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EXPERIMENT No. 1

Object : To determine the moment of inertia of an irregular body, about an axis passing through its centre of gravity and perpendicular to its plane by dynamical method (Inertia table).

Apparatus used : Inertia table, irregular body whose moment of inertia is to be determined, regular body whose moment of inertia can be calculated by measuring its dimensions and mass, stop watch, spirit level, physical balance with weight box and vernier callipers.

Formula used :

The moment of inertia I_1 of the irregular body is determined with the help of the following formula

$$\boxed{I_1 = I_2 \times \frac{T_1^2 - T_0^2}{T_2^2 - T_0^2},}$$

where I_2 = moment of inertia of the regular body,

T_0 = time period of inertia table alone,

T_1 = time period with the irregular body on the inertia table.

T_2 = time period with the regular body on the inertia table.

If the regular body is a disc then

$$I_2 = (1/2)\, MR^2.$$

where M = mass of the disc,

R = radius of the disc.

Description of apparatus :

The inertia table is shown in fig. (1). One end of a wire is attached to the middle of the cross bar while the other end carries a circular table. The table is made horizontal by means of three balancing weights m_1, m_2 and m_3 placed in the concentric groove cut on the upper surface using a spirit level. The base of the inertia table is made horizontal with the help of screws S_1, S_2 and S_3 (not shown) using spirit level. A mirror is attached to the wire to count the number of oscillations with the help of lamp and scale arrangement (if used). The cross bar is supported by the pillar PP fixed to a heavy base.

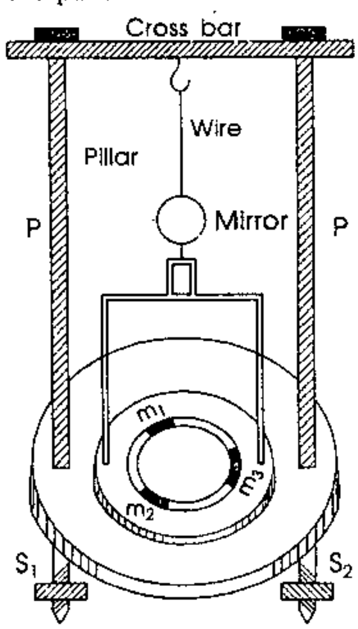

Fig. (1)

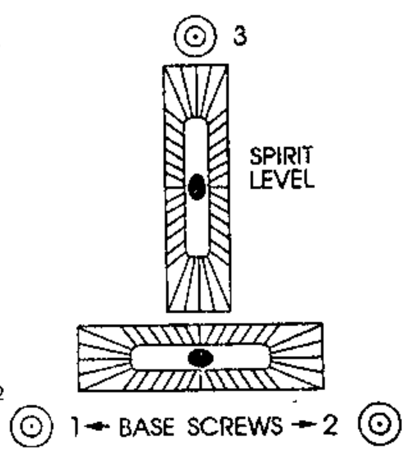

Fig. (2)

Procedure :

(i) Make the base of inertia table horizontal by using the following procedure :

Place the spirit level along a line joining the screws 1 and 2 as shown in fig. (2). Now bring the bubble in spirit level in the middle with the help of levelling screws 1 and 2. Again place the spirit level in a perpendicular direction and make the bubble to be in the middle by adjusting the third screw. It should be remembered that in the second position levelling screws 1 and 2 are not touched. The base is now horizontal.

(ii) Make the table horizontal with the help of small weights in the concentric groove and spirit level.

(iii) Slightly rotate the disc in its own plane and release it in such a way that it rotates about the wire as axis executing oscillations. Find the time taken by 10, 15, 20, 25 and 30 oscillations and thereby T_0.

(vi) Put the irregular body on the inertia table and find T_1.

(v) Remove the irregular body and place the regular body on inertia table whose moment of inertia is known by its dimensions. Thus find T_2.

(vi) Weigh the regular body (disc) and note the mass M.

(vii) Find the diameter of the disc with the help of vernier callipers.

Observations :

(1) Mass of the disc = ... kg.

(2) Table for the measurement of diameter of given disc.
(See page 3P)

(3) Table for the determination of T_0, T_1 and T_2
(See page 3P)

Calculations :

$$I_1 = I_2 \times \frac{T_1^2 - T_0^2}{T_2^2 - T_0^2}$$

$$= \frac{1}{2} MR^2 \times \frac{T_1^2 - T_0^2}{T_2^2 - T_0^2}$$

$$= \ldots\ldots\ldots\ldots\ \text{kg} \times \text{m}^2$$

Result :

Moment of inertia of the irregular body

$$= \ldots\ldots\ldots\ldots\ \text{kg} \times \text{m}^2.$$

Sources of error and Precautions :

1. The base and inertia table should always be set horizonal.
2. There should not be up and down as well as to and fro motion of the table.
3. The table should be rotated by a few degrees only.
4. There should not be any kink in the wire.
5. Periodic time should be noted very carefully.

Theoretical error :

$$I = \frac{1}{2} MR^2 \frac{T_1^2 - T_0^2}{T_2^2 - T_0^2}$$

$$= \frac{M (D/2)^2 (T_1 - T_0)(T_1 + T_0)}{2 (T_2 - T_0)(T_2 + T_0)}$$

Taking log and differentiating,

$$\frac{\delta I_1}{I_1} = \frac{\delta M}{M} + \frac{2\delta D}{d} + \frac{\delta (T_1 - T_0)}{(T_1 - T_0)} + \frac{\delta (T_1 + T_0)}{(T_1 + T_0)} + \frac{\delta (T_2 - T_0)}{(T_2 - T_0)} + \frac{\delta (T_2 + T_0)}{(T_2 + T_0)}$$

$$= \ldots\ldots\ldots\ldots$$

Maximum permissible error

$$= \ldots\ldots\ldots\ldots\ \%.$$

Table for the measurement of diameter of the given disc :

$$\text{Least count of vernier callipers} = \frac{\text{value of one div. of main scale in cm}}{\text{total no. of divisions on vernier scale}}$$

$= \ldots$ cm.

Zero error of vernier callipers $= \pm \ldots$ cm.

S. No.	Reading along any direction Θ			Reading along a perpendicular direction Φ			Uncorrected diameter $(X+Y)/2$ cm.	Mean uncorrected diameter cm.	Mean** corrected diameter (D) cm.	Mean radius $R = (D/2)$ cm.
	M.S. reading	V.S.* reading	Total X-cm.	M.S. reading	V.S. reading	Total Y-cm.				
1.	...	...	...	...	...	...	...			
2.	...	...	...	...	...	...	...	...	...	...
3.	...	..	...	...	..	...	...			

Radius $R = \ldots$ cm $= \ldots\ldots\ldots$ meter

*V.S. reading = no. of divisions of vernier scale that coincide with any division on main scale × least count of vernier callipers.

**Mean corrected diameter = Mean uncorrected diameter ± zero error.

Table for the determination of T_0, T_1 and T_2 :

S. No.	No. of oscillations	Time taken by														
		Inertia Table alone			Time period T_0	Mean T_0 sec.	Inertia Table + irregular body			Time period T_1 sec.	Mean T_1 sec.	Inertia Table + disc.			Time period T_2	Mean T_2 sec.
		Min.	Sec.	Total sec.			Min.	Sec.	Total sec.			Min.	Sec.	Total sec.		
1.	10	...	...	...	...		...	..	...	...		..	...	...	...	
2.	15	...	..	...	...		...	...	...	. .		...	...	..	...	
3.	20	..	..	...	...	...	...	...	...	...	...	...	...	...	...	...
4.	25	...	...	...	...		...	...	...	...		...	...	..	...	
5.	30	. .	...	...	...		...	...	...	...		...	...	...	...	

Viva-Voce

Q. 1. ***What do you mean by inertia ?***

Ans. According to Newton's first law of motion, every body offers a resistance to any change in its state of rest or uniform motion, unless it is compelled by externally impressed force to change that state. This property of the body is known as inertia. Inertia depends upon the mass of the body.

Q. 2. *What is moment of inertia ?*

Ans. A body capable of rotation about an axis, opposes any change in its state of rest or of uniform angular rotation about that axis. The inertia in this case is known as rotational inertia or moment of inertia.

Q. 3. *Define moment of inertia.*

Ans. (i) The moment of inertia of a body about an axis is defined as the sum of the products of the mass and square of the distance of particles from axis of rotation.

(ii) We know that kinetic energy of rotation of a body is given by

$$E = (1/2)\, I\, \omega^2 \text{ when } \omega = 1, \text{ then } 2E = I.$$

Thus the moment of inertia of a body is numerically equal to twice the kinetic energy of rotation, if angular velocity is unity.

(iii) The moment of inertia of a body about an axis is equal to the torque required to produce unit angular acceleration in it about the axis.

Q. 4. *What is radius of gyration ? What is its unit ?*

Ans. (i) The quantity whose square when multiplied by the total mass of the body gives the moment of inertia of the body about that axis, is known as radius of gyration.

(ii) Radius of gyration may be defined as the distance from the axis, at which, if the whole mass of the body were to be concentrated, the moment of inertia would have been the same about the given axis as with its actual distribution of mass. The unit of radius of gyration is cm. because it is simply a distance.

Q. 5. *What is the theorem of perpendicular axes ?*

Ans. According to this theorem, the moment of inertia of a plane lamina about a perpendicular axis, is equal to the sum of moments of inertia of the lamina about two axes at right angles to each other, in the plane of the lamina and intersecting at a point where the perpendicular axis passes.

Q. 6. *What is the theorem of parallel axes ?*

Ans. According to this theorem, the moment of inertia of a body about any axis is equal to its moment of inertia about a parallel axis, through its centre of gravity, and the product of its mass and the square of the distance between the two axes.

Q. 7. *On what factors does moment of inertia of a body depend ?*

Ans. It depends upon (i) mass of the body, (ii) distribution of mass of the body about axis of rotation and (iii) distance of centre of gravity from the axis of rotation.

Q. 8. *What is the physical significance of moment of inertia ?*

Ans. In rotational motion, moment of inertia plays the same role as mass in translational motion.

Q. 9. *What are the units and dimensions of moment of inertia ?*

Ans. Unit = $kg \times m^2$, and dimension = $M L^2$.

Q. 10. *How do you oscillate the inertia table ?*

Ans. The table is rotated slightly (by a few degrees) by hand in its own plane and then left to itself. The table performs torsional oscillations.

Q. 11. *What type of oscillations the table execute ?*

Ans. Simple harmonic oscillations in horizontal plane.

Q. 12. *Is it necessary to keep small amplitude of the oscillations of the table as in case of simple pendulum ?*

Ans. No. Here the amplitude should not be so large that the elastic limit of the wire is exceeded.

Q. 13. *What type of wire will you choose for your experiment ?*

Ans. We shall choose a thin and long suspension wire so that periodic time may be large

$$T = 2\pi \sqrt{(I/C)} \text{ where } C = \pi \eta r^4/2l$$

Q. 14. *How does the periodic time of oscillations depend ?*

Ans. This is directly proportional to square root of I and l and inversely as r^2.

Q. 15. *Will the time period change if instead of a small cylinder, we place a long cylinder of the same mass on the table ?*

Ans. No. We know that the time period is independent of length of cylinder because for a cylinder $I = MR^2/2$.

Q. 16. ***What for are the concentric circles drawn on inertia table ?***

Ans. They help us in placing a body centrally upon inertia table.

Q. 17. ***About which axis, you are finding the moment of inertia of irregular body ?***

Ans. The moment of inertia is found about an axis passing through its centre of gravity and perpendicular to its plane.

Q. 18. ***Can you find out the moment of inertia of a liquid column contained in a cylindrical jar ?***

Ans. No, because liquids do not offer any resistance to shear.

Q. 19. ***What adjustments are made before performing the experiment?***

Ans. The following two adjustments are made :

(i) Base of the apparatus is made horizontal by levelling screws.

(ii) Inertia table is made horizontal by means of balancing weights placed in circular groove.

Q. 20. ***Can you change the position of balancing weights any time during the experiment ?***

Ans. No.

EXPERIMENT No. 2

Object : To determine the moment of inertia of a flywheel about its own axis of rotation.

Apparatus used : Flywheel, metre scale, vernier callipers, stop watch, set of weights and a pan.

Formula used :

The moment of inertia I of the flywheel is given by

$$\boxed{I = \frac{m\,r\left(\dfrac{g\,t^2\,n_1}{4\,\pi\,n_2^{\,2}} - r\right)}{\left(1 + \dfrac{n_1}{n_2}\right)}}$$

where m = mass suspended at the end of string,

r = radius of the axle,

n_1 = number of revolutions made by the wheel before the mass is detached from the wheel.

n_2 = number of revolutions made by the flywheel to come to rest after the mass is detached.

t = time taken by the wheel in n_2 revolutions,

g = acceleration due to gravity.

Description of apparatus :

A flywheel is a large heavy wheel, through the centre of which passes a long cylindrical axle. The centre of gravity lies on its axis of rotation so that when it is mounted over ball bearings, it comes to rest in any desired position. To increase the moment of inertia, it is usually made thick at the rim as shown in fig. (1). To count the number of

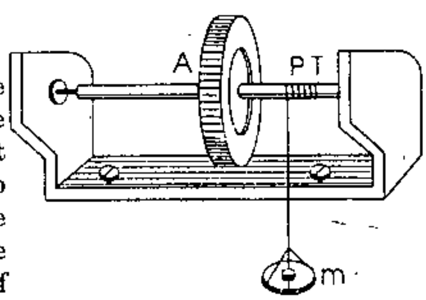

Fig. (1)

revolutions made by wheel, a line is marked on the circumference. A string is wound on the axle, attached to the peg P and carries a mass m.

Procedure :

(i) Attach a mass m (about 500 gm.) to one end of a thin thread and a loop is made at the other end which is fastened to the peg.

(ii) The thread is wrapped evenly round the axle of the wheel.

(iii) Allow the mass to descend slowly and count the number of revolutions n_1 during descent.

(iv) When the thread has unwound itself and detached from the axle after n_1 turns, start the stop watch. Count the number of revolutions n_2 before the flywheel comes to rest and stop the stop watch. Thus n_2 and t are known.

(v) With the help of vernier callipers, measure the diameter of the axle at several points. Thus find r.

(vi) Repeat the experiment with three different masses.

(vii) Calculate the value of I using the given formula.

Observation : See tables on page 8P.

Calculations :

$$I = \frac{m\,r\left(\dfrac{g\,t^2\,n_1}{4\,\pi\,n_2^2} - r\right)}{\left(1 + \dfrac{n_1}{n_2}\right)}$$

$$= \ldots\ldots\ldots\ldots\ \text{kg} \times \text{m}^2$$

Result : The moment of inertia of the flywheel is .... $\text{kg} \times \text{m}^2$.

Precautions and Sources of error :

(i) There should be uniform winding on the axle.
(ii) The string loop should be loose.
(iii) Friction should be made small by greasing the ball bearings.
(iv) The diameter of the axle should be measured at various points.
(v) Mass should fall freely.
(vi) Mass must start with zero velocity.

Theoretial error :

If r is small, then

$$I = \frac{m\,g\,.\,2\pi\,n_1\,t^2\,.\,r}{8\,\pi^2\,n_2\,(n_1 + n_2)}$$

Taking log and differentiating, we get

$$\frac{\delta I}{I} = \frac{2\delta t}{t} + \frac{\delta n_1}{n_1} + \frac{\delta n_2}{n_2} + \frac{\delta(n_1 + n_2)}{n_1 + n_2} + \frac{\delta r}{r}$$

$$= \ldots\ldots\ldots\ldots\ .$$

Maximum error = ...%.

Viva-Voce

Q. 1. *What is a flywheel ?*

Ans. It is a large sized heavy wheel mounted on a long axle supported on ball bearing.

Q. 2. *Why the mass of a flywheel is concentrated at rim ?*

Ans. This increases the radius of gyration and hence the moment of inertia of the flywheel.

Q. 3. *What is the practical utility of a flywheel ?*

Ans. It is used in stationary engines to ensure a uniform motion of the machine coupled to the engine.

Q. 4. *Is flywheel used in mobile engines also ?*

Observations :

(1) Table for determination of n_1, n_2 and t

S. No.	Total load applied m kg	No. of revolutions of flywheel before the mass detached n_1	No. of revolutions of flywheel to come to rest after mass detached n_2	Time for n_2 revolutions t sec.
1.	...	...	...	...
2.	...	...	...	...
3.	...	...	...	...
4.	...	...	...	...

(2) Table for the determination of radius of axle.

Least count of vernier callipers $= \dfrac{\text{value of one div. of main scale in cm}}{\text{total no. of divisions on vernier scale}} = \ldots$ cm.

Zero error of vernier callipers $= \pm \ldots$ cm.

S. No.	Reading along any direction ⊖			Reading along a perpendicular direction ⦶			Uncorrected diameter $(X+Y)/2$ cm.	Mean Uncorrected diameter cm.	Mean** corrected diameter (D) cm.	Mean radius $R = (D/2)$ cm.
	M.S. reading	V.S.* reading	Total X-cm.	M.S. reading	V.S. reading	Total Y-cm.				
1.	...	...	...	...	...	...	...			
2.	...	...	...	...	...	...	...	...	...	...
3.	...	...	...	...	...	...	...			

Radius R = ... cm = ... meter

*V.S. reading = no. of divisions of vernier scale that coincide with main scale × least count of vernier callipers.

**Mean corrected diameter = Mean uncorrected diameter ± zero error.

Ans. No, it is not needed in mobile engines, because the heavy body of vehicle itself serves the purpose of flywheel.

Q. 5. ***How and why does the flywheel start rotating ?***

Ans. When a weight is hanged near the axle, it has certain amount of potential energy. After releasing it, its potential energy is converted into kinetic energy of its own motion, into kinetic energy of rotating of flywheel and in overcoming the force of friction between the axle and ball bearings.

$$\therefore \qquad m\,g\,h = \frac{1}{2}\,m\,v^2 + \frac{1}{2}\,I\,\omega^2 + 2\,\pi\,n_1\,F.$$

Q. 6. ***Why the flywheel continues its revolutions even after the cord has slipped off the axle ?***

Ans. It continues its revolutions due to its large moment of inertia.

Q. 7. ***Then, why does it stop after a very short time ?***

Ans. The energy of the flywheel is dissipated in overcoming the friction at the ball bearings.

Q. 8. ***What is the purpose of finding n_2 ?***

Ans. The friction offered by the ball bearings is very small but it is not negligible. To account for the work done by weight against friction, the number of revolutions made by flywheel after the weight is detached should be found.

Q. 9. ***Can you use a thin wire instead of a string ?***

Ans. No, we cannot use a wire because metals are pliable and so when the wire unwinds itself, some amount of work will also be done in straightening the wire.

Q. 10. ***Why do you keep the loop slipped over the peg loose ?***

Ans. We keep the loop slipped over the peg loose so that it may get detached as soon as the string unwinds itself and does not rewind in opposite direction.

Q. 11. ***What is the harm if the thread overlaps in winding round the axle ?***

Ans. In this case the couple acting on the wheel will not be uniform and hence the flywheel will not rotate with uniform acceleration.

❑❑❑

EXPERIMENT No. 3

Object : To study the variation of moment of inertia of a system with the variation in the distribution of mass and hence to verify the theorem of parallel axes.

Apparatus used : Maxwell's needle apparatus with solid cylinders only and a stop watch or a light aluminium channel about 1·5 metre in length and 5 cm. in breadth fitted with a clamp at the centre to suspend it horizontally by means of wire, two similar weights, stop watch and a metre scale.

Formula used :

The time period T of the torsional oscillations of the system is given by

$$\boxed{T = 2\,\pi\sqrt{\left[\frac{I_0 + 2\,I_s + 2\,m_s\,x^2}{c}\right]}}$$

where I_0 = moment of inertia of hollow tube or suspension system,

I_s = moment of inertia of solid cylinder or added weight about an axis passing through their centre of gravity and perpendicular to their lengths,

m_s = mass of each solid cylinder or each added weight,

x = distance of each solid cylinder or each added weight from the axis of suspension,

c = torsional rigidity of suspension wire.

Squaring the above equation

$$T^2 = \frac{4\,\pi^2}{c}\,[I_0 + 2\,I_s + 2\,m_s\,x^2]$$

$$= \frac{8\,\pi^2\,m_s\,x^2}{c} + \frac{4\,\pi^2}{c}\,(I_0 + 2\,I_s)$$

This equation is of the form $y = m\,x + c$. Therefore, if a graph is plotted between T^2 and x^2, it should be a straight line.

Description of the apparatus :

The main aim of this experiment is to show that how the moment of inertia varies with the distribution of mass. The basic relation for this is $I = \Sigma m x^2$. Two equal weights are symmetrically placed on this system. By varying their positions relative to the axis of rotation, the moment of inertia of the system can be changed.

The Maxwell's needle with two solid cylinders can be used for this purpose. The two weights are symmetrically placed in the tube on either side of the axis of rotation and their positions are noted on the scale engraved by the side of the groove on the hollow brass tube as shown in fig. (1). The time period of the torsional oscillations is now determined. Now the positions of these cylinders are changed in regular steps which cause the variation in distribution of mass. By measuring the time periods in each case, the moment of inertia of the system is determined. In this way, the variation of moment of inertia of the system is studied by the variation in the distribution of mass. For the successful performance of the experiment, the moment of inertia of the suspension system should be much smaller than the moment of inertia of the added weights so that a large difference in the time period may be obtained by varying the position of the added weights. For this purpose a light aluminium channel of about 1·5 metre in length and 5 cm. in breadth may be used as shown in figure (2).

