CTME

CENTRE OF TECHNOLOGY IN MARINE ENGINEERING

FUNDAMENTAL OF THERMODYNAMICS FOR MARINERS

Written by :

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In the name of Allah, the Most Beneficent, Most Merciful

Praise be to Allah, Peace and blessings of Allah be upon His Messenger, Muhammad, and all his family and companions.

Thanks Allah s.w.t for his guidance and mercy. The completion of this book "FUNDAMENTAL OF THERMODYNAMICS FOR MARINERS" could not have been possible without the participation and assistant from colleagues and students. Their contribution are sincerely appreciated and gratefully acknowledged.

The book covers fully syllabus prescribed by the Ministry of Higher Education and it is hopefully to be helpful to all the students, research scholars and for the teachers. It would be delightful that this book covers wide readership all over the country and abroad who are teaching and learning the fundamental of MARINE engineering .This book is written as reference and guidance for colleague's who's teaching this subject. Any constructive feedback or recommendation about the book will be highly appreciated and incorporated into the next edition.

PREFACE

Bismillahirrahmanirrahim…

With His grace and bestowed upon us, this textbook has been completed fully as a guide for students and lecturers. The book was written for the use of Polytechnic students as a reference based on the content of the syllabus DKM10073 Thermodynamics, accompanied by a note for each topic to help students understand better about this course.

In addition, we would like to thank you for choosing this book as a medium of learning and hopefully it can be beneficial to all. Finally, it is hoped that the objective of this book is issued as a reference to the student achievement and students always succeed in life.

ABSTRACT

According the International Maritime Organization (IMO), all marine student must acquire skill in operating marine machinery by learning theory in classroom and practical in marine workshop provided by the training provider (Politeknik Ungku Omar). The purpose developing this e-book is to provide a complete series e-content of Thermodynamics note to the students. The contents in this e-book is in accordance with the syllabus approved by Malaysian Marine Department (MarDept). The e-book includes notes, list of examples questions and self-assessment exercise as necessary for the student reference.

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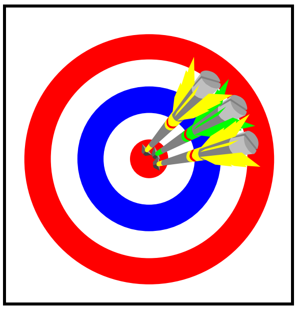
TOPIC 1

THERMODYNAMICS PROPERTIES

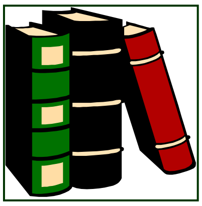


OBJECTIVES

General Objective : To understand the concept of units and dimensions

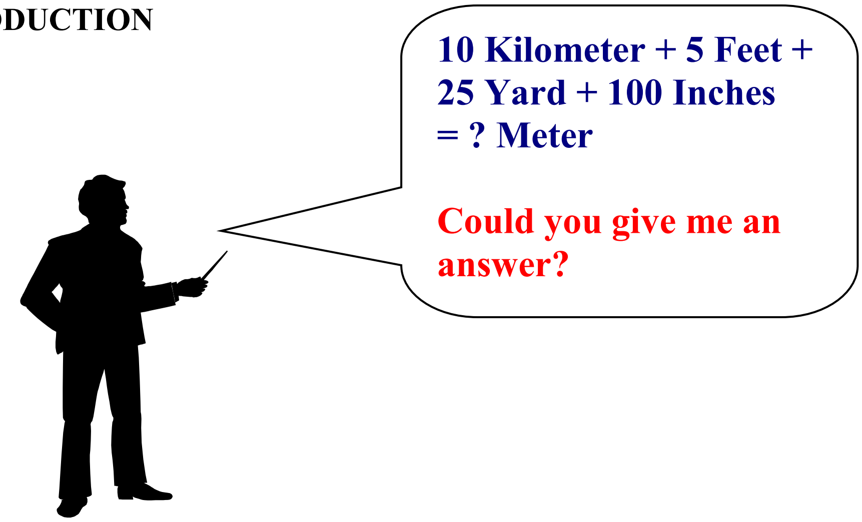
Specific Objectives : At the end of the unit you will be able to:

- state the difference between fundamentals and derived quantities
- describe the physical quantities of thermodynamics
- understand the conversion units of thermodynamics
- calculate the examples of conversion factors and temperature unit



INPUT

1.0 INTRODUCTION



Did you realize that the work of an engineer is limited unless he has a source of power to drive his machines or tools? However, before such a study can begin, it is necessary to be sure of the number of definitions and units, which are essential for a proper understanding of the subject. We are familiar with most of these items in our everyday lives, but science demands that we have to be exact in our understanding if real progress is to be made.

When engineering calculations are performed, it is necessary to be concerned with the *units* of the physical quantities involved. A unit is any specified amount of a quantity by comparison with which any other quantity of the same kind is measured. For example, meters, centimeters and millimeters are all *units of length*. Seconds, minutes and hours are alternative *time units*.

1.1 Fundamental and Derived Quantities

In the present discussion, we consider the system of units called SI (International System of Units) and it is a legally accepted system in many countries. SI units will be used throughout this module.

Length, mass, time, electric current, thermodynamic temperature and luminous intensity are the six fundamental physical quantities. These six quantities are absolutely independent of one another. They are also called the 'Indefinables' of mechanics. The SI base units are listed in Table 1.1-1.

Table 1.1-1 Fundamental units

Quantity	Unit	Symbol
Mass	kilogram	kg
Time	second	s
Length	meter	m
Thermodynamic temperature	degree Kelvin	K
Electric current	ampere	A
Luminous intensity	candela	cd

All other physical quantities, which can be expressed in terms of one or more of these, are known as '*derived quantities*'. The unit of length, mass, time, electric current, thermodynamic temperature and luminous intensity are known as '*fundamental units'*. Physical quantities like area, volume, density, velocity, acceleration, force, energy, power, torque etc. are called *derived quantities* since they depend on one or more of these fundamental quantities. The units of the derived quantities are called derived units as shown in Table 1.1-2.

