Fluid Mechanics and Acoustics

Fluid Mechanics and Acoustics

ISBN 978-81-946968-5-8

Website: www.skyfox.co

Email:skyfox@skyfox.org.in

sky fox

Fluid Mechanics and Acoustics

Dr. R. Ravibaskar
Dr. A. Ajay Praveenkumar
Sahaya Rose Causana

Fluid Mechanics and Acoustics

AUTHOR INFORMATION:

Dr. R. Ravibaskar., M.Sc., M.Phil., Ph.D.,
Associate Professor
Department of Physics
DMI – St. Eugene University
P.O.Box: 330081, Chibombo
Zambia.

Dr. A. Ajay Praveen Kumar., M.Sc., B.Ed., M.Phil., Ph.D.,
Senior Lecturer
Department of Physics
DMI – St. Eugene University
P.O.Box: 330081, Chibombo
Zambia.

Mrs. Sahaya Rose Causana., M.Sc., M.Ed.,
Lecturer
Department of Physics
DMI – St. Eugene University
P.O.Box: 330081, Chibombo
Zambia.

First Electronic Edition : **July 2020**
Cover Art and Design : **Authors**

ISBN : **978-81-946968-5-8**
DOI : **https://doi.org/10.22573/spg.020.BK/S/002**

Publisher Contact & Support

Skyfox Publishing Group
#987, Medical College Road
Thanjavur-613004
Tamil Nadu, India.
Phone: +918300123232
Email: skyfoxpublishing@gmail.com / skyfox@skyfox.org.in
Website: www.skyfox.co

Headquarters & Marketing Office

Skyfox Publishing Group
333 Cedar Street, PO Box 208002,
New Haven, United States.
CT 06520-8002.
Tel: 203.737.5603 / Fax: 203.785.7446
Email: skyfoxpublishing@gmail.com / skyfox@skyfox.org.in
Website: www.skyfox.co

From the desk of
Dr. T. X. A. ANANTH, BBA, MSW, MBA, MPhil, PhD,
President – University Council

Dear Learner,

Welcome to DMI – St. Eugene University!

I am sure you are expert in using the PC Tablets distributed by us. Now your world is open to Internet and using the tablet for your educational learning purposes. The very same book you are holding in your hand now is available in your V-Campus portal. All the teaching and learning materials are available in your portal.

As our Chancellor, Rev.Fr. Dr. J. E. Arulraj , mentioned, it is not just the success for DMI-St. Eugene University alone, it is success for the technology, it is success for the great nation of Zambia and it is success for the continent of Africa.

You can feel the improvement in the quality of the learning materials in the printed format. Improvement is done in quality of the content and the printing. Use it extensively and preserve it for your future references. This will help you to understand the subjects in a better way. The theories of the subjects have been explained thoroughly and the problems have been identified at learners' level. This book is made up of five units and every unit is mapped to the syllabus and discussed in detail.

I am happy at the efforts taken by the University in publishing this book not only in printed format, but also in PDF format in the Internet.

With warm regards

Dr. T. X. A. ANANTH
President – University Council

Chapter I Elasticity:

Three types of elastic moduli-Poisson's ratio-Bending of beams-Expression for bending moment – Depression of the loaded end of a Cantilever –uniform-non uniform bending – theory – experiment in and microscope method - work done in uniform bending –Koenig's method – non-uniform bending - theory - expression for couple per unit twist - determination of rigidity modulus-Static torsion method with scale and telescope -Rigidity modulus by torsion pendulum with mass

Chapter II Viscosity:

Coefficient of critical velocity – Poiseulli's formula for coefficient of viscosity and its correction – determination of coefficient of viscosity by capillary flow method-comparison of viscosities Oswald's viscometer – viscosity of a highly viscous liquid Stoke's method for the Coefficient of a highly viscous liquid-variations of viscosity with temperature and pressure-viscosity of gases-Mayer's formula for the rate of flow of a gas through a capillary tube - Rankine's method for the determination of viscosity of a gas.

Chapter III Surface tension and Osmosis:

Surface energy – angle of contact and its determination - excess of pressure inside curved surface –formation of drops – Experimental study of variation of Surface tension with temperature – drop weight method of determining surface tension and interfacial surface tension - angle of contact of mercury - Quincke's method- surface tension and vapour pressure osmosis– experimental determination of osmotic pressure- Laws of osmosis pressure –osmotic and vapour pressure of a solution.

Chapter IV Sound:

Definition of free, damped and forced vibrations–Theory of forced vibrations - Resonance – Sharpness of resonance - Fourier's theorem – application for Saw – tooth wave and square wave.- Sonometer – determination of A.C. frequency using sonometer–Determination of frequency using Melde's apparatus.

Chapter V Ultrasonic:

Ultrasonic – Production Piezoelectric method, magneto – striction method, detection, properties, applications - **Acoustics:** Acoustics of buildings – reverberation time – derivation of Sabine's formula- determination of absorption coefficient.

Chapter I
ELASTICITY

Introduction

Elasticity is the property of solid materials to return to their original shape and size after the forces deforming them have been removed. Recall Hooke's law first stated formally by Robert Hooke in The True Theory of Elasticity or Springiness (1676).

Most likely we'd replace the word "extension" with the symbol (Δx), "force" with the symbol (F), and "is directly proportional to" with an equals sign (=) and a constant of proportionality (k), then, to show that the springy object was trying to return to its original state, we'd add a negative sign (–). In other words, we'd write the equation

$$F = – k\Delta x$$

This is Hooke's law for a spring a simple object that's essentially one-dimensional. Hooke's law can be generalized to Stress is proportional to strain. where strain refers to a change in some spatial dimension (length, angle, or volume) compared to its original value and stress refers to the cause of the change (a force applied to a surface).

The coefficient that relates a particular type of stress to the strain that results is called an elastic modulus (plural, moduli). Elastic moduli are properties of materials, not objects. There are three basic types of stress and three associated moduli.

Elastic moduli

modulus (symbols)	stress (symbol)	strain (symbol)	configuration change
Young's (E or Y)	normal to opposite faces (σ)	length $\varepsilon = \Delta\ell/\ell 0$	longer and thinner or shorter and fatter
shear (G or S)	tangential to opposite faces (τ)	tangent $\gamma = \Delta x/y$	rectangles become parallelograms
bulk (K or B)	normal to all faces, pressure (P)	volume $\theta = \Delta V/V0$	volume changes but shape does not

The international standard symbols for the moduli are derived from appropriate non-English words — E for élasticité (French for elasticity), G for

glissement (French for slipping), and K for kompression (German for compression). Some American textbooks have decided to break with tradition and use the first letter of each modulus in English — Y for Young's, S for shear, and B for bulk.

Stresses on solids are always described as a force divided by an area. The direction of the forces may change, but the units do not. The SI unit of stress is the newton per square meter, which is given the special name pascal in honor of Blaise Pascal (1623–1662) the French mathematician (Pascal's triangle), physicist (Pascal's principle), inventor (Pascal's calculator), and philosopher (Pascal's wager).

$$[P_a=N/m^2]$$

Hooke's law

Within the elastic limits, the strain produced in a body is directly proportional to the stress which causes it.

i.e., strain α stress

(or) stress α strain

stress / strain = a constant

This constant is called 'modulus of elasticity'.

Types of strains

Strain: Change in dimensions to original dimensions is known as Strain.

(i) Linear Strain

When a wire or bar is subjected to two equal and opposite forces, namely pulls, at its ends, there is an increase in the length. If the forces are tensile, the body is elongated. If the forces are compressive, the length is shortened in the direction of the forces. This is called the 'linear strain'.

The linear strain is defined as the ratio of change in length to the original length. If the change (increase or decrease) in length is ' l ' in a wire or bar of original length L,

As the linear strain is ratio of lengths, it has no unit.

Linear strain = Change in length / Original length = l/L

(ii) Bulk (or) Volume Strain

When a force is applied uniformly and normally to the entire surface of the body, there is a change in volume of the body, without any change in its shape. This strain is called 'bulk or volume strain'.

Volume strain is defined as the ratio of change in volume to the original volume. It has also no unit.

If 'v' is the change in volume produced in a body of original volume 'V',

Bulk (or) volume strain = change in volume / original volume = v/V

(iii) Shearing (or) Rigidity strain

When a force is applied parallel to one face of a body, the opposite side being fixed, there is a change in shape but not in size of the body. This strain is called the shearing strain.

Solids alone can have a shearing strain. It is measured by the angle of the shear 'θ' in radian.

Three moduli of elasticity

There are three types of moduli depending upon the three kinds of strain.

Young's modulus

It is defined as the ratio of linear stress to linear strain.

Let a wire of initial length L and cross-sectional area ' A', undergo an extension l, when a stretching force 'F', is applied in the direction of its length.

The modulus of elasticity, in this case, is called Young's modulus and is given by

i.e., Young's modulus (E) = $\frac{Linear\ stress}{Linear\ strain}$

Then, longitudinal or linear stress = $\frac{F}{A}$

and longitudinal strain $= \frac{l}{L}$

$(E) = \frac{Linear\ stress}{Linear\ strain} = \frac{F/A}{l/L} = \frac{FL}{Al}$

The unit for Young's modulus is newton metre-2 with symbol N m^{-2}. The single term unit which is widely used for Young's modulus is 'pascal' with symbol 'Pa'.

Bulk (or) Volume modulus (k)

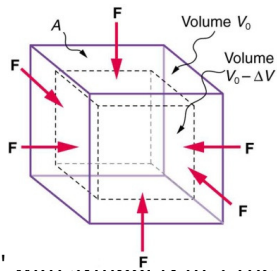
It is defined as the ratio of bulk stress to bulk strain.

When a body is subjected to a uniform compressive force, its volume decreases and the strain produced is a bulk or volume strain. If 'v' is the change in volume and V is the original volume, then

If F is the total compressive force acting on a total area A, then bulk stress = F/A = P

Bulk modulus (k) $= \frac{Bulk\ Stress}{Bulk\ Strain}$

If P is the stress applied i.e. (force/unit area) then,



bulk strain $= \frac{v}{V}$

bulk modulus k $= \frac{P}{v/V} = \frac{P.V}{v}$

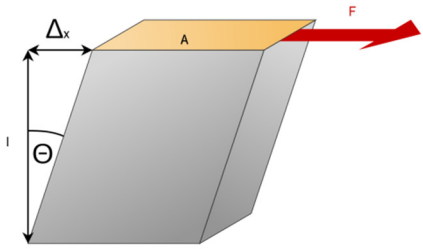
The unit for bulk modulus is 'newton metre-2' ..... single term unit which is widely used for bulk modulus is 'pascal' with symbol 'Pa'.

Shearing (or) Rigidity modulus 'n'

The ratio of the shearing stress applied to the body to the shearing strain produced is called the rigidity modulus and denoted by the letter 'n'.

If T is the tangential force/unit area and if θ is the angle of shear measured in radian, then

Rigidity modulus n = $\frac{T}{\theta} = \frac{F}{A\theta}$



The unit for rigidity modulus is 'newton metre^{-2} radian^{-1}' with symbol Nm^{-2} rad^{-1}. The other unit which is widely used for rigidity modulus is 'pascal radian^{-1}' with symbol 'Pa rad^{-1}'.

Poisson's ratio: σ

When a tensile stress is applied to a wire, the wire undergoes not only an extension of length in the direction of the force but also a contraction in its thickness. The ratio of decrease in thickness to the original thickness in lateral direction is known as lateral contraction.

The ratio of lateral contraction to linear elongation is called Poisson's ratio.

$$\text{Poisson's ratio } \sigma = \frac{Lateral\ contraction}{Linear\ elongation}$$

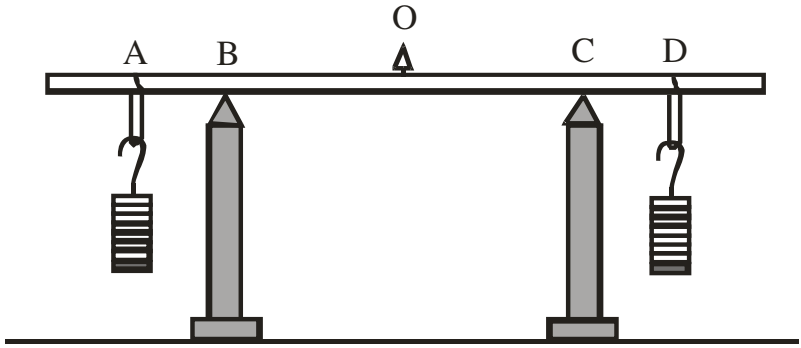
Bending of beams

A beam is a body having uniform cross section, the length of which is very large compared to its thickness. When such a beam is fixed at one end and loaded at the other end, it is called a cantilever.

A beam is supported symmetrically on two knife edges A and B at the same level. It is loaded symmetrically with two equal weights W, W, beyond the knife edges, at C and D, so that AC=BD=a. Now the beam is elevated at the centre. This type of bending is called uniform bending of beam.

A beam is supported symmetrically on two knife edges A and B near its ends in a horizontal level. A weight hanger W is suspended by means of a loop of thread from a point which is exactly midway between the two knife edges. Now the beam is depressed at the centre. This type of bending is called non-uniform bending of beam.

