor conductor of heat (such as wood), while the plane is a good conductor (such as copper). Note that as the block slides down the plane, the latter rises in temperature.

The solution is contained in the following table :

System	Q	W	ΔE
(a) Block	0	+	–
(b) Plane	0	–	+
(c) Block + Plane	0	0	0

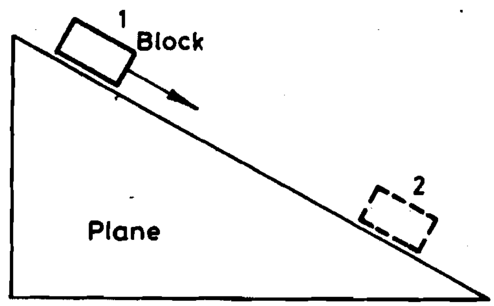

Figure 4.5 : Block sliding down a rough inclined plane

Explanation :

(a) **Block :**

- Q is zero because the system is a poor conductor of heat ; no heat transfer can occur at its interface with the plane even though the latter is at a higher temperature.
- W is positive because, even though the actual external effect is an increase in temperature of the plane, the block could have carried out the same process, and had as its sole effect the raising of a weight ; as, for example, if the plane had been lubricated and the block connected to a suitable pulley mechanism.
- Since $(Q - W)$ is thus negative, it follows that ΔE is negative. The block experiences a decrease in its gravitational potential energy.

(b) **Plane :**

- Q is zero for the same reason it is zero for the block ; no thermal communication.
- W is negative for the plane, because it is positive for the block.
- Hence $(Q - W)$ is positive, and so is ΔE. It is the internal energy of the plane which has increased.

(c) **Block + Plane :**

The combined system, block + plane, does not interact with its surroundings in any manner. Hence, both Q and W are zero for this system. By definition, therefore, ΔE also equals zero. The decrease in the gravitational potential energy of one part of the system (the block) is exactly balanced by the increased internal energy of another part of the system (the plane).

Example 4.4

(b) The block in this problem is made of a good conductor of heat, while the inclined plane is made of a poor conductor of heat. The block slides down the plane, and becomes warmer. State whether the heat, work and increase in energy are positive, negative, or zero, for (a) the block, (b) the plane, and (c) the block and the plane.

Solution :

In this case, the block is made of a good conductor of heat (say, copper), while the plane is made of a poor conductor of heat (say, wood). In this case, as the block slides down the plane, it is the block which becomes warmer.

The solution is contained in the following table :

System	Q	W	E
(a) Block	0	0	0
(b) Plane	0	0	0
(c) Block + Plane	0	0	0

Explanation :

(a) Block :

- Q is zero, because, as before, there is no thermal communication between the block and the plane.
- W is zero ; this requires some thinking. As the block loses height and becomes warmer, it can not have the rise of a weight as its sole external effect. Let us suppose that the real process is replaced by the following two processes : First, the block slides without friction down the plane to its final position, thereby raising a weight ; the temperature of the block is unchanged. Next, the temperature of the block is raised to the value attained in the real process by heat transfer from a hot body.
- Thus, in completely establishing the final state of the real process, two effects have occurred in the imaginary surroundings, namely, the rise of a weight and heat transfer from a hot body. The rise of the weight has not been the sole effect, and hence we can not conclude that work has been performed.
- Consequently ΔE also equals zero ; the decrease in gravitational potential energy of the block is exactly balanced by the increase in its own internal energy.

(b) Plane :

- Q and W are zero for the plane, because they are zero for the block.

(c) Block + Plane :

- Q, W and ΔE are all zero, because the combined system experiences no interaction with its surroundings.

SAQ 1

State whether the heat, work and increase in energy are positive, negative or zero in each of the following processes. In each case, the system to be considered is the lead-acid battery.

(a) A lead-acid battery discharges adiabatically and supplies current to a resistor.

(b) The lead-acid battery discharges adiabatically and supplies current to an electric motor.

(c) The lead-acid battery undergoes the same change from the same initial state as in (a), while standing on open circuit for a long time.

SAQ 2

(a) An insulated rigid vessel contains some fuel and air at a pressure of 10 bar and 25°C. The fuel is ignited, thereby causing a rise in the pressure and temperature of the contents of the vessel. The final temperature is 600°C. Considering the vessel and its contents to be the system, determine the increase in energy of the system.

4.13 A HISTORICAL NOTE

One of the pioneers of the concept of the First Law was a physician, not a physicist : Julius Robert Mayer. In 1840, he sailed to Java as the ship's doctor. While bleeding patients in the tropics, he observed that their blood was much brighter red than that taken from the veins of patients in Germany. Since it was known that the red colour of venous blood was due to oxygen that had not been used for oxidation of body fuel, Mayer had no trouble in deducing that venous blood in Java was redder than venous blood in Germany because less combustion was required to supply the needed body heat in Java than in Germany. Less internal combustion was required when the body was in warm surroundings than when it was in cold surroundings. Mayer took the decisive step of postulating that the heat developed by internal combustion should be balanced against the body's heat loss to the surroundings and the work the body performs. That is, Mayer was observing that heat and work were equivalent, being merely two different manifestations of a general property called energy.

Mayer's ideas came in for ridicule from the local townspeople, and the established physicists of the day ignored them. As if this were not enough, he had the misfortune to see all his discoveries made elsewhere by others and credited to them. In 1843 and the following years, Joule investigated the convertibility of work and heat, and measured the mechanical equivalent of heat. Many of Joule's statements parallelled those of Mayer. In 1847 Helmholtz independently discovered and clearly set forth the principle of conservation of energy and applied it to several branches of physics. There was scarcely a thing that Mayer wrote that some one else did not write later and receive praise for.