Table 1.1-2 Derived units

Quantity	Unit	Symbol	Notes
Area	meter square	m^2	
Volume	meter cube	m^3	1 m^3 = 1 x 10^3 litre
Velocity	meter per second	m/s	
Acceleration	Meter per second squared	m/s^2	
Density	kilogram / meter cube	kg/m^3	
Force	Newton	N	1 N = 1 kgm/s^2
Pressure	Newton/meter square	N/m^2	1 N/m^2 = 1 Pascal 1 bar = 10^5 N/m^2 = 10^2 kN/m^2

1.1.1 Force

Newton's second law may be written as force α (mass x acceleration), for a body of a constant mass.

i.e. $F = kma$ (1.1)

(where m is the mass of a body accelerated with an acceleration a, by a force F, k is constant)
In a coherent system of units such as SI, k = 1, hence:

$F = ma$ (1.2)

The SI unit of force is therefore kgm/s^2. This composite unit is called the Newton, N.

i.e. 1 N = 1 kg.m/s^2

1.1.2 Energy

Heat and work are both forms of energy. The work done by a force is the product of the force and the distance moved in the same direction.

The SI unit of work = force x distance in the Newton meter, Nm.
A general unit for energy is introduced by giving the Newton meter the name Joule, J.

i.e. 1 Joule = 1 Newton x 1 meter
or 1 J = 1 Nm

A more common unit for energy in SI is the kilo joule (1 kJ = 10^3 J)

1.1.3 Power

The use of an additional name for composite units is extended further by introducing the *Watt*, W as the unit of power. Power is the rate of energy transfer (or work done) by or to a system.

i.e. 1 Watt, W = 1 J/s = 1 N m/s

1.1.4 Pressure

Pressure is the force exerted by a fluid per unit area. We speak of pressure only when we deal with gas or liquid. The pressure on a surface due to forces from another surface or from a fluid is the force acting at 90^o to the unit area of the surface.

i.e. pressure = force/ area

$$P = F/A \tag{1.3}$$

The unit of pressure, is N/m^2 and this unit is sometimes called the Pascal, Pa. For most cases occurring in thermodynamics the pressure expressed in Pascal will be a very small number. This new unit is defined as follows:

$$1 \text{ bar} = 10^5 \text{ N/m}^2 = 10^5 \text{ Pa}$$

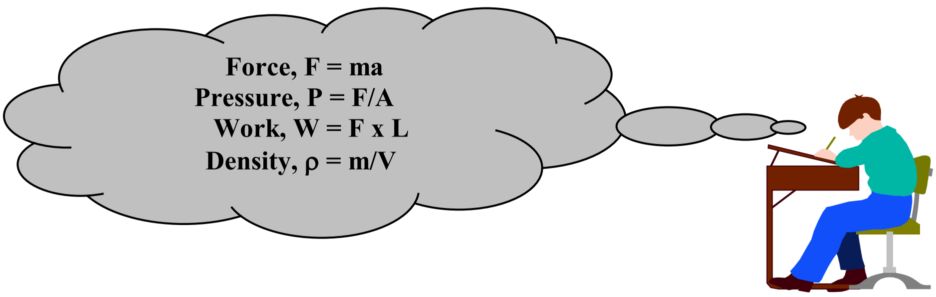
1.1.5. Density

Density is the mass of a substance per unit volume.

$$\text{Density} = \frac{\text{mass}}{\text{volume}}$$

$$\rho = \frac{m}{V} \tag{1.4}$$

The unit of density is kg/m^3 .



Example 1.1

Calculate the pressure of gas underneath the piston in equilibrium for a 50 kg mass that reacts to a piston with a surface area of 100 cm^2.

Solution to Example 1.1

$$\text{Pressure (P)} = \frac{\text{force}}{\text{area}}$$

$$= \frac{50 \times 9.81}{0.01}$$

$$= 49.05 \text{ N/m}^2$$

Tips !

Force = mass x acceleration
Pressure = force/area

Example 1.2

A density of $\rho = 850$ kg/m^3 of oil is filled to a tank. Determine the amount of mass m in the tank if the volume of the tank is $V = 2$ m^3.

Solution to Example 1.2

We should end up with the unit of kilograms. Putting the given information into perspective, we have

$$\rho = 850 \text{ kg/m}^3 \text{ and } V = 2 \text{ m}^3$$

It is obvious that we can eliminate m^3 and end up with kg by multiplying these two quantities. Therefore, the formula we are looking for is

$$\rho = \frac{m}{V}$$

Thus,

$$m = \rho V$$

$$= (850 \text{ kg/m}^3)(2 \text{ m}^3)$$

$$= 1700 \text{ kg}$$

Activity 1A

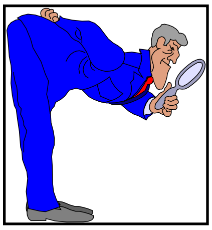
TEST YOUR UNDERSTANDING BEFORE YOU CONTINUE WITH THE NEXT INPUT…!

1.1 What is the work done by an expanding gas if the force resisting the motion of the piston is 700 N and the length of the stroke is 0.5 m ?

1.2 What is the force required to accelerate a mass of 30 kg at a rate of 15 m/s^2 ?

1.3 The fuel tank of a large truck measures 1.2m x 0.9m x 0.6m. How many litres of fuel are contained in the tank when it is full?

1.4 A weather research instrument is suspended below a helium filled balloon which is a 3.8m diameter sphere. If the specific volume of helium is $5.6m^3/kg$, what is the weight of helium in the balloon? Explain briefly why the balloon rises in the atmosphere.



Feedback to Activity 1A

1.1 Work = Force x Distance

$= (700 \text{ N})(0.5 \text{ m})$

$= 350 \text{ Nm or J}$

1.2 Force = mass x acceleration

$F = ma$

$= (30 \text{ kg})(15 \text{ m/s}^2)$

$= 450 \text{ kg.m/s}^2 \text{ or N}$

1.3 Volume = 1.2 x 0.9 x 0.6 = 0.648 m^3

Since 1m^3 = 1000 litres

Then, contents of full tank = 0.648 x 1000

= 648 litres

1.4 Radius of volume, r = $\frac{d}{2}$

$= \frac{3.3}{2} = 1.9 \text{ m}$

Volume of balloon, $V = \frac{4}{3}\pi r^3$

$= \frac{4}{3}\pi (1.9)^3$

$= 28.73 \text{ m}^3$

Mass of helium in balloon, $m = \frac{V}{v}$

$= 28.73/5.6$

$= 5.13 \text{ kg}$

$\therefore w = mg$

$= 5.13 \times 9.81$

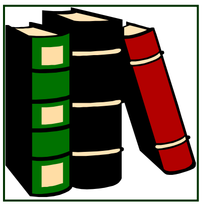
$= 50.3 \text{ N}$

Density of helium, $\rho = \dfrac{1}{v}$

$= \dfrac{1}{5.6}$

$= 0.1786 \text{ kg/m}^3$

The balloon rises in the atmosphere because the density of helium is less than the density of atmosphere.



