EXAMPLE 13: A fixed 0.15kg solid disc pulley with a radius of 0.075m is acted on by a net torque of 6.4mN. what is the angular acceleration of the pulley ? **Use: T = Iα then $\frac{1}{2}$ mr^2 . ANS: 1.52 $\times 10^4$rad/m^2**

CHAPTER 10

TEMPERATURE AND THERMOMETRY

Temperature : temperature which is the degree of hotness or coldness of a body depends on the sense of touch. In this way, it is only assessed in an approximate way, relative hotness or coldness of bodies. Judgments made by use of sense of touch are very unreliable .

On a thermodynamic scale, the thermometric property x_{tr} is measured at the triple point of water, 273.16K, and measured again at an unknown temperature T as x_t , then by definition:

$$T = \frac{x_t}{x_{tr}} \times 273.16K$$

where x can be volume, V or pressure, P or temperature , T , or resistance, R

EXAMPLE 1 : I the resistance of a certain thermometer is 80.35ohms at the triple point of water. If the resistance is 86.26ohms at a certain temperature, find the temperature.

SOLUTION : R_t = 86.28ohms, R_{tr} = 80.35ohms

$$T = \frac{R_t}{R_{tr}} \times 273.16K = \frac{86.28}{80.35} \times 273.16K = 293.3K$$

DIFFERENT TEMPERATURE SCALE

1. Celsius scale : on this scale the fundamental interval is divided into 100 equal parts. Its ice point is 0^{o}c and its steam point is 100^{o}c.

2. Fahrenheit scale : the fundamental interval is made up of 180 divisions, with ice point being 32^{o}F and steam point being 212^{o}F.

3. Kelvin scale : its fundamental interval is divided into 100 parts, with ice point (triple point of water) being 273.16K and steam point

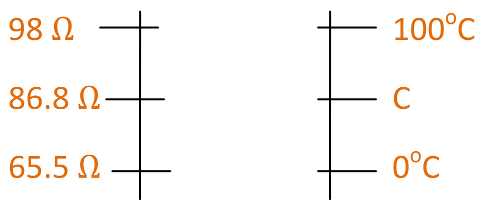
Being 373.16K

4. Rankine scale : it has a fundamental interval of 180 divisions with ice point being 492^{o}R and steam point being 672^{o}R. *it is used in engineering applications.*

In the following examples the formula we will be using is $\frac{middle\ value - down\ value}{upermost\ value -\ down\ value}$

EXAMPLE 2 : the resistance of a certain platinium thermometer is 65.5Ω at 0^{0}C and 98Ω at 100^{o}C. if the resistance is 86.8Ω when placed in hot water, find the temperature of hot water.

SOLUTION:



Using the formula : $\frac{middle\ value - down\ value}{upermost\ value -\ down\ value}$

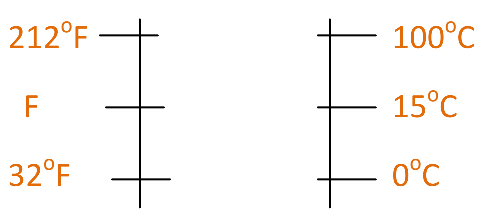
$$\frac{86.6 - 65.5}{98 - 65.5} = \frac{C - 0}{100 - 0}$$

$\frac{21.3}{32.5} = \frac{C}{100}$ always cross multiply

C = 2130/32.5 = 65.5^{o}C

EXAMPLE 3 : which of the following is the closest to 15^{o}C ? (a) 8.3^{o}F (b) 27^{o}F (c) 40^{o}F (d)50^{o}F

SOLUTION : it means convert 15^{o}C to **^{o}F**



$\frac{F-32}{212-32} = \frac{12-0}{100-0}$

$\frac{F-32}{180} = \frac{15}{100}$ always cross multiply

100(F – 32) = 180 × 15 divide through by 100

F – 32 = 27, F = 59°F

EXAMPLE 4 : convert (a)50°F and (b) 36°R to degree Celsius. **Answers : (a) 10°C (b) -253.3°C**

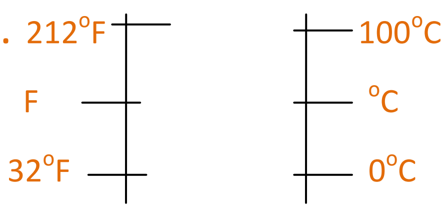
EXAMPLE 5 : a person running a fever has a body temperature of 39.4°C . what is this temperature on the Fahrenheit scale ?

HINT : it means convert to °F . ANSWER:103°

EXAMPLE 6 : derive the formula for interconversion of temperatures in the following cases. (a) from Fahrenheit to Celsius (b) from Fahrenheit to Kelvin (c) from Celsius to Kelvin (d) from Fahrenheit to rankine

SOLUTION :

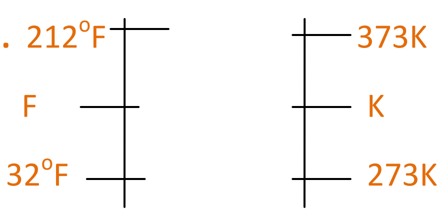
a.



Using the same procedure in the previous examples, we get **F = $\frac{9}{5}$(°C + 32), and,**

C = $\frac{5}{9}$(F - 32)

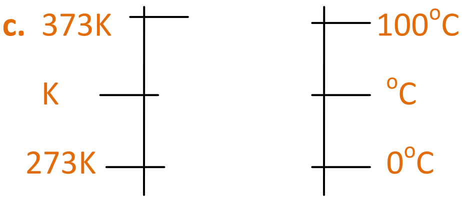
b.



We get, **K = $\frac{5}{9}$(F - 32) + 273 and**

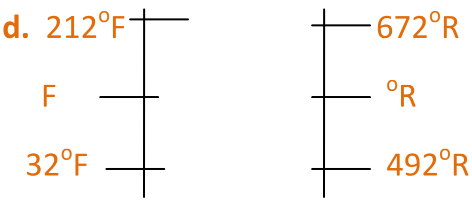
F = $\frac{9}{5}$(K - 273) + 32

c.



°C = K – 273 and K = °C + 273

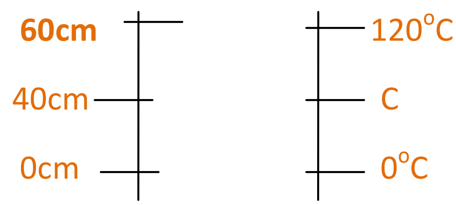
d.



F = R – 460 and R = F + 460

EXAMPLE 7 : a lagged copper rod of uniform cross-sectional area has a length of 60cm. the free ends of the rod are maintained at 120°C and 0°C respectively at a steady state. Calculate the temperature at a point 20cm from the high temperature end.

SOLUTION:



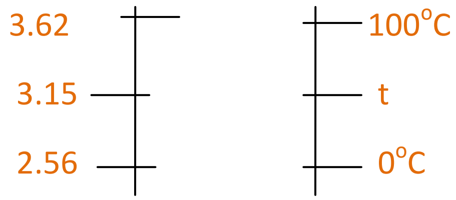
20cm from the high end means (in the diagram) (60 – 20) = 40cm

$\frac{40-0}{60-0} = \frac{C-0}{120-0}$, $\frac{2}{3} = \frac{C}{120}$, C = 80°C

EXAMPLE 8 : a constant volume thermometer registers 180mmHg at 0°C and 490mmHg at 100°C. Find the temperature when the pressure is 315mmHg. ***Answer : 43.54°C***

EXAMPLE 9 : A platinum wire has resistance of 2.56, 3.62 and 3.15ohms respectively at 0°C, 100 °C and 55°C respectively. Calculate the difference between 55°C and the corresponding platinum temperature.

SOLUTION :

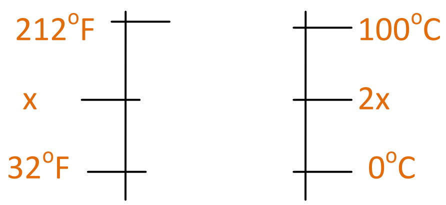


$\frac{3.15-2.56}{3.62-2.56} = \frac{t-0}{100-0}$, $\frac{0.59}{1.06} = \frac{t}{100}$, $t = 55.66^oC$

Difference = $55.66 - 55 = 0.66^oC$

EXAMPLE 10 : at what temperature will the Celsius scale read twice the Fahrenheit scale?

SOLUTION :



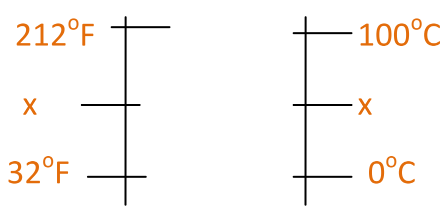
$\frac{x-32}{212-32} = \frac{2x-0}{100-0}$, $\frac{x-32}{180} = \frac{2x}{100}$,

$100(x - 32) = 360$, $100x - 3200 = 360x$, $x = -12.3^oC$

Thus, $2x = 2(-12.3) = -24.6^oC$

EXAMPLE 11 : at what temperature will the Celsius scale and Fahrenheit scale give the same reading.

SOLUTION:

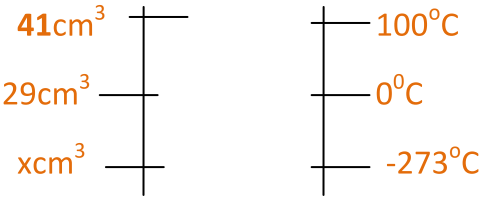


$\frac{x-32}{212-32} = \frac{x}{100-0}$, $\frac{x-32}{180} = \frac{x}{100}$

$100(x-32) = 180x$, $x = -40^oC$

EXAMPLE 12 : the volume of air at constant pressure in a gas is $29cm^3$ at 0^oC and $41cm^3$ at 100^oC. find the volume at absolute zero on this scale.