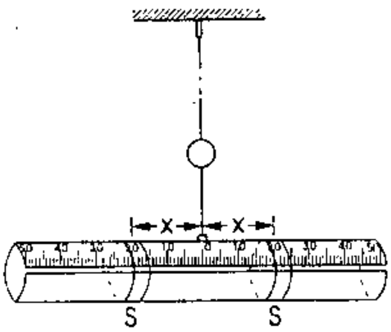

Fig. (1)

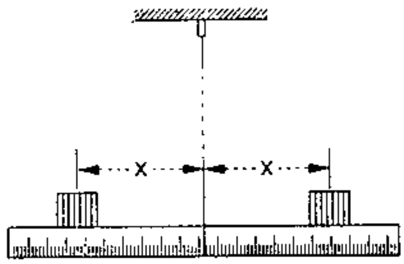

Fig. (2)

Procedure :

(i) As shown in fig. (1), put the two solid cylinders symmetrically on either side in the hollow tube of Maxwell's needle and note the distance x of their centre of gravity from the axis of rotation.

Or, As shown in fig. (2), put the two equal weights on the aluminium channel symmetrically on either side of axis of rotation and note the distances x of their centre of gravity from the axis of rotation.

(ii) Rotate the suspension system slightly in the horizontal plane and then release it gently. The system executes torsional oscillations about the suspension wire.

(iii) Note the time taken by 25–30 oscillations with the help of a stop watch and then divide the total time by the number of oscillations to calculate the time period T.

(iv) Now displace both the cylinders or added weights by a known distance say 5 cm. away from the axis of rotation and determine the time period as discussed above.

(v) Take atleast 5 or 6 such observations at various values of x by displacing the weights in regular steps of 5 cm.

(vi) Now plot a graph between x^2 on X-axis and corresponding values of T^2 on Y-axis. The graph is shown in fig. (3).

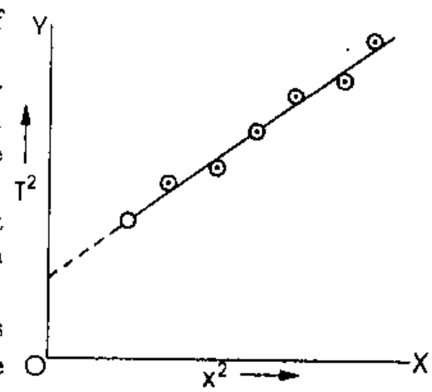

Fig. (3)

Observations :

Table for time period T and the distance x of the weight.

S. No.	Distance of the cylinder or added weight from axis of rotation x meter	x^2 (m^2)	Time Period				T^2 sec^2.
			Number of oscillations n	Time taken t sec.	Time period $T = (t/n)$ sec.	Mean time period T, sec.	
1.	x_1	x_1^2	20 25 30	... ...	... ...	...	...
2.	x_2	x_2^2	20 25 30	... ...	... ...	...	...
3.	x_3	x_3^2	... ...	... ...	... ...	...	...

Result : Since the graph between T^2 and x^2 comes out to be a straight line, it verifies that the basic theorem $I = \Sigma m x^2$ from which theorem of parallel axes follows, is valid.

Sources of error and Precautions :

(i) The suspension wire should be free from kinks.

(ii) The suspension system should always be horizontal.

(iii) The two solid cylinders or added weights should be identical.

(iv) Oscillations should be purely rotational.

(v) The suspension wire should not be twisted beyond elastic limits.

(vi) Periodic time should be noted carefully.

Object : (i) Determination of C, couple per unit twist, of the suspension wire.

(ii) Determination of I_s, the moment of inertia of the suspended system and I_0, the moment of inertia of the system with two added masses at $x = 0$, about an axis passing through the suspension wire.

Formula used :

The couple per unit twist C is given by $C = 8\pi^2 m_s (\Delta x^2/\Delta T^2)$

If T_s and T_0 are the periods of oscillation with the suspension system alone, and the system plus the two bodies at $x = 0$, then

$$I_s = 2 m_s x^2 \frac{T_s^2}{T_x^2 - T_0^2} \quad \text{and} \quad I_0 = m_s x^2 \frac{T_0^2 - T_s^2}{T_x^2 - T_0^2}.$$

Procedure :

Same as discussed in experiment no. 3.

Observations :

(i) Mass of the solid cylinder or added weights $m_s = ...$ kg

(ii) Time period $T_s = ...$ sec.

(iii) Time period $T_0 = ...$ sec.

(iv) Same observations as of experiment 3.

Calculations :

From the graph of exp. 3 obtain the value of $(\Delta T^2/\Delta x^2)$.

Now $$C = 8\pi^2 m_s \left(\frac{\Delta x^2}{\Delta T^2}\right) = \ldots \text{ Newton-meter per unit twist}$$

Using T_x^2 values for different x values from the observation table, calculate,

$$I_s = 2 m_s x^2 \frac{T_s^2}{T_x^2 - T_0^2} = \ldots \text{ kg . m}^2$$

$$I_0 = 2 m_s x^2 \frac{T_s^2}{T_x^2 - T_0^2} = \ldots \text{ kg . m}^2$$

Vice-Voce

Q. 1. ***How the moment of inertia of a system can be changed ?***

Ans. The moment of inertia of a system can be changed by varying the distribution of mass.

Q. 2. ***Which apparatus you are using for this purpose ?***

Ans. We are using Maxwell's needle for this purpose.

Q. 3. ***How do you vary the distribution of mass here ?***

Ans. By changing the positions of two weights symmetrically inside the tube.

Q. 4. ***What will be the effect on time period of the system by varying the distribution of mass ?***

Ans. The time period T increases as x increases.

Q. 5. ***Can you verify the theorem of parallel axes with this experiment?***

Ans. Yes. If a graph is plotted between T^2 and x^2, it comes out to be a straight line. This verifies the theorem of parallel axes.

Q. 6. ***What type of motion is performed by the needle ?***

Ans. The needle performs the simple harmonic motion.

Q. 7. ***Should the amplitude of vibration be small here ?***

Ans. It is not necessary because the couple due to torsional reaction is proportional to the angle of twist. Of course, the amplitude should not be so large that the elastic limit is crossed as the wire is thin and long.

□□□

EXPERIMENT No. 4

Object : To estimate the time period of a simple pendulum using the theory of errors, graph-Gaussian distribution.

Apparatus used : Metallic bob with hook, thread, vernier callipers, stop watch, metre scale and clamp.

Formula used :

The time period T of a simple pendulum is given by

$$\boxed{T = 2\pi\sqrt{\left(\frac{l}{g}\right)}}$$

where, l = effective length of the pendulum *i.e.*, length of the thread + radius of the bob

g = acceleration due to gravity.

Description of apparatus : The simple pendulum is shown in fig. (1). An ideal simple pendulum consists of a heavy particle suspended by a weightless, inextensible and perfectly flexible string from a point about which it can vibrate without friction. These conditions are difficult to realise in practice. Hence a metallic bob suspended by means of a cotton thread constitutes a simple pendulum.

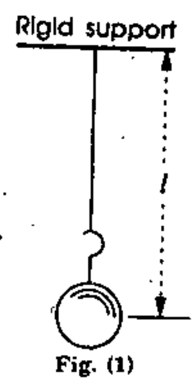

Fig. (1)

Procedure : The following procedure is adopted :

(i) Find the vernier constant and zero error of vernier callipers. Determine the diameter and hence the radius of the bob with the help of vernier callipers.

(ii) Tie the bob to one end of the cotton thread. The other end of the thread is clamped to a rigid support.

(iii) Take the bob to either side of the point of suspension and release it. The pendulum begins to oscillate.

Q. 11. ***What is a simple pendulum ?***

Ans. A simple pendulum is just a heavy particle, suspended from one end of an inextensible, weightless string whose other end is fixed to a rigid support.

Q. 12. ***Suppose a clear hole is bored through the centre of the earth and a ball is dropped in it, what will happen to the ball ?***

Ans. The ball will execute simple harmonic motion about centre of earth.

Q. 13. ***Define a compound pendulum.***

Ans. A compound pendulum is a rigid body, capable of oscillating freely about a horizontal axis passing through it (not through its centre of gravity) in a vertical plane.

Q. 14. ***What do you understand by centre of suspension and oscillation?***

Ans. *Centre of suspension :* It is a point where the horizontal axes of rotation intersects the vertical section of the pendulum taken through centre of gravity.

Centre of oscillation : This is another point, on other side of centre of gravity at a distance k^2/l from it and lying in the plane of oscillation. k being radius of gyration and l, the distance of centre of suspension from centre of gravity.

Q. 15. ***How does the period vary with distance of knife edge from centre of gravity of the pendulum ?***

Ans. The time period is infinite at centre of gravity. It decreases rapidly and becomes minimum when the distance is equal to radius of gyration. At still greater distances the period again increases.

Q. 16. ***What do you mean by equivalent simple pendulum ?***

Ans. This is a simple pendulum of such a length that its periodic time is same as that of a compound pendulum.

Q. 17. ***What is the length of equivalent simple pendulum ?***

Ans. We know that

$$T = 2\pi\sqrt{\frac{(k^2/l + l)}{g}} = 2\pi\sqrt{\frac{L}{g}}$$

where $L = \sqrt{\left(\frac{k^2}{l} + l\right)}$, known as length of equivalent simple pendulum.

Q. 18. ***About how many and which points is the period of a compound pendulum the same ?***

Ans. The time period about centre of suspension and centre of oscillation is the same. By reversing the pendulum, we have two more points (centre of suspension and oscillation) about which the time period is same. In this way, there are four points collinear with C.G. about which time period is same. Two points lie on one side of C.G. and two on the another side of C.G.

Q. 19. ***What is the periodic time, when centre of suspension coincides with C.G. of compound pendulum?***

Ans. The periodic time becomes infinite.

Q. 20. ***What will be the form of l^2 vs. $(T^2 \times l)$ graph and why ?***

Ans. The graph will be a straight line because

$$T^2 \times l = \frac{4\pi^2}{g} l^2 + \frac{4\pi^2}{g} k^2$$

This is of the form

$$y = mx + c.$$

❑❑❑

EXPERIMENT No. 5

Object : To study simple harmonic under-damped oscillations and to calculate (i) time period T of oscillation, (ii) angular frequency ω, (iii) relaxation time τ and (iv) the quality factor Q of the oscillations.

Apparatus required : A long (nearly 1·5 meter) wooden bar like meter scale; 2 to 3 meter long suspension wire, two dampers (thin semicircular aluminium plate of nearly 0·10 m radius), two 0·10 kg. weights and a stopwatch.

Formula used :

(i) The time period T of the oscillations is given by

$$\boxed{T = \frac{\Delta t}{n},}$$

where Δt is the time interval of n oscillations.

(ii) Angular frequency

$$\boxed{\omega = \frac{2\pi}{T}}$$

(iii) The relaxation time τ is given by

$$\boxed{\tau = -\frac{\Delta t}{4{\cdot}60 \times \log_{10} \theta(t)}}$$

where $\theta(t)$ is the displacement interval for time interval Δt.

(iv) The quality factor $Q = \omega\, t$.

Description of the apparatus :

The apparatus is shown in fig. (1). A 1·5 metre scale is suspended from a rigid support by means of a suspension wire. The suspension wire should be large enough to ensure reasonably large period of oscillation. Just below the metre scale a table with circular scale is placed so that angular deflection of the scale may be noted. To keep the suspension wire tight, two dampers are placed on the metre scale and two 100 gm. weights are placed for varying the moment of inertia of the system and hence time period. By changing the positions of these weights, the time period of the system can be changed.

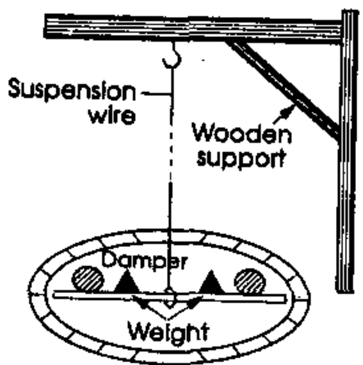

Fig. (1)

Procedure :

(i) Set up the arrangement as shown in fig. (1) with length of the suspension wire nearly about 2–3 metre.

(ii) Now give the scale a fairly large angular displacement and let it go. It should be observed that the oscillations should be in a horizontal plane.

(iii) After few oscillations, start taking reading of angular displacement on the circular scale at intervals of 10 secs. Continue this process till the amplitude of the oscillations falls to about one fifth of its initial value.

(iv) By varying the positions of the dampers or the 0·1 kg. weights take the new sets.

Observations :

Position of 0·1 kg weights = ... meter
Position of dampers = ... meter

Table for angular displacement and time.

Time sec.	Displacement, div.	Time, sec.	Displacement, div.
..	...	...	..
...	...	...	...
...	...	...	...
...	...	...	...

Calculations :

A graph is plotted between time and displacement. This graph is known as time displacement graph and is shown in (fig. 2). The curve passing through the peaks is drawn. This curve gives the fall of amplitude with time. With this graph we note the time interval Δt for say n oscillations. Now we calculate $T = \Delta t/n$ and hence $\omega = 2\pi/T$. We also note the amplitudes $\theta(t)$ at several values of t and calculate $\log_{10} \theta(t)$. We then tabulate these values as shown in table. A graph is then plotted between t and $\log_{10} \theta(t)$.

Time in sec.	Amplitude $\theta(t)$	$\log_{10} \theta(t)$
50	...	...
100	..	...
150	...	...
200	...	...
250	...	..
:	...	...
500	...	..

The graph is shown in fig. (3). Now calculate T, ω, τ and Q as follows :

(i) From fig. (2) take time interval Δt for n oscillations, say for four oscillations Δt = 350 sec., then

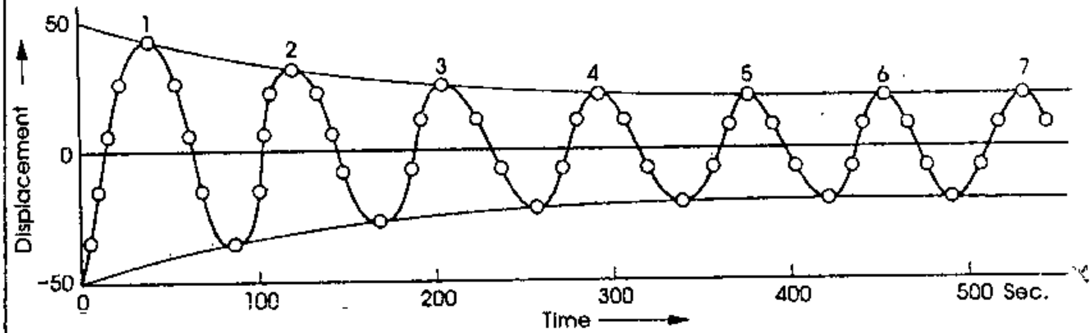

Fig. (2)

$$T = \frac{\Delta t}{4} = \frac{350}{4} = 87{\cdot}5 \text{ sec.}$$

(ii) Angular frequency

$$\omega = 2\pi/T = \text{......sec}^{-1}$$

(iii) The relaxation time

$$\tau = -\frac{\Delta t}{4{\cdot}60 \times \log_{10} \theta(t)}$$

$$= -\frac{1}{4{\cdot}60}\frac{CB}{AC}$$

from fig. (3)

$$= + \text{......sec.}$$

(iv) Quality factor

$$Q = \omega\,\tau = \text{.......}$$

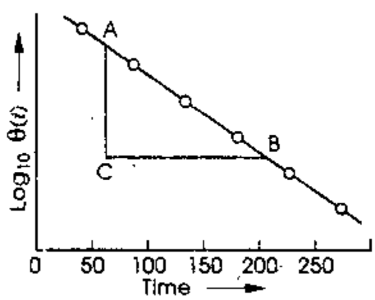

Fig. (3)

Results :

(i) Time period T = ...sec.

(ii) Angular frequency ω = ...sec^{-1}

(iii) The relaxation time τ = + ...sec.

(iv) Quality factor Q = ...

Precautions and Sources of Error :

(i) The time period of the system should be large.
(ii) The motion must be steady and horizontal.
(iii) Special care should be taken to avoid air currents.
(iv) The scale should not touch the table.
(v) Time period should be measured accurately.

Viva-Voce

Q. 1. *What type of oscillations are in this experiment ?*

Ans. The oscillations are simple harmonic underdamped oscillation.

Q. 2. *How do you change the time period ?*

Ans. The time period is changed by changing the position of damper or the weights.

Q. 3. *What important precaution you take in this experiment ?*

Ans. The oscillations should be in a horizontal plane.

Q. 4. *How do you calculate the angular frequencies ?*

Ans. The angular frequency is calculated by using the formula $\omega = 2\pi/T$, where T is the periodic time.

Q. 5. *What would be the shape of the graph drawn between time and log of amplitude of vibration ?*

Ans. Straight line.

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EXPERIMENT No. 6

Object : To determine Young's modulus, modulus of rigidity and Poisson's ratio of the material of a given wire by Searle's dynamical method.

Apparatus used : Two identical bars, given wire, stop watch, screw gauge, vernier callipers, balance, candle and match box.

Formula used :

The Young's modulus (Y), modulus of rigidity (η) and Poisson's ratio (σ) are given by the formula,

$$Y = \frac{8\pi I l}{T_1^2 r^4} \quad \text{... (1)}$$

$$\eta = \frac{8\pi I l}{T_2^2 r^4} \quad \text{... (2)}$$

$$\sigma = \frac{T_2^2}{2T_1^2} - 1 \quad \text{... (3)}$$

where I = moment of inertia of the bar about a vertical axis through its centre of gravity.
l = length of the given wire between the two clamping screws.
r = radius of the wire.
T_1 = time period when the two bars execute simple harmonic motion together.
T_2 = time period for the torsional oscillations of a bar.

Description of the apparatus :

Two identical rods AB and CD of square or circular cross section connected together at their middle points by the specimen wire, are suspended by two silk fibres from a rigid support such that the plane passing through these rods and wire is horizontal as shown in fig. (1a).

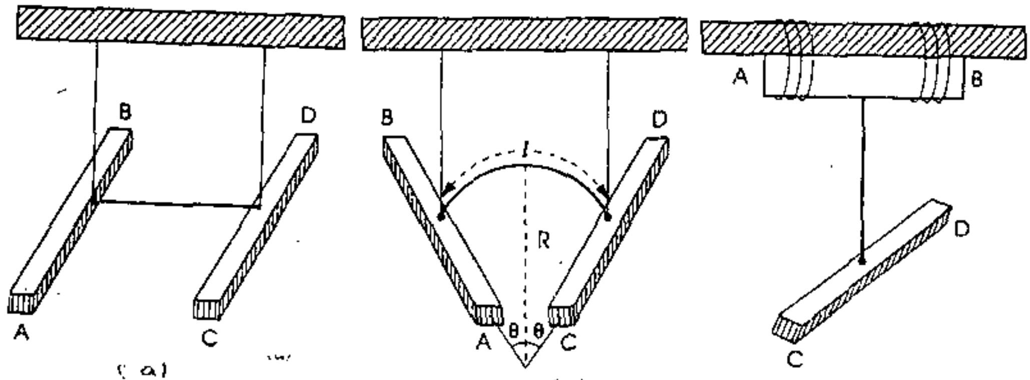

Fig. (1). (b)

Procedure :

(i) Weigh both the bars and find the mass M of each bar.

(ii) The breadth b of the cross bar is measured with the help of vernier callipers. If the rod is of circular cross-section then measure its diameter D with vernier callipers.

(iii) Measure the length L of the bar with an ordinary meter scale.

(iv) Attach the experimental wire to the middle points of the bar and suspend the bars from a rigid support with the help of equal threads such that the system is in a horizontal plane [fig. (1) a].

(v) Bring the two bars close together (through a small angle) with the help of a small loop of the thread as shown in [fig. (1) b].

(vi) Burn the thread. Note the time period T_1 in this case.

(vii) Clamp one bar rigidly in a horizontal position so that the other hangs by the wire [fig. (1) c]. Rotate the free bar through a small angle and note the time period T_2 for this case also.

(viii) Measure the length l of the wire between the two bars with meter scale.

(ix) Measure the diameter of the experimental wire at a large number of points in a mutually perpendicular directions by a screw gauge. Find r.

Observations :

(i) Table for the determination of T_1 and T_2. Least count of the stop watch = ... sec.

S. No.	No. of oscillations (n)	Time T_1			Time period $T_1 = (a/n)$ sec	Mean T_1 sec.	Time T_2			Time period $T_2 = (b/n)$ sec	Mean T_2 sec.
		Min.	Sec.	Total sec. (a)			Min.	Sec.	Total sec. (b)		
1	5	...	...	...	...		...	...	...	...	
2	10	...	...	...	...		...	...	...	...	
3	15	...	...	...	...	...	...	...	...	...	...
4	20	...	...	...	...		...	...	...	...	
5	25	...	...	...	...		...	...	...	...	

(ii) Mass of either of the AB or CD rod = ... gm. = ... kg.

(iii) Length of the either bar (L) = ... cm.

(iv) Table for the measuremnet of breadth of the given bar.

$$\text{Least count of vernier callipers} = \frac{\text{value of one div. of main scale in cm}}{\text{total no. of divisions on vernier scale}} = \ldots\text{cm.}$$

Zero error of vernier callipers = ± ... cm.