Experiment to determine the Young's modulus of the material of a beam by uniform bending method



The given bar is supported symmetrically on two knife edges in a horizontal level, so that a quarter of the bar projects beyond each knife edge. Two weight hangers are suspended from two loops of string tightly attached at distances about 5 cm from each end so that their distances from the knife edges are equal. A pin is fixed vertically at the midpoint of the bar. A traveling microscope is focused on the pin such that the horizontal crosswire coincides with the tip of the pin. The reading in the vertical scale of the microscope is noted. Weights are added in steps of M kg and the corresponding readings of the image of the pin in the microscope are noted. Similarly readings are taken while unloading and tabulated.

The mean elevation y is found for a load of M kg. The distance 'l' between the knife edges is measured. The distance 'a' between the point of suspension of the weight and the nearest knife edge is also measured. The breadth 'b' of the bar found accurately with the vernier calipers and its thickness d is found with a screw gauge. Young's modulus is calculated using the formula.

$$E = \frac{3Mgal^2}{2bd^3y}\ Nm^{-2}$$

Load in Kg	Microscope reading			evation y For M kg
	Load increasing	Load decreasing	Mean	
x M x+2M x+				

Factors Affecting Elasticity

The following are some of the important factors which affect the elastic properties of solids.

• **Stress:** The action of large constant stress or the repeated number of cycles of stresses acting on a body affect the elasticity of the body gradually. Considering this fact, the working stress on an engineering material is kept well below its ultimate tensile strength.

• **Temperature:** The elasticity of material decreases with the increase of temperature. A carbon filament which is highly elastic at normal temperatures becomes plastic when it is at high temperatures. Lead is not a good elastic material but at low temperatures, it becomes a very good elastic material. Creep resistance is a property by which the material can withstand its elastic property without fracture at high temperatures and during quick loading. Dispersion hardened materials and coarse hardened materials have better creep resistance at high temperature. Hence they can withstand their elastic properties even at high temperatures.

• **Impurities:** The elastic property of a material may increase or decrease due to the addition of impurities. If we add carbon in minute quantities to molten iron, the elastic properties of iron are increased enormously. But when the carbon content is more than 1% in iron, then the strength of iron decreases. Similarly, the addition of potassium in gold increases the elastic properties of gold.

If any addition of impurity atoms distorts the lattice structure of the base metal, then the elastic property of the base metal decreases. This kind of impurity atoms generally have different atomic radii and electronic structures from those of the base metal atoms and therefore act as centres of distortion which decrease the elastic properties of the base metal.

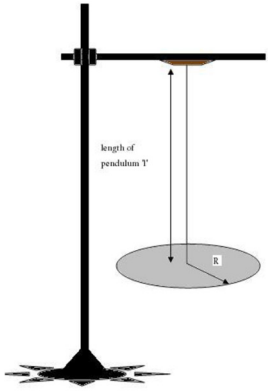
• **Crystalline nature:** For a given metal, the modulus of elasticity is more when it is in single crystal form. But in the polycrystalline state, its modulus of elasticity is comparatively small, while its mechanical properties like ductility, malleability, machinability, etc., increase. Hence, polycrystalline form of metals is used in most of the engineering works.

• **Heat treatment and metal processing:** A grain of elastic material consists of many small interlocking crystals. Various heat treatment processes are adopted to get the desired physical and mechanical proper-ties through the changes in micro constituents of the material. Annealing (heating and then slow cooling) is adopted to increase softness and ductility in the materials. But it decreases the tensile strength and yield point of the material due to formation of large crystal grains.

Hammering and rolling are metal processing techniques to make thin plates and sheets. They break the grains into fine grains and increase its elastic properties. Metals with fine grains are stronger than metals with large or coarse grains. However for high temperature applications, materials with large grains are used since they have high creep resistance.

Moment of inertia of a Torsion Pendulum

A body suspended by a thread or wire which twists first in one direction and then in the reverse direction, in the horizontal plane is called a torsional pendulum. The first torsion pendulum was developed by Robert Leslie in 1793. A simple schematic representation of a torsion pendulum is given below,



The period of oscillation of torsion pendulum is given as,

$$T = 2\pi\sqrt{\frac{I}{C}} \ldots\ldots\ldots (1)$$

Where I=moment of inertia of the suspended body; C=couple/unit twist But we have an expression for couple per unit twist C as,

$$C = \frac{1}{2}\frac{\pi n r^4}{l} \ldots\ldots\ldots [2]$$

Where *l* =length of the suspension wire; r=radius of the wire; n=rigidity modulus of the suspension wire

Substituting (2) in (1) and squaring, we get an expression for rigidity modulus for the suspension wire as,

$$n = \frac{8\pi \boldsymbol{I} l}{r^4 T^2} \ldots\ldots\ldots\ldots (A)$$

We can use the above formula directly if we calculate the moment of inertia of the disc, I as $(1/2)MR^2$.

Now, let I0 be the moment of inertia of the disc alone and I_1 & I_2 be the moment of inertia of the disc with identical masses at distances d_1&d_2 respectively. If I1 is the moment of inertia of each identical mass about the vertical axis passing through its centre of gravity, then

$$I_1 = I_0 + 2\ I^1 + 2md_1^2 \ldots\ldots\ldots (3)$$

$$I_2 = I_0 + 2I^1 + 2md_2^2 \ldots\ldots\ldots (4)$$

$$I_2 - I_1 = 2m(d_2^2 - d_1^2) \ldots\ldots\ldots (5)$$

But from equation (1),

$$T_0^2 = 4\pi^2 \frac{I_0}{C} \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

$$T_1^2 = 4\pi^2 \frac{I_1}{C} \ldots\ldots\ldots\ldots\ldots\ldots (7)$$

$$T_2^2 = 4\pi^2 \frac{I_2}{C} \ldots\ldots\ldots\ldots\ldots\ldots (8)$$

$$T_2^2 - T_1^2 = \frac{4\pi^2}{C}(I_2 - I_1) \ldots\ldots\ldots (9)$$

Where T_0, T_1, T_2 are the periods of torsional oscillation without identical mass, with identical pass at position d_1, d_2 respectively.

Dividing equation (6) by (9) and using (5),

$$\frac{T_0^2}{\left(T_2^2 - T_1^2\right)} = \frac{I_0}{[I_2 - I_1]} = \frac{I_0}{2m\left(d_2^2 - d_1^2\right)} \ldots\ldots\ldots (10)$$

Therefore, the moment of inertia of the disc,

$$I_0 = 2m\left(d_2^2 - d_1^2\right)\frac{T_0^2}{\left(T_2^2 - T_1^2\right)} \ldots\ldots\ldots\ldots\ldots (11)$$

Bending of Beams

A beam is defined as a rod or bar. Circular or rectangular of uniform cross section whose length is very much greater than its other dimensions, such as breadth and thickness. It is commonly used in the construction of bridges to support roofs of the buildings etc. Since the length of the beam is much greater than its other dimensions the shearing stresses are very small.

Assumptions

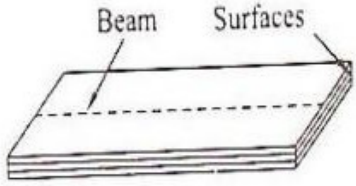
While studying about the bending of beams, the following assumptions have to be made.

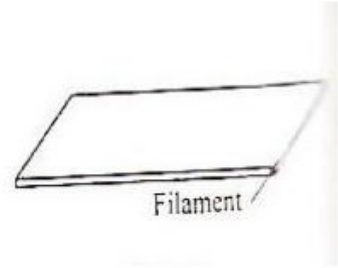
1. The length of the beam should be large compared to other dimensions.

2. The load (forces) applied should be large compared to the weight of the beam
3. The cross section of the beam remains constant and hence the geometrical moment of inertia is also remains constant
4. The shearing stresses are negligible
5. The curvature of the beam is very small

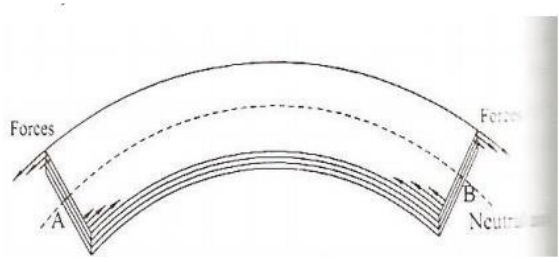
Bending of a Beam and neutral axis

Let us consider a beam of uniform rectangular cross section in the figure. A beam may be assumed to consist of a number of parallel longitudinal metallic fibers placed one over the other and are called as filaments as shown in the figure.



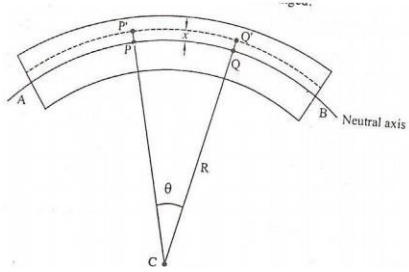


Let the beam be subjected to deforming forces as its end as shown in the figure. Due to the deforming force the beam bends. We know the beam consist of many filaments. Let us consider a filament AB at the beam. It is found that the filaments (layers) lying above AB gets elongated, while the filaments lying below AB gets compressed. Therefore the filaments i.e layer AB which remains unaltered is taken ass the reference axis called neutral axis and the plane is called neutral plane. Further, the deformation of any filaments can be measured with reference to the neutral axis.



EXPRESSION FOR BENDING MOMENT

Let us consider a beam under the action of deforming forces. The beam bends into a circular arc as shown in the figure. Let AB be the neutral axis of the beam. Here the filaments above AB are elongated and the filaments below AB are compressed. The filament AB remains unchanged.



Let PQ be the chosen from the neutral axis. If R is the radius of curvature of the neutral axis and θ is the angle subtended by it at its center of curvature 'C', then we can write original length

$$PQ=R\theta \qquad - 1$$

Let us consider a filament P'Q' at a distance 'X' from the neutral axis. We can write extended length

$$P'Q'=(R+x)\theta \qquad - 2$$

From equations 1 and 2 we have, Increase in length = P'Q'-PQ

On increase in its length=(R=x)θ-Rθ

$$\text{Increase in length} = x\theta \qquad - 3$$

We know linear strain = increase in length \ original length Linear strain = xθ\Rθ=x\R - 4

We know, the youngs modulus of the material Y=stress\linear strain

Or

stress=y*linear strain - 5

Substituting 4 in 5, we have

Stress=Yx\R

If δA is the area of cross section of the filament P'Q', then

The tensile force on the area δA=stress*Area

ie. Tensile force=(Yx\R).δa

We know the memont of force= force*Perpendicular distance Moment of the tensile force about the neutral axis AB
Or

$$PQ = \frac{Yx}{R}.\delta A.x$$

$$PQ = \frac{Y}{R}.\delta A.x^2$$

The moment of force acting on both the upper and lower halves of the neutral axis can be got by summing all the moments of tensile and compressive forces about the neutral axis

$\therefore$ The moment of all the forces about the neutral axis $= \frac{Y}{R}.\sum x^2 \delta A$

Here $I_g = \sum x^2 \delta A = AK^2$ is called as the geometrical moment of inertia.

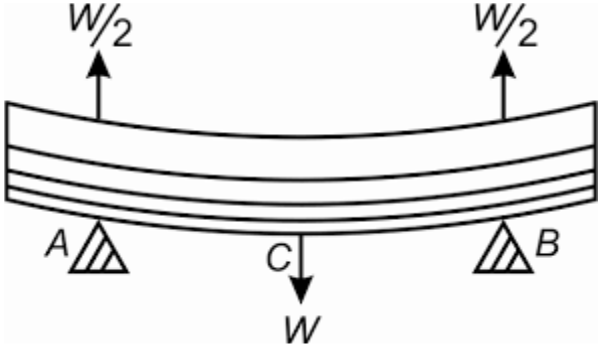
Where, A is the total area of the beam and K is the radius of Gyration.

$\therefore$ Total Moment of all the forces Or Internal bending Moment $= \frac{YI_g}{R} \longrightarrow 6$

NON-UNIFORM BENDING-DEPRESSION OF THE MID POINT OF A BEAM LAODED AT THE MIDDLE THEORY

Let us consider a beam of length 'l' (distance between the two knife edges) supported on the two knife edges A and B as shown in the figure. The load of weight 'W' is suspended at the centre 'C'. It is found that the beam bends and the maximum displacement is at the point 'D'Where the load is given.

Due to the load (W) applied, at the middle of the beam the reaction W/2 is acted vertically upwards at each knife edges. The bending is celled Non-Uniform bending



The beam may be considered as two cantilevers, whose free end carries a load of W/2 and fixed at the point 'D'.

Hence we can say the elevation of A above D as the depression below 'A'. We know the depression of a cantilever

$$y = \frac{WI^3}{3YI_g} \longrightarrow 1$$

Therefore substituting the value l and l/2 and was W/2 in the expression for the depression of the cantilever we have

$$y = \frac{(W/2)(l/2)^3}{3YI_g} \longrightarrow 2$$

Or $$y = \frac{WI^3}{48YI_g} \longrightarrow 3$$

DEPRESSION OF A CANTILEVER WHEN LOADED AT ITS END CANTILEVER

A cantilever is a beam fixed horizontally at one end loaded to the other end. THEORY:

Let us consider a beam fixed at one end and loaded at its other end as shown in the figure. Due to load applied at the free end, a couple is created between the two forces

a. Force (load 'W') applied at the free end towards downward direction and
b. Reaction(R) acting in the upward direction at the supporting end

The external bending couple tends to bend in the clockwise direction. But since one end of the beam is fixed, the beam cannot rotate. Therefore external bending couple must be balanced by another equal and opposite couple, created due to elastic nature of the body i.e. called as internal beading moment. Under equilibrium condition

External bending moment = Internal bending Moment

Let 'l' be the length of the cantilever OA fixed at 'O'. Let 'W' be the weight suspended (loaded) at the free end of the cantilever. Due to the load applied the cantilever moves to a new position OA' as shown in this figure.