INPUT

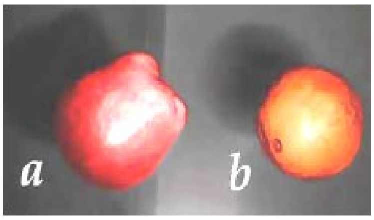
1.2 Unit Conversions

We all know from experience that conversion of units can give terrible headaches if they are not used carefully in solving a problem. But with some attention and skill, conversion of units can be used to our advantage.

Measurements that describe physical quantities may be expressed in a variety of different units. As a result, one often has to convert a quantity from one unit to another. For example, we would like to convert, say, 49 days into weeks. One approach is to multiply the value by ratios of the equivalent units. The ratios are formed such that the old units are cancelled, leaving the new units.

The Dimensional Homogeneity

- Despite their causing us errors, units/dimensions can be our friends.
- All terms in an equation must be dimensionally homogeneous.
  - That is, we can't add apples to oranges…
  - Neither can we add J/mol to J/kg s.
- By keeping track of our units/dimensions, we can automatically do a reality check on our equations.
- But the fun doesn't stop there…
- A dimensional analysis can help to determine the form of an equation that we may have forgotten.



The example of unit conversions are:

- 1 kg = 1000 g
- 1 m = 100 cm = 1000 mm
- 1 km = 1000 m = (100 000 cm @ 10^5 cm) = (1 000 000 mm @ 10^6 mm)
- 1 hour = 60 minutes = 3600 seconds
- 1 m^3 = 1000 litre, or 1 litre = 1 x 10^{-3} m^3
- 1 bar = 1 x 10^5 N/m^2 = 1 x 10^2 kN/m^2

Multiple and sub-multiple of the basic units are formed by means of prefixes, and the ones most commonly used are shown in the following table:

Table 1.2 Multiplying factors

Multiplying Factor		Prefix	Symbol
1 000 000 000 000	10^{12}	tera	T
1 000 000 000	10^{9}	giga	G
1 000 000	10^{6}	mega	M
1 000	10^{3}	kilo	k
100	10^{2}	hector	h
10	10^{1}	deca	da
0.1	10^{-1}	desi	d
0.01	10^{-2}	centi	c
0.001	10^{-3}	milli	m
0.000 001	10^{-6}	micro	μ
0.000 000 001	10^{-9}	nano	n
0.000 000 000 001	10^{-12}	pico	p

Example 1.3

Convert 1 km/h to m/s.

Solution to Example 1.3

$$\therefore \frac{1\,\text{km}}{\text{j}} = \frac{1\,\text{km}}{\text{j}} \text{ x } \frac{1000\text{ m}}{1\,\text{km}} \text{ x } \frac{1\text{ j}}{3600\text{ s}}$$

$$= \frac{1000\text{ m}}{3600\text{ s}}$$

$$= 0.278\text{ m/s}$$

Example 1.4

Convert 25 g/mm^3 to kg/m^3.

Solution to Example 1.4

$$1\ kg = 1000\ g$$

$$1\ m = 1000\ mm$$
$$1\ m^3 = 1000 \times 1000 \times 1000\ mm^3$$
$$= 10^9\ m^3$$

$$\therefore \frac{25\,g}{mm^3} = \frac{25\,g}{mm^3} \times \frac{10^9\ mm^3}{1\,m^3} \times \frac{1\,kg}{1000\,g}$$
$$= \frac{25 \times 10^9 \times 1\,kg}{1000\,m^3}$$
$$= 25 \times 10^6\ kg/m^3$$

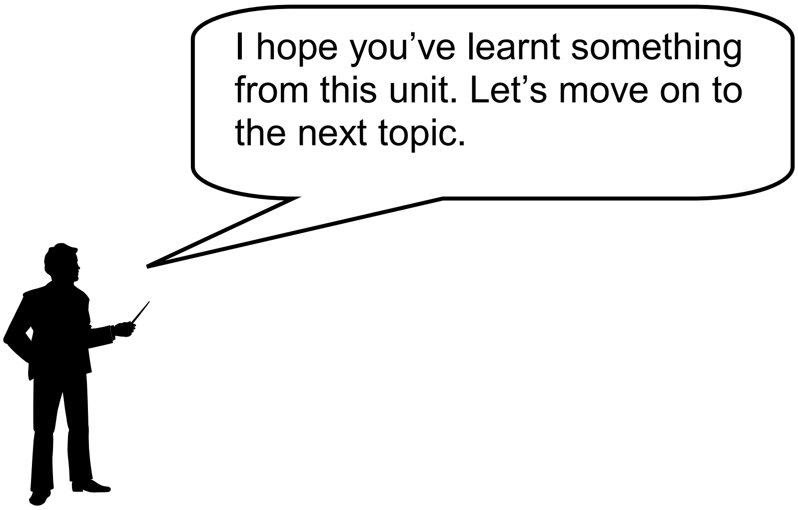
How could I convert g/mm^3 to kg/m^3?

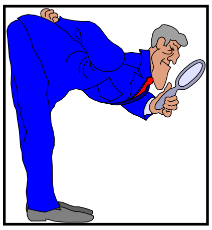
Activity 1B

TEST YOUR UNDERSTANDING BEFORE YOU CONTINUE WITH THE NEXT INPUT…!

1.5 Convert the following data:
- a) 3 N/cm^2 to kN/m^2
- b) 15 MN/m^2 to N/m^2

1.6 Convert 15 milligram per litre to kg/m^3.





Feedback To Activity 1B

1.5 a) 1 kN = 1000 N

$1\ m^2 = 100 \times 100 = 10^4\ cm^2$

$$\therefore \frac{3\ N}{cm^2} = \frac{3\ N}{cm^2} \text{ x } \frac{10^4\ cm^2}{1\ m^2} \text{ x } \frac{1\ kN}{1000\ N}$$

$$= \frac{3 \text{ x } 10^4\ kN}{1000\ m^2}$$

$$= 30\ kN/m^2$$

b) $1\ MN = 10^6\ N/m^2$

$$\therefore \frac{15\ MN}{m^2} = \frac{15\ MN}{m^2} \text{ x } \frac{10^6\ N}{1\ MN}$$

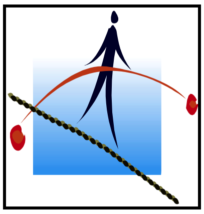
$$= 15 \text{ x } 10^6\ N/m^2$$

1.6 1 kg = 1 000 000 mg

$1\ m^3 = 1000$ litre

$$\therefore \frac{15\ mg}{litre} = \frac{15\ mg}{litre} \text{ x } \frac{1\ kg}{1\,000\,000\ mg} \text{ x } \frac{1000\ litre}{1\ m^3}$$

$$= 15 \text{ x } 10^{-3}\ kg/m^3$$



SELF-ASSESSMENT 1 A

You are approaching success. **Try all the questions** in this self-assessment section and check your answers with those given in the Feedback to Self-Assessment on the next page. If you face any problem, discuss it with your lecturer. Good luck.