S. No.	Reading along any direction ϴ			Reading along a perpendicular direction ⦶			Uncorrected diameter $b = (X + Y)/2$ cm.	Mean corrected breadth b cm.
	M.S. reading	V.S.' reading	Total X-cm.	M.S. reading	V.S. reading	Total Y-cm.		
1	...	...	...	...	...	...	...	
2	...	...	...	...	...	...	...	...
3	...	...	...	...	...	...	...	

b = ... cm = ... meter.

If the bars are of circular cross section then the above table may be used to determine the diameter D of the rod.

(v) Length (l) of wire = ... cms.

(vi) Table for the measurement of diameter of the given wire.

Least count of screw gauge $= \dfrac{\text{value of one div. of main scale in cm}}{\text{total no. of divisions on vernier scale}} = \ldots$ cm.

Zero error of screw gauge = ± ... cm.

S. No.	Reading along any direction Θ			Reading along a perpendicular direction Θ			Uncorrected diameter $(X+Y)/2$ cm.	Mean Uncorrected diameter cm.	Mean** corrected diameter (d) cm.	Mean radius $r = (d/2)$ cm.
	M.S. reading	V.S.* reading	Total X-cm.	M.S. reading	V.S. reading	Total Y-cm.				
1	...	...	...	...	...	...	...			
2	...	...	...	...	...	...	...	...	...	...
3	...	...	...	...	...	...	...			

r = ... cm = ... meter

*V.S. reading = no. of divisions of vernier scale that conincide with main scale × least count of vernier callipers.

**Mean corrected diameter = Mean uncorrected diameter ± zero error.

Calculations :

$$I = \frac{M(L^2 + b^2)}{12}$$

$= \ldots$ kg × m² [For square cross-section bar]

$$I = M\left(\frac{L^2}{12} + \frac{D^2}{16}\right) = \ldots \text{ kg} \times \text{m}^2 \text{ [For circular bar]}$$

(i) $$Y = \frac{8\pi I l}{T_1^2 r^4} = \ldots \text{ newton/meter}^2$$

(ii) $$\eta = \frac{8\pi I l}{T_2^2 r^4} = \ldots \text{ newton/meter}^2$$

(iii) $$\sigma = \frac{T_2^2}{2T_1^2} - 1 = \ldots$$

Result :

$Y = \ldots$ newton/meter^2

$\eta = \ldots$ newton/meter^2

$\sigma = \ldots\ldots$

Standard Result :

$Y = \ldots$ newton/meter^2

$\eta = \ldots$ newton/meter^2

$\sigma = \ldots\ldots$

Percentage error : $Y =$ **...%.** $\eta =$ **...%, and** $\sigma =$ **...%.**

Precautions and Sources of Error :

(i) Bars should oscillate in a horizontal plane.
(ii) The amplitude of oscillations should be kept small.
(iii) The two bars should be identical.
(iv) Length of the two threads should be same.
(v) Radius of wire should be measured very accurately.

Theoretical error : $$Y = \frac{8\pi I l}{T_1^2 r^4} = \frac{8\pi l}{T_1^2 \left(\frac{d}{2}\right)^4} \times \frac{M(L^2 + b^2)}{12}$$

Taking log and differentiating

$$\frac{\delta Y}{Y} = \frac{\delta l}{l} + \frac{\delta M}{M} + \frac{\dfrac{2L\,\delta L}{(L^2+b^2)}}{12} + \frac{\dfrac{2b\,\delta b}{(L^2+b^2)}}{12} + \frac{2\,\delta T_1}{T_1} + \frac{4\,\delta d}{d}$$

= ......

Maximum permissible error = ...%.

Similarly find it for η and σ.

Viva-Voce

Q. 1. ***How are Y and η involved in this method ?***

Ans. First of all the wire is placed horizontally between two bars. When the bars are allowed to vibrate, the experimental wire bent into an arc. Thus the outer filaments are elongated while inner ones are contracted. In this way, Y comes into play. Secondly, when one bar oscillates like a torsional pendulum, the experimental wire is twisted and η comes into play.

Q. 2. ***Is the nature of vibrations the same in the second part of the experiment as in the first part ?***

Ans. No. In the second case, the vibrations are torsional vibrations.

Q. 3. ***Should the moment of inertia of the two bars be exactly equal?***

Ans. Yes. If the two bars are of different moment of inertia, then their mean value should be used.

Q. 4. ***Do you prefer to use heavier or lighter bars in this experiment ?***

Ans. We shall prefer heavier bars because they have large moment of inertia. This increases the time period.

Q. 5. ***Can not you use thin wires in place of threads ?***

Ans. No, because during oscillations of two bars, the wires will also be twisted and their torsional reaction will affect the result.

Q. 6. ***From which place to which place do you measure the length of wire and why?***

Ans. We measure the length of the wire from centre of gravity of one bar to the centre of gravity of the other because it is the length of the wire which is bent or twisted.

Q. 7. ***Is there any restriction on the amplitude of vibration in both part of experiments ?***

Ans. When the two rods vibrate together, the amplitude of vibration should be small so that the supporting threads remain vertical and there is no horizontal component of tension in the threads. In case of torsional oscillations there is no restriction on the amplitude of oscillations but the wire should not be twisted beyond elastic limits.

Q. 8. ***Why do the bars begin oscillating when the thread tied to them is burnt ? Do they perform S.H.M.?***

Ans. When the wire is bent into circular arc and the thread is burnt, the wire tries to come back to its original position due to elastic reaction. In doing so it acquires kinetic energy. Due to this energy the wire overshoots the initial position and becomes curved in another direction. The process is repeated and the bar begins to oscillate.

Yes, the rod performs simple harmonic motion.

Q. 9. ***What do you mean by Poisson's ratio ?***

Ans. Within the elastic limits, the ratio of the lateral strain to the logitudinal strain is called Poisson's ratio.

$$\sigma = \frac{\text{Lateral strain}}{\text{Longitudinal strain}}.$$

Q. 10. ***What are various relationship between elastic constants ?***

Ans.
$$Y = 2\eta(1+\sigma), \qquad Y = 3K(1-2\sigma)$$
$$\sigma = \frac{3K - 2\eta}{6K + 2\eta}, \qquad Y = \frac{9\eta K}{\eta + 3K}.$$

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EXPERIMENT No. 7

Object : To study the oscillations of a rubber band and a spring.
Apparatus used : Rubber bands (cycle tube), a pan, mounting arrangement, weight of 50 gm., stop watch and spring.
Formula used :

(1) For experimental verification of formula

$$\boxed{\frac{T_1}{T_2} = \sqrt{\left(\frac{m_1 g}{m_2 g}\right)} \times \sqrt{\left(\frac{K_{x'_0}}{K_{x_0}}\right)}}$$

where T_1 = Time period of a rubber band when subjected to a load $m_1 g$.

T_2 = Time period of the same rubber when subjected to load $m_2 g$.

K_{x_0} = Force constant of rubber band corresponding to equilibrium extension x_0.

$K_{x'_0}$ = Force constant of rubber band corresponding to equilibrium extension x'_0.

where x_0 and x'_0 are the equilibrium extensions corresponding to loads $m_1 g$ and $m_2 g$.

This formula can also be verified with a spring.

(2) The entire potential energy U (joule) of the system is given by

$$U = U_b - mg.x$$

where U_b = potential energy of the rubber band or springs.

x = displacement from the equilibrium position due to a load mg.

$-mg.x$ = gravitational energy of mass m which is commonly taken as negative.

Procedure : (1) Set up the experimental arrangement as shown in fig. (1) in such a way that when a load is subjected to the rubber band, the pointer moves freely on metre scale. Remove the load and note down the pointer's reading on metre scale when rubber band is stationary.

(2) Place a weight of 0·05 kg on the pan. Now the rubber band is stretched. Note down the pointer reading on the meter scale.

(3) Continue the process (2) of loading the rubber band in steps of 0·05 kg and note the extension with the elastic limit.

(4) The reading of the pointer is also recorded by removing the weights in steps. If the previous readings are almost repeated then the elastic limit has not exceeded. For a particular weight, the mean of two corresponding readings gives the extension for that weight.

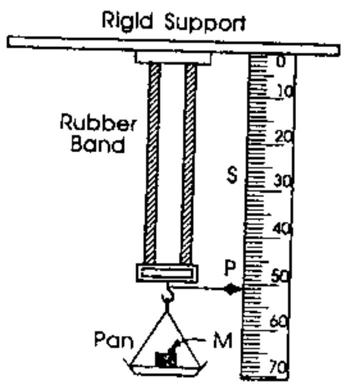


Fig. (1)

(5) Again place 0·05 kg in the pan and wait till the pointer is stationary. Now slightly pull down the pan and release it. The pan oscillates vertically with amplitude decreasing quickly. Record the time of few oscillations with the help of sensitive stop watch. Calculate the time period. Repeat the experiment for other loads to obtain the corresponding time periods.

(6) Draw a graph between load and corresponding extension. The graph is shown in fig. (2). Take different points on the curve and draw tangents. Obtain the values of Δm and Δx for different tangents. Calculate the force constant using the following formula

$$K_{x_0} = g\left(\frac{\Delta m}{\Delta x}\right)_{x_0}$$

Record the extensions from graph and corresponding force constants in the table.

(7) Calculate the time periods by using the formula

$$T_1 = 2\pi\sqrt{\left(\frac{m_1}{K_{x_0}}\right)} \quad \text{and} \quad T_2 = 2\pi\sqrt{\left(\frac{m_2}{K_{x_0}'}\right)}$$

Compare the experimental time periods with calculated time periods.

(8) From load extension graph, [fig. (2)], consider the area enclosed between the curve and the extension axis for different loads increasing in regular steps. The areas are shown in fig. (3). The area gives U_b corresponding to a particular extension.

(9) Calculate U_m for mass = 0·1 kg. and and obtain the value of U by the formula $$U = U_b + U_m$$

(10) Draw a graph in extension and the corresponding energies *i.e.*, U_b, U_m and U. The graph is shown in fig. (4).

(11) Same procedure can be adopted in case of a spring.

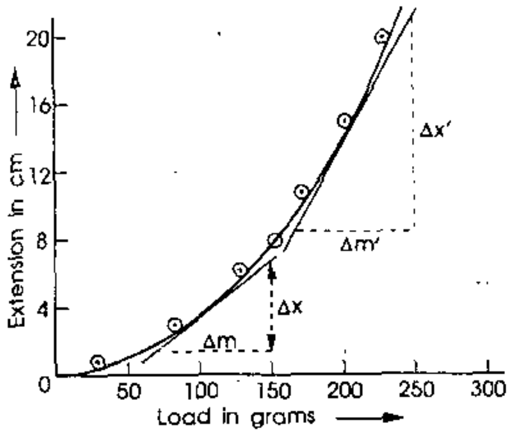


Fig. (2)

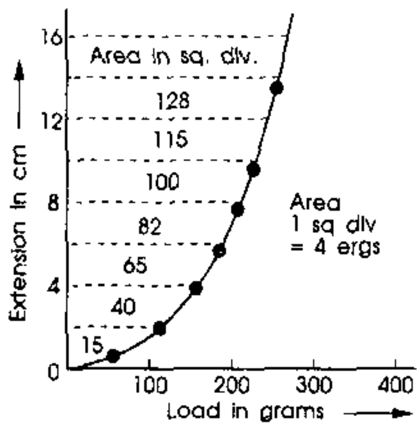


Fig. (3)

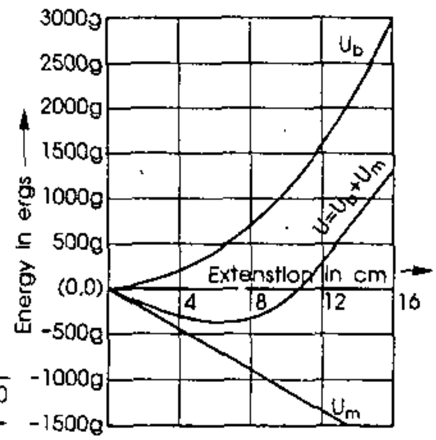


Fig. (4)

Observations and Calculations :

Table 1. For load extension graph :

S. No.	Mass suspended in kg.	Reading of pointer with load		Mean $(a+b)/2$ meter	Extension of band meter
		Increasing (a) meter	Decreasing (b) meter		
1	0	...	...	...	...
2	0·05	...	...	...	...
3	0·1	...	...	...	...
4	0·15	...	...	...	...
5	0·2	...	...	...	...
6	0·25	...	...	...	...
7	0·3	...	...	...	...

Original length of the rubber band = ... cm.

Table 2. For oscillations of the band :

S. No.	Mass suspended kg.	No. of oscillations	Time sec.	Time period (observed)	Equil. extension from graphs	K from graph nt./met.	Period (Cal.)
1	0·05	...	...	...	...	...	...
2	0·15	...	...	...	...	...	...
3	0·25	...	...	...	...	...	...

Table 3. Computation of U_b, U_m versus extension ; $m = 0{\cdot}1$ kg.

S. No.	U_b joule	U_m for $m = 0{\cdot}1$ kg joule	$U = U_b + U_m$ joule
0	0	0	0
2	$(15 \times 4)\,g = 60\,g$	$-\,200\,g$	$-\,140\,g$
4	$(60\,g + 40 \times 4\,g) = 220\,g$	$-\,400\,g$	$-\,180\,g$
6	$(220\,g + 65 \times 4\,g) = 480\,g$	$-\,600\,g$	$-\,120\,g$
8	$(480\,g + 82 \times 4\,g) = 808\,g$	$-\,800\,g$	$+\;8\,g$
10	$(808\,g + 100 \times 4\,g) = 1208\,g$	$-\,1000\,g$	$+\,208\,g$
12	$(1208\,g + 115 \times 4\,g) = 1668\,g$	$-\,1200\,g$	$+\,468\,g$
14	...	...	...

Results : (1) The force constant of rubber band is a function of extension a in elastic limit.

If the same experiment is performed with spring, then it is observed that the force constant is independent of extension a within elastic limit.

(2) From table 2, it is observed that the calculated time periods are the same as experimentally observed time periods.

(3) U_b , U_m and U versus extension are drawn in the graphs of fig. (4).

Sources of errors and Precautions :

(1) The rubber band should not be loaded beyond 8% of the load required for exceeding the elastic limit.

(2) Time period should be recorded with sensitive stop watch.

(3) The experiment should also be performed by decreasing loads.

(4) The experiment should be performed with a number of rubber bands.

(5) Amplitude of oscillations should be small.

(6) For graphs, smooth curves should be drawn.

Viva-Voce

See Viva-Voce of Experiments Nos. 16 and 17.

❑❑❑

EXPERIMENT No. 8

Object : To determine the coefficient of viscosity of water, by Poiseuille's method.

Apparatus required : A capillary tube of uniform bore and a constant level reservoir fitted on a board, a manometer, travelling microscope, stop watch and graduated jar.

Formula used :

The coefficient of viscosity η of a liquid is given by the formula

$$\boxed{\eta = \frac{\pi P r^4}{8 V l} = \frac{\pi (h \rho g) r^4}{8 V l} \quad \text{kg/(m-sec)} \quad \text{or Poise}}$$

where r = radius of the capillary tube

V = volume of water collected per second

l = length of the capillary tube

ρ = density of liquid ($\rho = 1{\cdot}00 \times 10^3$ kg/m^3 for water)

h = difference of levels in manometer.

Description of Apparatus :

The apparatus used for the purpose of determination of the coefficient of viscosity of water is shown in fig. (1).

The capillary tube C is well fitted in T and T whose upper parts are jointed by rubber tubing to two upright glass tube forming the manometer. With the help of the pinch cock K, a steady flow of water is maintained through the capillary tube. The water is collected in a graduated cylinder on the other side of the capillary tube *i.e.* the volume of water flowing per second can be determined. The pressure difference is recorded by noting the difference in heights of the liquid in the mano- meter.

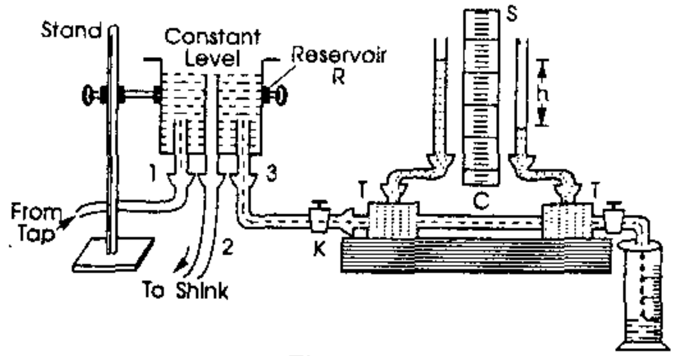


Fig. (1)

According to the formula, the pressure difference is made constant by a constant pressure device. It consists of a reservoir provided with three tubes. The water enters through tube (1) and flows into the capillary tube through tube (3) while the excess of water comes out through tube (2). The height of water level is maintained constant in the reservoir, hence the pressure difference is constant at the two ends. By raising or lowering the reservoir, the pressure is changed.

Procedure :

(i) Allow the water to enter the constant level reservoir through tube (1) and leave through tube (2) in such a way that water comes drop by drop from the capillary tube. This is adjusted with the help of pinch cock K. It should be remembered that all the bubbles should be removed from the capillary.

(ii) When everything is steady, collect the water in a graduated jar for few minutes and thus calculate the volume V of the water flowing per second.

(iii) Note the difference of the level of water in the manometer. This gives h.

(iv) Vary h by raising or lowering the reservoir. For each value of h, find the value of V. Take atleast six readings in this way.

(v) Measure the length l and diameter of the tube.

(vi) Draw a graph between h and V and find the value of $\left[\frac{h}{V}\right]$ from the graph.

Observations :

S. No.	Manometer reading		Pressure difference h (meter)	Measurement of V		V meter^3/sec
	One end (meter)	Other end (meter)		Total volume of water collected (meter)^3	Time t (sec).	
1.	...	...	...	...	...	...
2.	...	...	...	...	...	...
3.	...	...	...	...	...	..
4.	...	...	...	...	...	...
5.	...	...	...	...	...	...
6.	...	...	...	...	...	...

Table for the measurement of the diameter of the capillary tube.

$$\text{L.C. of microscope} = \frac{\text{Value of one div. of main scale in cm.}}{\text{Total no. of divisions on vernier scale.}} = \ldots \text{ cm.}$$

S. No.	Reading along any direction θ			Reading along a perpendicular direction ϕ			Diameter d $[X+Y)/2]$ cm.	Mean diamter d cm.	Mean radius $r = d/2$ cm.
	one end read-ing	second end readng	differe-nce X-cm.	one end readng	second end read-ing	differ-ence Y-cm.			
1.	...	...	...	...	...	...	...		
2.	...	...	...	...	...	...	...	...	..
3.	...	...	...	...	...	...	...		

$r = \ldots$ cm $= \ldots$ meter

Calculations : The coefficient of viscosity η for water is given by

$$\eta = \frac{\pi \rho g r^4}{8l}\left(\frac{h}{V}\right)$$

Draw a graph between h and V. The graph is shown in fig. (2).

Find the value of $\left(\frac{h}{V}\right)$ from the graph.

$\eta = \ldots$ Poise

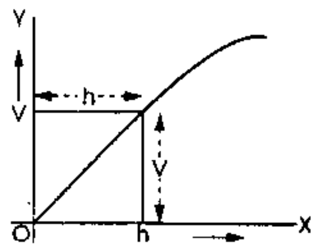


Fig. (2)

Result : The coefficient of viscosity of water at ...°C

= ... Poise

Standard result = ... Poise

Percentage error = ...%.

Precautions and Sources of error :

(i) The tube should be placed horizontally to avoid the effect of gravity.

(ii) The value of h should not be made large and should be so adjusted that the water comes out as a slow trickle.

(iii) The radius should be measured very accurately as it occurs in fourth power in the formula.

(iv) The pressure difference should be kept small to obtain streamline motion.

Theoretical error :

$$\eta = \frac{\pi \rho g r^4}{8l}\left(\frac{h}{V}\right) = \frac{\pi \rho g (d/2)^4 h t}{8 l V'}$$

where V' is the total volume of water collected in t secs. and d is the diameter of the capillary.

Taking log and differentiating

$$\frac{\delta\eta}{\eta} = 4\frac{\delta d}{d} + \frac{\delta h}{h'} + \frac{\delta t}{t} + \frac{\delta l}{l} + \frac{\delta V'}{V'}$$

$$= \ldots$$

$\therefore$ Maximum permissible error = ...%.

Viva-Voce

Q. 1. ***What do you mean by viscosity ?***

Ans. The property of a liquid by virtue of which it opposes the relative motion between its different layers is known as viscosity.

Q. 2. ***Define coefficient of viscosity.***

Ans. The coefficient of viscosity is defined as the viscous force acting per unit area between two adjacent layers moving with unit velocity gradient.

Q. 3. ***What is stream line motion ?***

Ans. When a liquid flows through a tube in such a manner that each molecule of the fluid travels regularly along the same path as its preceeding molecule, the motion is said to be streamline.

Q. 4. ***What is turbulent flow ?***

Ans. Beyond critical velocity, the paths and velocities of the liquid change continuously and haphazardly then the flow is called turbulent flow.

Q. 5. ***What is the effect of pressure and temperature on coefficient of viscosity ?***

Ans. The coefficient of viscosity increases with rise of pressure and decreases with rise of temperature.

Q. 6. ***In Poiseuille's method what overcomes the viscous force ?***

Ans. The constant pressure difference at the two ends of the tube.