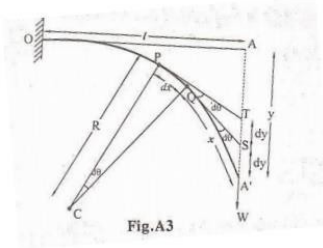


Fig.A3

Let us consider an element PQ of the beam of length dx, at a distance OP=x from the fixed end. Let 'C' be the center of curvature of the element PQ and let 'R' be the radius of the curvature.

Due to the load applied at the free end of the Cantilever, an external couple (Distance between the two equal and opposite forces) is (l-x).

$\therefore$ The External Bending Moment = W* (l-x) $\longrightarrow$ 1

We know the internal bending moment = $\frac{YI_g}{R}$ $\longrightarrow$ 2

We know under thermal equilibrium

External bending moment = Internal bending Moment

Therefore, we can write Eqn 1 = Eqn 2

$$W^* (l-x) = \frac{YI_g}{R}$$

Or $$R = \frac{YI_g}{W(l-x)} \longrightarrow \quad 3$$

Two tangents are drawn at points P and Q, which meet the vertical line AA' at T and S respectively

Let the smallest depression produced from T to S = dy and Let the angle between the two tangents = dϴ

Then we can write

The angle between CP and CQ is also $d\theta$ i.e. $\angle PCQ = d\theta$

$\therefore$ We can write the arc length PQ = R. $d\theta$ =dx

$$d\theta = \frac{dx}{R} \longrightarrow \quad 4$$

Substituting equation 3 in equation 4, we have

$$d\theta = \frac{dx}{\left[YI_g / W(l-x)\right]}$$

$$d\theta = \frac{W}{YI_g}(l-x)dx \longrightarrow \quad 5$$

From the $\Delta QA'S$ we can write Sin $d\theta = \frac{dy}{(l-x)}$

If $d\theta$ is very small then we can write

$$dy = (l-x)\,d\theta \longrightarrow \quad 6$$

Substituting equation 5 in equation 6 we have

$$dy = \frac{W}{YI_g}(l-x)^2.dx \longrightarrow \quad 7$$

Total depression at the end of the cantilever can be derived by integrating the equation 7 within the limits '0' to '1'.

Therefore $$y = \frac{W}{YI_g}\int_0^l (l-x)^2 .dx$$

$$y = \frac{W}{YI_g}\int_0^l (l^2 - 2lx + x^2)dx$$

$$y = \frac{W}{YI_g}\left[l^2 x - \frac{2lx^2}{2}. + \frac{x^3}{3}\right]_0^l$$

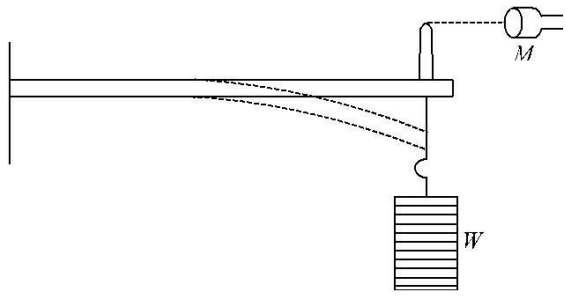
$$y = \frac{W}{YI_g}\left[l^3 - l^3. + \frac{l^3}{3}\right]$$

$$y = \frac{W}{YI_g}\left[\frac{l^3}{3}\right]$$

$\therefore$ Depression of the Cantilever at free end $y = \frac{Wl^3}{3YI_g}$ $\longrightarrow$ 8

EXPERIMENT FOR CANTILEVER

The experimental arrangement used to find the Young's modulus by cantilever is shown in Figure. One end of the given beam is fixed while the other end is left free. A load W is suspended at the free end of the beam and a pin is fixed vertically above it. Using a microscope, the tip of the image of the pin is coincided at the point of cross-section. The main scale and Vernier scale readings are noted from the microscope. Then the load is gradually increased step by step and the corresponding readings are noted. The readings are also taken by decreasing the load as above. The observed readings are tabulated. From the observation, the depression y of the given beam for a load M is determined.



The length of the beam from the fixed end to the weight hanger is measured as l. The Young's modulus of the cantilever is given by:

We know that W = mg

Substitute W value in Eq;

$$\frac{Mgl^3}{3ylg}$$

Determination of the depression of the beam

Load	Microscope reading			Depression y for M kg (m)
	Loading (m)	Unloading (m)	Mean (m)	
W				
W+50				
W+100				
W+150				
W+200				

Chapter II

VISCOSITY

Introduction

Let us consider a liquid flowing over a horizontal surface. The layer in contact with the surface is at rest. The top most layer have the maximum velocity. The intermediate layers have intermediate velocity. To maintain this relative motion of the layers, an external force must be acting on the liquid. Otherwise the liquid will come to rest due to internal frictional forces acting between the layers of the liquid. These internal frictional forces that bring the liquid to rest are known as viscous force and this property is known as viscosity.

The property by virtue of which the relative motion between the layers of a liquid is maintained is called viscosity. We can also say viscosity is the resistance to flow.

Coefficient of viscosity of a liquid

Let F be the viscous force acting between two layers of a liquid separated by a distance dx. Let dv be the difference in velocity between the two layers. Let A be the area of the layers. The velocity gradient dv/dx acts perpendicular to direction of flow of the liquid.

The viscous force F is found to be directly proportional to

i. the area of the layers 'A'

ii. the velocity gradient dv/dx

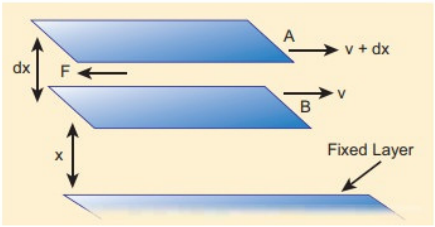
$$F \alpha \frac{Adv}{dx}$$

$$F = \frac{\eta A dv}{dx}$$

If A = 1 and dv/dx = 1, then F = η

Where η is constant, called Coefficient of viscosity of the liquid

Coefficient of viscosity of a liquid is defined as the viscous force acting between two layers of a liquid having unit area of layers and unit velocity gradient normal to the direction of flow of the liquid.



SI unit of η:

$\eta = \frac{F}{A\frac{dv}{dx}}$ Substituting the respective units of the quantities on the R.H.S,

The unit of coefficient of viscosity $\eta = \frac{N}{m^2\frac{ms^{-1}}{m}}$

$= Nsm^{-2}$

Dimensional formula of η:

$\eta = \frac{F}{A\frac{dv}{dx}}$ Substituting the respective dimensional formula of the quantities on the R.H.S,

The dimensional formula of coefficient of viscosity $\eta = \frac{MLT^{-2}}{L^2\frac{LT^{-1}}{L}}$

$= ML^{-1}T^{-1}$

Stream line flow (laminar flow) and turbulent flow

To maintain the flow of a liquid through a tube, some pressure should be given at one end of the tube to overcome the viscous drag. For a given external pressure, the velocity of flow depends on the coefficient of viscosity. At low pressure the velocity is less than a certain velocity called the critical velocity and the liquid flows in an orderly manner and the flow is called steady flow or streamline flow.

In stream line flow,

1. The liquid particles flow in an orderly manner. i.e., the liquid particles flow along straight lines, each line is called the line of flow.

2. The lines of flow are parallel to the axis of the tube.

3. The velocity of all particles in a line of flow is a constant.

4. The velocity of flow is always less than the critical velocity.

5. Stream line flow will happen only when the driving pressure is small.

6. The flow of water through a capillary tube at the rate of 5 to 6 drops per minute is an example for stream line flow.

When the external pressure causing the flow of the liquid is high, the flow of the liquid is said to be turbulent.

In turbulent flow,

1. There is no orderliness in the flow of liquid.

2. The liquid particles will not flow along straight lines, but will flow in curved paths in a zig-zag manner.

3. The different particles of the liquid will flow in different directions with different velocities.

4. The velocity of flow is always greater than the critical velocity.

5. Turbulent flow will happen when the driving pressure is high.

6. The flow of water from a tap is an example for turbulent flow.

Critical velocity

When the external pressure driving the flow of liquid increases slowly, the velocity of flow of liquid will also increase gradually. At a particular velocity the flow of liquid will change from laminar flow to turbulent flow. This velocity is called critical velocity. In other word the critical velocity is defined as

the velocity at which the streamline flow ceases out and the turbulent flow sets in.

Distinction between streamline motion and turbulent motion

Sl. No.	Stream line motion	Turbulent motion
1	Flow of liquid is orderly.	Flow of liquid is zigzag and random.
2	At any point along a straight line parallel to the axis of the tube, velocity is constant	Velocity varies along the straight line parallel to the axis of the tube.
3.	Velocity is proportional to the pressure.	Velocity is proportional to the square root of pressure
4.	Velocity will always be less than critical velocity	Velocity will always be greater than critical velocity.

Reynolds number

Reynolds number is a pure number, which determines the type of flow of a liquid, whether a streamline flow or a turbulent flow through a cylindrical pipe. It has no units and dimensions. It is given by the expression.

Where V is velocity of the liquid, ρ is the density of the liquid, η is the coefficient of viscosity of the liquid and D is the diameter of the pipe. This equation is applicable only for liquids flowing through cylindrical pipe.

$$R = \frac{V \rho D}{\eta}$$

Experiments show that the flow of a viscous liquid is laminar or streamlined, if Reynolds number is less than 2000. The flow of a viscous liquid is turbulent if Reynolds number is more than 2800. Between 2000 and 2800 there is a transition region in which the flow may change from streamline to turbulent. Narrow tubes and highly viscous liquids tend to promote streamline motion, while wider tubes and liquids of low viscosity leads to turbulence.

Experiment to determine comparison of coefficient of viscosity of two liquid- Capillary flow method

Aim:

To compare the coefficient of viscosity of two given liquids by capillary flow method.

Formula:

The comparison of coefficient of viscosity

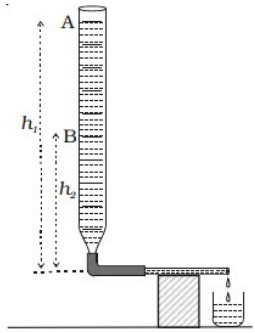
$$\eta_1/\eta_2 = \rho_1/\rho_2 \times t_1/t_2$$

η_1 = coefficient of viscosity of first liquid

η_2 = coefficient of viscosity of second liquid

ρ_1 = Density of the first liquid

ρ_2 = Density of the second liquid



Description:

The graduated burette without stopper is mounted vertically in the stand. A rubber tube is connected to the bottom of the burette. To the other end of the tube, a capillary tube is inserted and placed in a perfectly horizontal position.

Procedure:

The burette is cleaned and filled with one of the liquids using a funnel. Adjust the tube till the liquid through the tube comes out drop by drop. A stop clock is started when the liquid level reaches 0 cc and time taken for every 5 cc from 5,10, 15,20..till 50 cc, is noted .The burette and the tube are cleaned, rinsed and filled with the second liquid The time taken to cross the every consecutive 5 ml is noted. The readings are tabulated .The time taken for the t_1 and t_2 are noted. The mean value of t_1/t_2 is calculated.

Burette reading (cc)	Time (S)		t_1 / t_2
	liquid-I(t_1)	liquid-II (t_2)	
0-5 5-10 - - - 45-50.			

Terminal velocity

When a small metallic sphere is gently placed on the surface of a highly viscous liquid it descends down with acceleration. As its velocity increases, the viscous force opposing the motion of the sphere also increases.

At some stage the apparent weight of the sphere becomes equal to the force due to viscous drag. So the resultant force on the sphere is zero. Therefore the sphere moves down with a constant velocity known as terminal velocity.

Terminal velocity is that velocity at which the apparent weight of the sphere is equal to the viscous force acting on the sphere moving in a high viscous liquid.

Experimental determination of the coefficient of viscosity of a high viscous liquid by Stokes' method

Aim:

To determine the coefficient of viscosity of highly viscous liquid (Castor oil) by Stokes' method.

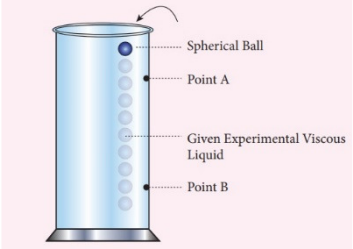
Formula:

The coefficient of viscosity of the highly viscous liquid

$$\eta = \frac{2}{9}\frac{(\rho - \sigma)g(r^2 t)}{h}$$

Where,

ρ = the density of the material of the solid sphere (glass beads)
σ = the density of the liquid (castor oil)
g = the acceleration due to gravity
r = the radius of the glass beads
t = the time taken by the solid sphere to travel the marked distance h, inside the high viscous liquid.
h = the distance between the marks B and C



EXPERIMENTAL SET UP OF MEASURING VISCOSITY BY STOKE'S METHOD

Description:

The pure, transparent, highly viscous liquid (castor oil) is taken in the tall glass jar. On the outer surface of the jar, two markings B and C or C and D are made at a distance of say 50 cm. The marking B should be well below the free surface of the liquid. Then only the sphere can attain terminal velocity when travelling from B to C or C to D.