1. A gas is contained in a vertical frictionless piston-cylinder device. The piston has a mass of 4 kg and a cross-sectional area of 35 cm^2. A compressed spring above the piston exerts a force of 60 N onto the piston. If the atmospheric pressure is 95 kPa, determine the pressure inside the cylinder.

2. A force of 8 N is applied continuously at an angle of 30^o to a certain mass. Find the work done when the mass moves through a distance of 6 m.

3. A man weighing 60 kg goes up a staircase of 5 m in height in 20 secs. Calculate his rate of doing work and power in watts.

4. The density of water at room temperature and atmospheric pressure is 1.0 g/cm^3. Convert this to kg/m^3. Find also the specific volume of water.

Feedback to Self-Assessment

Have you tried the questions????? If "**YES**", check your answers now.

1. 123.4 kPa

2. 41.57 J

3. 147 J, 147 watt.

4. 1000 kg/m^3 ; 0.001 m^3/kg

INPUT

1.3 TEMPERATURE UNITS

Temperature scales are defined by the numerical value assigned to a standard fixed point. By international agreement the standard fixed point is the easily reproducible triple point of water. These are represented by the state of equilibrium between steam, ice and liquid water.
In this unit we learn how to convert temperatures into Celsius, Fahrenheit, Kelvin and Rankine scales.

The Celsius temperature scale uses the unit degree Celsius (º*C*), which has the same magnitude as the Kelvin. Thus the temperature differences are identical on both scales. However, the zero point on the Celsius scale is shifted to 273*K*, as shown by the following relationship between the Celsius temperature and the Kelvin temperature:

$$T(^\circ C) = T(K) - 273 \qquad \ldots(1)$$

By definition, the Rankine scale, the unit of which is the degree Rankine (*R*) is proportional to the Kelvin temperature according to

$$T(R) = 1.8T(K) \qquad \ldots(2)$$

A degree of the same size as that on the Rankine scale is used in the Fahrenheit scale, but the zero point is shifted according to the relation

$$T(^\circ F) = T(R) - 460 \qquad \ldots(3)$$

substituting Eqs. (1) and (2) into Eq. (3), it follows that

$$T(°F) = 1.8T(°C) + 32$$

Example 1.5

Convert 200ºC to K.

Solution to Example 1.5

$$\begin{aligned} K &= °C + 273 \\ &= 200 + 273 \\ &= \underline{\underline{473\ K}} \end{aligned}$$

Example 1.6

Convert 250 ºC to ºF

Solution to Example 1.6

$$\begin{aligned} °F &= 32 + 1.8°C \\ &= 32 + 1.8(250) \\ &= \underline{\underline{482\ °F}} \end{aligned}$$

Example 1.7

Convert 365 ºF to R

Solution to Example 1.7

$$\begin{aligned} R &= 460 + °F \\ &= 460 + 365 \\ &= \underline{\underline{825\ R}} \end{aligned}$$

Example 1.8

Convert 200 ºF to R

Solution to Example 1.8

$$
\begin{aligned}
R &= 460 + {}^\circ F \\
&= 460 + 200 \\
&= \underline{\underline{660\ R}}
\end{aligned}
$$

Example 1.9

Convert 450 R to K

Solution to Example 1.9

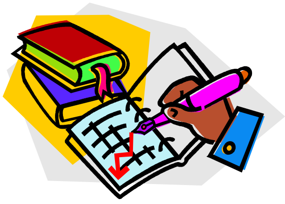
$$
\begin{aligned}
K &= \frac{R}{1.8} \\
&= \frac{450}{1.8} \\
&= \underline{\underline{250\ \ K}}
\end{aligned}
$$

Example 1.10

Convert 410 K to ºF

Solution to Example 1.10

$$
\begin{aligned}
{}^\circ F &= 1.8\,(K - 273) + 32 \\
&= 1.8\,(410 - 273) + 32 \\
&= \underline{\underline{278.6{}^\circ F}}
\end{aligned}
$$



ACTIVITY 1C

TEST YOUR UNDERSTANDING BEFORE YOU CONTINUE WITH THE NEXT INPUT…!

1.1 Write the formula to convert the following temperature scales.

^{o}C to K	⇨	
^{o}F to R	⇨	
R to K	⇨	

1.2 Solve the problems below:

i) Air entering a wet scrubber is at 153 ^{o}C. What is the temperature expressed in degree Rankine?

ii) The gas stream temperature entering a fabric filter is 410 ^{o}F. What is the temperature expressed in degree Kelvin?

SELF-ASSESSMENT 1B

You are approaching success. **Try all the questions** in this self-assessment section and check your answers with those given in the Feedback on Self-Assessment. If you face any problems, discuss it with your lecturer. Good luck.

1.1 Convert the temperatures below according to the specified scales:

a) 175 º*C* to º*F*, *K* and *R*.

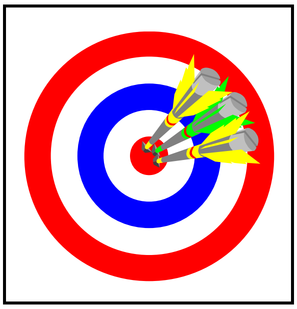
b) 518 º*R* to º*C*, º*F* and *K*.

c) 214 º*F* to º*C*, *R* and *K*.

d) 300 *K* to º*C*, *R* and º*F*.

TOPIC 2

THERMODYNAMICS ENERGY



OBJECTIVES

General Objective : To understand the basic concept of First Law of Thermodynamics and Thermodynamics Energy

Specific Objectives : At the end of the unit you will be able to:

- define the definitions and show the application of internal energy

2.1 Internal Energy

Internal energy is the sum of all the energies a fluid possesses and stores within itself. The molecules of a fluid may be imagined to be in motion thereby possessing kinetic energy of translation and rotation as well as the energy of vibration of the atoms within the molecules. In addition, the fluid also possesses internal potential energy due to inter-molecular forces.