Q. 7. ***Is it necessary to keep the pressure difference constant ?***

Ans. Yes. If the pressure difference is not constant, then the rate of flow of water through the capillary tube will change.

Q. 8. ***Does the flow of liquid depend only on its viscosity ?***

Ans. For velocities below critical velocity, the rate of flow is governed by viscosity and is independent of density. However, for higher velocities, the rate of flow depends to a greater extent on density rather than viscosity.

Q. 9. ***Why the capillary should be of uniform cross section ?***

Ans. If the capillary is not of uniform cross section, the rate of flow through it will not be linear.

Q. 10. ***On what factors does the rate of flow of water through the capillary tube depends ?***

Ans. It depends upon (i) pressure difference p, (ii) radius of capillary tube r and (iii) length of capillary tube.

Q. 11. ***Can not you use a tube of larger diameter ?***

Ans. No, the rate of flow of water will be quite large even for a small pressure difference and the motion will not be stream line.

Q. 12. ***Can you use this apparatus to determine the viscosity of a gas?***

Ans. No.

Q. 13. ***Why do you keep the capillary tube horizontal ?***

Ans. When the tube is horizontal, the flow is not affected by gravity.

EXPERIMENT No. 9

Object : To determine terminal velocity of a body in a viscous medium (e.g. glycerine) by Stoke's law.

Apparatus required : Stoke's viscometer, viscous liquid, steel balls of different sizes, stop watch, screw gauge, thermometer and meter scale.

Formula used :

If after attaining terminal velocity, the steel ball falls through a known distance, h, in time, t, then terminal velocity is

$$v = \frac{h}{t} \text{ m/s}$$

The theoretical relation to compare the experimental values obtained is

$$v = \frac{2}{9}\frac{(d-\rho)}{\eta} g\, r^2 \text{ Poise}$$

where, d = density of the substance of the body (e.g. density of steel in case of steel balls)

ρ = density of viscous liquid (e.g. glycerine)

g = acceleration due to gravity

r = radius of falling body (steel balls)

η = coefficient of viscosity of viscous liquid.

Description of the apparatus : *Same as in experiment no. 26* (to determine coefficient of viscosity by Stoke's method)

Procedure : *Same as in experiment No. 26.*

The important consideration is that the first mark should be sufficiently below the upper surface of the liquid so that when ball falls through h_1 or h_2, it should have attained the constant velocity—the so called terminal velocity. Therefore, h_1/t_1 or h_2/t_2 will give the value of terminal velocity.

Observations :

(i) Temperature of water bath = ...°C

(ii) Density of the material of the ball, d = ... kg/m^3

(iii) Density of the viscous liquid, ρ = ... kg/m^3

(iv) Coefficient of viscosity of the liquid, η = ... poise

(v) Measurement of the diameter of the balls : Table same as in expt. No. 26.

(vi) Measurement of h/t, the terminal velocity : Table same as in expt. No. 26.

Calculations : Theoretical values of terminal velocity are calculated using the relation

$$v = \frac{2}{9}\frac{(d-\rho)}{\eta} g\, r^2$$

Find v_1, for ball-1 on putting its radius, r_1; v_2 for ball- 2 on putting its radius, r_2 etc. Tabulate them as follows for various balls :

Table : Values of terminal velocity.

S. No.	Experimental values, *h/t*, m/sec	Theoretical value m/sec	Difference
1.	...	...	...
2.	...	...	...
3.	...	...	...

Precautions and Sources of error : Same as in expt. No. 26.

Viva-Voce

Q. 1. ***What is Stoke's law ?***

Ans. According to Stoke's law, the retardation F, due to the viscous drag for a spherical body of radius r moving with a velocity v in a medium whose coefficient of viscosity is η, is given by

$$F = 6\,\pi\,v\,r\,\eta \text{ newton}$$

This relation is known as Stoke's law.

Q. 2. ***Why do you take small balls in experiment ?***

Ans. The terminal velocity v is directly proportional to the square of the radius of ball hence for small balls, the terminal velocity will be small and time needed to travel between the given marks will be large.

Q. 3. ***Why do you wet the balls before allowing them to fall through the liquid ?***

Ans. To ensure that no air film is formed around the ball in falling through the liquid.

Q. 4. ***For what types of liquids, this method is suitable ?***

Ans. This method is suitable only for highly viscous liquids.

Q. 5. ***In equilibrium state which forces act on the body ?***

Ans. The following three forces act on the body :

(i) Weight of the ball $= (4/3)\,\pi\,r^3\,d\,g$ acting vertically downward.

(ii) Upthrust of the liquid $= (4/3)\,\pi\,r^3\rho g$ acting vertically upwards.

(iii) Viscous force $= 6\,\pi\,\eta\,r\,v$ acting vertically upwards.

Q. 6. ***How the above forces balance in equilibrium ?***

Ans. $(4/3)\,\pi\,r^3\,d\,g = (4/3)\,\pi\,r^3\,\rho\,g + 6\,\pi\,\eta\,r\,v.$

Q. 7. ***What would be the expression for terminal velocity ?***

Ans. $$v = \frac{2\,r^2}{9}\frac{g\,(d-\rho)}{\eta}$$

Q. 8. ***On what factors the terminal velocity depends ?***

Ans. The terminal velocity of a body of small size falling through a viscous medium is (i) directly proportional to the square of its radius (r^2), (ii) directly proportional to the difference in densities of the body and the medium ($d - \rho$) and, (iii) inversely proportional to the coefficient of viscosity of the medium (η).

Q. 9. ***Why the tiny rain drops appear to us to be floating about as clouds?***

Ans. The tiny drops of water have a radius as small as 0·001 cm. and their terminal velocity, as they fall through air ($\eta = 0{\cdot}00018$) comes to about 1·2 cm/sec. Hence they appear to us to be floating about as clouds.

Q. 10. ***How can you study the variation of viscosity with temperature with the help of this apparatus ?***

Ans. This can be studied by maintaining the water bath at different temperatures.

❑❑❑

EXPERIMENT No. 10

Object : To draw velocity and momention vectors in case of two dimensional collision.

Apparatus required : A collision apparatus, two steel balls of different mass and radii, sheets of paper and carbon paper of large size.

Description of the arrangement :

Collision apparatus, fig. (1), is a very smooth curved plane on which balls are rolled on from a certain height. P_1, P_2 are two balls, whose centres, when P_1 is at the end of plane, and P_2 is placed on another stand, are not in line so that when they collide-there will be a two dimensional collision. Position of their centres is marked on a sheet stretched below the stand on a smooth ground as O_1 and O_2 with the help of a plumb line. Below the sheet is a carbon fixed on a white thick paper to give imprints on it, the moment balls fall on it.

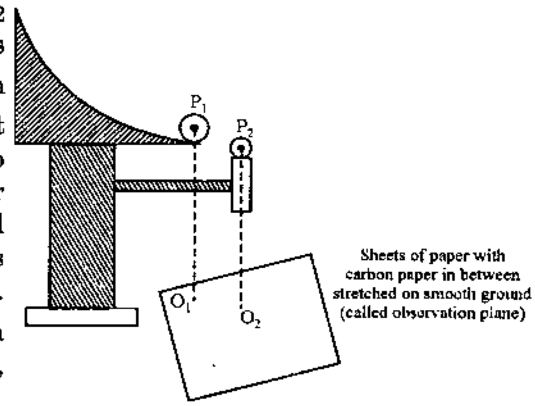


Fig. (1)

Procedure :

(i) First remove ball P_2 and allow P_1 to roll from a certain height on the curved plane (collision should remain elastic) and let it fall on the paper. Mark its position as P_1^0.

(ii) Now place ball P_2 in its position and allow ball P_1 to roll from the same height and let it strike P_2. After collision they fall on paper and let their marks be designated as P_1' and P_2' (prime indicating state after collision).

Observation and plotting of velocity and momentum vectors.

As height from ground of P_1 and P_2 is almost the same, the time to arrive at the observation plane (ground) is same and is taken as Δt. Therefore

$$O_1P_1' = V_1' \,\Delta t \rightarrow \text{after collision for ball } P_1$$

$$O_2P_2' = V_2' \,\Delta t \rightarrow \text{after collision for ball } P_2$$

$$O_1P_1^0 = V_1^0 \,\Delta t \rightarrow \text{when ball } P_1 \text{ alone falls.}$$

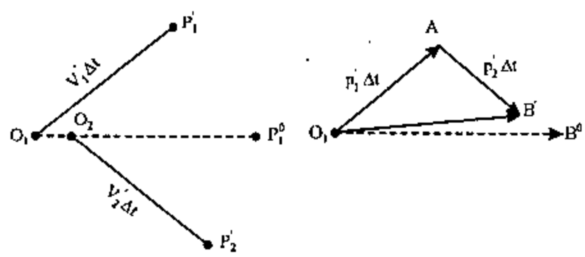
This description gives velocity vectors. Similarly

$$p_1' = m_1 O_1 P_1' \text{ is corresponding momentum vector parallel to } O_1P_1'$$

$$p_2' = m_2 O_2 P_2' \text{ is corresponding momentum vector parallel to } O_2P_2'$$

$$p_1^0 = m_1 O_1 P_1^0 \text{ is corresponding momentum vector parallel to } O_1P_1^0$$

Now as shown in fig. (2), we plot velocity and momentum vectors.



(a) Velocity vectors ($m_1 > m_2$) (a) Momentum vectors

Fig. (2)

Directions and magnitude of $\overrightarrow{OB}'$ and $\overrightarrow{OB}^{\circ}$ is different. It shows that in a collision, momentum of an individual body is not conserved ; instead momentum of the system is conserved. Note if the mass of the balls be equal then, as one of the balls is initially at rest, the recoiling balls always move off at right angles to one-another. It can be verified from diagram for velocity vectors.

EXPERIMENT No. 11

Object : To convert a Weston galvanometer into an ammeter of a given range.

Apparatus required : A Weston galvanometer, accumulator, high resistance box, voltmeter, ammeter of the same range as given for conversion, plug key, resistance wire and apparatus for determining the galvanometer resistance by Kelvin's method (if the resistance of galvanometer is not given).

Formula used :

The shunt resistance S required to convert the galvanometer into an ammeter is given by

$$\boxed{S = \frac{I_g}{I - I_g} G,} \quad \ldots (1)$$

where I_g = the maximum current that passes through the galvanometer for full scale deflection.

I = range of the ammeter in which the galvanometer is to be converted (say 3 amp.), and

G = galvanometer resistance.

The value I_g is given by

$$I_g = C_s N, \quad \ldots (2)$$

where N = total number of divisions on the scale of the galvanometer on one side of the zero of scale (say 30).

C_s = current sensitivity or figure of merit, and is given

by
$$C_s = \frac{E}{n(R+G)}, \quad \ldots (3)$$

where E = e.m.f. of the cell,

R = resistance introduced (R.B.) in the circuit of galvanometer,

n = deflection in galvanometer on introducing R in galvanometer circuit,

G = galvonometer resistance.

Now the length l of the shunt wire can be calculated by formula

$$l = \frac{S}{\rho} \quad \ldots (4)$$

where S = shunt resistance, calculated from eq. (1)

ρ = resistance per unit length of shunt wire.

or length can be calculated by using

$$l = \frac{\pi r^2 S}{k} \quad \ldots (5)$$

where r is the radius of wire used and k the specific resistance of the material of wire.

Value of k can be had from table of constants. For copper $k = 1.78 \times 10^{-6}$ ohm. cm. Then by measuring the radius of the wire, r, the length, l, of the wire can be found. But make sure that wire is of pure copper.

Theory : For the measurement of the strength of the current flowing in a circuit an ammeter is used. This is always used in series so that the whole current may pass through it. The ammeter should have negligible resistance in order that it may not alter the current in the circuit. In fact, an ideal ammeter should have zero resistance.

A galvanometer as such cannot be used as an ammeter due to the following reasons :

(i) The resistance of the galvanometer coil is appreciable.

(ii) It can measure only a limited current corresponding to the maximum deflection on the scale.

Both these objects are overcome by connecting a low resistance in parallel (shunt) with a pivoted type moving coil galvanometer. Due to this combination the effective resistance of the galvanometer is decreased. The value of the shunt depends upon the range of the required ammeter.

To convert a galvanometer into an ammeter of given range, we must determine experimentally the resistance of the galvanometer coil, the current sensitivity and the shunt. This is done in the following way :

Let C_S = current sensitivity of the galvanometer,

N = total number of divisions on the scale,

I_g = the maximum current that passes through the galvanometer for the full scale deflection,

I = rangeof the ammeter in which the galvanometer is to be converted,

S = the value of shunt required.

Then $I_g = C_S \times N$.

Considering fig. (1) the potential difference between A and B as

$$V_A - V_B = (I - I_g)\,S = I_g \times G$$

or
$$S = \frac{I_g\,G}{I - I_g}$$

where G is the galvanometer resistance. Hence knowing the value of the shunt, galvanometer can be converted into an ammeter of the given range I. The galvanometer resistance is determined by Kelvin's method using a Post Office Box.

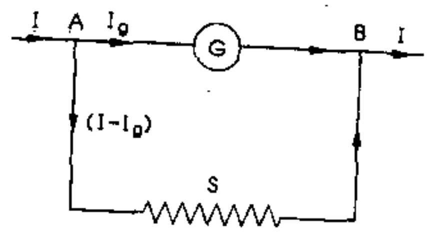


Fig. (1)

Procedure :

(A) Determination of the galvanometer resistance (G).

If the galvanometer resistance is not given, determine it with the help of Kelvin's method. Let $G = 120$ ohms.

(B) Determination of the figure of merit of the galvanometer.

(i) Set up the electrical circuit as shown in figure (2).

(ii) Measure the E.M.F. E of the accumulator by voltmeter. Note down the initial reading of the galvanometer and adjust the resistance box to a high value say 5,000 ohms.

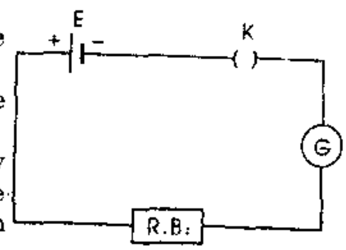


Fig. (2)

(iii) Close the key K and adjust the resistance box to get approximately the full scale deflection. Let R be the resistance in resistance box to obtain n divisions deflection in galvanometer taking into account the zero reading.

(iv) Calculate C_S using the formula

$$C_S = \frac{E}{n\,(R + G)}$$

(v) Again calculate $I_g = C_S \times N$,

where N is total number of divisions on one side of the scale of galvanometer.

(C) Determination of shunt resistance and length of the shunt wire.

Calculate
$$S = \frac{I_g \times G}{I - I_g}$$

where I is range of the ammeter in which galvanometer is to be converted.

Now
$$l = \frac{S}{\rho}$$

where ρ is resistance per unit length of the wire used for shunt (given),

or
$$l = \frac{\pi r^2 S}{k}$$

where k is the specific resistance of the material of wire. r is the radius of wire. For copper $k = 1.78 \times 10^{-6}$ ohm. cm. In order to use this value of k, it is necessary that wire is of pure copper.

(D) Calibration of the converted galvanometer.

(i) Set up the electrical circuit as shown in figure (3).

(ii) For a particular setting of R_h close the key K and note down the ammeter and galvanometer readings.

(ii) Convert the galvanometer reading into amperes and find the difference between the readings of the two instruments.

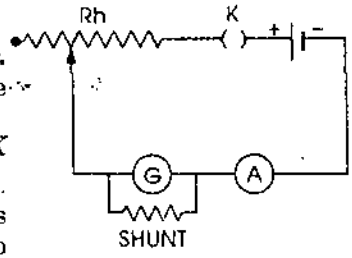


Fig. (3)

(iv) Change the value of R_h and repeat the above procedure till the whole range of the converted galvanometer is covered.

(v) Draw a graph taking converted galvanometer readings as abscissae and corresponding ammeter readings as ordinates. The graph is shown in figure (4).

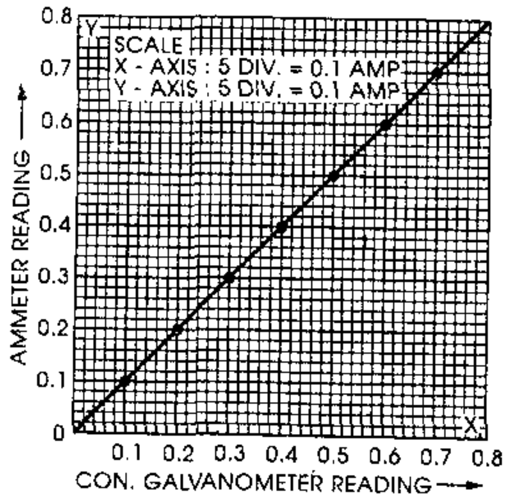


Fig. (4)

Observations :

(A) Determination of galvanometer resistance :

Note down the observations for Kelvin's method for the determination of galvanometer resistance.

Galvanometer resistance $G = \ldots$ ohm.

(B) Determination of I_g :

E.M.F. E of the cell = ... volt.

No. of division (on one side of zero of scale) on the galvanometer $(N) = \ldots$

S. No.	Resistance introduced in resistance box R ohms.	Deflection in galvanometer n	Figure of merit C_s	$I_g = C_s N$ amp.	Mean C_s
1	...	...	...	...	
2	...	...	...	...	...
3	...	...	...	...	

(C) Calibration of shunted galvanometer :

S. No.	Reading of shunted galvanometer		Ammeter reading I' in amp.	Error $(I - I')$ amp.
	In divs.	In ampere (I)		
1	...	...	...	...
2	...	...	...	...
3	...	...	...	...
4	...	...	...	...
5	...	...	...	...
6	...	...	...	...

Calculations :

(i) Figure of merit $C_S = \dfrac{E}{n\,(R+G)}$

$= \ldots$

(ii) $I_g = C_s \times N$

$= \ldots$amp.

(iii) Shunt resistance $S = \dfrac{I_g}{I - I_g} \times G$

$= \ldots$ ohm.

(iv) Length of shunted wire $= \frac{\pi r^2 S}{k} = \ldots$ cm.

Result : The length of the shunt wire of S.W.G. .... required to convert the given galvanometer into an ammeter of range of .... amp. = ...cm.

Precautions and Sources of error :

(i) The accumulator used should be fully charged.

(ii) The galvanometer and ammeter readings should initially be at zero mark.

(iii) The ammeter used for calibration of shunted galvanometer should be of nearly the same range.

(iv) The resistance box used in determining the figure of merit should be of high resistance. Before putting the key, it should be kept at high value otherwise the galvanometer may be damaged.

(v) While connecting the shunt exact length should be connected in parallel to the galvanometer.

Viva-Voce

Q. 1. ***What is an ammeter ?***

Ans. It is an instrument designed to read current flowing in an electrical circuit. It is placed in series with the circuit.

Q. 2. ***What will happen if it is connected in parallel to the circuit ?***

Ans. It will measure only the part of current flowing through it and not the total current.

Q. 3. ***Why the resistance of an ammeter be kept low ?***

Ans. If the resistance of the ammeter is made high, it will change the value of the current in the circuit.

Q. 4. ***How is the resistance made low ?***

Ans. It is done by connecting a low resistance (shunt) in parallel with galvanometer.

Q. 5. ***What is the order of resistance of a moving coil ammeter ?***

Ans. It is of the order of .01 ohm.

Q. 6. ***How do you convert a galvanometer into an ammeter ?***

Ans. After deciding the range of ammeter, we find the resistance of shunt. Then from resistance we find the length of shunt to be connected in parallel with the galvanometer.

Q. 7. ***How can you change the range of ammeter ?***

Ans. By changing the resistance of shunt.

Q. 8. ***Suppose we want to increase its range then what should we do ?***

Ans. The resistance of the shunt is to be decreased.

Q. 9. ***Find the value of shunt resistance needed to increase the range of an ammeter of 1 amp, having resistance of 0.9 ohm, to 10 amp.***

Ans. $I_g = I \frac{S}{G+S}$ where $I_g = 1$ amp., $S = ?$, $G = 0.9$ ohms and $I = 10$ amp.

Therefore $\quad I = 10 \frac{S}{S+0.9}$

or $\quad 9S = 0.9$

or $\quad S = 0.1$

Thus resistance of the shunt is to be decreased to 0.1 ohm. from 0.9 ohm., if we want to extend the range from 1 ampere to 10 amperes.

Q. 10. ***What is a milliammeter ?***

Ans. It is a low range ammeter.

Q. 11. ***How will you change ammeter into milliammeter ?***

Ans. Resistance of milliammeter is more than the resistance of an ammeter. Therefore to convert an ammeter into a milliammeter, the resistance of the shunt is increased.

Q. 12. ***Can you measure alternating current with this ammeter ?***

Ans. For it, a hot wire ammeter is needed.

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EXPERIMENT No. 12

Object : To convert Weston galvanometer into a voltmeter of the given range.

Apparatus required : A Weston galvanometer, accumulator, high resistance box, voltmeter of the same range as given for conversion, plug key, a rheostat and apparatus for determining the galvanometer resistance by Kelvin's method (if the resistance of galvanometer is not given).

Formula used.

To convert the galvanometer into a voltmeter of a given range the series resistance R needed for it is given by

$$\boxed{R = \frac{V}{I_g} - G} \quad \dots (1)$$

where G = galvanometer resistance.

V = the required voltmeter range.

I_g = value of the current required to get a full scale deflection in the galvanometer.

$$I_g = C_s \, . N \quad \dots (2)$$

where N = total number of divisions on the scale of the galvanometer (on one side of zero).