SOLUTION : ***absolute zero*** *means -273°C*

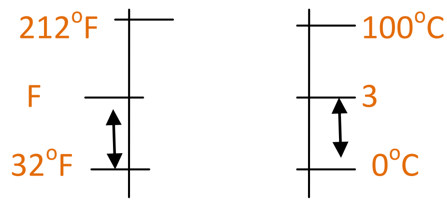


do it the same way……………………

answer = -3.76cm^3

EXAMPLE 13 : convert 3^o rise in Celsius temperature scale to Fahrenheit scale .

SOLUTION:



$\frac{F-32}{212-32} = \frac{3-0}{100-0}$, $\frac{F-32}{180} = \frac{3}{100}$,

$100(F - 32) = 540$, $F = 37.4^oF$

Thus for 3^o rise in Celsius temperature,

$F = (37.4 - 32) = 5.4^oF$

EXAMPLE 14 : the resistance R of a copper wire depends on temperature T via the equation:

$R = R_o[\ 1 + \alpha(T - T_o)\ ]$ where R_o is the resistance at temperature T_o . if the resistance increases by 10%, find the corresponding change in temperature ($\alpha = 3.8 \times 10^{-3}K^{-1}$).

SOLUTION : let $R_o = x$, $R = \frac{110x}{100}$ (10% increase)

Substitute into $R = R_o[\ 1 + \alpha(T - T_o)\ ]$

$\frac{110\cancel{x}}{100} = \cancel{x}[\ 1 + 3.8 \times 10^{-3}(T - T_o)]$

$1.1 = 1 + 3.8 \times 10^{-3}(T - T_o)$,

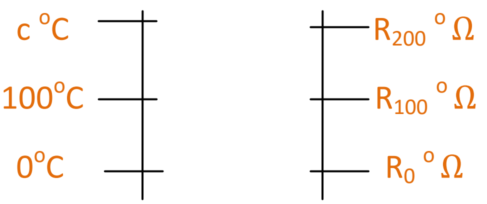
$1.1 - 1 = 3.8 \times 10^{-3}(T - T_o)$

$$\frac{0.1}{3.8 \times 10^{-3}} = (T - T_o), \quad T - T_o = 26.3K$$

EXAMPLE 15 : the resistance R_t of a platinum wire at t^oC, measured on the gas scale is given by $R_t = R_o(1 + aT + bT^2)$ where $a = 3.8 \times 10^{-3} C^{-1}$ $b = -5.6 \times 10^{-7} C^{-1}$. What temperature will the platinum thermometer indicate when the

Temperature on the Celsius scale is 200^oC ?

SOLUTION :



$$\frac{c - 0}{100 - 0} = \frac{R_{200} - R_0}{R_{100} - R_0}$$

Since $R_t = R_o(1 + aT + bT^2)$, then

$R_{200} = R_o(1 + 200a + 200^2 b)$ and

$R_{100} = R_o(1 + 100a + 100^2 b)$

$$c = \frac{\{R_o(1 + 100a + 100^2 b) - R_o\} \times 100}{R_o(1 + 100a + 100^2 b) - R_o}$$

$$= \frac{\{R_o + 200R_o a + 200^2 R_o b - R_o\} \times 100}{R_o + 100R_o a + 100^2 R_o b - R_o}$$

$$= \frac{\{200R_o a + 200^2 R_o b\} \times 100}{100R_o a + 100^2 R_o b}$$

$$= \frac{200R_o\{a + 200b\} \times 100}{100R_o(a + 100b)}$$

$$= \frac{200(3.8 \times 10^{-3} - 200 \times -5.6 \times 10^{-7}}{3.8 \times 10^{-3} - 100 \times -5.6 \times 10^{-7}}$$

$c = 197^oC$

EXAMPLE 16 : the resistance of a platinum wire at 0^oC, $100\ ^oC$ and $444.6\ ^oC$ is found to be 5.5, 7.5 and 14.5ohms respectively. The resistance of a wire at a temperature t^oC is given by the equation $R_t = R_o(1 + \alpha t + \beta t^2)$. Find the values of α and .

ANSWERS : $\alpha = 3.62 \times 10^{-3} C^{-1}$, $\beta = 1.28 \times 10^{-7} C^{-1}$

TYPES OF THERMOMETER

1. Liquid-in-glass thermometer : it is constructed in such a way that the liquid contained in a small thin-walled glass bulb is capable of expanding along the tiny bore of a thick-walled hermetical sealed capillary tube. **This is based on the fact that matters expand when heated.** For a tube of uniform bore, the change in length of the liquid column when heated is proportional to its expansion.

for a liquid-in-glass thermometer, mercury is chosen because :

1. *it is easily seen, even in very low narrow bore*

2. it has a uniform coefficient of expansion over a wide range of temperature (between -39^oC and 357^oC, its freezing and boiling points respectively)

3. it does not wet glass

4. it is a good conductor of heat

5. it has a low specific heat

One of the weaknesses of mercury-in-glass thermometer is the low limit within which its readings are accurate (-39^oC and about 300^oC). The upper limit can however, be extended by 000^o by introduction of inert gas like **nitrogen** to the top of the mercury column. As the mercury expands, the pressure of the inert gas increases, thereby extending the boiling point of mercury. In this way, temperature up to 600^oC can be recorded. Reducing the lower limit by using mercury-in-glass, below -39^oC is difficult. Hence, for such lower temperature, another kind of liquid is used—**alcohol.** Alcohol has a freezing point of -114.9^oC. lower temperature up to -200^oC can be achieved by using a liquid called **pentane.**

2. Gas thermometer : mercury-in-glass thermometers are not very reliable when very accurate measurements are required. For purpose of standardization, gas thermometers are used. The thermometric substance is a gas and the thermometer is either of the constant

Pressure type, where the volume of a gas is measured at different temperatures at constant pressure, or with the volume kept constant as the pressure changes with temperature. This latter type – *constant volume gas thermometer* is more convenient and is widely used. **The advantages of this kind of thermometer include :**

(i) *gas thermometers are very sensitive because gas produce large proportionate increase in volume and pressure when heated .*

(ii) *since gas can be at high state of purity, the readings can be reproduced to a high degree of accuracy.*

(iii) a wide range of temperature can be covered. **Temperature up to 1500^oC can be measured with a constant volume gas thermometer.**

3. resistance thermometer : it is built on the principle of variation of the resistance of a metal conductor with changes in temperature. *One of the best is platinum resistance thermometer – it can cover a range from -200^oC to 1200^oC . its advantage is that it is convenient to use and even temperatures of very hot* objects (**e.g furnace)** can be taken at a distance using the leads. *Its main disadvantages lie in the fact that it does not respond rapidly to changing temperature.*

4. the thermoelectric thermometer : the function of this thermometer depends on the ***seebeck effect.*** *The seebeck effect shows that if two dissimilar metals are joined in series to make a complete circuit, then on heating one of the junctions, a current flows round the circuit.*

Current cannot flow unless there is an EMF.

5. pyrometers : it is a type of thermometer used in determining the temperatures in *furnace* by observing the radiation from it.

Unlike other types of thermometers, no part of the instrument is required to be in contact with hot body before the temperature could be recorded. **That is why they are known as RADIATION PYROMETERS.**

Types

1. total radiation thermometers : they are used where the radiation source is large such as that through open door of a furnace.

2. optical pyrometers : they are known as to record high temperatures by taking advantage of their response on the light of a small body such as a lamp filament.

Advantages

1. they can measure temperatures above the range of thermometers. Since they can measure temperatures quit above the melting point of metals.

2. they do not require being in contact with a hot body before the temperature can be known.

Disadvantages

Calibration of the pyrometer is usually required for the true temperature value of a body to be known.

CHAPTER 11

WORK DONE (W) BY SYSTEM OF EXPANDING GAS AND CALORIMENTRY

W = P dv (dv = change in volume(v))

$W = P(v_2 - v_1)$

EXAMPLE 1 : a gas is expanding against a constant pressure of 1atm from 10 to 16 litres, what is the work done by the gas

[take 1 lit. atm = 101.33j]

SOLUTION: **$W = P(v_2 - v_1)$**= 1(16 –10)= 6 lit. atm

But 1 lit. atm = 101.33j

6 lit. atm = x hence, x = 607.98j

HEAT

Heat is the energy transferred between a

system and its surroundings as a result of temperature difference only. The direction of this energy flow is always from the region of higher temperature to a region of lower temperature,. It is measured in **joules,** othere of its units are : calories (cal), and british thermal unit(BTU)**.**

The relationship between the various units of heat are :

1 Cal = 0.004BTU

1 BTU = 252 cal

1 Cal = 4.186j

1 Kcal = 4186j (or 4.2Kj)

Power, **p** = $\frac{energy\ or\ work}{time}$

EXAMPLE 2 : the rate at which energy is expended by a machine is 25.7W. if this energy is completely converted to heat energy, how many Kilocalories are expended in 5s.

SOLUTION : p = 25.7W, t = 5s

W = pt = 25.7(5) = 128.5j, convert to Kcal

1 Kcal = 4186j

X = 128.5j thus $x = 3.07 \times 10^{-2}$ Kcal

HEAT CAPACITY, SPECIFIC HEAT CAPACITY AND CALORIMETRY

The measurement of quantity of heat is called **calorimetry.**

The quantity of heat(Q) which a body contains is proportional to the mass of the body(m) and also the change in temperature

$(\theta_2 - \theta_1)$. Thus, **$Q = mc(\theta_2 - \theta_1)$.** If $(\theta_2 - \theta_1)$ is negative heat is lost but if positive heat is gained. Where **c** is the **specific heat capacity**.

Definition

The specific heat capacity, c , of a substance is the quantity of heat required to raise the temperature of a unit mass of that substance by 1°C or 1K. *Its S.I unit is* ***jkg^{-1} °C^{-1}***

HEAT CAPACITY OF THERMAL CAPACITY (H)

It is the quantity of heat required to raise the entire mass of a body by 1°C of 1K

H = mc, thus Q = H($\theta_2 - \theta_1$).