Suppose we have 1 kg of gas in a closed container as shown in Figure 2.1 For simplicity, we shall assume that the vessel is at rest with respect to the earth and is located on a base horizon. The gas in the vessel has neither macro kinetic energy nor potential energy. However, the molecules of the gas are in motion and possess a molecular or 'internal' kinetic energy. The term is usually shortened to **internal energy**. If we are to study thermal effects then we can no longer ignore this form of energy. We shall denote the specific (per kg) internal energy as u J/kg.

Now suppose that by rotation of an impeller within the vessel, we add work dW to the closed system and we also introduce an amount of heat dQ. The gas in the vessel still has zero macro kinetic energy and zero potential energy. The energy that has been added has simply caused an increase in the internal energy.

The change in internal energy is determined only by the net energy that has been transferred across the boundary and is independent of the form of that energy (work or heat) or the process path of the energy transfer. In molecular simulations, molecules can of course be seen, so the changes occurring as a system gains or loses internal energy are apparent in the changes in the motion of the molecules. It can be observed that the molecules move faster when the internal energy is increased. Internal energy is, therefore, a thermodynamic property of state. Equation 2.1 is sometimes known as the non-flow energy equation and is a statement of the First Law of Thermodynamics.

$$dU = \mathrm{d}Q - \mathrm{d}W$$

or, $$U_2 - U_1 = Q_{12} - W_{12} \tag{2.1}$$

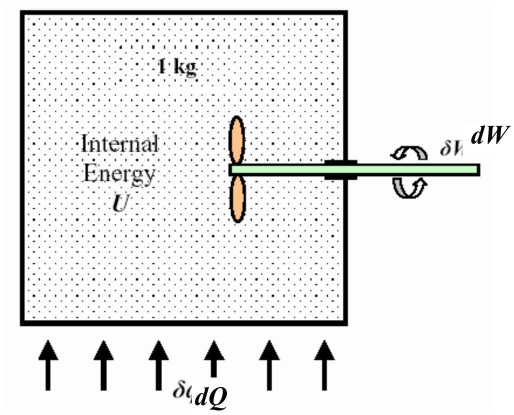


Figure 2.1 Added work and heat raise the internal energy of a close system

Example 2.1

A system is allowed to do work amounting to 500 kNm whilst heat energy amounting to 800 kJ is transferred into it. Find the change of internal energy and state whether it is an increase or decrease.

Solution to Example 2.1

$$U_2 - U_1 = Q_{12} - W_{12}$$

now,

$W_{12} = +500$ kNm = 500 kJ
$Q_{12} = +800$ kJ

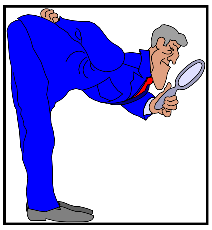
$\therefore \quad U_2 - U_1 = 800 - 500$
$= 300$ kJ

Since $U_2 > U_1$, the internal energy has increased.

Activity 2A

TEST YOUR UNDERSTANDING BEFORE YOU CONTINUE WITH THE NEXT INPUT…!

2.1 A close system undergoes a process in which there is a heat transfer of 200 kJ from the system to the surroundings. The work done from the system to the surroundings is 75 kJ. Calculate the change of internal energy and state whether it is an increase or decrease.



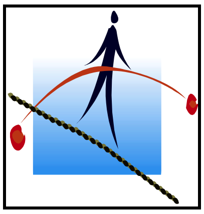
Feedback To Activity 2A

2.1 $U_2 - U_1 = Q_{12} - W_{12}$

now,
Q_{12} = -200 kJ
W_{12} = 75 kJ

∴ $U_2 - U_1 = (-200) - (75) = -275$ kJ
(Since $U_2 - U_1$ = -ve, the internal energy is decreased)

CONGRATULATIONS, IF YOUR ANSWERS ARE CORRECT THEN YOU ARE SUCCESSFUL.



SELF-ASSESSMENT

You are approaching success. **Try all the questions** in this self-assessment section and check your answers with those given in the Feedback to Self-Assessment on the next page. If you face any problem, discuss it with your lecturer. Good luck.

1. A thermodynamic system undergoes a process in which its internal energy decreases by 300 kJ. If at the same time, 120 kJ of work is done by the system, find the heat transferred to or from the system.

2. The internal energy of a system increases by 70 kJ when 180 kJ of heat is transferred to the system. How much work is done by the gas?

3. During a certain process, 1000 kJ of heat is added to the working fluid while 750 kJ is extracted as work. Determine the change in internal energy and state whether it is increased or decreased.

4. If the internal energy of a system is increased by 90 kJ while the system does 125 kJ of work to the surroundings, determine the heat transfer to or from the system.

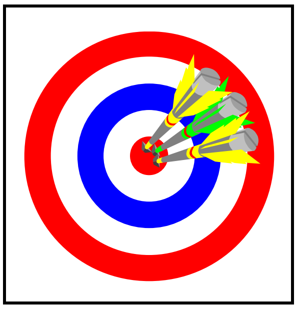
Feedback to Self-Assessment

Have you tried the questions????? If "**YES**", check your answers now.

1. Q = - 180 kJ
2. W = 110 kJ
3. $U_2 - U_1$ = 250 kJ (Since U_2 - U_1 = +ve, the internal energy is increased)
4. Q = 215 kJ

TOPIC 3

THERMODYNAMIC SYSTEMS

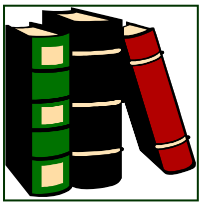


OBJECTIVES

General Objective : To understand the basic concept of thermodynamics systems

Specific Objectives : At the end of the unit you will be able to:

- Define the fundamental concepts of system, boundary, surrounding, open system and close system
- explain the property, state and process of the working fluid and provide example



INPUT

3.0 Introduction

Every science has a unique vocabulary associated with it, and thermodynamics is no exception. Precise definition of the basic concepts forms a sound foundation for the development of science and prevents possible misunderstandings. In this unit, the systems that will be used are reviewed, and the basic concepts of thermodynamics such as system, energy, property, state, process, cycle, pressure and temperature are explained. Careful study of these concepts is essential for a good understanding of the topics in the following units.

3.1 Definitions of system, boundary, surrounding, open system and close system

A **thermodynamic system**, or simply a **system**, is defined as a *quantity of matter or a region in space chosen for study.* The fluid contained by the cylinder head, cylinder walls and the piston may be said to be the system.

The mass or region outside the system is called the **surroundings**. The surroundings may be affected by changes within the system.

The **boundary** is the surface of separation between the system and its surroundings. It may be the cylinder and the piston or an imaginary surface drawn as in Fig. 3.1, so as to enable an analysis of the problem under consideration to be made.