C_s = current sensitivity or figure of merit.

$$= \frac{E}{n\,(R+G)} \quad \dots (3)$$

where E = E.M.F. of the cell.

R = resistance introduced in the circuit of galvanometer.

n = deflection in galvanometer on introducing resistance R in the galvanometer circuit.

G = galvanometer resistance.

Theory : To measure the potential difference between two points, a voltmeter is employed. It is always connected in parallel to the branch across which the potential is to be measured. It must have a high resistance so that it may not draw appreciable current otherwise the current in the circuit will decrease, resulting in the fall of potential difference to be measured. Thus ideal voltmeter should have infinite resistance.

A moving coil galvanometer cannot be used as a voltmeter because its resistance is not very high. Its resistance is made high by placing a high resistance in series with the galvanometer. The high resistance can be calculated as folows :

Let G = galvanometer resistance.

I_g = maximum current in the galvanometer for full scale deflection.

V = maximum potential difference to be measured.

Using figure (1) and applying Ohm's law, we write

$$I_g = \frac{V}{R+G}$$

or

$$R + G = \frac{V}{I_g}$$

$$R = \frac{V}{I_g} - G$$

In this way R can be calculated.

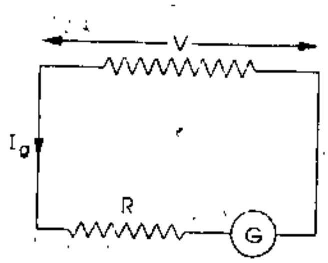

Fig. (1)

Procedure :

(A) Determination of the galvanometer resistance (G) :

If the galvanometer resistance is not given, determine it with the help of Kelvin's method.

(B) Determination of figure of merit of the galvanometer (C_g) :

Thus has been discussed in the previous experiment No. 3.

(C) Determination of series resistance :

Using the formula $R = \frac{V}{I_g} - G$, calculate the series resistance R required to change the galvanometer into voltmeter of the given range of V volt that is, if we want to convert galvanometer into a voltmeter of 3 volts then $V = 3$ volt.

(D) Calibration of the converted galvanometer :

(i) Set up the electrical connections as shown in figure (2). The two base terminals of a rheostat R_h are connected in series with a battery B and key K. The galvanometer together with its series resistance (introduce a resistance box) is connected in parallel to the rheostat R_h. Between the same points, a voltmeter is also connected.

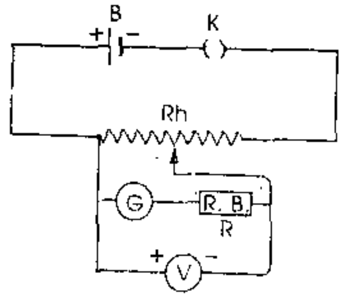

Fig. (2)

(ii) By shifting the position of the sliding contact on the rheostat, take a number of readings in galvanometer and voltmeter respectively. Convert the galvanometer reading in volt and calculate the error between the two readings.

(iii) Plot a graph between converted galvanometer reading in volt and corresponding reading in voltmeter. The graph will be a straight line. The graph is shown in figure (3).

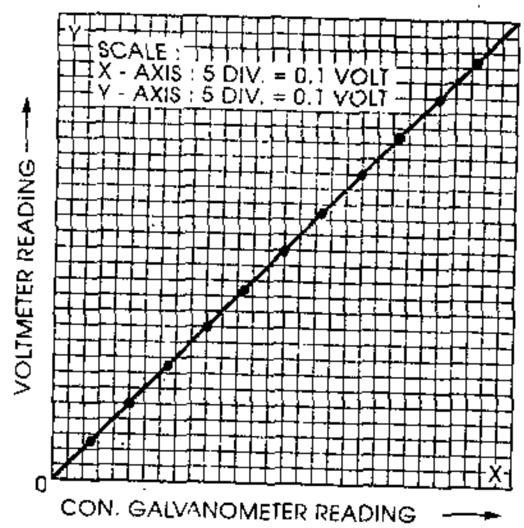

Fig. (3)

Observations :

(A) Determination of galvanometer resistance.

Note down observations for Kelvin's method for the determination of galvanometer resistance.

(B) Determination of I_g :

E.M.F. of the cell = ... volt.

No. of divisions on the galvanometer N = ...

S. No.	Resistance introduced in resistance box R	Deflection in galvanometer n	Figure of merit C_s	$I_g = C_s \times N$ amp.	Mean I_g amp.
1	...	...	...	...	
2	...	...	...	...	...
3	...	...	...	...	

(C) Calibration of shunted galvanometer :

S. No.	Reading of shunted galvanometer		Voltmeter reading, V', volt	Error $(V - V')$ volts.
	In divs.	In volt (V)		
1	...	...	...	...
2	...	...	...	...
3	...	...	...	...
4	...	...	...	...
5	...	...	...	...
6	...	...	...	...

Calculations :

(i) Figure of merit $C_S = \dfrac{E}{n\,(R+G)}$

(ii) $I_g = C_S \times N = \ldots$ amp.

(iii) Series resistance $R = \dfrac{V}{I_g} - G = \ldots$ ohm.

Result : The resistance required to convert the given galvanometer into voltmeter of range of ... volts is ... ohms.

Sources of error and Precautions :

See previous experiment.

Viva-Voce

Q. 1. *What is a voltmeter ?*

Ans. It is an intstrument used to measure the potential difference between two points directly in volts, when connected *across* those ponts.

Q. 2. *What should be the resistance of a voltmeter ?*

Ans. It should be high.

Q. 3. *Why ?*

Ans. In order to read the actual potential difference between two points in a circuit, it is essential that on connecting the voltmeter this potential difference should not change. For this, the current drawn by the voltmeter should be very small. This requires that resistance of voltmeter be large.

Q. 4. *How can you convert a galvanometer into voltmeter ?*

Ans. After deciding about the range of voltmeter to be designed, we find the value of high resistance that is to be connected in series with galvanometer resistance. The combination will then act as voltmeter.

Q. 5. *How can you change the range of voltmeter ?*

Ans. We can increase its range by increasing its resistance. It can be done by connecting an additional resistance in series with it.

Q. 6. *How will you increase the range of a voltmeter of resistance 120 ohms. of 1 volt upto 3 volts ?*

Ans. Using the relation $R = \dfrac{V}{I_g} - G = \dfrac{3}{1/120} - 120 = 360 - 120$

$= 240$

That is, we shall put in its series an additional resistance of 240 ohms.

Q. 7. *What is a millivoltmeter ?*

Ans. It is a low range voltmeter.

Q. 8. *How can you change a voltmeter into millivoltmeter ?*

Ans. By decreasing its resistance because the resistance of millivoltmeter is much less than that of a voltmeter.

Q. 9. *Can you measure alternating potential difference with it ?*

Ans. For this, a hot wire instrument is needed.

Q. 10. *Can you change an ammeter into a voltmeter ?*

Ans. Yes, by putting a suitable high resistance in series with ammeter.

Q. 11. *Is voltmeter also convertible into an ammeter ?*

Ans. Yes, by shunting the voltmeter with a low resistance.

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EXPERIMENT No. 13

Object : (i) To determine the Galvanometer resistance.

Procedure : (i) Set up the galvanometer and lamp and scale arrangement.

(ii) Make the electrical connections as shown in fig. (1).

(iii) Introduce a resistance of 200 ohm, in the resistance box.

(iv) Press the key K and note down the galvanometer deflection as well as the value of current flowing in the circuit with the help of milliammeter.

(v) Repeat the above procedure by introducing different resistances in the R.B.

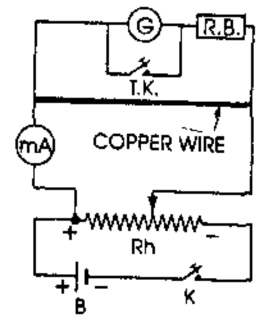

Fig. (1)

Observations : Table for Galvanometer resistance.

S. No.	Current in i mA	Resistance introduced R ohm.	Deflection θ	i/θ
1	...	...	...	...
2	...	...	...	...
3	...	...	...	...
4	...	...	...	...
5	...	...	...	...
6	...	...	...	...

Calculations :

Draw a graph between resistance and i/θ as shown in fig. (2). The graph is a straight line which cuts the x-axis on the other side at a point M. Then OM is the galvanometer resistance.

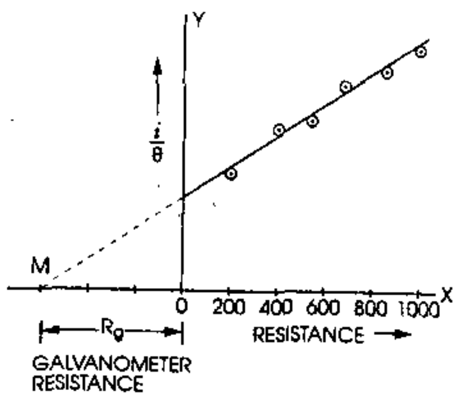

Fig. (2)

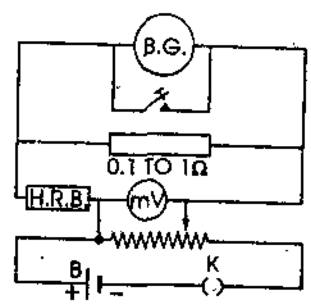

Fig. (3)

(ii) To determine the current sensitivity :

(i) Make the electrical connections as shown in Fig. (3).

(ii) Introduce shunt resistance 0.1 Ω in the resistance box.

(iii) Introduce a resistance of 500 Ω in the high resistance box (H.R.B.).

(iv) Press the key K and note down the deflection of the galvanometer and millivoltmeter reading.

(v) Repeat the above procedure for different values of high resistance.

Observations : Table for current sensitivity.

S. No.	Millivoltmeter reading mV.	Shunt resistance S	Resistance H.R.B. (R ohms)	Deflection θ
1	...	...	...	...
2	...	...	...	...
3	...	...	...	...
4	...	...	...	...
5	...	...	...	...
6	...	...	...	...
7	...	...	...	...
8	...	...	...	...

Calculations:

The current sensitivity, C_s, is given by $C_s = \dfrac{V \times S \times 10^6}{\theta . R . G}$

where V = voltage applied in the circuit.
S = Shunt resistance,
θ = Deflection in the galvanometer,
R = Resistance introduced in high R.B.
G = Galvanometer resistance.

Viva-Voce

Q. 1. ***To what use a ballistic galvanometer is put to ?***

Ans. For measuring charge.

Q. 2. ***What are the essential features of a ballistic galvanometer ?***

Ans. (i) The moment of inertia of the moving part should be large so that whole of the charge passes before the coil starts to move.

(ii) Coil should be wound on a non-conducting and non-magnetic frame e.g. ivory or bamboo.

Q. 3. ***What will happen if the coil is wound on a metallic frame ?***

Ans. The galvanometer will become dead beat.

Q. 4. ***What do you mean by dead beat galvanometer ?***

Ans. A galvanometer is dead beat when its coil does not swing. The coil, when deflected, comes to rest on either side.

Q. 5. ***How do you affect the motion of the coil by making moment of inertia of moving part large ?***

Ans. Infact, we want that periodic time of the oscillation of the coil be large. For this as $T = 2\pi \sqrt{(I/C)}$, I is kept large and C (restoring couple per unit twist of the suspension fibre) is made small. The moment of inertia is made large by winding a large coil on an ivory or bamboo frame and C is made small by taking strip of phosphor bronze as suspension fibre.

Q. 6. ***What do you understand by the ballistic constant of a ballistic galvanometer ?***

Ans. The ballistic constant (K) of a galvanometer is that constant which when multiplied by the throw of galvanometer (θ) gives the amount of charge (q) that passed through it. This is, $q = K\theta$.

Q. 7. ***What is its unit ?***

Ans. Coulomb/m.m. if throw is measured in m.m.,
Coulomb/radian if throw is measured in radian.

Q. 8. ***On what factors does the value of ballistic constant depend ?***

Ans. Ballistic constant is given by

$$K = \frac{T}{2\pi} \cdot \frac{C}{NHA}$$

that

(i) K is directly proportional to time period T of the coil.

(ii) *K is directly proportional to the restoring couple per unit twist of the* suspension fibre.

(iii) K is inversely proportional to no. of turns in the coil (N), to the area of coil (A) and to the strength of the magnet (H).

Q. 9. ***Does the ballistic constant depend upon the distance between the scale and the mirror ?***

Ans. Yes, if throw is measured in m.m. because K is then defined as coulomb/m.m.

Q. 10. ***What is λ ?***

Ans. It is logarithmic decrement.

Q. 11. ***What is it ?***

Ans. It is a correction for damping. The relation $q = K\theta_0$ has been deduced on the assumption that no damping to the motion of the coil is present. But in practice there is always damping which reduces the first throw, θ_1, of the galvanometer. Thus this throw θ_1 is to be corrected. It is done through the relation

$$\theta_0 = \theta_1 (1 + \lambda/2),$$

where θ_0 is first throw provided no damping is present, and λ is given by

$$\frac{\theta_1}{\theta_2} = \frac{\theta_2}{\theta_3} = \frac{\theta_3}{\theta_4} = \ldots = e^{\lambda}$$

Q. 12. ***What is damping due to ?***

Ans. It is due to air and due to induced currents produced in the coil itself. The first is called mechanical damping while latter is called electromagnetic damping.

Q. 13. ***How is the damping reduced ?***

Ans. By winding the coil on a non-metallic frame. A metallic frame cut into two separate parts may also be used.

Q. 14. ***What is current sensitivity of a moving coil galvanometer ?***

Ans. The current sensitivity of a moving coil galvanometer is defined as the deflection in millimeters on a scale at a distance of one meter for a current of one microampere.

Q. 15. ***How can you increase the sensitivity ?***

Ans. (i) A strong magnet is to be used for producing magnetic field in which the coil moves.

(ii) By increasing the number of turns and area of the coil.

(iii) By using flat strip of phosphor bronze for suspension. In this way restoring couple per unit twist, C, is reduced.

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EXPERIMENT No. 14

Object : To plot graph showing the variation of magnetic field with distance along the axis of a circular coil carrying current and to estimate from it the radius of the coil.

Apparatus required : Tangent galvanometer of the Stewart and Gee type, a strong battery, a rheostat, a commutator, plug key and connecting wires.

Formula used :

The field F along the axis of a coil is given by

$$\boxed{F = \frac{2\pi n r^2 i}{10 (x^2 + r^2)^{3/2}}}$$

where n = number of turns in the coil

r = radius of the coil

i = current in ampere flowing in the coil.

x = distance of the point from the centre of the coil.

If F is made perpendicular to H earth's horizontal field, the deflection θ of the needle is given by

$$F = H \tan\theta.$$

Thus $$\frac{2\pi n r^2 i}{10 (x^2 + r^2)^{3/2}} = H \tan\theta.$$

Description of the apparatus. The apparatus called Stewart and Gee tangent galvanometer is shown in fig. (1). It consists of a circular coil of many thin insulated copper wires. It is fixed with its plane vertical on the horizontal bench AB. A magnetometer compass box is placed inside the coil such that it can slide on the bench AB in such a way that the centre of the needle always lies on the axis of the coil. The distance of the needle from the centre of the coil can be read on the graduated scale fixed on the arms of the magnetometer.

Procedure :

(i) Place the magnetometer compass box on the sliding bench so that its magnetic needle is at the centre of the coil. By rotating the whole apparatus in the horizontal plane, set the coil in the magnetic meridian roughly. In this case the coil, needle and its image all lie in the same vertical plane. Rotate the compass box till the pointer ends read 0–0 on the circular scale.

(ii) To set the coil exactly in the magnetic meridian set up the electrical connections as shown in fig. (1). Send the current in one direction with the help of commutator and note down the deflection of the needle. Now reverse the direction of the current and again note down the deflection. If the deflections are equal then the coil is in magnetic meridian otherwise turn the apparatus a little, adjust pointer ends to read 0–0 till these deflections become equal.

(iii) Using rheostat R_h adjust the current such that the deflection of nearly 70 to 75° is produced in the compass needle placed at the centre of the coil. Read both the ends of the pointer. Reverse the direction of the current and again read both the ends of the pointer. The mean of four readings will give the mean deflection at $x = 0$.

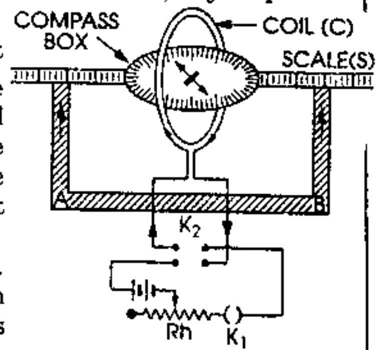

Fig. (1)

(iv) Now shift the compass needle through 2 cm. each time along the axis of the coil and for each position note down the mean deflection. Continue this process till the compass box reaches the end of the bench.

(v) Repeat the measurements exactly in the same manner on the other side of the coil.

(vi) Plot a graph taking x along the X-axis and tan θ along the Y-axis.

(vii) Mark the points of inflexion on the curve. The distance between the two points will be the radius of the coil.

S. No.	Distance of needle from the centre, x Cm.	Deflection on East arm						tan θ	Deflection on West arm						tan θ
		Current one way		Current reversed					Current one way		Current reversed				
		θ_1	θ_2	θ_3	θ_4		θ in deg.		θ_1	θ_2	θ_3	θ_4		θ in deg.	
1	2	...	...	...	...	...	...	...	...	...	...	...	...	...	...
2	4	...	...	...	...	...	...	...	...	...	...	...	...	...	...
3	6	...	...	...	...	...	...	...	...	...	...	...	...	...	...
4	8	...	...	...	...	...	...	...	...	...	...	...	...	...	...
5	10	...	...	...	...	...	...	...	...	...	...	...	...	...	...
6	12	...	...	...	...	...	...	...	...	...	...	...	...	...	...
7	14	...	...	...	...	...	...	...	...	...	...	...	...	...	...
8	16	...	...	...	...	...	...	...	...	...	...	...	...	...	...

Graph. Variation of field along the axis of circular coil is shown in fig. (2).

Result : The graph shows the variation of magnetic field along the axis of a circular coil carrying current.

The distance between the points of inflexion P, Q and hence the radius of the coil = ... cm.

Precautions and Sources of error :

(i) The coil should be carefully adjusted in the magnetic meridian.

(ii) All the magnetic materials and current carrying conductors should be at a considerable distance from the apparatus.

(iii) The current passed in the coil should be of such a value as to produce a deflection of nearly 75°.

(iv) Current should be checked from time to time and for this purpose an ammeter should be connected in series with the battery.

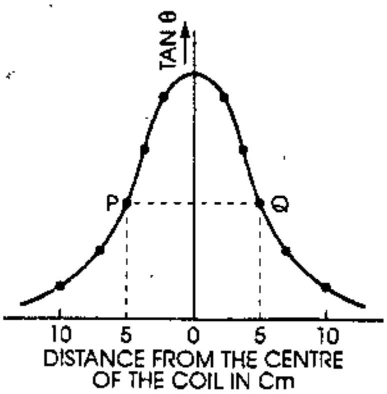

Fig. (1)

(v) Parallax should be removed while reading the position of the pointer. Both ends of the pointer should be read.

(vi) The curve should be drawn smoothly.

To study the variation of magnetic field along the axis of Helmholtz galvanometer.

Procedure : Exactly same as in above experiment No. 10. But the plot of tan θ and distance from the mid point of the two coils will be as shown in fig. (3).

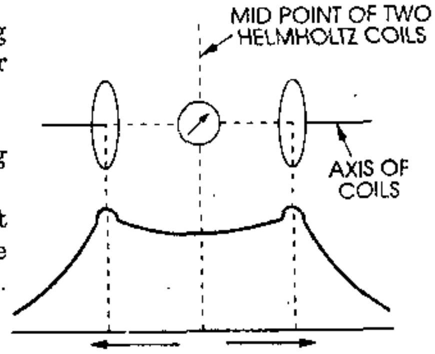

Fig. (3)

Viva-Voce

Q. 1. ***What is the magnitude of field at the centre of the coil ?***

Ans. It is

$$H = \frac{2\pi ni}{10r}$$

where r is the radius of the coil and n is the number of turns in it. Thus field at the centre increases if we increase no. of turns in the coil.

Q. 2. ***What is the direction of this field ?***

Ans. If in the face of the coil, we look at, the current is flowing in clockwise direction then that face of the coil acts as south pole. Thus direction of the field will be away from us.

Q. 3. ***How does the field vary along the axis of the coil ?***

Ans. It varies as shown in the graph. The points at which curve changes its direction of curvature are called points of inflexion. The distance between them is equal to the radius of the coil.

Q. 4. ***Is the field uniform at the centre ?***

Ans. It is uniform only over a very small region at the centre.

Q. 5. ***How can you get more wide region of uniform field ?***

Ans. By the use of Helmholtz galvanometer which consists two exactly similar coils placed coaxially.

Q. 6. ***How do you get uniform field in the case of Helmholtz galvanometer ?***

Ans. There are two coils. Any decrease in the intensity of the magnetic field due to one coil is compensated by a corresponding increase in the field due to the other coil [fig. (3)] so that field in the region at the centre becomes uniform.

Q. 7. ***Is it true for any direction of current in the two coils ?***

Ans. Yes, but current should flow in the two coils in the same direction.

Q. 8. ***If any current carrying conductor is placed close to the coil then will it effect your measurement ?***

Ans. Yes, it will also produce magnetic field which may affect the measurement.