Procedure:

First the least count, zero error and zero correction of screw gauge are determined. Then using the screw gauge, the diameters of the given glass beads are measured. The radii of the beads are calculated. Values of r and s are taken from standard tables.

The sphere is placed gently on the surface of the highly viscous liquid and dropped. When it crosses the marking B, a stop clock is started and when it crosses the marking C, the clock is stopped. The time taken (t) to travel by the sphere from B to C is recorded in the tabular column. The distance between B and C is noted as 'h'. The same procedure is repeated for all the given spheres. Then the coefficient of viscosity of highly viscous liquid (castor oil) is calculated, using the formula.

To find r^2t:

Glass beads	**Radius (r)**	**Radius^2 (r^2)**	**Time taken (t)**	**r^2t**
Unit	mm	mm^2	s	mm^2s
Bead 1				
Bead 2				
Bead 3				

The average of r^2t = ___mm^2s

= _____ $\times 10^{-6} m^2s$

Chapter III
SURFACE TENSION AND OSMOSIS

Introduction

The free surface of a liquid at rest behaves like a stretched elastic membrane with a tendency to contract in area. The following simple experiments will illustrate this property.

1. When a camel hairbrush is dipped into water, the hairs remain spread out. When the brush is taken out, the hairs cling together on account of the films of water between them contracting.

2. A film of the soap solution is formed in a wire ring.

If a wetted loop of thread is gently placed on the film, the film is unaffected and the thread remains in any form in which it is placed on the film. But if the film is pricked inside the loop, the film outside contracts on all sides and hence the circular loop is formed. The area of the film is reduced to a minimum.

The above examples show that a force acts on the surface of liquid to reduce the surface area to a minimum. This force is known as surface tension. A water drop takes the spherical shape because for a given volume, sphere has the minimum surface area. This is due to surface tension.

Surface tension

Surface tension is the force acting on unit length of an imaginary line drawn on the free surface of a liquid, the force acting normal to the line and parallel to the surface. The unit of surface tension is Nm-1 and its dimension is MT^{-2}.

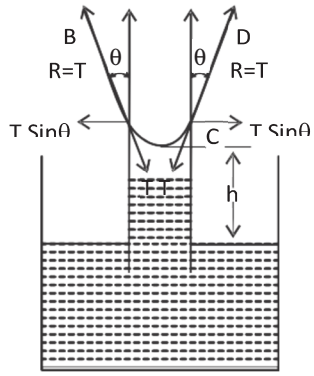
Angle of contact

The angle of contact is the angle by which the tangent drawn to the liquid surface at the point of contact with the solid, makes with the surface of the solid, the angle being measured within the liquid.

For liquids like water and kerosene which spread on glass, the angle of contact $\theta = 0°$. In the case of mercury and clean glass, the angle of contact $\theta = 137°$. For ordinary water and glass, the angle of contact $\theta = 8°$.

When a glass rod is dipped vertically in water, which wets the glass, the water is drawn up around the glass rod at all points of contact. Here, the angle of contact is acute. When a glass rod is dipped vertically in mercury, which does not wet the glass, the liquid is depressed around the glass rod at all points of contact. Here, the angle of contact is obtuse.

Expression for the surface tension by capillary rise



Let a capillary tube of uniform radius (r) be dipped vertically into a liquid of density ρ taken in a beaker. Let the liquid rises through a height (h) in the capillary tube. Let θ be the angle of contact with glass and T be the surface tension of the liquid. The surface tension is acting tangential to the liquid surface. The reaction R=T, offered by the walls of tube acts at an angle θ to the verticals. This reaction T along AB can be resolved vertically as Tcosθ and horizontally as Tsinθ. Similarly the reaction T along CD can also be resolved along the horizontal and vertical directions. The horizontal components along the circumference are equal and opposite in direction. So they get cancelled. So the total force due to surface tension is only due to vertical components.

The total upward force acting through the length of the meniscus 2πr

$$= \qquad 2\,\pi\, r.\, T\cos\theta$$

This force balances the weight of the liquid column of height h and radius r.

The weight of the liquid column = π r2h ρ g

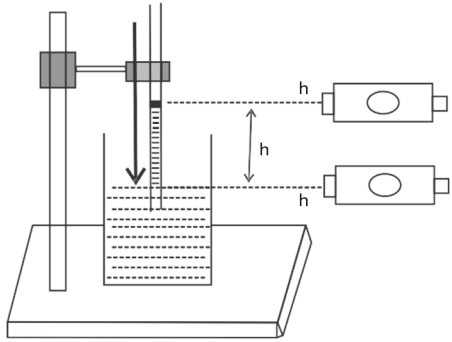
$$2\pi rT\cos\theta = \pi r^2 h\rho g$$

$$T = hr\rho g / 2\cos\theta$$

In the case of water θ = 0° and hence cosθ = 1

Hence for water, Surface tension T = hrρg / 2

Experimental determination of the surface tension of water by capillary rise method



A capillary tube of uniform cross sectional area is first cleaned with dilute acid and washed with distilled water and dried. It is then clamped vertically with one end inside the water taken in a beaker. Due to surface tension, water rises to a definite height in the tube. A pointer is attached to the capillary tube such that it just touches the surface of the water in the beaker.

Using a travelling microscope the reading in the vertical scale corresponding to the lower meniscus of the water in the tube is taken. The beaker is removed and the microscope is brought down and the reading corresponding to the tip of the pointer is taken. The difference between the two readings gives the height of the capillary rise of water 'h' in the capillary tube. The diameter and hence the radius 'r' of the capillary tube is also determined with the help of microscope. If ρ is the density of water and g, the acceleration due to gravity, then surface tension of water,

$$T = hr\rho g / 2$$

Applications of capillarity

1. Lubricating oil spread easily on all parts because of their low surface tension.
2. Cotton dresses are preferred in summer because cotton dresses have fine pores which act as capillaries for sweat.

3. Dirt get removed when detergents are added while washing clothes because surface tension of water is reduced.
4. The absorption of ink by a blotting paper is due to capillary action, as the blotting paper is porous. When it is placed over the ink, the ink raises into the pores. Also rise of oil in the wick of a lamp is due to capillary action.
5. If one end of a towel is dipped into a bucket of water and the other end hangs over the bucket, the entire towel soon becomes wet due to capillary action.
6. The supply of water to the leaves at the top of even a tall tree is through capillary rise.
7. A fabric can be waterproof, by adding suitable waterproofing materials to the fabric. This addition increases the angle of contact, thereby making the fabric waterproof.

Adhesive Force

The force of attraction acting between the molecules of different substances is called adhesive force, e.g., the force of attracts acting between the molecules of paper and ink, water and glass, etc.

Cohesive Force

The force of attraction acting between the molecules of same substance is called cohesive force. e.g., the force of attraction acting between molecules of water, glass, etc. Cohesive forces and adhesive forces are van der Waals' forces.

These forces varies inversely as the seventh power of distance between the molecules.

Molecular Range

The maximum distance upto which a molecule can exert a force of attraction on other molecules is called molecular range.

Molecular range is different for different substances. In solids and liquids it is of the order of 10^{-9} m.

If the distance between the molecules is greater than 10^{-9} m, the force of attraction between them is negligible.

Surface Energy

If we increase the free surface area of a liquid then work has to be done against the force of surface tension. This work done is stored in liquid stuface as potential energy,

This additional potential energy per unit area of free surface of liquid is called surface energy.

Surface energy (E) = S x &ΔM

Where, S = surface tension and ΔA = increase in surface area.

(i) Work Done in Blowing a Liquid Drop

If a liquid drop is blown up from a radius r1 to r2 then work done for that is,

$W = S \cdot 4\pi (r_2^2 - r_1^2)$

(ii) Work Done in Blowing a Soap Bubble

As a soap bubble has two free surfaces, hence work done in blowing a soap bubble so as to increase its radius from r1 to r2 is given by,

$W = S.8\pi(r_2^2 - r_1^2)$

(iii) Work Done in Splitting a Bigger Drop into n Smaller Droplets

If a liquid drop of radius R is split up into n smaller droplets, all of same size. then radius of each droplet

$r = R.\ (n)^{-1/3}$

Work done, $W = 4\pi(nr^2 - R^2)$

$= 4\pi SR^2\ (n^{1/3} - 1)$

(iv) Coalescance of Drops

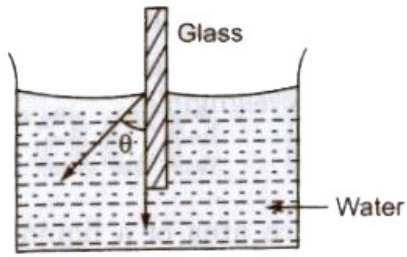
If n small liquid drops of radius reach combine together so as to form a single bigger drop of radius R=n1/3.r, then in the process energy is released. Release of energy is given by

$\Delta U = S.4\pi(nr^2 - R^2)$

$= 4\pi S\pi n(1 - n^{1/3})$

Angle of Contact

The angle subtended between the tangents drawn at liquid surface at solid surface inside the liquid at the point of contact, is called of contact.



Angle of contact depends upon the nature of the liquid and solid contact and the medium which exists above the free surface of liquid.

When wax is coated on a glass capillary tube, it becomes water-proof.

The angle of contact increases and becomes obtuse. Water does not in it. Rather it falls in the tube by virtue of obtuse angle of contact.

If θ is acute angle, i.e; θ <90°, then liquid meniscus will be concave upwards.

- If θ is 90°, then liquid meniscus will be plane.
- If θ is obtuse, i.e; θ >90°, then liquid meniscus will be convex upwards.
- If angle of contact is acute angle, i.e; θ <90°, then liquid will wet the surface.
- If angle of contact is obtuse angle, ie; θ > 90°, then liquid will not wet the surface.

Angle of contact increases with increase in temperature of Angle of contact decreases on adding soluble impurity to a liquid.

Angle of contact for pure water and glass is zero. For ordinary water and glass is 8°. For mercury and glass is 140°. For pure water silver is 90°. For alcohol and clean glass θ = 0°.

Capillarity

The phenomenon called capillarity. Of rise or fall of liquid column in a capillary tube is Ascent of a liquid column in a capillary tube is given by

$h = (2S \cos \theta / r\rho g) - (r / 3)$

If capillary is very narrow, then

$h=2S \cos \theta / r\rho g$

where, r = radius of capillary tube, p = density of the liquid, and θ = angle of contact and S = surface tension of liquid.

- If θ < 90°, cos e is positive, so h is positive, i.e., liquid rises in a capillary tube.
- If θ > 90°, cos 9 is negative, so h is negative, i.e., liquid falls in a capillary tube.
- Rise of liquid in a capillary tube does not violate law of conservation of energy.

Some Practical Examples of Capillarity

1. The kerosene oil in a lantern and the melted wax in a candle, rise in the capillaries formed in the cotton wick and burns.
2. Coffee powder is easily soluble in water because water immediately wets the fine granules of coffee by the action of capillarity.
3. The water given to the fields rises in the innumerable capillaries formed in the stems of plants and trees and reaches the leaves.

Zurin's Law

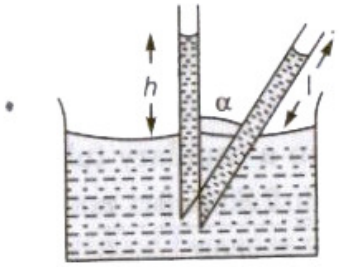
If a capillary tube of insufficient length is placed vertically in a then liquid never come out from the tube its own, as

$Rh = \text{constant} \Rightarrow R_1h_1 = R_2h_2$

where, R = radius of curvature of liquid meniscus and

h = height of liquid column.

When a tube is kept in inclined position in a liquid the vertical height remains unchanged then length of liquid column.



$$\cos\alpha = \frac{h}{l}$$

$$l = \frac{h}{\cos\alpha}$$

Liquid rises (water in glass capillary) or falls (mercury in capillary) due to property of surface tension

$T = R\rho gh / 2\cos\theta$

where, R = radius of capillary tube, h = height of liquid, p = density of liquid, e = angle of contact, T = surface tension of liquid and 9 = acceleration due to gravity.

Excess Pressure due to Surface Tension

(i) Excess pressure inside a liquid drop = 2S / R

(ii) Excess pressure inside an air bubble in a liquid = 2S / R

(iii) Excess pressure inside a soap bubble = 4S / R

where, S = surface tension and R = radius of drop/bubble.

(iv) Work done in spraying a liquid drop of radius R into n droplets of radius r = T x increase in surface area

$= 4\pi TR^3 (1/r - 1/R)$

Fall in temperature

$\Delta\theta = 3T/J (1/r - 1/R)$

Where, J = 4.2 J/cal.

(v) When n small drops are combined into a bigger drop, then work done is given by

$W = 4\pi R^2 T (n^{1/3} - 1)$

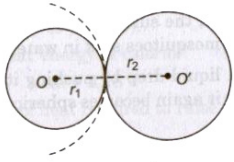
Temperature increase

$\Delta\theta = 3T/J (1/r - 1/R)$

(vi) When two bubbles of radii r_1 and r_2 coalesce into a bubble of radius r isothermally, then

$r^2 = r_1^2 + r_2^2$

(vii) When two soap bubbles of radii '1 and '2 are in contact with each other, then radius (r) of common interface.