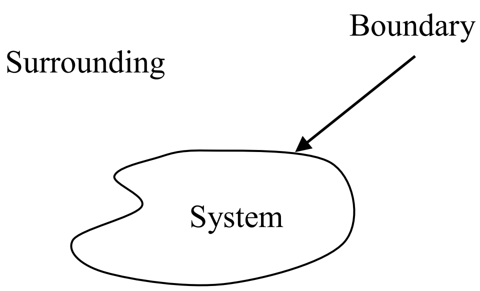


Figure 3.1 System, surroundings and boundary

A system can either to be *close* or *open*, depending on whether a fixed mass or a fixed volume in space is chosen for study. A **close system** (also known as a control mass) consists of a fixed amount of mass, and no mass can cross its boundary. That is, no mass can enter or leave a close system, as shown in Fig. 3.2. But energy, in the form of heat or work can cross the boundary, and the volume of a close system does not have to be fixed.

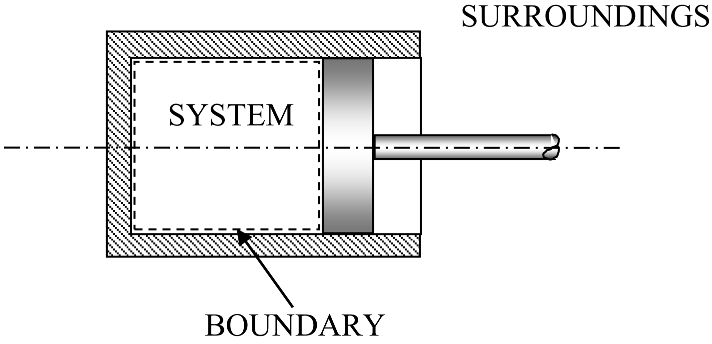


Fig. 3.2 A closed system with a moving boundary

An **open system**, or a control volume, as it is often called, is a properly selected region in space. It usually encloses a device, which involves mass flow such as a boiler, compressor, turbine or nozzle. Flow through these devices is best studied by selecting the region within the device as the control volume. Both mass and energy can cross the boundary of a control volume, as shown in Fig. 3.3.

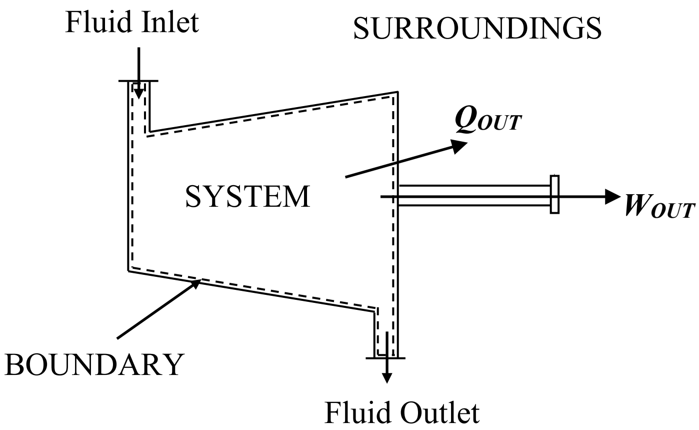


Fig 3.3 Open system in boiler

3.2 Property, State and Process

Properties are macroscopic characteristics of a system such as mass, volume, energy, pressure, and temperature to which numerical values can be assigned at a given time without knowledge of the history of the system. Many other properties are considered during the course of our study of engineering thermodynamics. Thermodynamics also deals with quantities that are not properties, such as mass flow rates and energy transfers by work and heat. Properties are considered to be either **intensive** or **extensive.**

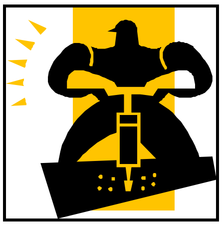
Intensive properties are those which are independent of the size of the system such as temperature, pressure and density.

Extensive properties are those whose values depend on the size or extent of the system. Mass, volume and total energy are some examples of extensive properties.

The word **state** refers to the condition of system as described by its properties. Since there are normally relations among the properties of a system, the state often can be specified by providing the values of a subset of the properties.

When there is a change in any of the properties of a system, the state changes and the system are said to have undergone a **process**. A process is a transformation from one state to another. However, if a system exhibits the same values of its properties at two different times, the state remains the same at these times. A system is said to be at a steady state if none of its properties changes with time. A process occurs when a system's state (as measured by its properties) changes for any reason. Processes may be reversible or actual (irreversible). In this context the word 'reversible' has a special meaning. A reversible process is one that is wholly theoretical, but can be imagined as one which occurs without incurring friction, turbulence, leakage or anything which causes unrecoverable energy losses. All of the processes considered below are reversible and the actual processes will be dealt with later.

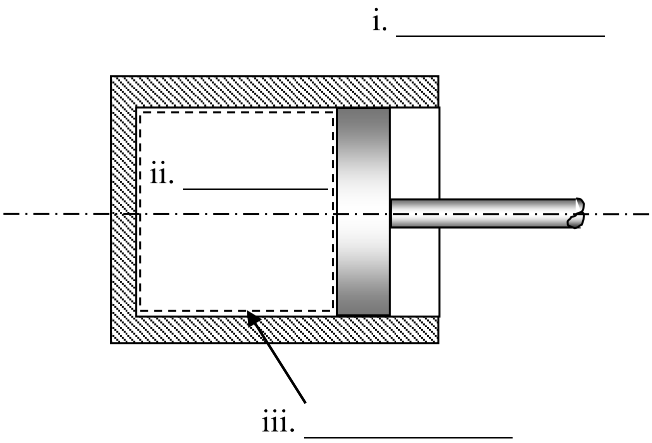
Processes may be constrained to occur at constant temperature (isothermal), constant pressure, constant volume, polytropic and adiabatic (with no heat transfer to the surroundings).



Activity 3A

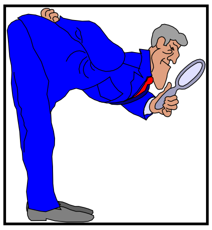
TEST YOUR UNDERSTANDING BEFORE YOU CONTINUE WITH THE NEXT INPUT…!

3.1 Fill in the blanks with suitable names for the close system in the diagram below.



3.2 Study the statements in the table below and decide if the statements are **TRUE (T)** or **FALSE (F)**.

	STATEMENT	**TRUE or FALSE**
i.	The mass or region inside the system is called the surroundings.	
ii.	In a close system, no mass can enter or leave a system.	
iii.	Intensive properties are those which are independent of the size of the system	
iv.	Mass, volume and total energy are some examples of intensive properties.	