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EXPERIMENT No. 15

Object : To determine the self inductance of given coil by Rayleigh's method.

Apparatus Required : Post office box, ballistic galvanometer, stop watch, decimal ohm box, an accumulator, given inductance, rheostat (4 or 5 ohms), tapping key, double key or Rayleigh key, a stretched resistance wire and connection wires.

Formula used : The self inductance (L) of the coil is given by

$$\boxed{L = \frac{r}{\phi}\frac{T}{2\pi}\theta\left(1+\frac{\lambda}{2}\right)}$$

where $r =$ small resistance (0.1 or 0.01 ohm) introduced in series with the inductance,

$\phi =$ steady deflection in ballistic galvanometer when r is introduced in the circuit,

$T =$ time period of the coil of galvanometer,

$\theta =$ first throw of galvanometer when inductance L is employed in the circuit,

$\lambda =$ logarithmic decrement,

$$= 2.3026 \times \frac{1}{10} \log_{10} \frac{\theta_1}{\theta_{11}}$$

when θ_1 and θ_{11} are first and eleventh observed throw of the glavanometer respectively.

Procedure :

(i) Set the galvanometer and lamp and scale arrangement such that the spot of light moves freely on both sides of zero of the scale.

(ii) Make the electrical connections as shown in fig. (1a).

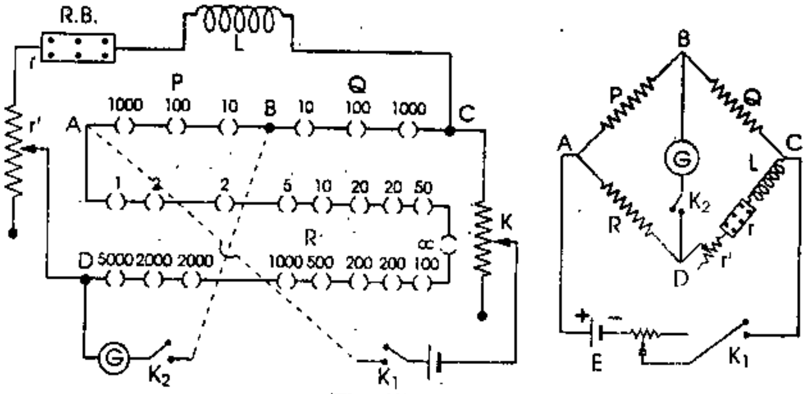

Fig. (1)

(iii) Fix the ratio $P : Q$ at 10 : 10. Pressing K_1 and K_2 adjust the resistance in R arm and the sliding contact on r' such that there is no deflection in the ballistic galvanometer. Here first of all the battery arm should be adjusted to have a near balance with the help of R and then rheostat r'. In this case the resistance, r, in resistance box should be zero.

(iv) Keeping K_1 and K_2 pressed, introduce a small resistance say 0.01 ohm in the resistance box and obtain the steady deflection ϕ in the galvanometer.

(v) Repeat the above procedure for other small values of r and obtain the steady deflection ϕ in each case.

(vi) Keeping $r = 0$ again obtain the balance point. With K_2 keeping pressed, break the cell circuit by releasing K_1. Note down the first throw θ. Repeat this observation two or three times, each time after checking steady balance.

(vii) Now to note θ_1 and θ_{11} first break cell circuit by releasing key, K_1 and then immediately after it, release galvanometer key K_2. The spot will oscillate on the scale. Measure θ_1 and θ_{11}. Repeat the process three or four times.

(viii) Now disconnect galvanometer from the bridge and by touching its connecting wires with mouth, make its coil oscillating. Note down the time for different oscillations and then calculate the time period T of the galvanometer coil.

Observations :

(1) Reading for the determination of θ and ϕ.

S. No.	Ballistic throw		Successive throws of galvanometer			Mean $\frac{\theta_1}{\theta_{11}}$	Determination of r/ϕ			
	θ	Mean	θ_1	θ_{11}	θ_1/θ_{11}		r	ϕ	r/ϕ	Mean r/ϕ
1	...		...	...	...		...	...	...	
2	...		...	...	...		...	...	...	
3	...	...	...	...	...	...	...	...	...	...
4	...		...	...	...		...	...	...	

(2) Reading for the determination of time period :

S. No.	No. of oscillations	Time taken	Total sec.	Time period	Mean sec.
1	5	min ... sec.	...	...	
2	10	...	...	...	
3	15	...	...	...	...
4	20	...	...	...	

Calculations : $$\lambda = 2.3026 \times \frac{1}{10} \times \log_{10} \frac{\theta_1}{\theta_{11}}$$

$$L = \frac{r}{\phi} \frac{T}{2\pi} \theta \left(1 + \frac{\lambda}{2}\right) = \ldots \text{ henry.}$$

Result : The self inductance of the coil $L = \ldots$ henry.

Precautions and Sources of error :

(i) The galvanometer coil should be freely moved in the space between the pole pieces.

(ii) Tapping key should be connected across the galvanometer.

(iii) To get a suitable deflection in the galvanometer a high adjustable resistance should be connected in series with cell.

(iv) All resistances used in the experiment should be noninductive.

(v) To secure maximum sensitiveness of the bridge all the four arms of the bridge should have nearly equal resistances.

(vi) The connection wires should be uncoiled.

(vii) The resistance introduced in the resistance box should be very small so that it may not affect the value of the steady current in that branch appreciably.

(viii) While determining the time period of the galvanometer, the galvanometer circuit should be kept open.

(ix) Keys K_1 and K_2 may have to be released in quick succession by personal judgement. For better results a Rayleigh key should be used.

Viva-Voce

Q. 1. ***Define self inductance.***

Ans. (i) For a medium with constant permeability, the magnetic flux, ϕ, linked with the circuit is proportional to the current, i, flowing in it. That is.

$$\phi \propto i \quad \text{or} \quad \phi = Li = L \text{ if } i = 1$$

where L is called inductance of the circuit. Therefore we can define L as the *flux linked with the circuit when unit current flows in it.*

$$e = -\frac{d\phi}{dt} = -L\frac{di}{dt} = -L \quad \text{if } \frac{di}{dt} = 1$$

That is, *self inductance is the e.m.f induced in the circuit when the rate of change of current is unity.*

(ii) Also, the work done in establishing a current in the circuit is given by.

$$W = 1/2\, Li^2$$

or $$2W = L \quad \text{if } i = 1$$

That is, self inductance is twice the work done in establishing the magnetic flux associated with the unit current in the circuit.

Q. 2. ***What is the unit of self-inductance ?***

Ans. It is expressed in henry.

Q. 3. ***Define a henry ?***

Ans. One henry is defined as the inductance of a circuit in which an e.m.f. of 1 volt is induced, when the current in it changes at the rate of 1 ampere per second.

Q. 4. ***Why do you take inductance coil in the form of helix, and not as a straight conductor ?***

Ans. Self inductance actually depends upon the flux linked with a circuit. Because flux linked with a straight conductor will be negliglibly small, hence its self inductance will also be small. Therefore the conductor is coiled in the form of helix which embraces a large flux. As large flux is linked with the coil, its self inductance will also be large.

Q. 5. ***Upon what factors does the value of flux depend ?***

Ans. If a coil with face area, A, number of turns, N, is placed in a magnetic field, B, then flux

$$\phi = B\,A\,N,$$

is linked with the coil, provided coil is placed at right angles to the lines of force.

Q. 6. ***Why do you observe steady deflection (ϕ) by introducing a small resistance (r) in the circuit? Why not large resistance ?***

Ans. So that it may not change the currents (both steady and transient) in the L-arm of the bridge (the relation, we use, has been deduced on this assumption).

Q. 7. ***What type of connecting wires should be used and why ?***

Ans. The connecting wire should be short and uncoiled to avoid inductive effects.

Q. 8. ***Define mutual inductance.***

Ans. If i be the current in one circuit and $N\phi$ be the flux linked with other circuit, then mutual inductance is defined as

$$M = N\phi_B \text{ for } i = 1 \text{ amp.}$$

That is, it is the flux linked with other circuit when unit current flows in one circuit.

Q. 9. ***Suppose L_1 and L_2 be the self inductance of the two circuits and k be coupling coefficient between them, then what is mutual inductance?***

Ans. It is $M = k\sqrt{(L_1 L_2)}$.

Q. 10. ***What is tight coupling ?***

Ans. When all the flux produced in one circuit is linked with other circuit ($k = 1$), there is no leakage of flux.

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EXPERIMENT No. 16

Object : To determine the self inductance of a coil by Anderson's method.

Apparatus Required : Post office box, A small variable resistance, galvanometer, audio oscillator, head phone, battery, plug keys, an inductance box and connection wires.

Formula used :

(i) When the bridge is balanced for D.C., then the unknown resistance s is given by

$$\boxed{s = \frac{R\,Q}{P}} \quad ...(1)$$

where s = resistance of inductance coil

P & Q = resistance in the two ratio arms of post office box, and

R = resistance introduced in the third arm of the post office box.

(ii) When the bridge is balanced for A. C., then

$$L = C\,[R\,Q + r\,(R + S)] \text{ henry} \quad ...(2)$$

where L = Self inductance of inductance coil

C = Capacity of condenser in Farad

r = Variable small resistance.

Procedure :

(i) For *D.C.* balance :

(1) Make the electrical connections as shown in fig. (1a) for the D.C. balance.

(2) Fix the ratio arms P and Q in the ratio 10 : 10.

(3) Press the keys K_1 and K_2 and adjust the resistances in R such that for one resistance the deflection is in one direction, while for the other consecutive resistance, the deflection is in the other direction.

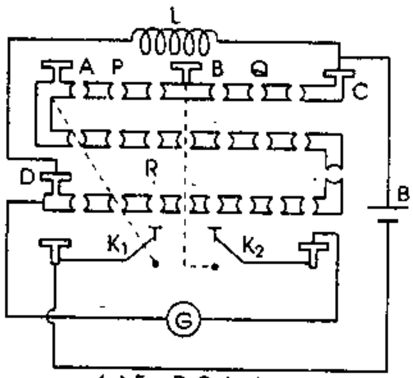
(4) Change the ratio arm to 100 : 10 and repeat the above procedure.

(5) Now change the ratio arm to 1000 : 10 and adjust the resistance in R arm such that there is no deflection in the galvanometer.

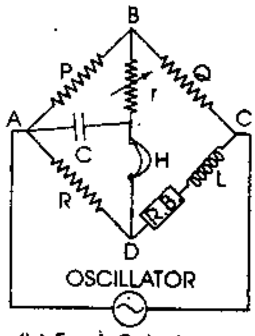
(6) Calculate the resistance, s, of the inductance coil using equation (1).

(ii) For *A.C.* balance :

(7) Make the electrical connections as shown in fig. (1b) for *A.C.* balance.



(a) For D.C. balance



(b) For A.C. balance

Fig. (1)

(8) Adjust the values of P, Q and R in such a way that the bridge is balanced for *D.C.* i.e.,

$$\frac{P}{Q} = \frac{R}{S}$$

If $P = Q = 10$ ohms and suppose resistance, s, of coil comes out to be 1 ohm (See point 6 of part *i*) and you keep, $R = 20$ ohms then to make $S = 20$ ohms in CD arm of the bridge, introduce 19 ohms from resistance box (R.B.)

(9) A humming sound will be heard in the head phone H. Without disturbing the *D.C.* balance adjust, r, such that there is complete silence in the head phone.

(10) Calculate L using equation (2).

(11) Repeat the experiment for different ratio of P and Q. Here the values of R should be taken such that in every case the *d.c.* balance is not disturbed.

Observationd :

Table for the *d.c.* resistance, *s*, of the inductance coil

S. No.	P	Q	R	$s = RQ/P$ ohm
1	10	10	... deflection Left	between
			... deflection Right	... and...ohm
2	100	10	... deflection Left	between
			... deflection Right	...and...ohm
3	1000	10	... No deflection	...ohm

Table for the inductance *L* :

S. No.	*P* ohm	*Q* ohm	*R* ohm	*r* ohm	*L* henry	Mean *L* millihenry
1	...	...	...	...	...	
2	...	...	...	...	...	
3	...	...	...	...	...	...
4	...	...	...	...	...	

Calculations :

1. $s = \frac{RQ}{P} = \ldots$ ohm.
2. $L = C\,[RQ + r\,(R + S)] = \ldots$ henry.

Result : The self inductance of the given coil = ... millihenry.

Sources of Error and Precatuions :

1. While obtaining D.C. balance, galvanometer key K_2 should be pressed after the battery key K_1.

2. Sometimes it is difficult to obtain balance by varying r. The condenser should be changed.

3. The condenser should be of small capacity.

Viva-Voce

Q. 1. ***Is there any condition necessary for obtaining the balance ?***

Ans. Value of CRQ must be less than the approximate value of L, otherwise r will come out to be negative which is absurd.

Q. 2. ***Is there any advantage in this bridge ?***

Ans. Yes, this bridge provides for double balance by the variation of resistance only.

Q. 3. ***What type of oscillator are you using ? What is its frequency ?***

Ans. It is a fixed frequency oscillator. Its frequency is 1 kc/s.

Q. 4. ***Define self inductance.***

Ans. It is the flux linked with the circuit when unit current flows in it,

$$\phi = Li = L \text{ if } i = 1.$$

Q. 5. ***What is its unit ?***

Ans. Henry.

Q. 6. ***Define one henry.***

Ans. One henry is defined as the inductance of a circuit in which an e.m.f. of one volt is induced, when the current in it dies at the rate of one ampere per second.

$$l = -\frac{d\phi}{dt} = -L\ \frac{di}{dt} = L \quad \text{if } \frac{di}{dt} = -1$$

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EXPERIMENT No. 17

Object : To determine the self-inductance by Maxwell's L/C bridge.

Apparatus Required : Post office box, the three resistance boxes of the range of 0 to 1000 ohms, galvanometer, audio oscillator, headphone, battery, plug keys, inductance coil, variable standard capacitor and connection wires.

Formula used :

(i) For *D.C.* balance :

The unknown resistance, s, of the inductance is given by

$$\boxed{s = \frac{R\,Q}{P}} \quad \ldots \text{(i)}$$

where P and Q = resistances in the two ratio arms of the post office box.

R = resistance introduced in the third arm of the post office box.

(ii) For *A.C.* balance :

The inductance L of the coil is given by

$$\boxed{L = Q\,R\,C} \quad \ldots \text{(ii)}$$

where C = capacity of the standard capacitor used when the bridge is balanced for $A.C.$

Procedure :

(i) For *D.C.* balance :

(1) Make the electrical connections as shown in fig. (1) for D.C. balance.

(2) Fix the ratio arms P and Q in the ratio 10 : 10.

(3) Press the keys K_1 and K_2 and adjust the resistance in R such that for one resistance the deflection is in one direction while for the other, deflection is in the other direction.

(4) Change the ratio arm to 100 : 10 and repeat the above procedure.

(5) Now change the ratio arm to 1000 : 10 and adjust the resistance in R arm such that there is no deflection in the galvanometer.

(6) Calculate the resistance, s, of the inductance coil using equation (i).

(ii) For *A.C.* balance :

(7) Make the electrical connections as shown in fig. (2).

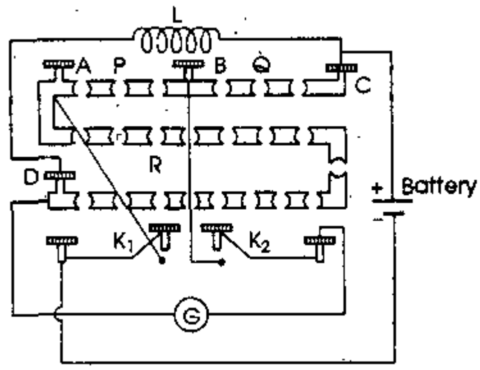


Fig. (1)

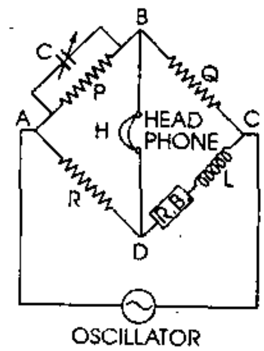


Fig. (2)

(8) Adjust the values of P, Q and R such that the bridge is balanced for *D.C.* For example, if $P = Q = 10$ ohm and the value of s is 1 ohm, and $R = 20$ ohm. then introduce 19 ohm from resistance box (R.B.) to make the total resistance, S, of C.D. arm equal to 20 ohms.

(9) A humming sound is now heard in the headphone H. Without disturbing P, Q and R adjust the capacitance C such that there is complete silence in headphone. Note down the value of C.

(10) Calculate the value of L using equation (ii).

(11) Repeat the experiment for different values of P and Q. Here the values of R should be taken such that in every case the *D.C.* balance is not disturbed. For example, when $P = 100$, and $Q = 10$ then for $S = 5$, the value of R should be 50.

Observations :

Table for the resistance, s, of the inductance coil :

S. No.	P ohm	Q ohm	R ohm	Deflection from initial position to	$s = R \times Q/P$ ohm
1	10	10	...	Left	
2	10	10	...	Right	between ... and ... ohm
3	100	10	...	Left	
4	100	10	...	Right	between ... and ... ohm
5	1000	10	...	Left	
6	1000	10	...	No deflection	... ohm.
7	1000	10	...	Right	

Table for inductance, L :

S. No.	P ohm	Q ohm	R ohm	C	L	Mean L henry
1	...	...	...	...	...	
2	...	...	...	...	...	
3	...	...	...	...	...	...
4	...	...	...	...	...	
5	...	...	...	...	...	

Calculations :

(i) $s = \dfrac{RQ}{P} = \ldots$ ohm.

(ii) $L = QRC = \ldots$ henry $= \ldots$ millihenry.

Result : The self inductance of the given coil = ... millihenry.

Sources of error and Precautions :

1. While obtaining *D.C.* balance, galvanometer key K_2 should be pressed after the battery key K_1.

2. While obtaining the condition of A.C. balance, the condition to D.C. balance should remain satisfied.

3. The standard variable condenser used be of small capacity.

EXPERIMENT No. 18

Object : To determine the self-inductance of a given coil by Maxwell's inductance bridge.

Apparatus Required : Two resistance boxes of range 0 to 10,000 ohms, one resistance box of range 0 to 1000 ohms, standard variable inductance, unknown inductance, audio frequency oscillator, head phone and connection wires.

Formula used :

The unknown inductance L is given by

$$\boxed{L = L_1 \frac{R}{P}}$$

where L_1 = known inductance

R and P = resistance introduced in resistance boxes arranged in R and P arms of a Wheatstone bridge, see fig. (1).

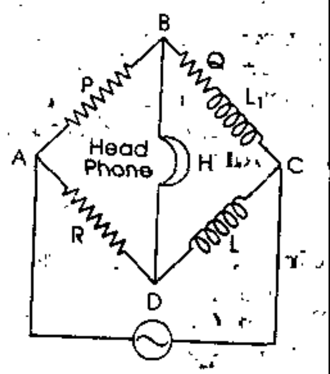
Procedure :

(i) Make the electrical connec- tions as shown in fig. (1).

(ii) The resistance R is adjusted of the order of the impedance* in DC arm. The resistance P is also adjusted to the same value.

(iii) Switch on the oscillator.

(iv) In case the standard inductance L_1 is variable, then by adjusting L_1 and resistance Q a balance is obtained i.e. when there is no sound in head phone. For different values of R and P the experiment is repeated. The values of L_1, R, Q and P are noted.



Audio Frequency Oscillator
Fig. (1)

OR

In case the standard inductance L_1 is not variable i.e. L_1 is constant, then by varying Q and P the balance is obtained. The experiment is repeated for different values of R. The values of Q are recorded in the table.

Observations :

Table for measurement of inductance L :

(i) When L_1 is variable.

S. No.	$R = L_1\omega$ ohm	$P = R$ ohm	L_1 mH	Q ohm	$L = L_1$ (millihenry)	Mean L (millihenry)
1	...	...	...	...	...	
2	...	...	...	...	...	
3	...	...	...	...	...	...
4	...	...	...	....	...	
5	...	...	...	...	...	

(e) lastly press S_1, S_4, and read voltmeter reading which is voltage across total impedance, i.e. L, C and R ($V_{applied}$).

(2) Change voltage selector to tapping-2 and take all (a) to (e) steps as above.

(3) Repeat the procedure for all values of transformer tappings.

IInd Set :

Change the resistance or inductance or both (i.e. $R_2 L_2 C$ or $R_1 L_2 C$ or $R_2 L_1 C$) and then again proceed exactly in the similar manner as explained for first set.

IIIrd Set :

Again change resistance or inductance or both and take similar observations :

Observations : First Set.

Voltage tapping	V_L volt	V_C volt	V_R volt	Applied voltage $V_{app.}$ volt	Ammeter reading I, mA
1	...	...	...	...	...
2	...	...	...	...	...
3	...	...	...	...	...
4	...	...	...	...	...
5	...	...	...	...	...
6	...	...	...	...	...
7	...	...	...	...	...

Make similar tables for 2nd and 3rd set.

Calculations :

First set : Draw four graphs as follows :

(1) One graph in current, I (milliammeter reading) and V_R. Calculate dV_R/dI from graph and then

$$R = \frac{dV_R}{dI} \times 10^3 \text{ ohms.}$$

(2) Another graph in current I and V_L. Calculate $\frac{dV_L}{dI}$ from it and then $L\omega = \frac{dV_L}{dI} \times 10^3$ where $\omega = 2\pi n = 2\pi \times 50 = 100\pi$. Thus calculate value of inductance.