Common interface

$$\frac{1}{r} = \frac{1}{r_1} - \frac{1}{r_2}$$

or

$$r = \frac{r_1 r_2}{r_2 - r_1}$$

Factors Affecting Surface Tension

1. Surface tension of a liquid decreases with increase temperature and becomes zero at critical temperature.
2. At boiling point, surface tension of a liquid becomes zero becomes maximum at freezing point.
3. Surface tension decreases when partially soluble impurities such as soap, detergent, dettol, phenol, etc are added in water.
4. Surface tension increases when highly soluble impurities such as salt is added in water.
5. When dust particles or oil spreads over the surface of water, its surface tension decreases.
   When charge is given to a soap bubble, its size increases surface tension of the liquid decreases due to electrification.
   In weightlessness condition liquid does not rise in a capillary tube.

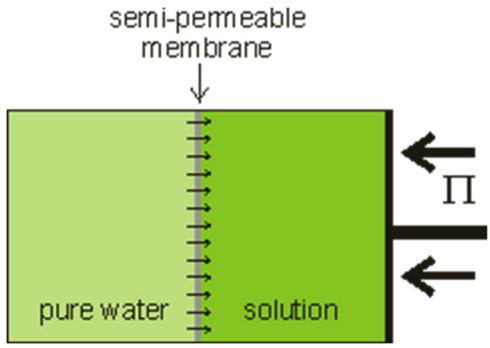
Some Phenomena Based on Surface Tension

1. Medicines used for washing wounds, as detol, have a surface tension lower than water.
2. Hot soup is more tasteful than the cold one because the surface tension of the hot soup is less than that of the cold and so spreads over a larger area of the tongue.
3. Insects and mosquitoes swim on the surface of water in ponds and lakes due to surface tension. If kerosence oil is sprayed on the water surface, the surface tension of water is lowered and the insects and mosquitoes sink in water and are dead.
4. If we deform a liquid drop by pushing it slightly, then due to surface tension it again becomes spherical.

Osmotic pressure

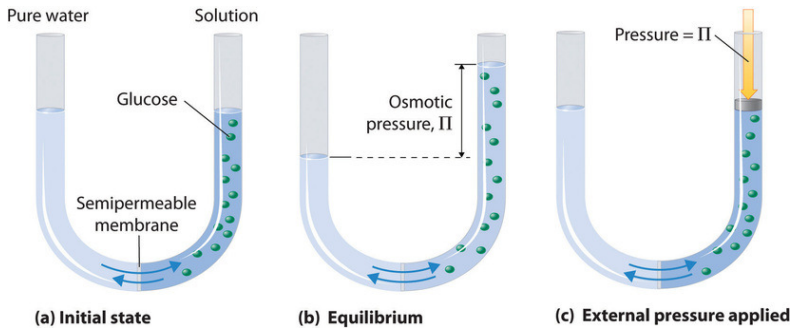
When pure liquid water is separated by a membrane, permeable to water but not solute, from a solution containing a non- volatile solute, water will pass from the pure water side until sufficient extra pressure (Π) is caused or applied to the solution side. Water moves from high to low water activity due to osmosis and, if allowed, would equalize the water activity on both sides of the membrane. The rate of this osmotically-linked flow has been shown to

equals the rate if a similar but hydrostatic pressure (in the opposite direction) was imposed. The pressure needed to stop the osmotic flow is the osmotic pressure (see below right). At this equilibrium, the vapor pressures of the solution and the pure water are identical (see below). Note that osmotic pressure is an equilibrium thermodynamic property a and gives no information concerning the rate of passage of the water, which depends primarily on the properties of the membrane. The osmotic pressure is the most biologically-important colligative property and correlates to other colligative properties. Solutes dissolved in a solvent lower both the chemical potential and the activity of the solvent in the solution relative to the chemical potential or activity of the pure solvent. Osmotic pressure, vapor pressure lowering, boiling point elevation, and freezing point depression, are all measures of the same chemical potential of the solvent, that does not have to be water. Either freezing point depression or osmotic pressure can be used to calculate the other. There is often confusion in the literature between the thermodynamic rationale and the kinetic process of osmosis. j The thermodynamics of the process (e.g., the colligative property) only describes the tendency for the process to occur but does not describe the mechanism or the rate of the flow of water in an osmotic process, apart from its (impending) direction. As such, all solutions possess the potential for osmotic pressure (but no actual osmotic pressure) if not adjacent to a semipermeable membrane. Also, there is no distension of the semipermeable membrane under osmotic pressure, but there may well be distension under hydrostatic pressure; the osmotic pressure only apparently acting around the pores of the semipermeable membrane whereas the hydrostatic pressure acts throughout the system. In this way, osmotic pressure m differs from hydrostatic pressure. Osmotic pressure is determined at thermodynamic equilibrium in an osmometer similar to the diagram (see above right) with no net flow through the membrane. In line with the other colligative properties (boiling point raising, freezing point lowering) as determined, it is a pressure difference, not an absolute pressure. It cannot be determined by any kinetic process. Below right is shown the U-tube configuration whereby water flows from the pure water arm to the solution arm until the excess pressure on the solution in the right-hand arm ($\rho \times g \times h$) is balanced by the osmotic pressure.



Semipermeable Membranes and Osmotic flow

Figure shows a simple osmotic cell. Both compartments contain water, but the one on the right also contains a solute whose molecules (represented by green circles) are too large to pass through the membrane. Many artificial and natural substances are capable of acting as semi-permeable membranes. The walls of most plant and animal cells fall into this category.



If the cell is set up so that the liquid level is initially the same in both compartments, you will soon notice that the liquid rises in the left compartment and falls in the right side, indicating that water molecules from the right compartment are migrating through the semipermeable membrane and into the left compartment. This migration of the solvent is known as osmotic flow, or simply osmosis.

The escaping tendency of a substance from a phase increases with its concentration in the phase. What is the force that drives the molecules through the membrane? This is a misleading question, because there is no real "force" in the physical sense other than the thermal energies all molecules possess. Osmosis is a consequence of simple statistics: the randomly directed motions of a collection of molecules will cause more to leave a region of high concentration than return to it; the escaping tendency of a substance from a phase increases with its concentration in the phase.

Diffusion and Osmotic Flow

Suppose you drop a lump of sugar into a cup of tea, without stirring. Initially there will be a very high concentration of dissolved sugar at the bottom of the cup, and a very low concentration near the top. Since the molecules are in random motion, there will be more sugar molecules moving from the high concentration region to the low concentration region than in the opposite direction. The motion of a substance from a region of high concentration to one of low concentration is known as diffusion. Diffusion is a consequence of a concentration gradient (which is a measure of the difference in escaping tendency of the substance in different regions of the solution).

There is really no special force on the individual molecules; diffusion is purely a consequence of statistics. Osmotic flow is simply diffusion of a solvent through a membrane impermeable to solute molecules. Now take two solutions of differing solvent concentration, and separate them by a semipermeable membrane. Being semipermeable, the membrane is essentially invisible to the solvent molecules, so they diffuse from the high concentration region to the low concentration region just as before. This flow of solvent constitutes osmotic flow, or osmosis.

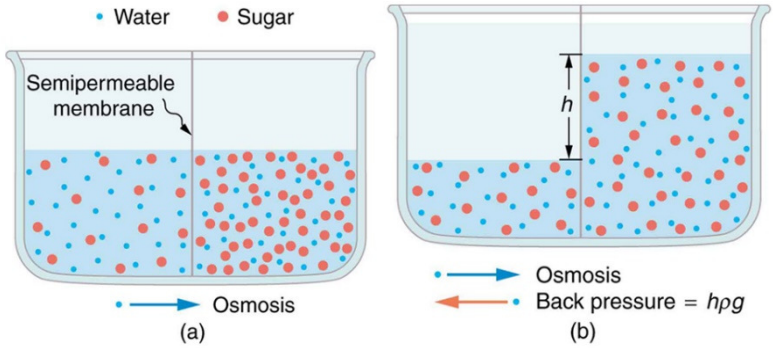


Figure shows water molecules (blue) passing freely in both directions through the semipermeable membrane, while the larger solute molecules remain trapped in the left compartment, diluting the water and reducing its escaping tendency from this cell, compared to the water in the right side. This results in a net osmotic flow of water from the right side which continues until the increased hydrostatic pressure on the left side raises the escaping tendency of the diluted water to that of the pure water at 1 atm, at which point osmotic equilibrium is achieved.

Osmotic equilibrium and osmotic pressure

One way to stop osmosis is to raise the hydrostatic pressure on the solution side of the membrane. This pressure squeezes the solvent molecules closer together, raising their escaping tendency from the phase. If we apply enough pressure (or let the pressure build up by osmotic flow of liquid into an enclosed region), the escaping tendency of solvent molecules from the solution will eventually rise to that of the molecules in the pure solvent, and osmotic flow will case. The pressure required to achieve osmotic equilibrium is known as the osmotic pressure. Note that the osmotic pressure is the pressure required to stop osmosis, not to sustain it.

Osmotic pressure is the pressure required to stop osmotic flow it is common usage to say that a solution “has” an osmotic pressure of "x atmospheres". It is important to understand that this means nothing more than that a pressure of this value must be applied to the solution to prevent flow of pure solvent into this solution through a semipermeable membrane separating the two liquids.

Chapter IV
SOUND

Introduction

Sound is produced due to the vibrations of the body. These vibrations are transferred to the air medium and propagated in all directions in the form of waves. When the vibrational sound waves reach our ear, the diaphragm of the ear vibrates with equal vibrations produced by the body. Hence we are able to hear the sound by the sensation perceived by the nerves of the ear.

The number of vibrations made in one second is known as frequency of the sound. It is expressed in hertz (Hz). The range of the frequency between 20 Hz and 20,000 Hz is the audible range, Human ears cannot respond to the sound below and above this range. In this sense, all vibrating bodies cannot produce audible sound. The vibrations of frequency below 20 Hz are called infrasonic and above 20,000 Hz are called ultrasonic.

Sound is a mechanical wave and hence it requires a medium to propagate. So we can't hear the sound in vacuum. It travels with the velocity of 330 ms-1 in air. Sound waves are reflected and refracted like light waves.

Wave motion

When a stone is thrown on a pond of water, ripples spread out in all directions on the surface of water. The stone disturbs the water medium at one place but the disturbance is transferred in all directions continuously. This continuous movement of the disturbance is called a wave.

If a wave passes in a medium, the particles of the medium vibrate about their mean position. The particles do not move along with the wave, only the vibrations are transferred from one particle to adjacent particle of the medium in the form of energy.

There are two types of wave motion. They are

1) Longitudinal wave motion and
2) Transverse wave motion

1) Longitudinal wave motion

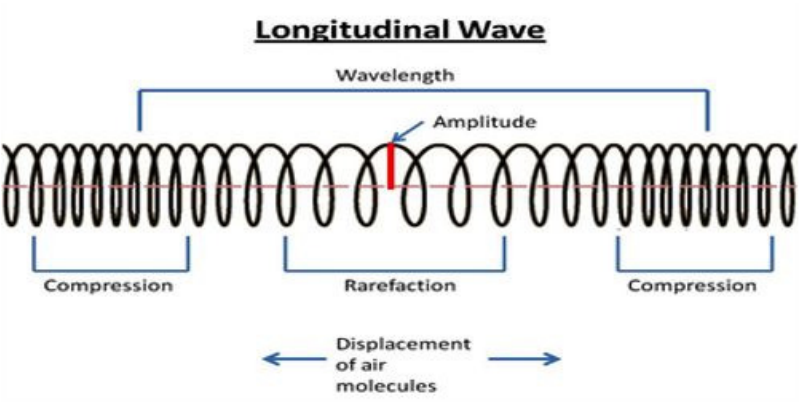
If the particles of the medium vibrate parallel to the direction of propagation of the wave, the wave is known as longitudinal wave.

Examples

1. The propagation of sound in air

2. The propagation of sound in gas

3. The propagation of sound inside the liquid



The longitudinal waves travel in a medium in the form of compressions and rarefactions. The place where the particles of the medium crowded together are called compressions and the places where the particles spread out are called rarefactions.

The compressions and rarefactions produced by a vibrating tuning fork are as shown in the figure. When the prong (arm) of the fork moves to the right, it compresses the medium in front of it to form compression. Meanwhile the prong returns to the left, a temporarily vacuum is created there. To fill it, the particles of the medium spread out in that place to form a rarefaction.

Thus as the prong of the fork vibrates to and fro, alternate compressions and rarefactions are trans- mitted in the medium. As a result, the particles of the medium simply move back and forth about their mean position parallel to the direction of the propagation of the wave.

2) Transverse wave motion

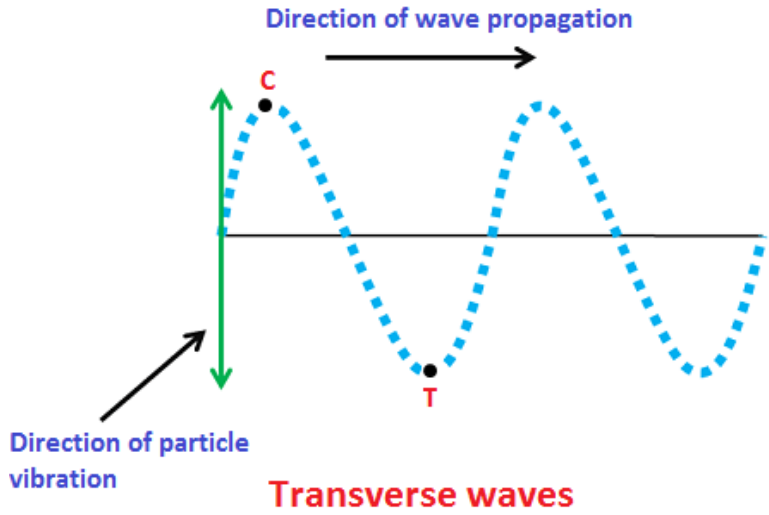
If the particles of the medium vibrate perpendicular to the direction of propagation of the wave, the wave is known as transverse wave.