Feedback To Activity 3A

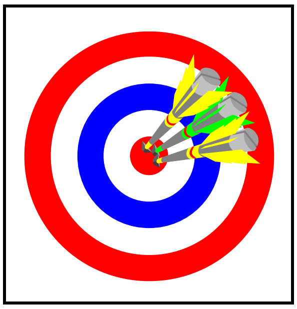
3.1 i. Surroundings
ii. System
iii. Boundary

3.2 i. False
ii. True
iii. True
iv. False

CONGRATULATIONS, IF YOUR ANSWERS ARE CORRECT YOU CAN PROCEED TO THE NEXT INPUT…..

TOPIC 4

ENERGY CHANGE

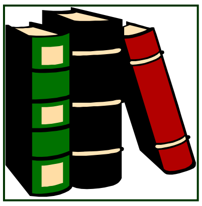


OBJECTIVES

General Objective : To understand the basic concept and the First Law of Thermodynamics

Specific Objectives : At the end of the unit you will be able to:

- state the definitions of the First Law of Thermodynamics
- describe the differences between work and heat transfer
- define the definitions and show the application of internal energy



INPUT

4.1 The First Law of Thermodynamics

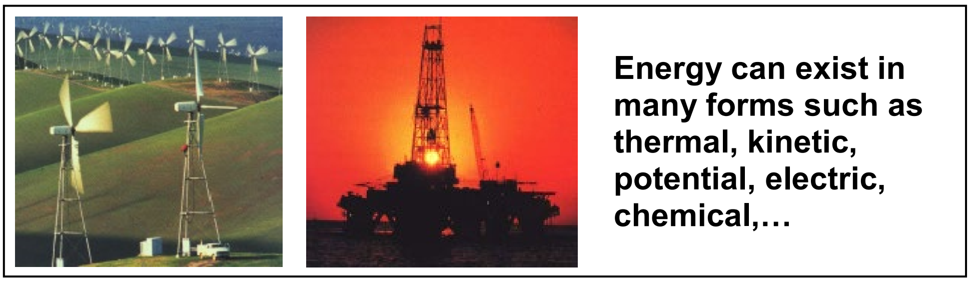


Figure 4.1 Pictures showing types of energy

The first law of thermodynamics is simply a statement of conservation of energy principle and it asserts that total energy is a thermodynamic property. Energy can neither be created nor destroyed; it can only change forms. This principle is based on experimental observations and is known as the *First Law of Thermodynamics.* The First Law of Thermodynamics can therefore be stated as follows:

> *When a system undergoes a thermodynamic cycle then the net heat supplied to the system from its surroundings is equal to the net work done by the systems on its surroundings.*
>
> **……The First Law of Thermodynamics**

In symbols,

$$\Sigma\, \mathrm{d}Q = \Sigma\, \mathrm{d}W \qquad (4.1)$$

where Σ represents the sum of a complete cycle.

4.2 Work and Heat Transfer

Work transfer is defined as a product of the force and the distance moved in the direction of the force. When a boundary of a close system moves in the direction of the force acting on it, then the system does work on its surroundings. When the boundary is moved inwards the work is done on the system by its surroundings. The units of work are, for example, Nm or J. If work is done on unit mass of a fluid, then the work done per kg of fluid has the units of Nm/kg or J/kg. Consider the fluid expanding behind the piston of an engine. The force F (in the absence of friction) will be given by

$$F = pA \qquad (4.2)$$

where

p is the pressure exerted on the piston and

A is the area of the piston

If dx is the displacement of the piston and p can be assumed constant over this displacement, then the work done W will be given by,

$$W = F \times dx$$
$$= pA \times dx$$
$$= p \times Adx$$
$$= p \times dV$$
$$= p(V_2 - V_1) \qquad (4.3)$$

where $dV = Adx$ = change in volume.

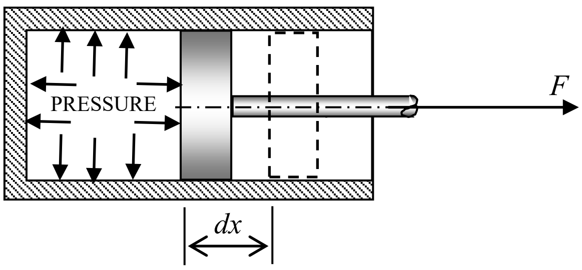


Figure 4.2 Work transfer

When two systems at different temperatures are in contact with each other, energy will transfer between them until they reach the same temperature (that is, when they are in equilibrium with each other). This energy is called heat, or thermal energy, and the term "heat flow" refers to an energy transfer as a consequence of a temperature difference.

Heat is a form of energy which crosses the boundary of a system during a change of state produced by the difference in temperature between the system and its surroundings. The unit of heat is taken as the amount of heat energy equivalent to one joule or Nm. The joule is defined as the work done when the point of application of a force of one newton is displaced through a distance of one meter in the direction of the force.

4.3 Sign Convention for Work Transfer

It is convenient to consider a convention of sign in connection with work transfer and the usual convention adopted is:

- if work energy is transferred from the system to the surroundings, it is donated as positive.
- if work energy is transferred from the surroundings to the system, it is donated as negative.

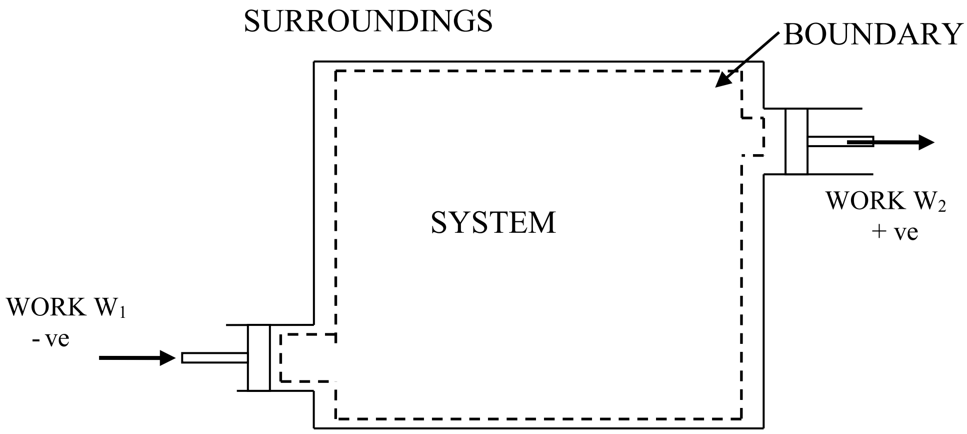


Figure 4.3 Sign Convention for work transfer

4.4 Sign Convention for Heat Transfer

The sign convention usually adopted for heat energy transfer is such that :

- if heat energy flows into the system from the surroundings it is said to be **positive**.
- if heat energy flows from the system to the surroundings it is said to be **negative**. It is incorrect to speak of heat in a system since heat energy exists only when it flows across the boundary. Once in the system, it is converted to other types of energy.