EVAPORATION AND SUBLIMATION

Some factors hasten or retard this process. They are :

a. area of surface exposed (b) Humidity

c. air speed on the exposed surface

d. temperature of the atmosphere

the larger the surface area, the higher the surface temperature, the higher the air speed and the less the humility, the greater the evaporation.

The saturated vapour pressure depends on ***temperature only.*** Examples of substance that undergo sublimation are : camphor, iodine.

METHODS OF MEASURING THE QUANTITY OF HEAT

1. method of mixtures

2. method of cooling (3) electrical method

4. continuous flow method

5. method depending on latent heat.

In all this methods, changes in temperatures are measured, except in ***number 5*** *above.*

The fundamental principle underlying calorimetry is the law of conservation of energy. In any thermal process :

Heat gain = heat loss

LATENT HEAT

It is the heat supplied or removed which causes a change of state without a change of temperature. It is an invisible heat, hence the thermometer does not detect it. **It depends on the mass and nature of the substance.**

Latent heat of fusion : *it is also called heat of transformation or latent heat of transformation.* it is the quantity of heat required to convert a substance from its solid to its liquid state without a change in temperature. *When only unit mass of the substance is considered, the heat involved is known as* ***specific latent heat****.*

Specific latent heat of fusion (L_f) *of a substance is the quantity of heat required to convert a unit mass of the solid at the melting point to its liquid form without a change in temperature.* **H = mL_f its S.I unit is j/kg**

The specific latent heat of vaporization(L_V) of a substance is the quantity of heat required to change unit mass of a substance from its liquid at the boiling point to vapour without a change in temperature. **H = mL_V . its S.I unit is j/kg**

NOTE : L_V is greater than L_f

EXAMPLE 3 : find the pressure increase of 1kg of water going over kainji falls, which is 51m high. Assume that all of the potential energy lost by the falling water is converted into heat energy, which is completely absorbed

by the falling water.

SOLUTION: m = 1kg, h = 51m, c_w = 4200j/kgK

The potential energy is completely converted into heat energy, thus: mgh = mc($\theta_2 - \theta_1$)

$1 \times 9.81 \times 51 = 1 \times 4200 \times (\theta_2 - \theta_1)$

$(\theta_2 - \theta_1) = \frac{1 \times 9.81 \times 51}{1 \times 4200} = 0.12^{o}C$

EXAMPLE 4 : a water fall is 500m high. If the water retains 65percent of the heat generated at the end of the fall, calculate the change in temperature due to the fall (specific heat capacity of water = 4200j/kgK)

SOLUTION : h = 500m, c = 4200j/kgK,

65% thus, $\frac{65}{100}\cancel{m}c(\theta_2 - \theta_1) = \cancel{m}gh$

$\frac{65}{100} \times 4200 \times (\theta_2 - \theta_1) = 10 \times 500$

Cross multiply, $(\theta_2 - \theta_1) = \frac{500000}{65 \times 4200} = 1.8^oC$

EXAMPLE 5 : a bathtub contains 70kg of water at 26^{o}C. 10kg of water at 90^{o}C is poured in. what is the final temperature of the mixture? Neglect heat losses to the air and to the bathtub.

SOLUTION: m_1=70kg, θ_1=26^{o}C, m_2=10kg, T = ?

θ_2 = 90^{o}C, note that $c_1 = c_2$ (i.e c of water)

Heat gained by 70kg of water = heat lost by 10kg of water, $m_1c_1(T - \theta_1) = m_2c_2(\theta_2 - T$

$\cancel{70} \times \cancel{c}(T - 26) = \cancel{10} \times \cancel{c}(90 - T)$

7T – 182 = 90 – T , 8T = 272 , T = 34^{o}C

EXAMPLE 6 : a 60g of water at 90^{o}C is poured into a container containing 20g of water at 30^{o}C. the temperature of the mixture will be ? **answer = 75^{o}C.** *it is done the same way.*

EXAMPLE 7 : an electric heater of 60w is used

to heat a metal block of mass 20kg for 5minute calculate the specific heat capacity of the metal block if the rise in temperature is 20^{o}C.

SOLUTION : θ_1=20^{o}C, m = 20kg, p = 60w,

t = 5min=300s

Energy = $mc(\theta_2 - \theta_1)$, pt = $mc(\theta_2 - \theta_1)$

$60 \times 300 = 20 \times c \times 20$, $c = \frac{6 \times 300}{20 \times 20}$ = 45j/kgK

EXAMPLE 8 : (a) calculate the total heat supplied when 10g ice at 0^{o}C is heated to form water at 10^{o}C. (b) calculate the total heat given out when 10g steam at 100^{o}C condenses to form water at 45^{o}C. (c_w = 4200j/kgK,

L_f = 336000j/kg, L_V = 2260000j/kg)

SOLUTION : m_g = 10g = 0.01kg,

a. the total heat supplied for the change from ice to water is : $Q = mL_f + mc(\theta_2 - \theta_1)$

$Q = 0.01\times 336000 + 0.01 \times 4200(10 - 0)$

Q = 3780j

b. the heat given out for the transformation from steam to water is : $Q = mL_V + mc(\theta_2 - \theta_1)$

$Q = 0.01\times 2260000 + 0.01 \times 4200(100 - 45)$

Q = 24910j

EXAMPLE 9 : 1kg of water in a beaker is heated from 25^{o}C to 40^{o}C in 20mins by an electric heater placed in hot water. Calculate the power of the heater. The water is replaced by an equal amount of glycerin and the temperature rises from 25^{o}C to 40^{o}C in 12mins. Calculate the specific heat capacity of glycerin. (specific heat capacity of water = 4.2kj/kgK)

SOLUTION : m =1kg, θ_1=25^{o}C, θ_2= 40^{o}C ,

t =20mins = 1200s, c = 4.2kj/K = 4.2×10^3j/kgK

$Q = mc(\theta_2 - \theta_1) = 1 \times 4.2\times10^3(40 - 25)$=63000j

$P = \frac{E}{t} = \frac{63000}{1200}$ = 52.5w

When t = 12min = 720s

E = pt = 52.5 × 720 = 37800j

$E = mc(\theta_2 - \theta_1)$, 37800 =1 × c × (40 – 25)

37800 = 15c, thus, c = 2520j/kgK

EXAMPLE 10 : a calorimeter has a specific heat capacity of 60j/K. 0.15kg of water at 20K is contained in the calorimeter. 1kg of the same liquid at 90K is added, and the final temperature of the mixture is 45K. calculate the specific heat capacity of the liquid.

SOLUTION : H_1 = 60j/K, θ_1 = 20K, m=1kg, θ_2=90K, T = 45K, c_L = ?

Heat gained by liquid and calorimeter at 20K = heat lost by liquid at 90K

$H_1(T - \theta_1) + m_2c(T - \theta_2) = m_3c_L(\theta_3 - T)$

60(45 – 20) + 0.15c(45-20) = 1c(90-45)

1500+3.75c =45c, 1500=45c-3.75, c =36.4j/kgK

EXAMPLE 11 : how much heat must be added to 1kg of ice at 0°C to convert it to steam at 100 °C than it is required to raise the temperature of 1kg of water from 0 °C to

100 °C ? (Sp latent heat of ice = 3.4×10^5j/kg)

SOLUTION : m = 1kg, θ_1 = 0°C, c = 4200j/kg°C

The heat required to convert 1kg of ice at 0°C to steam at 100°C is: $Q = mL_f + mc(\theta_2 - \theta_1) + mL_V$

Q = 1 × 34000 + 1 × 4200(100-0) + 1×2200000

Q = 3.02×10^6j

Also, the heat required to convert 10kg of water at 0°C to 100°C is : $Q_1 = mc(\theta_2 - \theta_1)$

$Q_1 = 1 \times 4200(100 - 0) = 4.2 \times 10^5$j

Change in heat= $Q - Q_1 = (3.02\times10^6) - (4.2\times10^5)$

= **2.6** × 10^6j

EXAMPLE 12 : how much heat is needed to change 10kg of ice at -20°C to steam at 120°C. take c_{ice} = 2100j/kg°C, c_w = 4186j/kg°C,

C_S =2010j/kg°C, $L_f = 3.33 \times 10^5$j/kg

$L_V = 22.26 \times 10^5$j/kg.

Answer : Q_{total} = 3.1×10^7j

EXAMPLE 13 : a 0.25kg cup at 20°C is filled with 0.25kg of **boiling coffee** . the cup and the coffee came to thermal equilibrium at 80°C. if no heat is lost, what is the specific heat capacity of the cup material? (Hint : consider the coffee to be essentially **boiling water**)

SOLUTION : m_1 = 0.25kg, θ_1 = 20°C, m_2 0.25kg θ_2 = 100°C(temperature of **boiling water**), T=80

$m_1c_1(T - \theta_1) = m_2c_2(\theta_2 - T)$

$0.25 \times c_1(80 - 20) = 0.25 \times 4200\,(100 - 80)$

$15c_1 = 21000$, $c_1 = 21000/15 = 1.4 \times 10^3$j/kg°C

EXAMPLE 14 : a heater supplies 240BTU of energy. What is this energy in joules?

SOLUTION : it means convert 240BTU to joules

1BTU = 252Cal

240 = x

X = 60480Cal, also

1Cal = 4.186j

60480 = x

X = 253169.28j, thus, 240BTU = 253169.28j

EXAMPLE 15 : a student eats a thanksgiving dinner that totaled 2800Kcal. He wants to use up that energy by lifting a 20Kg mass of 1m.

a. how many times must he lift the mass?

b. if he can lift the mass every 5sec, how long does this exercise take?(neglecting lowering)

SOLUTION : Q = 2800Kcal

1Kcal = 4186j

2800Cal = x

Q = x = 11720800j, m = 20kg, h = 1m

(a) energy = n(mgh)

11720800 = n (20 × 10 × 1)

n = $\frac{11720800}{200}$ =58604times, thus n ≅60,000times

(b) if $1_{(once)}$ = 5sec

Then, 60,000 = x

X = 300000sec, convert to hours by dividing by 3600, t = x = 83hr

CHAPTER 12

THERMAL PROPERTIES OF MATTER

EXPANSION : the addition of heat to any substance results to the expansion of solids, liquids and gases.