(3) Draw graph in I and V_C. Calculate $\frac{dV_C}{dI}$ from it and then $\frac{1}{C\omega} = \frac{dV_C}{dI} \times 10^3$. Thus calculate value of capacitor, ω is 100π.

(4) Fourth graph in current I and applied voltage. Calculate $\frac{dV_{app}}{dI}$ from it and then impedance $Z = \frac{dV_{app}}{dI} \times 10^3$ ohm.

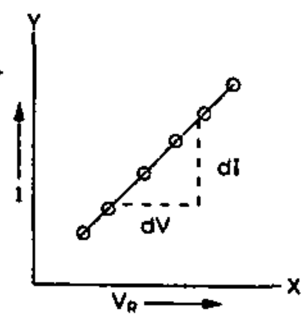


Fig. (3)

(5) **Power factor** for series LCR circuit is,

$$\cos\phi = \frac{R}{\sqrt{[R^2 + (L\omega - 1/C\omega)^2]}} = \frac{R}{Z} = \frac{RI}{ZI} = \frac{V_R}{V_{app}}$$

So plot a graph in V_R and V_{app} and obtain the value of $\frac{dV_R}{dV_{app}}$ from it, which will give the power factor $\cos\phi$.

Second and Third Set : Similar calculations after plotting graphs can be carried out for these sets.

Result : Values of elements applied in LCR series circuit as obtianed from observations are as follows :

$R_1 = \ldots$ Ohm $L_1 = \ldots$ Henry

$R_2 = \ldots$ Ohm $L_2 = \ldots$ Henry

$R_3 = \ldots$ Ohm $L_3 = \ldots$ Henry

$Z_1 (L_1 R_1 C)$ = ... Ohms (Provided in different sets only)
$Z_2 (L_1 R_2 C)$ = ... Ohm, the value of resistance is changed)
$Z_2 (L_1 R_3 C)$ = ... „

Sources of Error and Precautions :

(i) Ammeter should be connected in series while voltmeter in parallel.
(ii) A.C. ammeter and A.C. voltmeter are to be used.
(iii) Safety limit of condenser should be greater than main's voltage.
(iv) Do not touch the circuit elements L, C and R directly.

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EXPERIMENT No. 21

Object : To find the resonant frequency of series LCR circuit using a variable frequency source (A.F. oscillator).

Apparatus required : Audio frequency oscillator (with maximum output of atleast 2 volts and frequency variation from 0 to 20 *kc/s*), one milliammeter (range 0–10 mA), one inductance (5H), one resistance (100 ohm) and three capacitors ($1\mu f$, $2\mu f$, $3\mu f$).

Formula used :

Resonant frequency of series LCR circuit is given by

$$\boxed{f_0 = \frac{1}{2\pi\sqrt{(LC)}} \text{ c/s}}$$

At resonance, current in the circuit is maximum.

Procedure :

(i) Make electrical connections as shown in fig. (1).

(ii) Put C_1 in the circuit.

(iii) Vary oscillator frequency and stop at a value for which current in the circuit reaches maximum. It is resonant frequency.

(iv) Now put different values of C in the circuit and find resonant frequency by varying oscillator frequency as described in (iii).

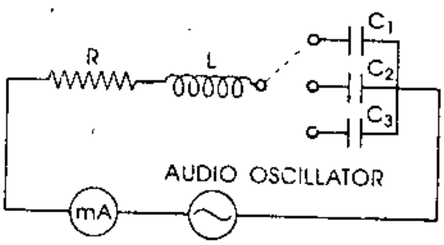

Fig. (1)

Observations :

S. No.	Value of C	Resonant frequency, f_0
1	...	...
2	...	...
3	..	...

Calculations :

Theoretical values of resonant frequencies are

$$(f_0)_1 = \frac{1}{2\pi\sqrt{(LC_1)}} = \dots \text{ c/s}$$

$$(f_0)_2 = \frac{1}{2\pi\sqrt{(LC_2)}} = \dots \text{ c/s}$$

$$(f_0)_3 = \frac{1}{2\pi\sqrt{(LC_3)}} = \dots \text{ c/s}$$

Result :

Exptal. value of resonant frequencies	Theoretical value of resonant frequencies	Difference
...	...	...
...	...	...
...	...	...

Sources of error and Precautions :

(i) Choice of values of circuit elements (so that current of mA order is obtained) is very important.

(ii) Avoid stray effects.

Viva-Voce

Q. 1. *What is meant by the impedance of an A.C. circuit ? What is its unit ?*

Ans. It is the effective resistance offered by the *a.c.* circuit to the passage of the alternating current through it. Its unit is ohm.

Q. 2. *What is reactance ?*

Ans. It is the effective resistance offered by the inductance or capacitance to the flow of the alternating current.

Capacitive reactance = $1/\omega C$

Inducative reactance = ωL,

where = $2\pi f$; f being the frequency of the alternating current.

Q. 3. *What is the effect on the relative phase of voltage and current in an a.c. circuit due to these reactances ?*

Ans. (i) In case of capacitive reactance, current leads the applied voltage by $\pi/2$ i.e. current becomes maximum earlier than voltage.

(ii) In case of inductive reactance, current lags behind the applied voltage by $\pi/2$ i.e. maximum voltage occurs in the circuit at one instant and the maximum current at a later instant ($T/4$ seconds later).

Q. 4. *Write expression of power in an a.c. circuit ?*

Ans. It is $\qquad P = EI \cos \phi$,

where ϕ is the phase difference between voltage, E and current, I.

(i) When circuit is purely resistive, $\phi = 0$ and

$$P_R = EI.$$

(ii) When circuit is purely inductive, $\phi = 90°$ and

$$P_L = 0.$$

(iii) When circuit is purely capacitive, $\phi = 90°$ and

$$P_C = 0.$$

Q. 5. *What is wattless current ?*

Ans. A current which consumes no power while flowing in an a.c. circuit is called wattless current e.g. in case of purely inductive circuit, current lags behind the applied voltage by $\pi/2$ so that power consumed

$$P = EI \cos 90° = 0$$

Q. 6. *What is resonance in a series resonant circuit ?*

Ans. When the inductive reactance (ωL) equals the capacitive reactance ($1/\omega C$), the circuit becomes purely resistive. The current in the circuit is in phase with applied voltage. The circuit is then said to be resonant. Resonant frequency is given by

$$\omega L = \frac{1}{\omega C}$$

so $$\omega = \frac{1}{\sqrt{(LC)}} \text{ c/s.}$$

Q. 7. *Compare parallel resonant circuit conditions with series resonant circuit conditions.*

Ans. Series resonant :

(i) current is maximum :

(ii) impedance is minimum.

Parallel resonant :

(i) current is minimum.

(ii) impedance is maximum.

Q. 8. *What is the use of resonant circuits ?*

Ans. They are used in radio sets to accept the waves of only one station while rejecting the waves of all other stations.

Q. 9. *Why does a condenser allow a.c. to pass while it does not allow d.c. to pass through it ?*

Ans. Capacitive reactance $= 1/\omega C$. For *d.c.* $\omega = 0$ so condenser offeres infinite reactance to the flow of direct current.

Q. 10 *Refer to your circuit. Suppose we change the value of R in it, will it affect the frequency of resonance ?*

Ans. No. By increasing or decreasing the resistance, R, magnitude of the current flowing in the circuit is affected.

Q. 11. *How ?*

Ans. The maximum (resonant) value of the current depends on the resistance R in the circuit, being smaller for larger R. If the resistance is doubled, current is halved.

Q. 12. *When the resonance is said to be sharp ?*

Ans. When the current falls sharply from its resonant value even at frequencies differing slightly from resonant frequency.

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EXPERIMENT No. 22

Object : To study the resonance in series LCR circuit with a source of given frequency (A.C. Mains).

Apparatus required : An auto transformer, inductance of 10H, resistance of 1.0KΩ, variable condenser unit (values in μf), four a.c. voltmeters of suitable ranges.

Theory and Formula used :

In series LCR circuit, voltage, E and current, I, are related by the relation

$$\boxed{I = \frac{E}{\left[R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2\right]^{1/2}}}$$

At resonance $\omega L = 1/\omega C$ and if I_r be the current at resonance then

$$I_r \, . \, \omega L = \frac{I_r}{\omega C}$$

$$V_L = V_C,$$

at resonance. Combined potential difference across C and L i.e. V_{CL} should be zero but never found such in practice due to choke coil resistance. V_{CL} is minimum at resonance.

Further, at resonance, impedance is minimum and consequently current is maximum. This means the voltage $V_R = I_r \, . \, R$ should also be maximum.

Thus, **at resonance.**

(1) $V_L = V_C$,

(2) V_{CL} is minimum, and

(3) V_R is maximum.

Procedure :

(1) Make electrical connec- tions as shown in fig. (1).

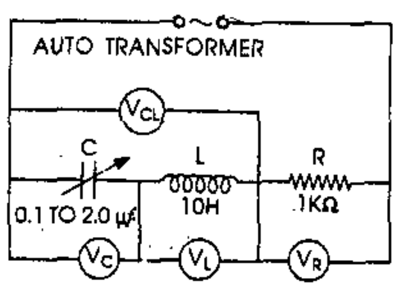

Fig. (1)

(2) Put $C = 0.1\,\mu f$, and note down readings of four voltmeters giving V_C, V_L, V_R and V_{CL}.

(3) Take several sets of observations by changing value of capacity in regular steps of 0.1 μf.

Observations :

S. No.	Capacitance introduced in the circuit in μf	Voltage across, C, V_C, volt	Voltage across L, V_L, volts	Voltage across R, V_R, volt	Voltage combined across C and L, V_{CL} volt
...	...	...	...	...	...
...	...	...	...	...	...
...	...	...	...	...	...
...	...	...	...	...	...

Calculations :

Values of V_L, V_C, V_R and V_{CL} are plotted as a function of C. The plots are shown in fig. (2) and fig. (3).

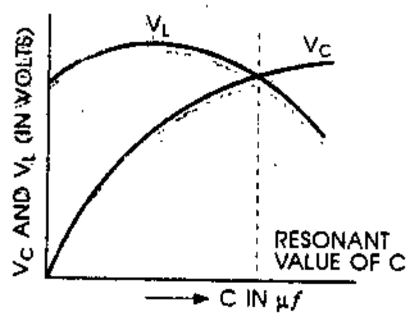

Fig. (2) Graph No. 1

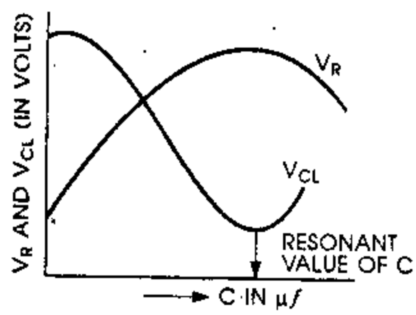

Fig. (3) Graph No. 2

Result :

(1) Resonant value of capacitance C, from graph No. 1, fig. (2) is = ... μf.

(2) Resonant value of capacitance, C, from graph No. 2, fig. (3) is = ... μf.

(3) We find that at resonance :

(a) $V_L = V_C$, (b) V_R is maximum and

(c) V_{Cl} is minimum,

Sources of error and Precautions :

(1) If using V.T.V.M. instead of voltmeters, zero adjustment should be made for the range selected.

(2) Suitable values of capacitance, as to give measurable change in voltages, should be chosen.

EXPERIMENT No. 23

Object : To study a transformer to determine its (i) transformation ratio, (ii) percentage efficiency, and (iii) copper losses.

Apparatus required : Stepdown Transformer under study, A.C. ammeters (two), A.C. voltmeters (two), Two potentiometers (1 KΩ, 5 watt), Board to mount the transformer.

Formula used :

(i) Transformation ratio, $K = \frac{V_s}{V_P} = \frac{I_p}{I_s}$

(ii) Efficiency $\eta = \frac{V_s I_s}{V_p I_p} \times 100\%$

(iii) Copper losses $W = V_p I_p + V_s I_s$

where, V_p = Voltage applied across primary winding
I_p = Current in the primary winding
V_s = Voltage across the secondary winding
I_s = Current in the secondary winding

Procedure :

(i) Circuit is shown in fig. (1). Circuit connections are made accordingly.

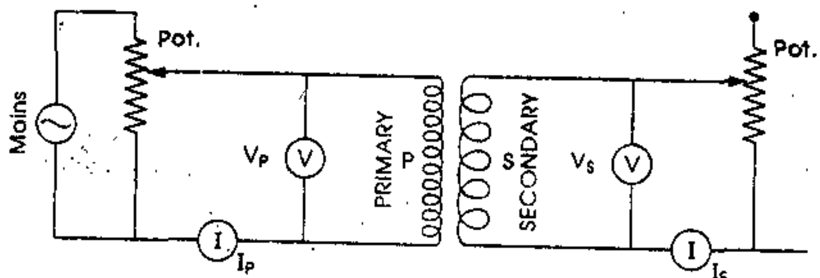

Fig. (1)

(ii) Give some suitable value of voltage by varying potentiometer to the primary so that values of V_s, I_s and I_p can be recorded. Note in voltmeter and ammeter connected in the primary the values of V_p and I_p. Also record V_s and I_s from meters connected in the secondary.

(iii) Vary the value of V_p with the help of potentiometer and note corresponding readings of V_s, I_s and I_p. Similarly take other observations.

Observations :

S. No.	V_p (volt)	I_p (amp)	V_s (volt)	I_s (amp)	$K = \frac{V_s}{V_p}$	$K = \frac{I_p}{I_s}$
1	...	...	...	...	...	...
2	...	...	...	...	...	...
3	...	...	...	...	...	...
4	...	...	...	...	...	...

Calculations :

(1) Voltage transformation ratio, $K_v = \frac{V_s}{V_p} = \ldots$

Current transformation ratio $K_I = \frac{I_p}{I_s} = \ldots$

(2) Efficiency $\eta = \frac{V_s I_s}{V_p I_p} \times 100 \ldots \%$

(3) Copper losses $W = V_p I_p + V_s I_s = \ldots$ watt.

Results : (1) Transformation ratio : Voltage = ...
Current = ...

(2) Efficiency = ... %

(3) Copper losses = ... watt.

Sources of error and Precautions :

(1) Primary of the transformer should be connected to the mains with help of flexible cord and at no point, connection should be naked.

(2) It is better to use stepdown transformer so that while handling secondary, one is safe.

Viva-Voce

Q. 1. ***What is a transformer ?***

Ans. It is an electrical device which is used to step up or step down the voltage applied at its input terminals.

Q. 2. ***How voltage is induced in secondary ?***

Ans. When alternating current flows in the primary, a changing magnetic flux is developed around it which becomes linked with the secondary. This changing magnetic flux induces an *e.m.f.* in the secondary according to Faraday's Law.

Q. 3. ***What is the difference in step up and step down transformer ?***

Ans. In step up transformer, primary coil consists few turns of thick copper wire (capable of carrying large current due to low resistance), while secondary coil large turns of thin copper wire. In step down transformer it is just opposite.

Q. 4. ***What is transformation ratio ?***

Ans. It is the ratio of the number of turns in the secondary to the number of turns in the primary coil.

Q. 5. ***What is efficiency of the transformer ?***

Ans. It is defined as the ratio of the output power obtained from secondary to the input power applied to the primary.

Q. 6. ***Why there are losses in a transformer ?***

Ans. They are due to ohmic resistance of the coil, the magnetisation and hysteresis losses of the iron core. As the alternating current flows through the primary and the secondary, heat is developed in the turns of the coil and energy is wasted, called copper losses.

❑❑❑

EXPERIMENT No. 24

Object : To obtain hysteresis curve (B.H. curve) for a given ferromagnetic material (thin rod or thin wires) on a C.R.O. using a solenoid and then to determine the related magnetic constant from it.

Apparatus required : C.R.O, Specimen in the form of several thin wires of iron, Solenoid (wound on a glass tube of diameter $\simeq$ 1 to 2 cm.), Primary coil C length of winding $\simeq$ 20 to 30 cm. (2 layers of SWG 22 or 24 enamelled wire), Secondary coil (10,000 turns of SWG 46 or 48 enamelled wire, length <10 cm., diameter about 5 cm.). Step down transformer (6V with 2 amp. capacity). A.C. ammeter (0-2 amp.), Rheostat (10 ohm), Resistors (two of one ohm, one of 47 KΩ carbon resistor), Carbon potentiometers (of 20 KΩ and 5KΩ), condensers (1μ*f* and 2μ*f*), A.C. voltmeter used across a known resistance.

Theory and Formula used :

The *specimen is put inside the solenoid* and is subjected to a varying magnetic field H. In this experiment fig. (1), magnetic field H is produced by passing *a.c.* in the solenoid given by

$$H = \frac{4\pi\, n\sqrt{2} I_{r.m.s.}}{10} \cos \omega t, \quad \text{.... (1)}$$

where $I_{r.m.s.}$ is the current in amp. measured by the ammeter and n is the no. of turns per cm. in the primary of solenoid. The potential difference developed across 1 ohm

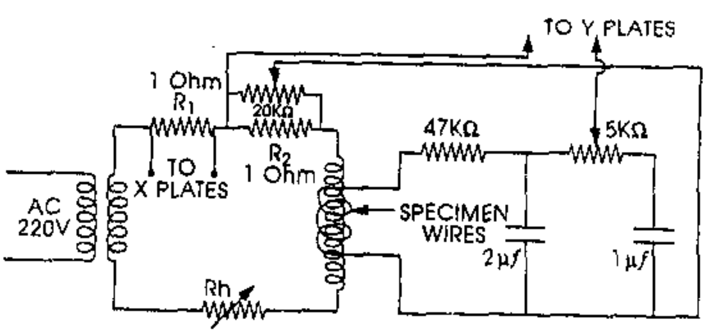

Fig. (1)

resistor R_1 is fed to XX plates of C.R.O., and consequently, X-deflection will be proportional to H.

The *e.m.f.* (e) across the secondary coil is a measure of $\frac{dB}{dt}$ and not of magnetic flux density B. Hence an integrating circuit is used. In fig. (1), resistor 47 KΩ and capacitor 2μ*f* represent this circuit. Then potential difference across 2μ*f* condenser at any instant is

$$V = \frac{Q}{C} \int_0^t \frac{i_p\,dt}{C} = \int_0^t \frac{e\,dt}{RC}$$

$$\propto \frac{B}{RC} \qquad \ldots(2)$$

provided $R >$ is far greater than reactance of the circuit. This potential difference, proportional to B, is applied to Y-deflection plates. Thus we obtain a hystersis (B-H) curve on CRO screen, by displaying H on X-and B on Y-deflection plates.

Procedure :

It is performed in the following steps :

(A) Getting a B-H curve of suitable shape. First complete the circuit shown in fig. (1). Switch on A.C. supply and adjust the rheostat R_h to give maximum current in the primary circuit.

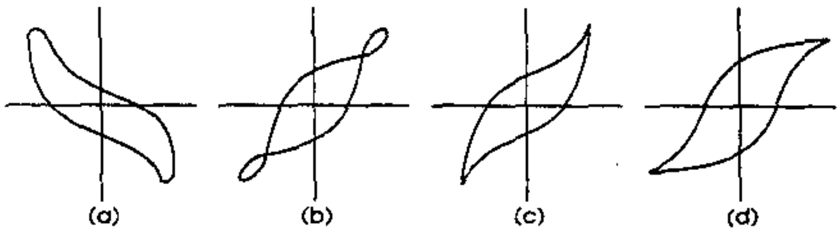

Fig. (2)

Adjust X and Y amplifiers of C.R.O. to get a pattern within the screen. Usually the pattern obtained is not of the correct shape as shown in fig. (2a-c). If shape of fig. (2a) appears, then interchange the secondary leads to C.R.O. which will bring the curve in proper quadrants. If shape like fig. (2b) is obtained 5KΩ potentiometer is to be adjusted to remove the loops or flats at the tips of the pattern. If we obtain shape like fig. (2c) (in which ends of the pattern overlap indicating the magnetic saturation but they are not parallel to H axis due to distribution of flux in the air core) then adjust 20KΩ potentiometer to make the ends of the pattern horizontal. If an increase in the resistance of 20KΩ potentiometer increases the slope at the ends of the curve instead of reducing it, the connections to Y plates must be interchanged. For all the adjustments, X and Y amplifiers of C.R.O. may be varied at will.

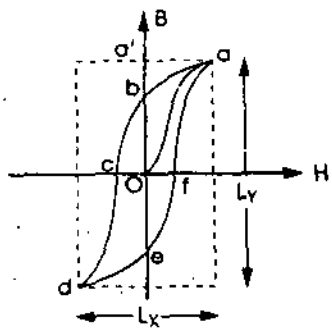

Fig. (3)

(B) Tracing of B–H curve. After getting a curve of suitable shape, we first set Y amplifier to zero to get a straight line which marks the H-axis and then set X-amplifier (Y-amplifier is not zero) to zero to get a straight line which marks B-axis. A tracing paper is put on the screen with the axes coinciding with H and B axes. Now adjust X and Y amplifiers to get a curve of suitable shape and trace it on the paper fig. (3).

(C) Calibration of H-axis. Measure the length L_x of the curve on the tracing paper. This corresponds to H_{max}. Therefore calibration constant for H axis is

$$C = \frac{2H_{max}}{L_x} \text{ oersted/cm.}$$

where $$H_{max} = \frac{4\pi n I_{r.m.s.}\sqrt{2}}{10} \text{ oersted}$$

(D) Calibration of B-axis :

1. Put X and Y amplifiers to their previous setting which can be achieved by coinciding the traced curve with the curve obtained on the screen.