4.14 SOME FURTHER IMPLICATIONS OF THE FIRST LAW

It appears that a sense of mystery surrounds the First law ; Bent has characterized it thus :

"Most people seem to believe this firmly; mathematicians because they believe it is a fact of observation; observers because they believe it is a theorem of mathematics; philosophers because they believe it is aesthetically satisfying, or because they believe no inference based upon it has ever been proven false, or because they believe new forms of energy can always be invented to make it true. A few neither believe it nor disbelieve it; these people maintain that the First law is a procedure for book- keeping energy changes, and about bookkeeping procedures it should be asked, not are they true or false, but are they useful".

In the matter of 'inventing' new forms of energy, the discovery of radioactivity produced a crisis in physics regarding the First law. (For details, refer to Bent). For an excellent analogy concerning the procedure of 'inventing' new forms of energy to perpetuate the truthfulness of the First law, refer to Feynman.

The First Law of thermodynamics prohibits the construction of a perpetual motion machine of the first kind [Figure 4.6]. (PMM I would be able to operate continuously, and steadily deliver work without communication with any other systems). No device for producing energy from nothing has ever worked. Patent applications on machines of this kind (and also of PMM II) are no longer entertained in France, England, and most other nations of the world.

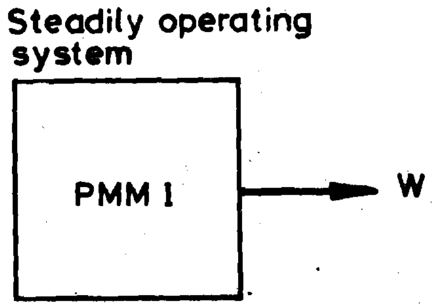

Figure 4.6 : Perpetual-Motion Machine of The First Kind

4.15 SUMMARY

This Unit deals with the formalization of the equivalence and relationship between the two types of energies in transition, viz., heat and work, through the First Law of Thermodynamics. When applied to a non-cyclic process it results in the definition of a property, viz, Energy. The Law of Conservation of Energy is a special case of the First Law for an isolated system. There are several modes of energy.

There is no logical relationship between heat and work. Joule's experiments conducted between 1840 and 1849 to establish the heat/work relationship were of two types : those utilizing heat and work to obtain equivalent effects, and those involving cyclic processes in which heat and work were caused to undo each other's effects rather than to reproduce them.

A cyclic process is one in which the initial and final states of the system executing the process are identical.

The First Law of Thermodynamics for a cyclic process is :

"When a system executes a cyclic process, the net work is proportional to the net heat".

The thermodynamic definition of Energy is accomplished through the First Law of Thermodynamics for a non-cyclic process :

"The increase of energy of a system during a change of state is numerically equal to the net heat minus the net work during the process" :

$$E_2 - E_1 = Q - W$$

Energy can be proved to be a property.

The thermodynamic definition of energy is required to deal with modes of energy other than mechanical energy. Internal energy is intimately related to the internal structure of the substances, in terms of the internal microscopic energy modes.

The Law of Conservation of Energy is stated as : "The energy of a system remains constant if the system is isolated from its surroundings as regards heat and work". In other words, the energy of an isolated system, such as our universe, remains constant. This law is less general than the First Law, since it does not state how the energy changes when the heat and work are not zero.

Some of the other modes of energy are chemical energy, strain energy, electrical energy, and magnetic energy.

A perpetual motion machine of the first kind (PMM I) would be able to operate continuously, and steadily deliver work without communication with any other systems, and would be violative of the I Law of Thermodynamics.

4.16 KEY WORDS AND PHRASES

Cyclic Process	:	A process in which the initial and final states of the system executing the process are identical.
First Law for a Cyclic Process	:	When a system executes a cyclic process, the net work is proportional to the net heat.
Definition of Energy	:	The increase of energy of a system during a process is equal to the net heat minus the net work during the process : $\Delta E = Q - W$.

Internal Energy	:	The mode of energy which is intimately related to the internal structure of the substances, in terms of the internal microscopic energy modes.
Law of Conservation of Energy	:	The energy of a system remains constant if the system is isolated from its surroundings as regards heat and work.

4.17 FURTHER READING

1. Angrist, S.W and Hepler, L.G., "ORDER AND CHAOS", Basic Books, Inc., 1967.
2. Bent, H.A., "THE SECOND LAW", Oxford University Press, 1965.
3. Dixon, J.R., "THERMODYNAMICS I : "AN INTRODUCTION TO ENERGY", Prentice Hall, Inc., 1975.
4. Feynman, R., "THE CHARACTER OF PHYSICAL LAW",
   The M.I.T. Press, Cambridge, 1965.
5. Spalding, D.B. and Cole, E.H., "ENGINEERING THERMODYNAMICS", Edward Arnold, 1975.

4.18 ANSWERS/SOLUTIONS TO SAQs

SAQ 1

(a) $Q = 0 \quad W > 0 \quad \Delta E < 0$

(b) $Q = 0 \quad W > 0 \quad \Delta E < 0$

(c) $Q < 0 \quad W = 0 \quad \Delta E < 0$

SAQ 2

(a) The First Law for this process is :

$Q - W = \Delta E$

$0 - 0 = \Delta E$ Hence $\Delta E = 0$

(b) $-50 - 0 = \Delta E$ $\qquad \Delta E = -50$ kJ

(c) $E_1 = 30$

After the process (a) $E_2 = 30$ kJ

After the process (b) $E_2 = -20$ kJ