ADVANTAGES OF EXPANSION

Expansion effects is usefully applied in :

1. thermostat in order to maintain a steady temperature as in electric pressing iron, gas cooker and electric heating and cooling systems

2. riverting two metal plates

3. construction of automatic fire alarms.

4. the fitting of metal rim on metal wheels by first heating the rim and slipping it so that on cooling it contracts and fits firmly on the wheel

DISADVANTAGES OF EXPANSION

1. it deforms a bridge structure fixed at both ends when the weather is hot.

2. it can make thick glass tumblers break when hot liquids are poured into them.

3. it affects the oscillation of the pendulum clock and the balance wheel when there is a change in temperature.

TYPES OF EXPANSION

1. LINEAR EXPANSION : the **linear expansivity** $\boldsymbol{\alpha}$**,** of a substance is defined as the increase in length per unit length per degree rise in temperature.

$$\boldsymbol{\alpha = \frac{L_2 - L_1}{L_1(\theta_2 - \theta_1)}}$$

$\mathbf{L_2}$ **and** $\mathbf{L_1}$ are final and initial lengths

Thus, $\boldsymbol{L_2 - L_1 = \alpha L_1(\theta_2 - \theta_1)}$

WORK DONE BY LINEAR EXPANSION OF A SOLID

Strain = e/L_1, $L_2 - L_1 = \alpha L_1(\theta_2 - \theta_1)$

Substitute, thus: **strain =** $\boldsymbol{\alpha L_1(\theta_2 - \theta_1)}$

Young's modulus, E = $\frac{stress}{strain} = \frac{F/A}{e/L}$

Thus, F = $\boldsymbol{AE\alpha(\theta_2 - \theta_1)}$

Work, w = F × d

2. AREA OR SUPERFICIAL EXPANSION : the **area expansivity,** $\boldsymbol{\beta}$ of a solid is the increase in are per unit area per Kelvin increase in temperature.

$\boldsymbol{\beta} = \dfrac{\mathbf{A_2 - A_1}}{\mathbf{A_2(\theta_2 - \theta_1)}}$, $\boldsymbol{\beta = 2\alpha}$

Thus, $\mathbf{A_2 - A_1 = \beta A_1(\theta_2 - \theta_1)}$

Note : $\mathbf{A = \pi r^2}$ **and** $\mathbf{A = \pi d^2/4}$

3. VOLUME OR CUBIC EXPANSION : the **volume expansivity,** $\boldsymbol{\gamma}$ is the increase in volume of a substance per unit volume per Kelvin rise in temperature.

$\boldsymbol{\gamma} = \dfrac{\mathbf{v_2 - v_1}}{\mathbf{v_2(\theta_2 - \theta_1)}}$, $\boldsymbol{\gamma = 2\alpha}$

$\mathbf{v_2 - v_1 = \gamma v_1(\theta_2 - \theta_1)}$

NOTE : the relationship between $\boldsymbol{\gamma}$ ***and*** $\boldsymbol{\beta}$ *is* $\gamma = \frac{3\beta}{2}$

EXAMPLE 1 : (a) what is the increase in length of a steel girder that is 1500cm long at 5°C when its temperature rises to 25°C ? (b) how much force is associated with the expansion of the girder if its cross-sectional area is 3000cm^3? (young modulus for steel = 2 × 10^{7}N/cm^2, and the coefficient of linear expansion of steel is equal to 1.2 × 10^{-5}/°C)

SOLUTION : $L_2 - L_1 = ?$, $L_1 = 1500$cm, $\theta_1 = 5^oC$ $\theta_2 = 25^oC$, from

$\alpha = \dfrac{L_2 - L_1}{L_1(\theta_2 - \theta_1)}$ thus, $L_2 - L_1 = \alpha L_1(\theta_2 - \theta_1)$

$L_2 - L_1 = 1.2 \times 10^{-5} \times 1500(25 - 5) = 0.36m$

b. $F = AE\alpha(\theta_2 - \theta_1)$

$=3000\times2\times10^7\times1.2\times10^{-5}(25-5)=1.44\times10^7N$

EXAMPLE 2 : a steel rod of length 2000cm and uniform cross-section area 3×10^{3}cm^3 at 28°C is heated to 45°C. find the change in the length and the force due to expansion by the rod.

(young modulus for steel = 2 × 10^{7}N/cm^2, and the coefficient of linear expansion of steel is equal to 1.2 × 10^{-5}/°C)

ANSWERS : $L_2 - L_1 = 0.41cm$, $F = 1.22\times 10^7N$

EXAMPLE 3 : what is the increase in length of a steel bar that is 1000cm long at 10°C when its temperature rises to 60°C. ($\alpha = 1.2 \times 10^{-5}/^oC$)

ANSWER : 0.6cm

EXAMPLE 4 : referring to example 4 above, how much force is associated with the expansion of steel bar if its cross-sectional area is 100cm^2 and young modulus = 2 × 10^{7}N/cm^2

ANSWER : 1.2 × 10^{6}N

EXAMPLE 5 : a petrol station takes delivery of 10cm^3 of gasoline at a temperature of 0°C. if the delivery of the same mass of petroleum were made when the temperature was 30°C, determine the increase in volume of the liquid delivered.

(coefficient of volume expansion =9.6 × 10^{-4}/K)

SOLUTION : $v_1 = 10cm^3$, $v_2 - v_1 = ?$, from

$\gamma = \dfrac{v_2 - v_1}{v_1(\theta_2 - \theta_1)}$ thus, $v_2 - v_1 = \gamma v_1(\theta_2 - \theta_1)$

$v_2 - v_1 = 9.6 \times 10^{-4} \times 10 \times (30 - 0) = 0.29m^3$

EXAMPLE 6 : a square plate of side 15cm is made of a metal of linear expansivity 2× 10^{-5}/K if the thickness of the plate is 5mm and the plate is heated from 25°C to 80°C, what is the cubical increase?

SOLUTION : $\alpha = 1.2 \times 10^{-5}/^{o}C$, T = 5mm=0.005m

L =15cm=0.15m, for a square, area, A, $= L^2$

$A = 0.15^2 = 0.0225m^2$, the volume $V = A \times T$

$V_1 = 0.0225 \times 0.005 = 1.125 \times 10^{-4}m^3$

$\gamma = 3\alpha = 3 \times 1.2 \times 10^{-5} = 6 \times 10^{-5}/K$

$v_2 - v_1 = 6 \times 10^{-5} \times 1.125 \times 10^{-5}(80 - 25)$

$= 3.7125 \times 10^{-7}\ m^3$

EXAMPLE 7 : if the length of a cylindrical solid metal is Lcm at 30°C and the linear expansivity is α, then the ratio of the new volume to the initial volume at 70°C is ?

SOLUTION :

$$\frac{V_2}{V_1} = \frac{\cancel{V_1}\{1 + \gamma(\theta_2 - \theta_1)\}}{\cancel{V_1}} = 1 + 3\alpha(70-30) = 1 + 120\alpha$$

EXAMPLE 8 : a wire of diameter 0.617mm and length 0.984m is suspended vertically from a rigid support and subjected to a tensile load of 8kg from its free end. If the wire is stretched by 1.3mm, find the young modulus of the wire.

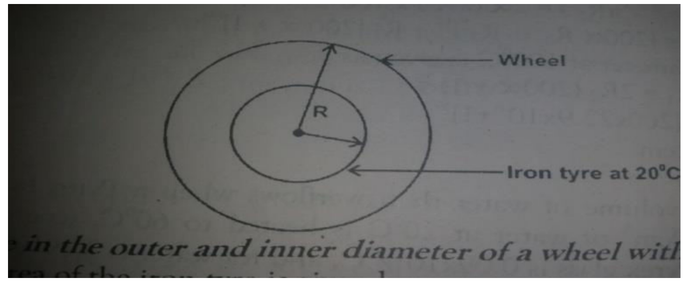
HINT: $g = 10m/s^2$, f =mg, $A = \pi d^2/4$, $E = \frac{F/A}{e/L}$

Answer : 2 $\times 10^{11}N/m^2$

EXAMPLE 9 : the outside diameter of a wheel is 1m. an iron tyre for this wheel has an inside diameter of 0.992m at 20°C. to what

Temperature must the tyre **be heated** in order to fit over the wheel? (coeficient of linear expansion of iron = $1.2 \times 10^{-5}/^{o}C$

SOLUTION : to fit over the wheel, the outside diameter becomes its $\mathbf{d_2}$. $\mathbf{d_2 = 0.992m,\ d_2 = 1m}$



$A_1 = \frac{\pi d_1^2}{4}$ and $A_1 = \frac{\pi d_1^2}{4}$

Then use : $\beta = \frac{A_2 - A_1}{A_1(\theta_2 - \theta_1)}$ **, ANS:** θ_2=694.75°C

EXAMPLE 10 : a lead rod is 100cm long. What must be the length of an iron rod if both must have equal expansion for all variations of temperature? (coefficient of linear expansion of lead is $27 \times 10^{-6}/^{o}C$, for iron is $12 \times 10^{-6}/^{o}C$)

SOLUTION : L_{1L} = 100cm, L_{1i} = ?