Examples

1. Ripples travelling on the water surfaces.

2. Waves travelling along a rope.

3. Other waves like light waves, heat radiations, radio waves etc.



The transverse waves travel in a medium in the form of crests and troughs. The points where the particles of the medium displaced maximum in the upward direction are called crests. The points where the particles displaced maximum in the downward direction are called troughs.

The crests and troughs produced by the transverse wave motion are as shown in the figure. In transverse wave, alternate crests and troughs are transmitted in the medium. As a result, the particles of the medium move up and down about their mean position perpendicular to the direction of propagation of the wave.

Progressive Waves

If a wave travels continuously in a medium without any disturbance, then the wave is said to be progressive wave. Longitudinal waves and Transverse waves are two types of progressive waves and they can travel continuously in any medium if there is no obstruction.

Amplitude

When sound wave propagates in a medium, the maximum displacement of the vibrating particles of the medium from their mean position is called amplitude.

Wavelength (λ)

The wavelength is the distance between two consecutive particles of the medium which are in the same state of vibration. It is also defined as the distance travelled by the wave during the time the vibrating particle completes one vibration. In longitudinal waves, the wavelength is the distance between two successive compressions or rarefactions. In transverse waves, the wavelength is the distance between two successive crests or troughs.

Period (T)

The time taken by the vibrating particle to make one vibration is called period.

Frequency (n)

The frequency is the number of vibrations made by the vibrating particle in one second.

Velocity (v)

The distance travelled by the sound wave in one second is known as velocity of sound.

Relation between Wavelength, Frequency and Velocity of a Wave

Let n be the number of vibrations made by the vibrating particle in one second. It is also known as its frequency.

Time taken for one vibration = period (T) = 1/n.

Let λ be the wavelength of the wave produced

Velocity of the wave is the distance through which the wave advances in the medium in one second.

Velocity of wave motion V = Distance travelled / Time taken

$$V = \lambda/T = \lambda/(1/n) = \lambda n$$

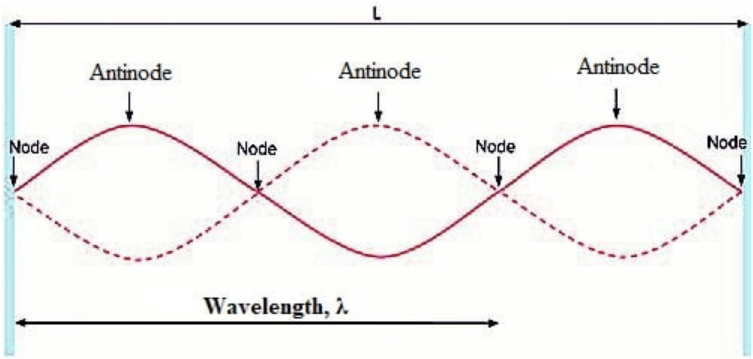
$$V = n\lambda$$

Stationary Waves

If a progressive wave travelling in a medium meets the surface of an obstacle, it is reflected. The reflected wave is superimposed on the incident wave to form a new type of wave called stationary wave. Also, when two identical waves having equal wavelength and amplitude travel in opposite directions they superimpose on each other forming stationary wave.

A stationary wave formed by a vibrating string is as shown in the figure. Consider a string P Q fixed at the end Q and it vibrates up and down at the free end P. Then a transverse wave is setup and it proceeds towards the fixed point Q and gets reflected back to the end P. Now the stationary wave is formed in the string.

At certain points of the medium, the displacement due to the two waves cancel each other and those points remain at rest. Such points are called nodes (N). At certain other points there is maximum displacement. Such points are called antinodes (A). The distance between two successive nodes or antinodes is $\lambda / 2$.



The distance between a node and the next antinode is λ / 4. The longitudinal waves also produce the stationary waves.

Surface acoustic wave

A surface acoustic wave (SAW) is an acoustic wave traveling along the surface of a material exhibiting elasticity, with an amplitude that typically decays exponentially with depth into the material. Materials with relatively high magnitude of Young's modulus (e.g., buildings) can be destroyed once exposed to strong SAWs (as in earthquakes), whereas, those with relatively low Young's modulus (e.g., bubbles and biological cells) can start to oscillate when driven by weak SAWs.

SAW device applications in radio and television

SAW resonators are used in many of the same applications in which quartz crystals are used, because they can operate at higher frequency. They are often used in radio transmitters where tunability is not required. They are often used in applications such as garage door opener remote controls, short range radio frequency links for computer peripherals, and other devices where channelization is not required. Where a radio link might use several channels, quartz crystal oscillators are more commonly used to drive a phase locked loop. Since the resonant frequency of a SAW device is set by the mechanical properties of the crystal, it does not drift as much as a simple LC oscillator, where conditions such as capacitor performance and battery voltage will vary substantially with temperature and age.

SAW filters are also often used in radio receivers, as they can have precisely determined and narrow passbands. This is helpful in applications where a single antenna must be shared between a transmitter and a receiver operating at closely spaced frequencies. SAW filters are also frequently used in television receivers, for extracting subcarriers from the signal; until the analog switchoff, the extraction of digital audio subcarriers from the intermediate frequency strip of a television receiver or video recorder was one of the main markets for SAW filters.

Early pioneer Jeffery Collins incorporated surface acoustic wave devices in a Skynet receiver he developed in the 1970s. It synchronised signals faster than existing technology.

They are also often used in digital receivers, and are well suited to superhet applications. This is because the intermediate frequency signal is always at a fixed frequency after the local oscillator has been mixed with the received signal, and so a filter with a fixed frequency and high Q provides excellent removal of unwanted or interference signals.

In these applications, SAW filters are almost always used with a phase locked loop synthesized local oscillator, or a varicap driven oscillator.

VIBRATIONS

Free Vibrations

The vibrations of any body with its natural frequency are called free vibrations. When a body is set in vibration and left free, it executes vibrations. The frequency depends upon the dimensions and elastic constants of the body. Such vibrations are called free vibrations and the frequency of vibration is known as the natural frequency. If a tuning fork is set in vibration, it vibrates with its own frequency. Such vibrations are called free vibrations or natural frequency.

Forced Vibrations

The vibrations of a body with a frequency induces vibrations on another vibrating agent are called forced vibrations.

Suppose a vibrating tuning fork is placed with its stem on a table, the vibrations of the fork are impressed on the table and the table is forced to vibrate. The vibrations set up on the table are called forced vibrations.

Resonance

I Law: The frequency of vibrating string is inversely proportional to its length, when the tension and linear density of the string are kept constant.

$$n \alpha 1 / l$$

II Law: The frequency of vibration is directly proportional to the square root of the tension, when the length and linear density of the string are kept constant.

$$n \alpha \sqrt{T}$$

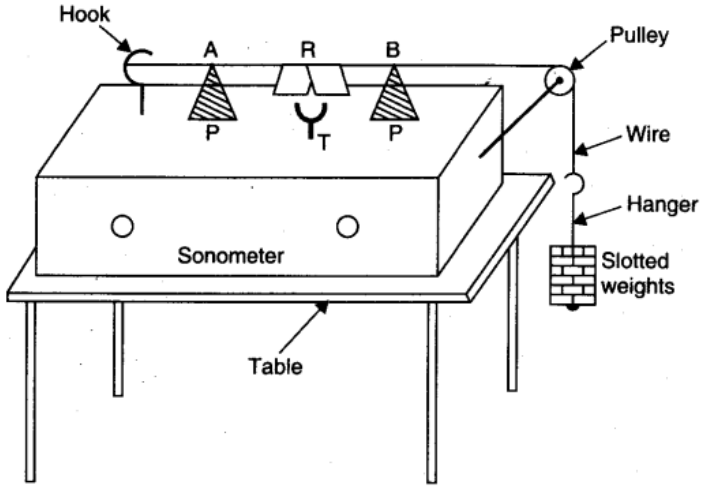
III Law: The frequency of vibration is inversely proportional to the square root of the linear density of the string, when the tension and length of the string are kept constant.

$$n \alpha \frac{1}{\sqrt{m}}$$

Sonometer

The phenomenon of resonance is used in sonometer. In sonometer, the frequency of a tuning fork is equal to the frequency of the vibrating string. Here resonance takes place and the string vibrates with maximum amplitude.

Experimental determination of frequency of a tuning fork using sonometer



The sonometer consists of a hollow wooden box. A nail is fixed at one end and a smooth pulley is fixed at the other end of the box. One end of a sonometer string is tied to the nail and other end of the string passes over the smooth pulley. The free end is attached to the weight hanger. A, B and C are three knife edges placed on the box under the string. A, B are fixed and C is movable.

A suitable tension (T = Mg) is applied to the string. A small paper rider is placed on the string in between A and C. The tuning fork of frequency 'n' is excited with a rubber hammer and its stem is kept on the sonometer box. Now the string is made to vibrate. The movable knife-edge C is adjusted such that the string vibrates with the same frequency of the fork. At that time, the paper rider placed on the string between A and C, is violently thrown off from the string. Now the vibrating length of the string AC= l is measured.

Let r be the radius of the string measured by using screw gauge and 'ρ' be the density of the material of the wire, then

$$\text{The linear density, } m = \pi r^2 \rho$$

The experiment is repeated by changing the value of tension (load). The readings are tabulated.

Sl.No.	Load (M)	Vibrating length AC = l	l^2	$\frac{M}{l^2}$

The frequency of the tuning fork, $n = \frac{1}{2}\sqrt{\left(\frac{M}{l^2}\right)\frac{g}{m}}$

The mean value of $\frac{M}{l^2}$ is substituted in the above formula and the frequency of the tuning fork 'n' is calculated.

Chapter V

ULTRASONIC

Introduction

Vibrating body produces sound. Human ear is sensitive to sound waves of frequencies ranging from 20 Hz to 20,000 Hz. Sound waves of frequencies greater than 20,000 Hz are called **ultrasonic waves**. Human beings cannot sense this sound.

Ultrasonic waves are generated by bats and dolphins and they use the reflection of the waves to find their way. Dogs can hear ultrasonic sounds.

Generation of Ultrasonic Waves

The methods by which ultrasonic waves can be generated ar

1. Magnetostriction generator
2. Piezo-electric generator.

Magnetostriction Generator Principle

Magnetostriction generator is base on the priniciple of magnetostriction effect. When a ferromagnetic rod like iron or nickel is kept in a magnetic field parallel to its length the rod expands or contracts producing a change in length. This is known as **Magnetostriction effect**.

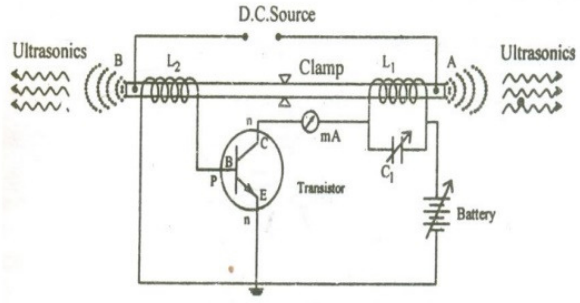
Construction

The magnetostriction generator consists of a nickel rod which is laminated, insulated and pasted to avoid Eddy current loss. The rod is clamped in the middle and coils $L1$ and $L2$ are wound on the two ends of the rod. Coil $L1$ is connected to the base circuit and coil $L2$ is connected to the collector circuit as in Fig 1.1. The inductor $L2$ and capacitor $C1$ form the tank circuit. The coil $L1$ is used as a feedback loop. The battery connected between the emitter and collector provides the necessary biasing.

Working

When the power supply is switched on, the collector current rises and sets up an alternating current of frequency f This alternating current flowing round the coil $L2$ provides an alternating magnetic field of requency f = along the length of the rod. Here l is the length of the rod, E the youngs modulus of the material of the rod, p its density and n = 1,2,3·· .. Now the rod starts vibrating due to the magnetostriction effect. When the frequency of vibration of the rod

matches the frequency of the tank circuit ultrasonic waves are produced. This can be achieved by adjusting the capacitor *C1* and tuning the developed alternating current frequency with the natural frequency of the rod.



The coil *L*1 helps in increasing the amplitude of the ultrasonic waves. The longitudinal expansion and contraction of the rod produces an e.m.f in the coil *L*1 which is applied to the base of the transistor which in turn increases the amplitude of high frequency oscillations in coil *L*2 due to positive feed-back.

Advantages

I. Magnetostriction oscillators are mechanically rugged.
II. The construction cost is low.
III. They are capable of producing large acoustical power with fairly good efficiency (as 60 %)

Drawbacks

I. It can produce frequencies upto 3 MHz only.
II. The frequency of oscillations depends on temperature.

Piezo Electric Generator

Principle-Piezo electric generator is based on the principle of inverse plezo electric effect

When certain crystals like quartz are subjected to mechanical stress electric charges appear on the opposites sides of the crystal. This effect is called **Piezo** electric effect, and effect is reversible. When electric field is applied on the opposite faces of the crystal, it undergoes mechanical deformation. This is the **inverse piezo electric effect**. This effect is used for generating ultrasonic

waves using piezoelectric oscillator. The materials which exhibit this effect are called Piezo electric transducers.