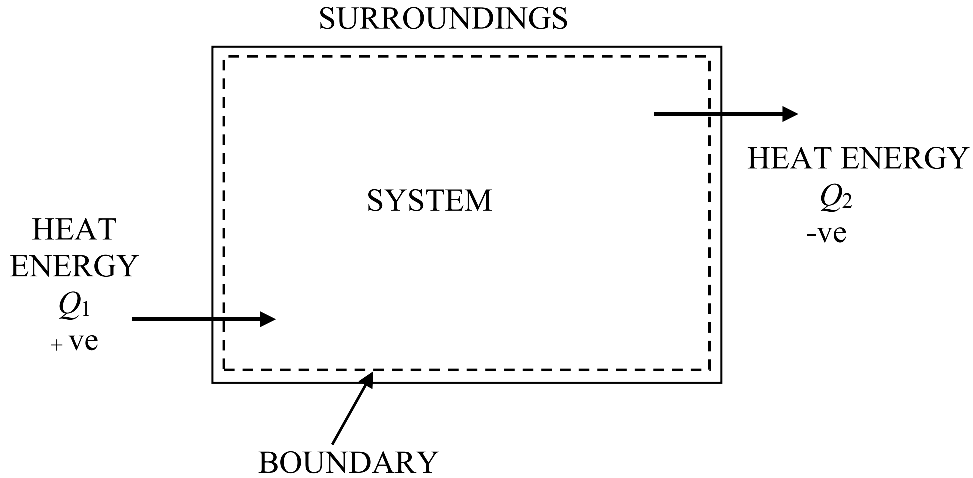
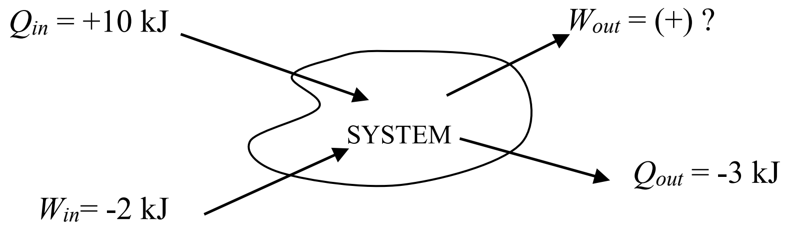


Figure 4.4 Sign convention for heat transfer

Example 4.1



The figure above shows a certain process, which undergoes a complete cycle of operations. Determine the value of the work output for a complete cycle, W_{out}.

Solution to Example 4.1

$$\Sigma Q = Q_{in} + Q_{out}$$
$$= (10) + (-3)$$
$$= 7 \text{ kJ}$$

$$\Sigma W = W_{in} + W_{out}$$
$$= (-2) + (W_{out})$$

Q_{in} is +10 kJ

Q_{out} is –3 kJ

W_{in} is –2 kJ

W_{out} is +ve

Hence $\Sigma Q - \Sigma W = 0$

$$\Sigma W = \Sigma Q$$
$$(-2) + (W_{out}) = 7$$
$$W_{out} = 9 \text{ kJ}$$

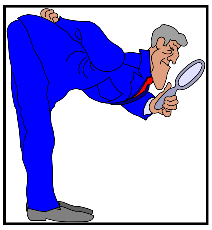
Activity 4A

TEST YOUR UNDERSTANDING BEFORE YOU CONTINUE WITH THE NEXT INPUT…!

4.1 During a complete cycle operation, a system is subjected to the following: Heat transfer is 800 kJ supplied and 150 kJ rejected. Work done by the system is 200 kJ.
Calculate the work transferred from the surrounding to the system.

4.2 Each line in Table 4.1 gives information about a process of a closed system. Every entry has the same energy unit i.e. kJ. Fill in the empty spaces in the table with the correct answers.

PROCESS	Q_{12}	W_{12}	$(U_2 - U_1)$
a.	+50	-20	i. ________
b.	+100	ii. ________	-30
c.	iii. ________	-70	+130
d.	-50	+20	iv. ________



Feedback To Activity 4A

4.1 $\Sigma Q = Q_{in} + Q_{out} = (800) + (-150) = 650$ kJ

$\Sigma W = W_{in} + W_{out} = (W_{in}) + (200)$

Hence $\Sigma Q - \Sigma W = 0$

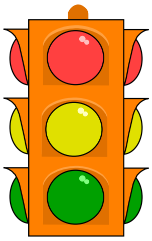
$\Sigma W = \Sigma Q$

$-(W_{in}) + (200) = 650$

$W_{in} = -450$ kJ

4.2
- i. 70
- ii. 130
- iii. 60
- iv. -70

CONGRATULATIONS, IF YOUR ANSWERS ARE CORRECT THEN YOU ARE SUCCESSFUL.



! Tips

Problem Solving Methodology

There are several correct and effective steps to problem solving. There are many variations as to what various authors give for their problem solving strategy. Some of these steps are:

- Read the **ENTIRE** problem carefully and all the way through before starting work on the problem. Make sure that you understand what is being asked.

- List the data based on the figures given in the question. This will include both explicit and implicit data items. Note that not all of the explicitly given data are always necessarily involved in the problem solution. Be wary of introducing implicit conditions that may be unnecessary for the problem solution.

- Draw a diagram of the physical situation. The type of drawing will depend upon the problem.

- Determine the physical principles involved in the particular problem. What are the pertinent equations and how can they be used to determine either the solution or intermediate results that can be further used to determine the solution. Often one equation will be insufficient to solve a particular problem.

- Simplify the equations as much as possible through algebraic manipulation before plugging numbers into the equations. The fewer times numbers are entered into equations, the less likely numerical mistakes will be made.

- Check the units on the quantities involved. Make sure that all of the given quantities are in a consistent set of units.

- Insert the given data into the equations and perform the calculations. In doing the calculations, also manipulate the units. In doing the calculations, follow the rules for significant figures.

- Is the result reasonable and are the final units correct?

GOOD LUCK, TRY YOUR BEST.

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