For lead: $L_{2L} - L_{1L} = \alpha_L L_{1L}(\theta_2 - \theta_1)$

For iron: $L_{2i} - L_{1i} = \alpha_i L_{1i}(\theta_2 - \theta_1)$, equate them

$\alpha_L L_{1L}\cancel{(\theta_2 - \theta_1)} = \alpha_i L_{1i}\cancel{(\theta_2 - \theta_1)}$

$27 \times 10^{-6} \times 100 = 12 \times 10^{-6} \times L_i$

L_i = 225cm

EXAMPLE 11 : a circular hole in an aluminum plate is 2.54cm in diameter at 0°C. what is the diameter when the temperature of the plate is increased to 100°C? (linear expansivity of aluminum is $2.29 \times 10^{-6}/^{o}C$)

Using : : $\beta = \frac{A_2 - A_1}{A_1(\theta_2 - \theta_1)}$ find A_2

Then using : $A_1 = \frac{\pi d_1^2}{4}$ find d_2, **ans : 2.552cm**

EXAMPLE 12 : calculate the volume of water that overflows when a pyrex beaker filled to the brim with $250cm^3$ of water at 20^oC is heated to 60^oC. (coefficient of volume expansion of pyrex glass is $0.09 \times 10^{-4}/^oC$, and for water is $2.1 \times 10^{-4}/^oC$)

SOLUTION : For the beaker :

$v_2 - v_1 = \gamma v_1(\theta_2 - \theta_1) = 0.09 \times 10^{-4} \times 250(60 - 20) = 0.09cm^3$. for water : $v_2 - v_1 = \gamma v_1(\theta_2 - \theta_1)$

$= 2.1 \times 10^{-4} \times 250(60 - 20) = 2.1cm^3$

The volume that overflows=2.1–0.09=$2.01cm^3$

EXAMPLE 13 : a wire of length 5m and uniform circular cross-sectional of radius 1.4mm was extended by 2mm by tension of 110N. calculate the average strain per unit volume.

average strain per unit volume $= \frac{1}{2}\left(\frac{F}{A} \times \frac{e}{L}\right)$

ANSWER : 3.57Kj

EXAMPLE 14 : an iron ball of diameter 15.23cm rest on a brass ring of internal diameter 15cm at a temperature of 20^oC. to what temperature must both be heated for the iron ball to pass through the ring ? ($\alpha_{iron} = 1.2 \times 10^{-5}/^oC$ and $\alpha_{brass} = 1.9 \times 10^{-5}/^oC$)

HINT : for the iron to pass through the ring, A_2 of brass must be equal to A_2 of iron. Just equate and solve. **Answer :** θ_2 = **2350.8°C**

EXAMPLE 15 : a brass rod is 1500cm long at 10^oC. to what temperature must the rod be heated to make it expand by 9mm?($\alpha_{brass} = 1.9 \times 10^{-5}/^oC$) **answer : 41.6°C.**

REAL AND APPARENT EXPANSION

Liquids have no definite shape of their own but simply conform to that of the containing vessel. On heating, the container and the liquid expand, thus the measured increase in

The volume of the liquid does not reflect the actual volume increase. In the expansion of a liquid, the containing vessel expands and makes the expansion of the liquid to appear less than it actually is. Thus we have two expansivities.

Apparent cubic expansivity (γ_a) of a liquid is the increase in volume per unit volume per degree rise in temperature when the liquid is heated in an expansible vessel.

Real or absolute cubic expansivity (γ_r) of a liquid is the increase in volume per unit volume per degree rise in temperature.

$$\gamma_a = \frac{\textbf{volume of liquid expelled}}{\textbf{Volume of liquid remaining} \times \textbf{temp. rise}}$$

$$\gamma_a = \frac{v_e}{v_r(\theta_2 - \theta_1)}$$ similarly

$$\gamma_a = \frac{m_e}{m_r(\theta_2 - \theta_1)}$$, **m = mass**

$$\gamma_r = \gamma_a + \gamma ,$$

γ **= cubic expansivity of the container**

EXAMPLE 16 : a density bottle weigh 16.5g when empty and 45.2g when filled with paraffin at 25^oC. when it had been heated to 80^oC and cooled again, it weighed 43.5g. calculate the coefficient of apparent and real expansion. (γ_{glass} = 0.000009/K)

SOLUTION : $m_b = 16.5$, $m_{b+p} = 45.2$,

M_{b+p} after heating = 43.5,

$M_e = 45.2 - 43.5 = 1.7g$

$M_r = 43.5 - 16.5 = 27g$

$$\gamma_a = \frac{m_e}{m_r(\theta_2 - \theta_1)} = \frac{1.7}{27\times(80-25)} = 0.0011/K$$

$\gamma = 3\alpha = 3 = 3 \times 0.000009 = 0.000027/K$

$\gamma_r = \gamma_a + \gamma = 0.0011 + 0.000027 = 0.001127/K$

EXAMPLE 17 : the mass of a gravity bottle and the liquid content inside is 65g at 30°C. when the bottle and its contents is heated to 100°C the mass of the bottle and its content become 58g. what is the real expansion of the liquid if the linear expansivity of the glass is 0.000008/K?

SOLUTION : $m_{b+L} = 65$, $m_b = 30$

M_{b+L} after heating = 58g

$M_e = 65 - 58 = 7g$, $m_r = 58 - 30 = 28g$

$$\gamma_a = \frac{m_e}{m_r(\theta_2 - \theta_1)} = \frac{7}{28\times(100-30)} = 3.57\times10^{-3}/K$$

$\gamma = 3\alpha = 3 = 3 \times 0.000008 = 0.000024/K$

$\gamma_r = \gamma_a + \gamma = 3.57\times10^{-3} + 0.000024 = 3.594\times10^{-3}/K$

VARIATION OF DENSITY (d) WITH TEMPERATURE

$$\gamma = \frac{d_1 - d_2}{d_2(\theta_2 - \theta_1)}$$

d_1 is density at lower temperature, and

d_2 is density at higher temperature

EXAMPLE 18 : what s the density of brass at 60°C if the density at 0 °C is 15.2g/cm³(linear expansivity of brass = 1.9 $\times10^{-5}$/K; cubical expansivity of brass = 5.7 $\times10^{-5}$/K)

SOLUTION : make d_2 subject of formula,

$$d_2 = \frac{d_1}{1 + \gamma(\theta_2 - \theta_1)} = \frac{15.2}{1 + 5.7\times10^{-5}(60-0)}$$

$= 15.1g/cm^3$

EXAMPLE 19 : the density of iron at 30°C is **4.**8g/cm³. What is the density at 80°C if the linear expansivity of iron is 1.2 $\times10^{-5}$/K?

Answer : **4.79g/cm³**

CHAPTER 15

KINETIC THEORY AND THERMODYNAMICS

There are basically types of gas laws :

1. Charles law: it states that the volume of a given mass of gas at constant pressure increases by $\frac{1}{273}$ of its volume at 0°C for every degree centigrade rise in temperature.

$V \propto T$, $\frac{v_1}{T_1} = \frac{v_2}{T_2}$

2. boyle's law : it states that the volume of a given mass of gas at constant temperature is inversely proportional to the pressure.

P $\propto \frac{1}{v}$, $p_1v_1 = p_2v_2$

3. pressure law : the pressure of a given mass of gas at constant volume increases by $\frac{1}{273}$ of its pressure at 0°C for every degree rise in temperature.

$P \propto T$, $\frac{p_1}{T_1} = \frac{p_2}{T_2}$

The ideal gas equation is given by : PV = nRT

$n = n_p/N_A$, n_p = number of particle and N_A is avogado's number = 6.02×10^{23} molecules.

EXAMPLE 1 : a fixed mass of gas occupying $6\times10^{-3}m^3$ and 27^oC is compressed at constant temperature until the pressure is doubled. What is the final volume?

SOLUTION : let $p_1 = p$, $p_2 = 2p$ (doubled)

$p_1v_1 = p_2v_2$, $\cancel{p} \times 6 \times 10^{-3} = 2\cancel{p} \times v_2$

$v_2 = 3 \times 10^{-3}m^3$

EXAMPLE 2 : a tank of volume $0.5cm^3$ contains oxygen at an absolute pressure $1.5 \times 10^6N/m^2$ and a temperature of 20^oC. assume that oxygen behaves like an ideal gas, how many moles of oxygen are in the tank? (molecular mass of oxygen = 32g, R = 8.31j/mole)

HINT : PV = nRT, **ANSWER : 308moles**

EXAMPLE 3 : an ideal gas in a container of volume $1000cm^3$ at 20^oC has a pressure of 1×10^4 N/m^2 . determine the number of gas molecules and the number of moles of gas in the container.

SOLUTION : $v = 1000cm^3 = 10^{-3}m^3$, n_p =?, n =?

$T = 20+273 = 293K$, $p = 1\times10^4 N/m^2$

$PV = nRT$, $1\times10^4 \times10^{-3} = n\times 8.31 \times 293$

$n = 4.1 \times 10^{-3}mol$,

$\mathbf{n = n_p/N_A}$, $4.1 \times 10^{-3} = n_p/6.02 \times10^{23}$

$\mathbf{n_p} = 2.4 \times10^{21}$molecules

the relationship between root mean square(r.m.s) speed and temperature is :

$$\frac{v_2}{v_1} = \frac{\sqrt{T_2}}{\sqrt{T_1}}$$

EXAMPLE 4 : a molecule of gas has r.m.s speed of 500m/s at 20^oC. what is the rms speed at 80^oC?

SOLUTION : $v_1 = 500m/s$, $T_1 = 20 + 273 = 293K$

$T_2 = 80 + 273 = 353K$,

$$\frac{v_2}{v_1} = \frac{\sqrt{T_2}}{\sqrt{T_1}}, \quad \frac{v_2}{500} = \frac{\sqrt{353}}{\sqrt{293}} \quad \text{cross multiply}$$

$v_2 = 548.8m/s \cong 550m/s$

EXAMPLE 5 : if the temperature of a gas increases from 20^oC to 40^oC, by what factor does the r.m.s speed increase ?

SOLUTION : convert temperature to kelvin

$$\frac{v_2}{v_1} = \frac{\sqrt{T_2}}{\sqrt{T_1}}, \quad \frac{v_2}{v_1} = \frac{\sqrt{313}}{\sqrt{293}}, = 1.03 = \frac{103}{100}$$

thus, 3% increase

THERMODYNAMICS

It deals with the transfer or action (dynamics) of heat.