Example : Quartz, barium titanate.

Natural quartz has a hexagonal structure with a pyramid attached to each end. The line joining the end points of the pyramid is called z-axis. The lines passing through the opposites corners are X-axis. The line perpendicular to opposite edges is Y-axis shown in (Fig 2). When the crystal is cut perpendicular to X-axis it is called X-cut crystal. When the crystal is cut perpendicular to Y-axis it is called Y-cut crystal.

The natural frequency of the quartz specimen Where, *t* - thickness of the material

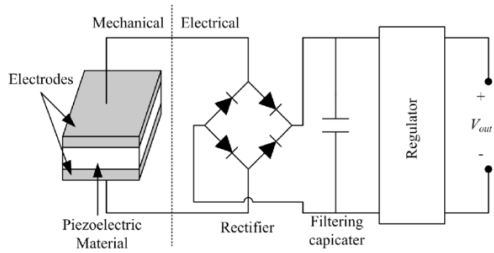
E - Youngs modulus of the material and

ρ - density of the material

Experimental setup

The circuit diagram is shown in Fig 1.3. This is a base tuned oscillator circuit. A slice of quartz crystal is placed between the metal plates *A* and *B* so as to form a parallel plate capacitor with the crystal as the dielectric. This is coupled to the electronic oscillation through primary coil *L3* of the transformer.

Coils *L2* and *L1* of oscillator circuit are taken from the secondary of the transformer. The collector coil *L2* is inductively coupled to base coil *L1*. The coil *L1* and variable capacitor *C*1 form the tank circuit of the oscillator.



Working

When the batttery is switched on, the oscillator produces high frequency oscillations. An oscillatory e.m.f is induced in the coil *L3* due to transformer action. So, the crystal is now under high frequency alternating voltage.

The capacitance of C_1 is varied in such a way that the frequency of oscillations produced is $f =$ and is in resonance with the natural frequency of the crystal. Now the crystal vibrates with large amplitude due to resonance and, high power ultrasonic waves are produced.

Advantages

I. Ultrasonic frequencies as high as 500 MHz can be generated.
II. The output power is high. It is not affected by temperature and humidity.
III. It is more efficient than magnetostriction oscillator.

Disadvantages

I. The cost of the quartz crystal is very high.
II. Cutting and shaping the crystal is very complex.

Detection of Ultrasonic Waves

Ultrasonic waves are beyond the audible limit. Hence it is very essential to develop a method to detect the ultrasonic wave. The various detection methods are

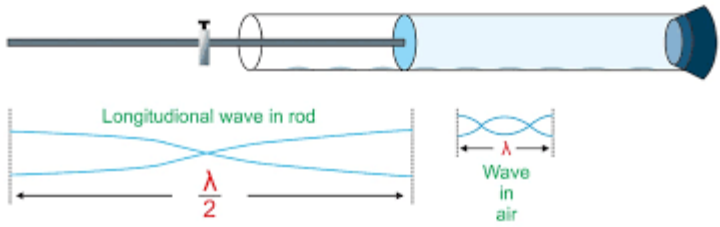
1. Kundt's tube method
2. Piezo electric detector
3. Thermal detector
4. Sensitive Flame method

(i) Kundt's Tube Method

The Kundt's tube apparatus consists of a long circular glass tube of length 1 m and diameter 0.03 - 0.04m. One end of the tube is fitted with an adjustable piston rod with cork. The quartz crystal placed in between the two metal plates is placed at the mouth of the other end of the tube. Lycopodium power is spread uniformly inside the tube.

Like sound waves, stationary waves are produced in the air contained in the long glass tube which is placed horizontally. The lycopodium powder gets collected in the form of heaps at the nodes and is blown off at the antinodes. By measuring the average distance between the adjacent heaps, the wavelengths and hence the ultrasonic velocity can be calculated.

The wavelength of the ultrasonic waves $\lambda = 2d$. Where is d the distance between the successive nodes. Ultrasonic velocity in the medium $V = f\lambda = 2fd$



(ii) Piezo electric detector

This method is based on the principle of piezo-electric effect. When one pair of the faces of a quartz crystal is exposed to ultrasonic waves, opposite charges are developed on the pair of opposite faces. These charges are amplified and detected using an electronic circuit.

(iii) Thermal detector

This is the most commonly used method of detection of ultrasonic waves. A fine platinum wire is placed in the region to be tested for ultrasonic waves. At nodes due to alternate compressions and rarefactions, alternate heating and cooling is produced. Change in temperature at the node brings about changes in the electrical resistance of the platinum wire. This is detected by means of wheatstone's bridge. No change in temperature occurs at the antinodes.

(iv) Sensitive Flame method

When ultrasonic waves are passed through a sensitive flame, the intensity of the flame will change due to the high frequency of the ultrasonic waves. By measuring the change in intensity of the flame, the ultrasonic waves can be detected.

Properties of Ultrasonics

1. Ultrasonic waves are longitudinal in nature.
2. They are highly energetic.
3. Like sound waves ultrasonic waves undergo reflection and refraction. They can also be absorbed.

4. When ultrasonic waves are passed through liquid, it produces stationary wave pattern and the liquid behave as an acoustic grating.
5. Ultrasonic waves can travel through longer distance.
6. The speed of propogation of ultrasonic wave increases with increase in frequency.
7. They produce cavitation effects in liquids.
8. Due to the small wavelength ultrasonics show very negligible diffraction.

Velocity of Ultrasonics waves in liquid using Acoustic grating

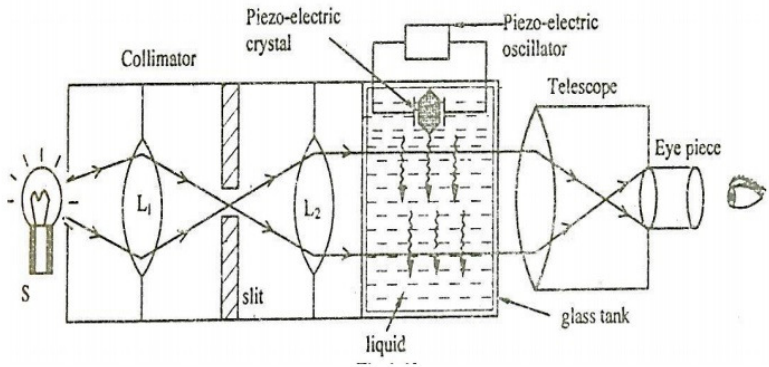
Principle

Ultrasonic wave consists of compression and rarefractions. When these waves are passed into liquid medium, the density of the liquid varies layer by layer and the liquid will act as a diffraction grating. This grating which is formed in liquid due to acoustical waves is called as acoustic grating.

When a monochromatic light is passed through this grating, the light gets diffracted. By determining the diffraction parameters, the velocity of ultrasonic waves can be determined.

Construction

The experimental setup for the formation of acoustic grating is shown in Fig. This consists of a glass tube filled with the liquid. A quartz crystal which is connected to an oscillating circuit is placed at the bottom of the glass tube. A monochromatic source of light and condenser lens are arranged at right angle to the tube.



Working

Light from the monochromatic source is passed into the liquid in a direction perpendicular to the direction of propogation of ultrasonic waves. When the ultrasonic wave travel through the liquid they get reflected from the opposite side of the vessel.

Longitudinal stationary waves are produced in the liquid medium due to the superposition of the forward and reflected waves. These stationary waves give rise to nodes and antinodes. At the nodes, the density of the liquid is maximum and so the refractive index is maximum. However at antinodes the density of the liquid is minimum and so the refractive index is minimum. Thus the nodes act as opacities and antinodes as transparencies and thereby the liquid column acts as an acoustic grating.

When the light falls on this acoustic grating the diffraction pattern is formed. The diffraction pattern consists of central maximum and first order maxima on both sides. This can be viewed through the telescope.

Let θ be the angle of diffraction for the m^{th} order and d the distance between two adjacent nodes or antinodes.

Then we have

$d \sin \theta = m \lambda$

where λ is the wavelength of light used.

By knowing the value of θ, m and λ, d can be determined. Let λL be the wavelength of ultrasonic wave in liquid

Then $d = \lambda L / 2$

$\lambda_L = 2d$

If f is the frequency of ultrasonic oscillations then, the velocity of ultrasonic waves $V = f\lambda L$

$V = 2df$ $(\because \lambda L = 2d)$

Cavitation

When ultrasonic pass through a liquid medium a large number of low pressure bubbles are produced. The high power compression and rarefraction of sound waves produced inside the liquid causes the continuous formation and collapse of millions of microscopic low pressure bubbles. This is called **cavitation.**

The collapsing of these bubbles produce tiny explosions relasing tremendous pressure of hundreds of atmospheres. The cavitations is effective at low frequencies between 20KHz - 40KHz. The size of vapour bubbles formed by cavitation is inversely proportional to the frequency of the ultrasonic waves.

The phenomenon of cavitation is used in

1. Ultrasonic cleaning
2. Emulsification
3. Locating minerals and oil deposits
4. Accelerating chemical reactions and
5. Forming stochiometric alloys and compounds.

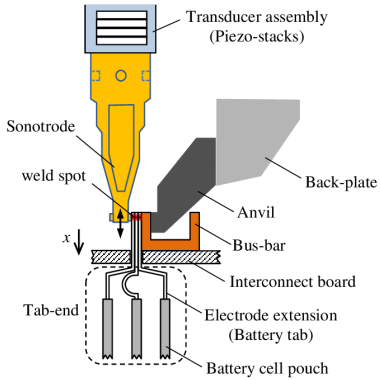
Industrial Applications

Ultrasonic Welding

The properties of some materials change on heating. In such cases, the electric or gas welding is not advisable. Such materials can be welded at room temperature with the help of ultrasonic waves. Proper welding can be achieved by sending ultrasonic waves in between the surfaces of the weld during welding called cold welding. This effect is attributed to the momentary relaxation of the bonds.

Construction

When materials are welded through ultrasonic waves, the energy required comes in the form of mechanical vibrations. The welding tool called sonotrode (hammer) is attached to a powerful ultrasonic generator. The part to be welded is placed on the anvil and located just below to tip of sonotrode as shown in Fig.



Working

When ultrasonic waves are produced, the sonotrode is made to vibrate ultrasonically. As a result, the parts to be welded are pressed simultaneously. The ultrasonic vibrating force disrupts the oxide layer of both materials. The atom diffuses from one part to the other when the oxides are dispersed. Since no oxides are at the interface, a true metallurgical bond is achieved. Thus the metals are joined by molecular transfer.

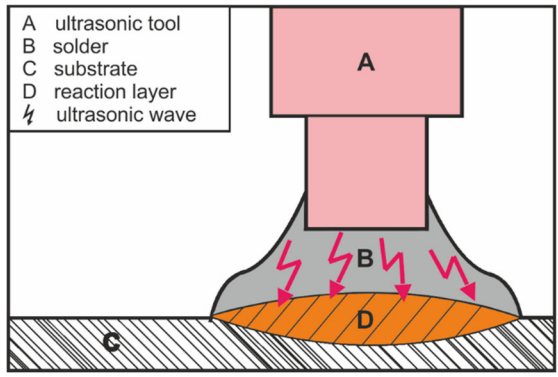
Ultrasonic Soldering

Metals like aluminium and copper form an oxide layer when contact with air. This oxide layer prevent solder from making contact with the metal.

Construction and Working

An ultrasonic soldering iron consist of an ultrasonic generator having a tip fixed at its lower and. The tip can be heat d by an electrical heating element. The experimental set up is shown in Fig.

When ultrasonic vibration is applied to the solder in the tank, many cavitation bubbles are created. The size of the bubbles increases until they become unstable and impolde. When a bubble impolde, the solder around the bubble accelerates towards the bubble middle. This solder can then hit the surface of a part creating a strong impact which simultaneously cleans the surface and destroys the oxide film on the metal. This allows soldering without using flux.



Thus during the working process the tip of the soldering iron melts the solder on aluminium and the ultrasonic vibration removes the aluminium oxide layer.

Ultrasonic Cleaning

Contamination that is soluble or emulsified can usually be removed by means of conventional method in conjunction with suitable solvent or detergent solution. However) it cannot adequately remove particles or matter in the micron and submicron size.

Though a number of methods have been used for the purpose of removing micro particles from hard surfaces, the complete removal of insoluble particulate contamination from hard substrate surfaces can be done only by ultrasonic cleaning method.