LAWS OF THERMODYNAMICS

1. Zeroth law : it states that if bodies A and B are in thermal equilibrium with a third body C (the thermometer) , then A and B are in thermal equilibrium with each other. **The essence of zeroth law is : *there exist a useful quantity called temperature.***

2. the first law : it states that the amount of heat supplied to a system is equal to the algebraic sum of the change in thermal energy of the system and the amount of external work done by the system. Thus **dQ = du + dw**

dQ = amount of heat supplied by the system

du = increase in internal energy of the system

dw = external work done by the system

this law establishes the relation between heat and work.

Also, **$R = c_p - c_v$ (mayer's formula)**

C_p = specific heat capacity at constant pressure

C_v = specific heat capacity at constant volume

R = *molar das constant*

EXAMPLE 6 : a system consists of 3kg of water. 25j of work is done on the system by stirring with a wheel, while 63j of heat is removed. What is the change in internal energy of the system.

SOLUTION : dw = -25j (done on the system)

dQ = -63j (heat removed) from dQ = du + dw

du = dQ – dw = -63 + 25 = -38j

since du < 0 then the internal energy of the system decreases.

EXAMPLE 7 : a refrigerator takes heat from its cold interior at a rate of 7.5KWnwhen the work required is done at a rate of 2.5KW. at what rate is heat exhausted to the kitchen.

SOLUTION : $dQ_p = du_p + dw_p = 7.5 + 2.5 = 10KW$

3. the second law : there are two conventional statements of this law : Clausius statements and Kelvin-plank statement. But at this level we will consider **Clausius statements** : *it says it is impossible for a self-acting machine, unaided by any external work agency, to transfer heat from a body at a lower temperature to a body at a higher temperature or heat cannot by itself pass from a cold to a hot body.*

Application of second law

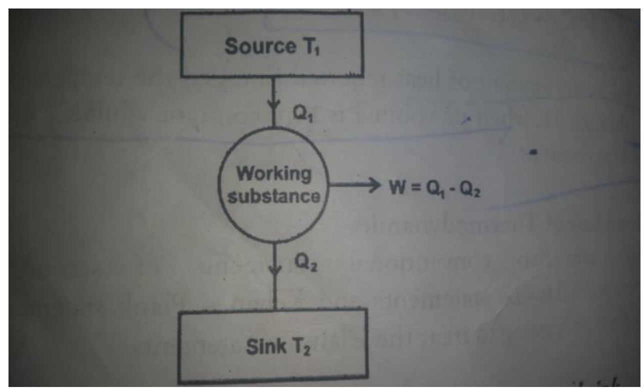
1. heat engines : it is a device which converts heat into work. It consists of three parts :

i. a source or high temperature reservoir at temperature T_1

ii. a sink or low temperature reservoir at temperature T_2

iii. a working substance

the working substance extracts heat Q_1 from source, does some work W and ejects remaining heat Q_2 to sink as shown below :



The efficiency (n) of heat engine is :

$$n = \frac{\text{work done}}{\text{heat taken from source}},$$

$$n = \frac{Q_1 - Q_2}{Q_1} = \frac{T_1 - T_2}{T_1}$$

Note : in calculations, always multiply the formulae by 100.

2. carnot's circle as refrigerator : when the Carnot's engine works a s a refrigerator, it absorbs heat Q_2 from the sink. An amount of work W is done on it by some external means and rejects heat Q_1 to the source.

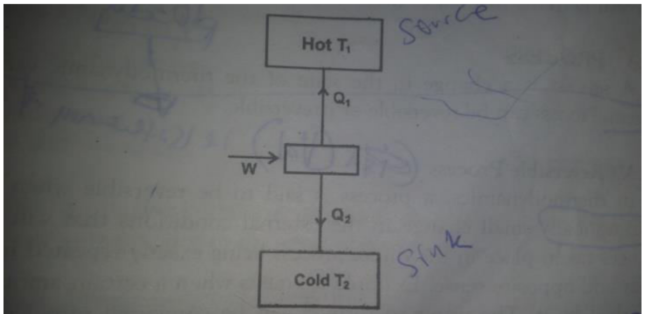


Fig. 13.2 A Carnot cycle working as refrigerator

The **coefficient of performance , k ,** is the ratio of the heat taken in from the cold body to the work needed to run the refrigerator.

$$\mathbf{K = \frac{Q_2}{W} = \frac{Q_2}{Q_1 - Q_2} = \frac{T_2}{T_1 - T_2}}$$

Also, in calculations multiply by 100

The relative efficiency is the ratio of the

Thermal efficiency to the carnot efficiency.

$\mathbf{n_{rel} = n_{th}/n_{carnot}}$ **,** also multiply by 100

3. thermal pump : it is a device that transfers energy from a low temperature reservoir to a high temperature one. To do this work must be done(according to second law) it will not happen on its own.

EXAMPLE 8 : a **carnot engine** is operated between two reservoir at temperature of 450K and 350K. if the engine receives 4200j of heat from the source in each cycle, calculate the amount of heat rejected to the sink in each cycle. Calculate the efficiency of the engine and the work done by the cycle in each cycle.

SOLUTUON : $T_2 = 350K$, $T_1 = 450K$, $Q_1 = 4200j$

$$\frac{Q_1 - Q_2}{Q_1} = \frac{T_1 - T_2}{T_1} \quad , \quad \frac{450 - 350}{450} = \frac{4200 - Q_2}{4200}$$

$$\frac{100}{450} = \frac{4200 - Q_2}{4200} \ , \ 420000 = 1890000 - 450Q_2$$

$Q_2 = 3267j$

$$n = \frac{T_1 - T_2}{T_1} \times 100 \ , \ \frac{450 - 350}{450} \times 100 = 22.22\%$$

Work $= Q_1 - Q_2 = 4200 - 3266 = 933j$

EXAMPLE 9 : a carnot engine whose low temperature reservoir is 7°C has an efficiency of 50%. It is designed to increase the efficiency to 70%. By how many degrees should the temperature of the high temperature reservoir be increased?

SOLUTION: convert temperatures to Kelvin

$$n = \frac{T_1 - T_2}{T_1} \times 100, \ 50 = \frac{T_1 - 280}{T_1} \times 100$$

$50T_1 = 100T_1 - 28000$, $T_1 = 560K$

$$n = \frac{T_1 - T_2}{T_1} \times 100, \ 70 = \frac{T_1 - 280}{T_1} \times 100$$

$70T_1 = 100T_1 - 28000$, $T_1 = 933.33K$

Thus, $933.33 - 560 = 373.3K = 100.3^oC$

EXAMPLE 10 : find the efficiency of the carnot's engine working between the steam point and the ice point.

SOLUTION : $T_1 = 100^oC = 373K$(i.e steam point)

$T_2 = 0^oC = 273K$ (i.e ice point) now proceed......

$$n = \frac{T_1 - T_2}{T_1} \times 100$$

answer : 26.81%

EXAMPLE 11 : a heat engine operates at a relative efficiency of 4%. If the temperature of the high-temperature and low-temperature reservoir are 400 and 100°C respectively, what are the carnot efficiency and the thermal efficiency.

SOLUTION : n_{rel} = 45%, T_1 = 400°C = 673K

T_2 = 100°C = 373K

$$n_{carnot} = \frac{T_1 - T_2}{T_1} \times 100 = \frac{673 - 373}{673} \times 100 = 44.6\%$$

$$n_{rel} = \frac{n_{th}}{n_{carnot}} \times 100, \quad 45 = \frac{n_{th}}{44.6} \times 100$$

cross multiply , n_{th} = 20.1%

PROCESSES

A process is a change in state of the thermodynamic variables of a system. Process can be reversible or irreversible.

1. REVERSIBLE PROCESS : in thermodynamics, a process is said to be reversible when there is an infinitesimally small change in the external

Conditions that will result in all changes taking place in the direct process being exactly repeated in the reversed order and opposite sense. E.G conversion of ice to water

2. IRREVERSIBLE PROCESS : it is a process which cannot be retracted in the opposite order by reversing the controlling factor. E.g all natural processes such as conduction, radiation, radioactive decay e.t.c

3. ISOTHERMAL PROCESS (du = 0) : *iso* processes are one in which one of the thermodynamic variables is held constant. Isothermal process involves the change in pressure and volume of a gas occurring at constant temperature or constant internal energy. **The work done in isothermal process is given as : w = RT $\log_e(v_2/v_1)$** Also, from first law, du = dQ – dw, when du=0, **dQ= dw**

Thus, the work done by an ideal gas is equal to the heat energy added to the gas.

EXAMPLE 12 : an ideal gas undergoes an isothermal process in doing 25j of work. What is the change in internal energy?

SOLUTION : no need to solve, for isothermal process du = 0

EXAMPLE 13 : A gas is compressed isothermally at 300K and 1 atm pressure from an initial volume of 0.5litres to final volume of 0.25litres in a tyre. Assuming the exit of the tyre is blocked, find the work done.(gas constant=8.31j/molK, 1atm =1.013× 10^5N/m).

SOLUTION : T = 300K, v_1 = 0.5L, v_2 = 0.25L

w = RT $\log_e(v_2/v_1)$ = 8.31× 300$\log_e(\frac{0.25}{0.5})$ =-1788j

divide by 1000, we have w = -1.728Kj

4. ADIABATIC PROCESS (dQ = 0) : it occurs when there is no heat change, i.e du = 0, between the gas and the surrounding. From

First law, dQ = du + dw, dQ = 0, **du = -dw**

Thermodynamic relations in adiabatic processes are given as :

$$\mathbf{P_1 v_1^{y} = p_2 v_2^{y}, \quad T_1 v_1^{y-1} = T_2 v_1^{y-1}}$$

$$\mathbf{\frac{P_1^{(1-\frac{1}{y})}}{T_1} = \frac{P_2^{(1-\frac{1}{y})}}{T_2}, \quad \text{where } y = \frac{c_p}{c_v}}$$

The work done is given by **dw = $nc_v(T_1 - T_2)$**

EXAMPLE 14 : Ten litres of nitrogen at 1 atm and 25°C is allowed to expand reversibly and adiabatically to 20 litres. What are the final pressure and temperature, given the ratio of the molar specific heat capacities is 1.4.

SOLUTION : v_1=10L, v_2=20L,

T_1 = 25+273=298K

P_1 = 1 atm, y = 1.4

$T_1 v_1^{y-1} = T_2 v_1^{y-1}$, $298\times 10^{1.4-1} = T_2 \times 20^{1.4-1}$

748.542 = 3.3142T_2 , T_2 = 225.8K also,

$P_1 v_1^{y} = p_2 v_2^{y}$, $1\times 10^{1.4} = p_2 \times 20^{1.4}$, P_2=0.379atm

5. ISOBARIC PROCESS (dw = Pdv) : it is a process takes place at constant pressure. The work done here is **w =P($v_2 - v_1$)**

6. ISOCHORIC PROCESS (dv = 0) : it is a process in which the volume remains constant. It is also called **isovolumetric or isometric process.** From first law, dQ = du + dw, dv = 0

dQ = du , *thus the increase in internal energy is equal to the heat supplied to the system*

EXAMPLE 15 : in an isometric process, the internal energy of the system decreases by 50j

a. what is the work done?

b. what is the heat exchange?

SOLUTION : dw = Pdv, dv = 0, thus w = 0

b. dQ = du + dw = -50 + 0 = -50j

thus, 50j of heat is removed from the system

7. ISOLATED PROCESS : a process is said to be isolated when there is no external work and into which there is no flow of heat. This implies that w = Q = 0. Thus, the first law reduces to **du = 0**. Therefore, the internal energy of an isolated system is **constant** .

THE KINETIC THEORY OF GASES

It attempts to explain the macroscopic properties **(p, v , T, n)** of a gas in terms of microscopic properties.

1. the temperature is a measure of the average kinetic energy of the molecules, i.e

$\frac{1}{2}\mathbf{Mv^2_{rms}}$ **,** $= \frac{3}{2}\mathbf{K_BT}$, m = mass of the molecule

K_B is Boltzmann constant = R/N_A=1.38×10^{-23}j

$V_{rms} = \sqrt{(3K_BT/M)} = \sqrt{(3RT/M)} = \sqrt{(3P/d)}$

d = density.

2. the total internal energy of an ideal monoatomic gas is given by :

K.E = $U_{monoatomic} = \frac{3}{2}nRT = \frac{3}{2}N_AK_BT$

the above is for translational motion.

K.E = $U_{diatomic} = \frac{5}{2}nRT = \frac{5}{2}N_AK_BT$

The above is for vibrational motion

K.E = $U_{diatomic} = NK_BT = nRT$ (rotational motion)

Where 3/2, 5/2……. Are degrees of freedom

EXAMPLE 16 : if one mole of a monoatomic gas has a total internal energy of 3.7 × 10^3j, what is the total internal energy of one mole of diatomic gas at the same temperature ?

SOLUTION : $U_{monoatomic} = \frac{3}{2}nRT = 3.7\times 10^3$

$nRT = \frac{3.7\times 10^3 \times 2}{3} = 2466.67$

$U_{diatomic} = \frac{5}{2}nRT = \frac{5}{2}\times 2466.67 = 6.2\times 10^3$j

CHAPTER 14

HEAT TRANSFER

There are three processes by which hear is being transferred between two regions of different temperatures :

1.CONDUCTION : this process of heat transfer which needs a material medium, but the heat energy is transferred not by actual movement of the materials but simply by the interaction of materials with each other and exchanging energy in the process.

$$H = \frac{dQ}{dt} = \frac{KA(T_2 - T_1)}{L}, \quad H = \text{heat current}$$

$\frac{(T_2 - T_1)}{L}$ is temperature gradient

K is thermal conductivity, it is a constant – depending on the material. Its unit is

$Js^{-1}m^{-1o}C^{-1}$ **or** $Wm^{-1o}C^{-1}$

EXAMPLE 1 : one end of a 30cm long aluminium rod is exposed to a temperature of 500°C. while the other end is maintained at 20°C. the rod has a diameter 2.5cm. if heat is conducted through the rod at a rate 142Kcal/hr. calculate the thermal conductivity of aluminium.

SOLUTION :

$T_2 = 500^oC$, $T_2 = 20^oC$,

L =30cm=0.3m, H = 142Kcal/hr = 164.88j/s

d = 2.5cm = 0.025m.

$$A = \frac{\pi d^2}{4} = \frac{\pi \times 0.025^2}{4} = 4.91 \times 10^{-4} m$$

$$= \frac{KA(T_2 - T_1)}{L}, \quad 164.9 = K \times \frac{4.91 \times 10^{-4}(500-20)}{0.3}$$

$49.47 = 0.23568K$, $K = 209.9Wm^{-1o}C^{-1}$

EXAMPLE 2 : energy released by radioactivity within the earth is conducted outward as heat through oceans. Assume the average temperature gradient within the solid earth beneath the ocean to be 0.07°C/m and the average thermal conductivity to be 0.84j/ms°C and determine the rate of heat transfer per square meter.

SOLUTION :

$$\frac{(T_2 - T_1)}{L} = 0.07^oC/m, \quad \frac{dH}{dA} = ?, \quad K = 0.84 j/ms^oC$$

$$\frac{dH}{dA} = \frac{K(T_2 - T_1)}{L} = 0.84 \times 0.07 = 5.88 \times 10^{-2} j/m^2s$$

EXAMPLE 3 : one end of a 50cm rod is exposed to a temperature of 600°C while the other end is maintained at 40°C. the rod has a diameter of 5cm. if heat is conducted through the rod at a rate of 150Kcal/hr. calculate the thermal conductivity of aluminium.

SOLUTION : $T_2 = 600$, $T_1 = 40$, L = 50cm = 0.5m

d = 5cm= 0.05m, H = 150Kcal/hr = 174.4j/s

$$A = \frac{\pi d^2}{4} = \frac{\pi \times 0.05^2}{4} = 1.96 \times 10^{-3} m^2$$

$$= \frac{KA(T_2 - T_1)}{L}, \quad 174.4 = K \times \frac{1.96 \times 10^{-3}(600-40)}{0.3}$$

$87.5 = 1.0976K$, $K = 79.45Wm^{2o}C^{-1}$

2. CONDUCTION : it is a transfer of heat energy that involves the actual movement of the heated medium. It is applicable only to fluid.

Convention is said to be **natural or free** convention when it is due to **density differences** caused by thermal expansion and **forced convention** when artificial means is responsible for the circulation. If we consider a solid at temperature T_s with surface area A_s in contact with a fluid whose main body temperature is T_f , it was discovered that the rate of heat flow, H, by convention from the solid surface to the fluid flowing over it (or vice visa) is given as : $\mathbf{H = hA_s(T_s - T_f)}$. *where h is convention coefficient , its unit is $j/sm^2\ {}^oC$ and depends on :*

1. nature of the surface (i.e flat, curved, horizontal of vertical)

2. nature of the fluid (liquid or gas)

3. fluid properties (density, viscosity, S.H.C and thermal conductivity) (4) fluid velocity

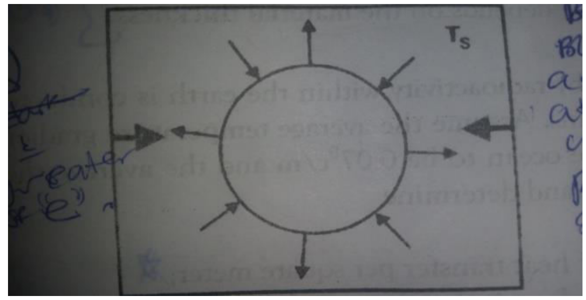
3. RADIATION : this mode of heat transfer requires no material medium, the energy simply moves through a vacuum in the form of electromagnetic waves. E.g heat flow from sun to the earth. *The intensity of radiant heat radiated by a surface depends on the **nature** as well as **the temperature of the surface.*** For a body of surface area A, and absolute temperature T, the rate at which radiant heat is emitted by the body is given as : $\mathbf{H = \sigma AeT^4}$

The formula above is **Stefan–Boltzmann's Law**

e is emissivity. Its value is between 0 and 1. **It depends on the nature of the surface.** The value of e is large for dark surfaces than for light ones. *For a dull black surface, e is close to 1.* For smooth copper surface e is about 0.3. the emissivity of human skin is about 0.70,

σ is Stefan-Boltzmann's constant = 5.67×10^{-8} w/m^2K^4.since all bodies absorb a different degree of thermal radiation incident on them, then the rate at which a body will absorb radiant energy when completely surrounded by an enclosure whose surface is maintained at absolute Kelvin temperature T_s is given as :

$\mathbf{H = \sigma AeT_s^4}$



the net rate of radiation from a body at temperature T with surroundings at temperature T_s is given as :

$\mathbf{H_{net} = Ae\sigma(T^4 - T_s^4)}$ **,** if T^4 is less than T_s^4, then H_{net} will be negative, indicating a net heat loss.

EXAMPLE 4 : a radiator has an emissivity of 0.70 and its exposed area is $1.5m^2$. the temperature of the radiator is 100^oC and the surrounding temperature is 20^oC. what is the net heat flow rate from the body?

SOLUTION : $H_{net} = Ae\sigma(T^4 - T_s^4)$

$= 1.5\times0.7\times5.67\times10^{-8}(373^4-293^4)=7.13\times10^2W$

EXAMPLE 5 : the operating temperature of a tungsten filament in an incandescent lamp is 2460K. and its emissivity is 0.35. find the surface area of the filament of a 100W lamp.

SOLUTION : $H = \sigma AeT^4$,

$100 = 5.67 \times 10^{-8} \times A \times 0.35 \times 2460^4$,

$100 = 726760.86A$, $A = 1.37 \times 10^{-4}m^2$

EXAMPLE 6 : (a) a sphere of radius 2cm with a black surface is cooled and then suspended in a large evacuated enclosure, the black walls of which are maintained at 27^oC, if the rate of change of thermal energy of the sphere is 1.849W when its temperature is -83^oC. calculate the value of Stefan's constant (b) if each square centimeter of the sun's surface radiates energy at the rate of $6.3 \times 10^3 W/cm^2$. Calculate the temperature of the sun's surface.