Mechanism

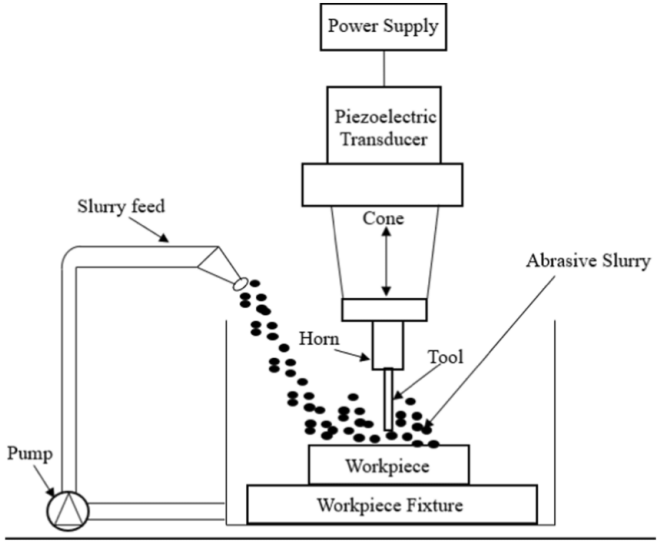
When Ultrasonic waves pass through a liquid, bubbles are formed due to cavitation. These bubbles get collapse at a tremendous rate. Thus the cleaning fluid particles, hit the surface with a great force due to this cavitation effect and the cleaning action is achieved by using ultrasonic waves.

Intricate machine parts, precision parts of a watch and parts of space craft can be thoroughly cleaned from greasy matter by placing them inside the cleaning fluid and by passing ultrasonic waves through the fluid.

Ultrasonic Driller

Ultrasonic drilling is particularly used for drilling any odd shaped hole like triangular, square etc, on a hard and brittle material like glass. The drilling set-up consists of an ultrasonic generator and a drill head as in Fig. The ultrasonic generator comprises an oscillator attached to the transducer. transducer is made of thin nickel sheets to avoid eddy current loss.

The drill bit is kept just above the work piece on which the hole has to be drilled. An abrasive powder like carborandum powder is spread over the work piece and a little amount of water is added to the powder. The oscillator is switched on and the drill bit is lowered to touch the powder-water mixture. The ultrasonic waves produce cavitation in the mixture. The low pressure bubbles formed collapse at a tremendous rate and thereby the abrasive powder particles are made to bombard the work piece with a great force and the required hole is drilled on the work piece.



Advantages of ultrasonic driller over the conventional driller

1. Any odd shaped hole can be drilled.
2. Drilling can be made on a brittle material.
3. No final finish is required.
4. Silent operation.
5. Cheap method.

Sonar

Sonar stands for Sound Navigation and Ranging. This is based on the principle of Echo-sounding. When ultrasonic wave is transmitted through water, it is reflected by the objects in the water and produce an echo. The change in frequency helps to determine the direction and their distance in the sea.

The transducer is mounted on the ships hull without any air gap between them. Piezo electric transmitter in sonar generates the short pulses of ultrasonic waves.

The timing at which the pulse generated is recorded at the CRO for reference and this electrical pulse triggers the transducer which is kept at the base.

These ultrasonic waves are transmitted through the water in the sea. On striking the object the waves are reflected back and received in the river.

By knowing the velocity of sound in sea water, the distance of the object from the ship can be calculated as

$v = 2d / t$ $d = v \times t / 2$

Thus the position, distance and the direction of the moving object can be calculated.

Non Destructive Testing

Non destructive testing (NDT) is a method by which materials are tested without destructing or damaging the material and by passing some radiations through the material. The goal of NDT is to detect defects and give information about their distribution. There are many non distructive tests in use.

The common methods are

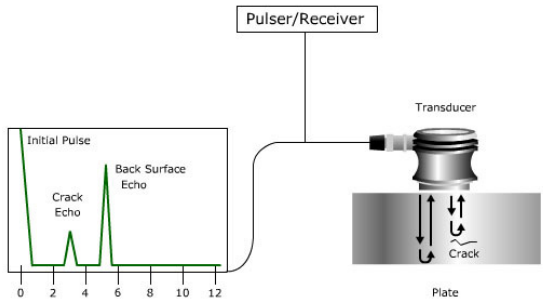
- Visual inspection
- Liquid penetrant testing
- Magnetic particle testing
- Eddy current testing
- Ultrasonic testing
- Radiography

Ultrasonic Flaw Detector

Ultrasonic waves travels in different medium with different velocities. Whenever there is a change in medium, the ultrasonic waves will be reflected back. Thus, from the intensity of the reflected echoes, the flaw can be detected without destroying the material.

Description

It consists of a piezo electric transducer coupled to the upper surface of the specimen (metal) without air gap between the specimen and the transducer. A frequency generator is connected to the transducer to generate high frequency pulses. The total set up is connected to an amplifier and to a cathode ray oscilloscope as shown in block diagram Fig.



The signal generated by the frequency generator is send to the piezoelectric transducer. Here the ultrasonic wave is split into two parts. One part is send to the specimen to collect information, whereas the other is send to the CRO for reference.

The wave travel through the specimen and is reflected back by the other end. The reflected ultrasonics (pulse B)are received by the transducer. These reflected signals are amplified and is found to be almost the same as that

of the transmitted signals as shown in Fig. which shows that there is no defect in the specimen.

If there is any defect on the specimen like a small hole the ultrasonics will be reflected by the holes i.e, defects due to the change in medium. These defects gives rise to another signal *'C'* in between pulses *'A'* and *'B'*. From the time delay between the transmitted and received pulses the position of the hole can be found. Also from the height of the pulse received the depth of the hole can be determined.

Advantages

1 It can reveal internal defects.
2 This method is highly sensitive to most of the cracks and flaws.
3 It gives immediate results.
4 It indicates the size and location of the flaws exactly.
5 Since there is no radiation in this process, it is a safe method.
6 The cost is very low.

Limitations

1 It is difficult to find the defects of the specimen which has complex shapes.
2 Trained, motivated technicians alone can perform this testing.

Pulse Echo System

The main components of a pulse echo system are transmitter, time-base generator, receiver, swept-gain generator and cathode ray oscilloscope (CRO). The transmitter gives sufficient amount of energy to the transducer, which emits a short burst of ultrasound waves. The built-in time-base generator gives a suitable voltage across the x-plates of the CRO, which helps a steady movement of the spot in the screen. The transducer is kept in close contact with the skin. A good couplant is used between the skin and the transducer to provide good coupling and also to avoid any excess reflection which occur at the air-solid boundary.

The ultrasound generated by the transducer is passed into the target. The ultrasound gets reflected back from the target. The same transducer (or a separate transducer) receives the reflected signal form the target of the patient. The received signal is amplified and then applied to the y-plates of the CRO.

There are several modes of display to amplify the received information on the CRT Screen. The most commonly used method in medical diagnostic are A-scan, B-scan and T - M scan or C-scan display. Let us discuss the various display method in detail.

A - Scan

A-scan is the simplest form of display and the prime factor in obtaining all the other scans. It gives only an one-dimensional image of the object. In this mode of display, the X-axis represent time taken by the pulse to the reach the reflecting surface and return back to the transducer. Y-axis represent the amplitude of the echoes. The size of the vertical displacement is a measurement of the echo amplitude.

Here, the transducer is fixed at one position and hence, any movement in the echo train is the result of movement of the interface target. The echo encephalogram is an example for A-scan display.

B - Scan

In the case of B-scan display, a brightness is related to the echo amplitude. The echo signal are not applied to the y-plates of the CRO as in the case of A-scan. Instead, they are used to control the brightness of the spot on the screen. This display gives a cross-sectional view of the test object and shows the position, orientation and depth of defects in the specimen. Here Y-axis represents the lapsed time and X-axis the position of the transducer. The schematic representation of the B-scan display is shown in Fig.

This method requires a skilled technical operator since an intimate contact between the probe and skin through oil is required to avoid excess reflection of any air space.

The wide spread application of B-scan ultrasound in diagnostics are to detect pregnancy, multiple foetuses, the age of the foetus, the position of the placenta, etc.,

T-M Scan or C- Scan

In the T-M mode or time-position scan, the movement of echo generating tissues is displayed as a function of time, as shown Fig. 1.13. Applying a low-velocity time base generator across the y-plates of the CRO modify the static B-scan system. The B - scan moves vertically at a constant low-velocity when the sweep time is approximately 3 seconds. Under this condition, if the reflecting interference spot moves, a horizontal deflection in the vertical line pattern is obtained as shown in Fig.

This type of display is very much useful in obtaining the pulsating structure such as heart, movement of the mitraval valve related to various period of the heart cycle etc.,

Sonograms

Sonograms are nothing but recordings of movement of heart. The graphic record of the heart sound is called **Phonocardiogram** and the instrument used to measure the heart sounds is called **phonocardiograph.**

Acoustic events of the heart can be divided into two categories ie., heart sounds and murmurs. Heart sounds have a transient character and are of short duration. Heart murmurs have a noisy characteristic and last for a longer time. In general, heart sounds are due to closing and opening of the valves, whereas the murmurs are due to the turbulent flow of blood in the heart and large vessels.

Recording set-up

A block diagram of the recording set up is shown in Fig. 1.14. The heart sounds are converted into electrical signals by means of a heart microphone fastened to the chest wall by an adhesive strip. The electrical signals from microphone are amplified by a phonocardiographic preamplifier followed by suitable filters and recorder. Further, the electrodes are also placed on the limps to pickup the electrical activity of the heart and these signals are amplified and recorded.

Special application of phonocardiogram

1 **Fetal Phonicardiogrtam:** A sthethoscopic microphone with a large chest piece is applied over that part of the maternal abdomen where auscultation revels fetal heart tones. Simultaneously with the fetal sound tracing, maternal ECG is recorded for comparison.

2 **Esophageal Phonocardiogram :** Basis of interest in the method lies in the fact that the heart sounds are collected from inside the chest. In general, sounds and murmurs have lower frequencies than when recorded by conventional techniques. The heart sounds are with shorter duration.

Acoustics

Acoustics of Buildings

Echo: The first reflected sound is known as echo. The sound produced by a source is propagated continuously in a medium if there is no disturbance. But if

it meets the hard surface of an obstacle, it is reflected. The clear echo depends upon the following factors.

1. Good reflector of sound

2. Maximum surface area of the reflector and

3. The distance of the reflector from the source of sound.

Reverberation

The sound produced in a hall suffers multiple reflections before it becomes inaudible. As a result of these reflections, the listener continues to receive sound, even if the source of sound is cut off. This prolonged reflection of sound in a room even after the sound source has been stopped is called reverberation. It is the persistence of sound due to multiple reflections from the walls, floor and ceiling of a hall. The reverberation is also called multiple echoes. In a room, the walls, floor and other flat surfaces reflect sound with a small loss of energy.

Reverberation time

If a building is to be acoustically correct, its reverberation time must be in optimum level. It should not be too long or too short. if it is too short, then the room becomes dead in sound aspect. If it is too long, then the reverberation will be there inside the building for long duration. The reverberation produces continuous sound with decreasing intensity up to a particular time after that it disappears. This time is known as reverberation time.

The reverberation time is defined as the time taken by the sound to fall from its original intensity to one millionth of its original intensity.

Sabine's formula

The theory of reverberation was developed by Sabine in 1900 and gave an expression for the reverberation time in terms of size of hall, area and absorption coefficient of various surfaces in the hall. The relation for reverberation time is called Sabine's formula.

Derivation

The effective absorbing area of the total surface S of absorption coefficient 'a' is given by,

$$A = aS$$

If a_1, a_2, a_3 etc. be the absorption coefficients at each reflection of the surfaces having areas s_1, s_2, s_3 etc. in a room, then the average value of the absorption coefficient 'a' is given by,

$$a = \frac{a_1 s_1 + a_2 s_2 + a_3 s_3 + -----}{s_1 + s_2 + s_3 + ---------} = \frac{\sum as}{S}$$

Here, S is the sum of all the surface areas in the hall and 'a' is the mean absorption coefficient. If I be the instantaneous average intensity (the energy per unit volume) of the hall and dI be the fall in intensity due to absorption in a short interval of time dt, then

$$dI = -anIdt \text{ ---------- } (1)$$

Here, n is the number of reflections of sound wave per second.

By statistical method, Jaeger showed that sound travels a mean distance of 4V / S between two successive reflections where V is the volume of hall and S is the total area of reflecting surface.

If v is the velocity of sound, then time interval between two successive reflections is given by,

$$\tau = \left(\frac{4V}{S}\right) \times \frac{1}{v}$$

Average number of reflections per second, $n = \frac{1}{\tau} = \frac{vS}{4V}$ ---------- (2)

Substituting the value of n from equation (2) in equation (1) we get,

$$\frac{dI}{dt} = -a\left(\frac{vS}{4V}\right)I \quad \Rightarrow \quad \frac{dI}{I} = -a\left(\frac{vS}{4V}\right)dt$$

Integrating within the limits from I_0, intensity at the instant the source is cut off and I, intensity in

time t, we get, $$\int_{I_0}^{I} \frac{dI}{I} = -\int_{0}^{t} a\frac{vS}{4V}dt$$

That is, $$\log_e\left(\frac{I}{I_0}\right) = -a\frac{vS}{4V}t$$

$$\frac{I}{I_0} = \exp\left[-a\frac{vS}{4V}t\right]$$

According to the definition of reverberation time – time interval in which intensity falls to one millionth of initial value, we get,

$$\frac{I}{I_0} = 10^{-6}$$

If $t = T$ is the reverberation time, then $$\exp\left[-a\frac{vS}{4V}t\right] = 10^{-6}$$

Or, $$a\frac{vS}{4V}T = 6ln10 = 6\times 2.303$$

Taking $v = 345\,\text{ms}^{-1}$, we get, $$T = \frac{13.8\,V}{345\,aS}$$

$$T = \frac{0.165V}{aS} = \frac{0.165V}{\sum as}$$

This is the Sabine's formula for the reverberation time in terms of volume of the hall, absorption coefficient and reflecting surface area.