Assuming stefan's law applies to the radiation.

SOLUTION : e = 1(black surface), r=2cm=0.02m

$A = 4\pi r^2 = 4\pi(0.02)^2 = 16\pi \times 10^{-4} m^2$

$T = 27^oC = 300K$, $T_s = -83^oC = 190K$,

$H_{net} = Ae\sigma(T^4 - T_s^{\ 4})$

$1.848 = 16\pi \times 10^{-4} \times 1 \times \sigma\ (300^4 - 190^4)$,

$\sigma = 5.4 \times 10^{-8} W/m^2K^4$

(b) $\frac{H}{A} = 6.3 \times 10^3 W/cm^2 = 6.3 \times 10^7 W/m^2$

$\frac{H}{A} = \sigma e T_s^{\ 4}$, $6.3 \times 10^7 = 1 \times 5.4 \times 10^{-8} \times T^4$

$T^4 = 1.166\times10^{15}$, $T = \sqrt[4]{(1.166 \times 10^{15})} = 5844.3K$

EXAMPLE 7 : suppose that your skin has an emissivity of 0.7 and that its exposed area is $0.27m^2$. how much net energy will be radiated per second from this area if the air temperature is 20^oC ? assume your skin temperature to be the same as normal body temperature, 37^oC.

Answer : H_{net} = -20W

CHAPTER 15

PHYSICAL STATE OF MATTER

Elasticity and Hook's law : if a body is deformed to its original size and shape when the external deforming force is removed, then the body is said to be elastic. The maximum deformation that an elastic body can undergo without a permanent change in its shape is called **the elastic limit.**

Hook's law states that the force applied to an elastic solid object is directly proportional to the extension, provided the elastic limit is not exceeded.

Thus F = ke

K depends on :

1. the size and shape of the body

2. the material of which the body is made

3. the temperature and pressure to which the body is subjected while the measurements are carried on.

4. in some cases, the direction in which the body is distended.

EXAMPLE 1 : a spring stretches by 7.5mm when a 50N weight is attached to it . (a) find the spring constant (b) if the 50N weight is removed and a 125N weight is attached in its place, find the stretched of the spring.

SOLUTION : e = 7.5mm = 0.0075m, F = 50N

a. F = ke, $50 = k \times 0.0075$, $k = 6.67 \times 10^3 N/m$

b. F = 125N, e = ? , F = ke , $125 = 6.67 \times 10^3 \times e$

$e = 1.87 \times 10^{-2} m$

YOUNG'S MODULUS (E)

Hook's law can be restated as follows : **the stress is proportional to the strain as long as the elastic limit has not been exceeded.**

The proportionality constant is called the Young's elastic modulus of elasticity and depends on the material being deformed and the nature of the deformation. **The S.I unit if E is N/m^2**

$E = \frac{stress}{strain} = \frac{F/A}{e\backslash L}$, note: e = ΔL

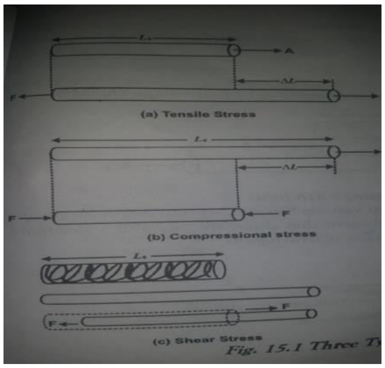


Fig. 15.1 Three T

NOTE : a tensile stress or tension tends to increase the length of an object; a compressional stress tends to shorten the length. A shear stress is produced when the force is applied tangentially to a surface area.

It an elastic object is subjected to various stresses, we can graph stress as a function of strain as show below

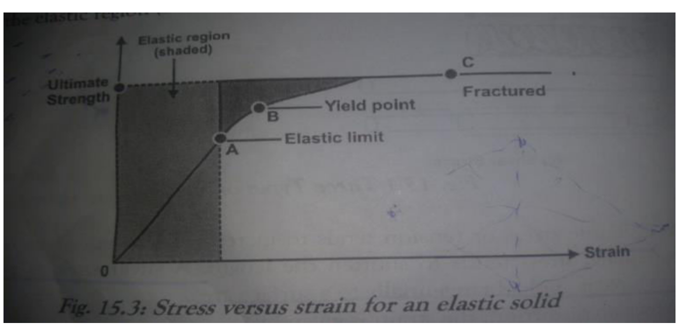


Fig. 15.3: Stress versus strain for an elastic solid

in the elastic region, the graph is a straight line and obeys Hook's law. The maximum stress that can be applied to the object without causing its permanent deformity is called **the elastic limit(it is labeled as A in the diagram).**

If the stress is increased beyond the elastic limit, the strain increases more rapidly than the stress(REGION **AB).** After the stress is removed the body does not regain its original shape and size, but shows a residual deformation. Thus, the region of elastic deformation is followed by the region of irreversible deformation, which is known as **plastic deformation.** In the portions of the plastic region where the curve slopes towards the horizontal axis, the object continues to enlongate, although the applied stress decreases. This behavior is known as **plastic flow.** At some point, the object breaks. Just before it breaks, the curve peaks, which gives the maximum stress that can be applied to the object without breaking it. This stress is called the **ultimate strength of the object.**

SHEAR MODULUS (G)

It is sometimes referred to as **modulus of rigidity.** A deformation in which the shape of an object but not its volume is changed.

$G = \frac{F/A}{\emptyset}$, F is applied shear force, A is surface area, Ø is shear angle. **The unit of G is N/m^2**

BULK MODULUS (B)

When force act uniformly over the entire surface of a body, the volume of the object change but its shape remains the same. We will only consider the forces which act perpendicular to the surface since they are the only forces which contribute to the volume changes. *Forces parallel to the surface only contribute to **shear stress.*** The **elastic modulus is called the bulk modulus.**

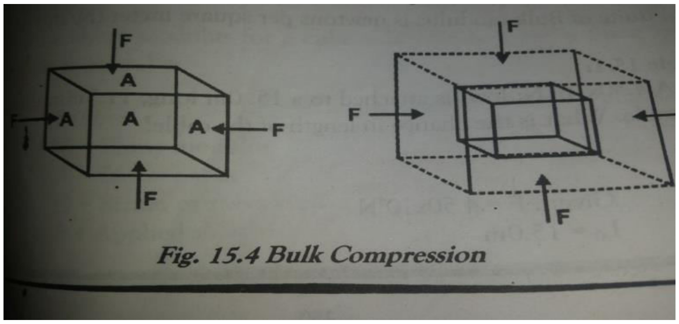


Fig. 15.4 Bulk Compression

B = 1/K, k is compressibility

EXAMPLE 2 : A 4.5×10^4N load is attached to a 15m long, 11.7mm diameter steel cable. What is the change in length of the cable.

HINT : $E = 20\times10^{10}N/m^2$(for steel)

$d=11.7mm=1.17\times10^{-2}m$, $A = \pi d^2/4 = \pi\times(1.17\times10^{-2})^2/4$

$=1.07\times10^{-4}m^2$,**use this :** $E = \frac{F/A}{e\backslash L}$ **, answer =** 3.14×10^{-2}m

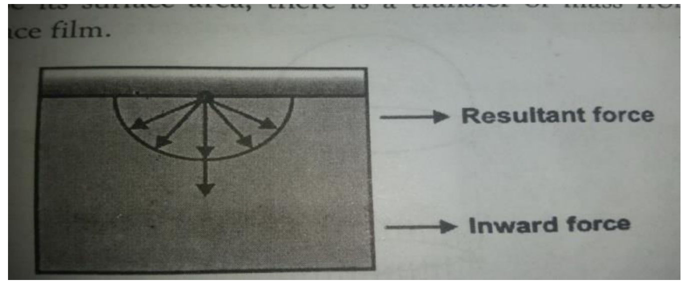
EXAMPLE 3 : a steel wire 2m in length and 2mm in diameter supports a 10kg mass. (a) what is the stress in the wire?

HINT : F = mg, stress = F/A, answer : $3.18\times10^7N/m^2$

SURFACE TENSION

It is the force acting along the surface of a liquid, causing the liquid surface to behave like a stretched elastic skin.

The particles in a thin layer near the surface of a liquid are subjected to the force acting from the other molecules of the liquid. **The resultant forces is directed inward normally to the surface.**



In the past questions below we will not write the options. We will only solve and write the answers

MOST DIFFICULT RECENT PAST QUESTIONS

NOTE : we have solved a lot of past questions as examples in this material.

1. what will the velocity of a stone 10m above the ground, if it is projected vertically upward from the top of a roof 35m with a velocity 10m/s.

SOLUTION : h_2= 10m, h_1 = 35m, $\theta = 90^o$

$v^2=(u\sin\theta)^2 - 2g(h_2 - h_1) = (10\sin90)^2 - 2\times10(10 - 35)$

$v = \sqrt{600} = 24.49$m/s

2. when a stone and a tennis ball of the same mass are thrown at a boy with the same velocity, he would prefer the tennis ball because the tennis ball will spend :

a. lesser time and lesser force when in contact with the boy (b) lesser time greater force when in contact with the boy (c) more time and greater force when in contact with the boy (d)more time and lesser force when in contact with the boy. **Answer is D**

3. find the resistance of a car of mass 521kg moving at 10m/s comes to rest in a distance of 350m.

SOLUTION : v = 0, u = 10m/s, s = 350m

$V^2 = u^2 - 2as$, $0^2 = 10^2 - 2\times350\times a$, a = 1/7m

F = ma = 521× 1/7 = 74.4N

4. what amount of work is done by a man who carries a load of 10kg on his head through a square distance of sides 1m, if he moves through ABCDA. **Answer is zero because work done in carrying a load around a closed loop or square is ZERO** regardless of the parameter given,

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