2. Now put X-amplifier to zero so that we get a line of length L_y equal to the height of the curve, (20 KΩ potentiometer is also made zero inorder to avoid any resistance being introduced in the secondary circuit by it).

3. Now slowly move the magnetic material out of the solenoid till the length of vertical line on screen reduced to (1/2) L_y. Then keeping the magnetic material in this position, change Y-amplifier to increase the line to its previous length L_y. Thus Y-amplification is now double of the original value.

4. Now move the specimen (magnetic material) further out till the line is reduced to 1/2 L_y length. Keeping specimen in this position, change Y-amplifier to increase the line to L_y length. Thus Y-amplification is now four times of the original value.

We go on doing like this, making Y-amplifications 8 or 16 times provided the specimen is not totally out of the solenoid. Let the amplification factor be F where $F = 2, 4, 8$ or 16 depending upon the steps taken to increase it.

5. Finally take the specimen out of solenoid and measure the length of the vertical line on C.R.O. screen. Let it be h. Then with the original amplification (at which the B-H curve was traced on paper) this length would have been h/F. This vertical deflection corresponds to twice the maximum magnetic flux due to aircore, given by

$$2(\phi_{air})_{max} = 2H_{max}\,\pi\, r^2,$$

where r is the mean radius of the primary of solenoid. So calibration constant for flux measurement is

$$A = \frac{2H_{max}\,\pi\, r^2}{h/F} \text{ Maxwell/cm.}$$

If B is the magnetic induction in the specimen iron wires and S their area of cross section, we have

$$B = \phi_{max}/S$$

Therefore the calibration constant of B is

$$A' = \frac{A}{S} = \frac{2H_{max}\,\pi r^2}{(h/F).\,S} \text{ gauss/cm.}$$

$$C = \frac{2H_{max}}{L_x} \text{ oersted/cm.}$$

$$H = \frac{4\pi\, nI_{r.m.s}\sqrt{2}}{10} \text{ oersted}$$

$$A' = \frac{A}{S} = \frac{2\,H_{max}\,\pi r^2}{(h/F)S} \text{ gauss/cm.}$$

Observations :

(A) Constants for Calibration of H-axis :

1. Current in primary circuit, $I_{r.m.s.} = \ldots$ amp.
2. No. of turns/cm. of primary of solenoid, $n = \ldots$

(B) Constants for Calibration of B-axis :

1. Mean radius of primary of solenoid, $r = \ldots$ cm.
2. Mean radius of one specimen wire $r' = \ldots$ cm.
3. Number of specimen wires used $n' = \ldots$
4. Area of cross section of specimen wires $S = \pi r^2 \times n'$ $= \ldots$ cm^2.
5. Amplification factor of Y-amplifier, $F = \ldots$
6. Height of vertical line on C.R.O. screen with air core, $h = \ldots$ cm.

(C) From B-H curve,

1. Breadth of curve, $L_x = \ldots$ cm.
2. Height of curve. $L_y = \ldots$ cm.

Calculations :

First we calculate $H_{\max} = \dfrac{4\pi \, nI_{r.m.s.} \sqrt{2}}{10} = \ldots$ oersted

Then we find

(1) Calibration constant for H-axis

$$C = \frac{2H_{\max}}{L_x} = \ldots \text{ oersted/cm.}$$

(2) Calibration constant for B-axis

$$A' = \frac{2H_{\max} \, \pi r^2 F}{hS} = \ldots \text{ gauss/cm.}$$

(3) From B-H curve we find :

(a) Retentivity corresponding to Y, if $Ob = \ldots$ cm. on the trace then retentivity $Ob \times A' = \ldots$ gauss

(b) Saturation corresponding to Y if $Oa' = \ldots$ cm. on the trace then $B_{\max} = Oa' \times A' = \ldots$ gauss

(c) Area of B-H curve on the trace, $S' = \ldots$ cm^2.

Therefore Hysteresis loss per cycle per unit volume

$$= \frac{1}{4\pi} \text{ (Area of } B\text{-}H \text{ curve)}$$

$$= \frac{1}{4\pi} S'.C.A'.$$

$$= \ldots \text{ ergs per cycle per cm}^3.$$

Result : (1) (B-H) curve for the given ferromagnetic substance ... is traced on the paper.

(2) The related magnetic constants are

Retentivity = ... Gauss

Coercivity = ... Oersted

Hysteresis loss per cycle per unit volume = ... ergs /cycle/cm^3.

Sources of Error and Precautions :

(i) The current in the primary of solenoid should be quite large so as to magnetise the specimen sufficiently.

(ii) If the ends of the curve do not overlap, magnetic saturation is not achieved. For this either use higher current (a 12 volt transformer may be used) or use soft iron.

(iii) Handle C.R.O. carefully.

Note on circuit :

(i) In the integrating circuit (47 KΩ with 2μ*f* condenser) we require R (47 KΩ) be much larger than the reactance of the circuit. In practice R cannot be made very large compared with reactance. Consequently there will be a phase between V and B (because then i_s and e will not have same phase). Therefore for phase correction we use 1 μ*f* condenser and a variable 5KΩ resistance.

(ii) The coupling between secondary and primary is partly through the iron and partly through air. The latter makes a contribution to B which is in phase with H (hence primary current). To neutralise this contribution, the potential drop over a resistance in the primary is suitably added (using 20 KΩ potentiometer) with the potential difference to be applied to YY-plates.

Viva-Voce

Q. 1. ***What do you mean by hysteresis loss ?***

Ans. It has been observed that when we magnetise a magnetic material, certain amount of work is to be done *i.e.* energy is spent in magnetisation. The same work is not recovered when the magnetising field is switched off. Thus this balance of energy left with the specimen, which is lost as heat, is called hysteresis loss.

Q. 2. *Why is the work not totally recovered ?*

Ans. Because some molecular magnets do not come back in their premagnetisation orientation. This is due to retentivity.

Q. 3. *What is retentivity ?*

Ans. The value of intensity of magnetisation (I) for which the magnetising field is zero is called retentivity.

Q. 4. *What is intensity of magnetisation (I) ?*

Ans. It is the magnetic moment per unit volume of the specimen of the material.

Q. 5. *What is hysteresis ?*

Ans. We observe that though the magnetising field becomes zero yet the intensity of magnetisation does not become zero. This lagging of intensity of magnetisation behind the magnetising field is called hysteresis.

Q. 6. *Why an integrating circuit is used with the secondary ?*

Ans. The *e.m.f.* across the secondary coil is a measure of rate of change of magnetic flux density (dB/dt) and not of magnetic flux density (B). Hence an integrating circuit is used so that a potential difference proportional to flux density (B) may be applied to Y-plates.

Q. 7. *What should be the value of resistor in the integrating circuit ?*

Ans. It should be high.

Q. 8. *Where from you get magnetising field (H) ?*

Ans. Magnetising field (H) is simply ni, where n is the number of turns per unit length in the primary and i is the current in the primary of solenoid. Therefore potential difference across a resistor introduced in the primary of the solenoid will be a measure of magnetising field.

Q. 9. *How do you get a B-H curve then ?*

Ans. Potential difference proportional to H is applied to X-plates of C.R.O. whereas potential difference proportional to B is applied to Y-plates of C.R.O.

Q. 10. *How do you relate the hysteresis loss with area of B-H curve?*

Ans. Hysteresis loss per unit volume per cycle of magnetisation

$$= \frac{1}{\mu_0} \text{ (area of } B\text{-}H \text{ curve).}$$

Q. 11. *What is μ_0 ?*

Ans. It is free space permeability.

Q. 12. *What is relative permeability ?*

Ans. It is the degree to which the magnetic field can penetrate a material.

Q. 13. *What is the relation between B-H and I ?*

Ans. $B = \mu_0 (H + I)$.

❑❑❑

EXPERIMENT No. 25

Object : To determine hysteresis loss by C.R.O.

Apparatus required : A step down transformer, specimen transformer hysteresis loss of which is to be calculated, capacitor (8 μF), Resistor (50 KΩ potentiometer), A.C. Voltmeter (0–10V), A.C. milliammeter (0–500 mA), Rheostat (10 ohm).

Formula used :

Hysteresis loss *per unit volume per cycle* is given by

$$\boxed{W = \frac{\text{i. V. Area of B-H loop}}{\text{f. } \pi \text{ Area of rectangle}} \text{ Joules/Cycle}}$$

where

I = current in primary winding in ampere

V = Voltage across primary winding corresponding to i.

f = 50 c/s

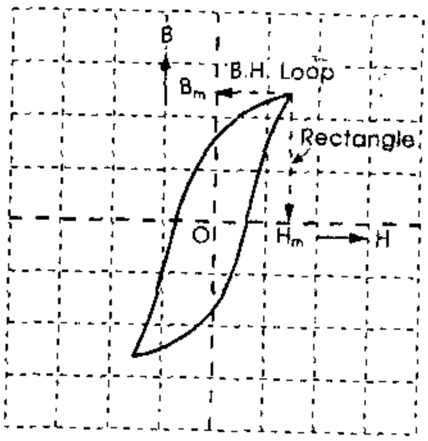

Fig. (1)

Area can be counted in millimeter^2 from the centimeter graph of B-H loop. Count the small squares of m.m.

Circuit diagram : Circuit is shown in fig. 2. Stepdown transformer converts 220 volts *a.c.* to 12 volts *a.c.* A-A points are connected to X-plates of C.R.O. and B-B points to Y-plates of C.R.O.

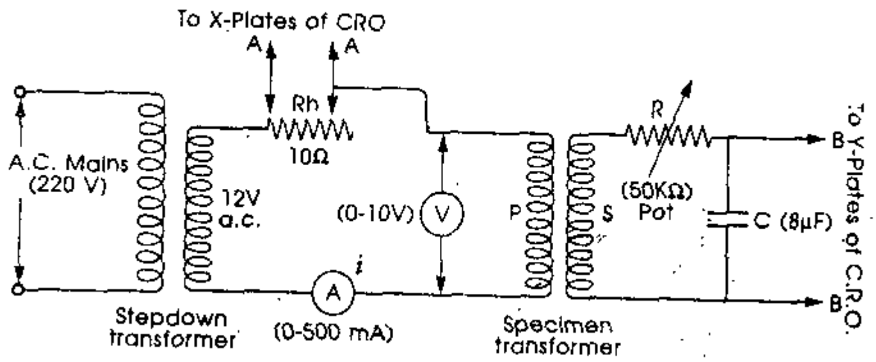

Fig. (2). Circuit diagram.

Procedure :

(i) Apply some voltage, V, with the help of rheostat, Rh. Connect XX plates and YY plates of C.R.O. Keep frequency selector of C.R.O. to External. Now adjust gain of the horizontal and vertical amplifiers of C.R.O. to obtain a suitable B-H curve on the screen. To obtain a correct curve adjust value of R, also may interchange BB terminals to Y-plates. Note voltage, V and current, i. Trace the curve on trace paper.

Note that once horizontal gain and vertical gain of amplifiers is selected, they are to be kept constant through out the experiment.

(ii) Vary rheostat, Rh, to some other value. That is, select new values of V and i, Trace the B-H curve on paper and write on it V and i values.

(iii) Take various readings by changing, V and hence current, i. Trace corresponding B-H curves on the trace paper and also indicate on the paper itself the value of voltage, V and current, i.

(iv) Resketch all B-H curves with V and i values on a centimeter graph. Find the areas in mm^2 required in the formula.

Observations :

S. No.	Current i, mA	Pot. diff. V, volt	Area of loop, mm^2	Area of rectangle, mm^2
1	...	...	...	...
2	...	...	...	...
3	...	...	...	...
4	...	...	...	...
5	...	...	...	...

Calculations : Hysteresis loss per unit volume per cycle is given by

$$W = \frac{\text{i. V. Area of B-H loop}}{\text{f. } \pi\text{. Area of rectangle}}$$

$= \ldots$ Joules/Cycle

Result : The hysteresis loss of the specimen transformer per unit volume per cycle is ... joules/cycle.

Precautions :

(i) Attenuator of C.R.O. should be kept at a suitable position. The positions of X and Y amplifiers should not be disturbed after adjusting it once in the whole experiment.

(ii) Variations in the supply voltage will affect the tracing of the curve on the paper.

(iii) Handle C.R.O. carefully.

□□□

EXPERIMENT No. 26

Object : To determine the magnetic moment, M of a magnet and horizontal component of earth's magnetic field, H at a place using deflection magnetometer and a vibration magnetometer.

Apparatus required : Deflection magnetometer, Vibration magnetometer, Given magnet, Stop watch, A rectangular brass rod.

Formulae used :

(i) From deflection magnetometer

$$\boxed{\frac{M}{H} = \frac{(d^2 - l^2)^2}{2d} \tan\theta = X \text{ (say)}} \quad \ldots (1)$$

where 2 l is the length of the magnet and d is the distance of the centre of the magnet from the centre of the needle. θ is the deflection.

(ii) From vibration magnetometer

$$\boxed{MH = \frac{4\pi^2}{T_2^2 - T_1^2} \times \frac{m(a^2 + b^2)}{12} = Y \text{ (say)}} \quad \ldots (2)$$

where m is the mass of rectangular brass rod, a and b the length and breadth of rectangular brass rod, T_1 is time period of oscillation of magnet alone, T_2 is time period of oscillation of the system consisting magnet and the brass rod.

(iii) From eqs. (1) and (2), we get

$$\boxed{M = \sqrt{XY}, \qquad H = \sqrt{\frac{Y}{X}}}$$

Procedure : Refer to fig. (1).

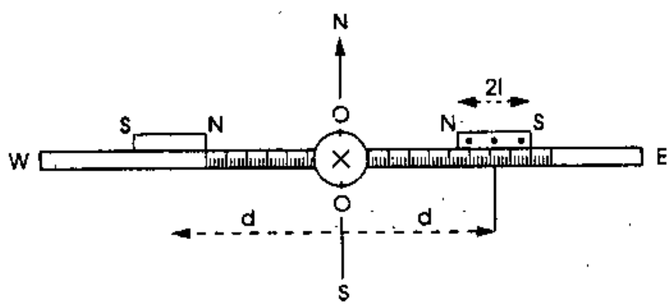

Fig. (1)

(A) *With deflection magnetometer :*

(i) Place deflection magnetometer in tan A position so that pointer is parallel to meter scale. Rotate the box so that pointer reads $0^\circ - 0^\circ$.

(ii) The given magnet is placed at a distance, d on east arm, deflections θ_1 and θ_2 are read and then magnet is reversed, deflections θ_3 and θ_4 are noted.

(iii) Similarly place magnet on west arm at the same distance, d, from the centre of the needle. Note, deflection θ_1' and θ_2'. Reverse the magnet and read θ_3' and θ_4'. Find mean of these eight readings.

(iv) Experiment can be repeated for various values of d.

(B) *With vibration magnetometer :*

(i) Place the given magnet in the suspension hook (stirrup) and set it into oscillations with the help of other magnet.

(ii) Find the time of some oscillations of the magnet and then calculate its time period, T_1.

(iii) Now put a rectangular brass rod on the magnet symmetrically with respect to the suspension thread. Set the system into oscillations and find time period, T_2, by recording time of some oscillations.

Observations :

(A) With deflection magnetometer :

$2l = \ldots$ cm.

Distance d, cm.	Magnet East				Magnet West				Mean θ	$\frac{M}{H}$ eq. (1)	$\frac{M}{H} = X$ mean
	Direct		Reverse		Direct		Reverse				
	θ_1	θ_2	θ_3	θ_4	θ_1'	θ_2'	θ_3'	θ_4'			
...	...	...	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...	

(B) With vibration magnetometer :

m = Mass of brass rod = ... gm.

l = Length of brass rod = ... cm.

b = Breadth of brass rod = ... cm.

No. of oscillations	Time with magnet		Mean T_1, sec	Time with Magnet and bar		Mean T_2, sec.	$(T_2^2 - T_1^2)$
	Time sec	Time Period. T_1 sec.		Time sec	Time period T_2 sec.		
...	...	...		...	...		
...	...	...	...	...	...	...	...
...	...	...		...	...		

Calculations :

(i) Find $X = \frac{M}{H} = \frac{(d^2 - l^2)^2}{2d} \tan\theta = \ldots$

(ii) Find $Y = MH = \frac{4\pi^2}{(T_2{}^2 - T_1{}^2)} \times \frac{m\,(a^2 + b^2)}{12}$

(iii) Find $M = \sqrt{XY} = \ldots$*C.G.S.* unit

$H = \sqrt{Y/X} = \ldots$ oersted

Result :

(i) Magnetic moment of the Magnet, $M = \ldots$ C.G..S. units

(ii) Horizontal component of earth's magnetic field $H = \ldots$ oersteds

Sources of error and Precautions :

(i) Magnet or system should vibrate in horizontal plane so that only H is effective.

(ii) There should be no twist in the suspension thread.

(iii) Amplitude of oscillations must be kept small.

UNIVERSAL PHYSICAL CONSTANTS

(1) Elementary Charge = $e = 1.602 \times 10^{-19}$ C
(2) Electron rest mass : $m_e = 9.110 \times 10^{-3}$ kg.
(3) Proton rest mass : $m_p = 1.6735 \times 10^{-27}$ kg
(4) Neutron rest mass : $m_n = 1.675 \times 10^{-27}$ kg.
(5) Atomic mass unit : 1 amu = 1.661×10^{-27} kg.
(6) Planck constant : $h = 6.626 \times 10^{-34}$ J.s
: $h' = h/2\pi = 1.055 \times 10^{-34}$ J.s.
(7) Boltzmann constant : $k = 1.381 \times 10^{-23}$ J.K^{-1}
(8) Stefan-Boltzmann constant : $\sigma = 5.670 \times 10^{-8}$ W.m^{-2}.K^{-4}
(9) Wien's displacement law constant ; $b = 2.898 \times 10^{-3}$ m.K
(10) Speed of light in vacuum : $c = 2.998 \times 10^{23}$ m.s^{-1}
(11) Avogadro number : $N_A = 6.022 \times 10^{23}$ per mole.
(12) Bohr magneton : $\mu_B = 9.274 \times 10^{-24}$ A.m^2
(13) Nuclear magneton : $\mu_n = 5.051 \times 10^{-27}$ A.m^2
(14) First Bohr radius : $a_0 = 5.292 \times 10^{-11}$ m.
(15) Classical electron radius : $\gamma_e = 2.818 \times 10^{15}$ m.
(16) Standard volume of ideal gas : $V_0 = 22.414 \times 10^{-3}$ m^3/mole
(17) Gravitational constant : $G = 6.673 \times 10^{-11}$ N.m^2.kg^{-2}
(18) Standard acceleration of free fall : $g = 9.807$ m.s^{-2}
(19) Faraday constant : $F = 9.649 \times 10^4$ C.mole^{-1}
(20) Rydberg constant : $R'_\infty = 1.098 \times 10^7$ per m
(21) Fine structure constant : $\alpha = 7.297 \times 10^{-3}$
(22) First radiation constant : $C_1 = 4.993 \times 10^{-24}$ J.m
(23) Second radiation constant : $C_2 = 1.439 \times 10^{-2}$ m.K
(24) Electron rest energy : $m_e c^2 = 0.511$ MeV
(25) Proton rest energy : $m_p c^2 = 938.259$ MeV
(26) Neutron rest energy : $m_n c^2 = 939.553$ MeV
(27) Ratio : $h/2e = 2.068 \times 10^{-15}$ Wb (weber)
Ratio : $h/e = 4.136 \times 10^{-5}$ J-s/C
Ratio : $h/2m_e = 3.637 \times 10^{-4}$ J-s/kg
Ratio : $h/m_e = 7.274 \times 10^{-4}$ J-s/kg
(28) Normal atomspheric pressure : $P_0 = 1.013 \times 10^5$ N/m^2
(29) Charge to mass ratio of the electron :
$e/m_e = 1.759 \times 10^{11}$ C/kg.
(30) Compton wavelengths of the electron, proton, neutron respectively :
(a) $\lambda_e = 2.426 \times 10^{-12}$ m
(b) $\lambda_p = 1.321 \times 10^{-15}$ m
(c) $\lambda_n = 1.320 \times 10^{-5}$ m.
(31) Magnetic moments of electron and proton respectively :
(a) $\mu_e = 9.285 \times 10^{-24}$ A.m^2
(b) $\mu_p = 1.411 \times 10^{-26}$ A.m^2.
The respective ratios μ_e and μ_p with μ_B may be computed.

Densities

At ordinary temperature (17° – 23°)

Substance	Density $\times 10^3$ kg/m^3	Substance	Density $\times 10^3$ kg/m^3
Metals and alloys		Liquids	
Aluminium	2.7	Alcohol	0.80
Iron. Pure	7.88	Benzene	0.88
Wrought	7.85	Ether	0.74
Cast	7.6	Glycerine	1.26
Steel	7.7	Lubricating oil	0.91
Brass	8.4-8.7	Mercury	13.60
Chromium	6.92	Aniline	1.02
Copper	8.89	Ether	0.736
Gold	19.3	Turpentine	0.87
Antimony	6.62		
Bismuth	9.78		
Silver	10.5		
Mica	2.6-3.2		
Platinum	21.45		
Tungsten	19.3		
Tin	7.3		
Lead	11.34		
Magnesium	1.74		
Nickle	8.8		
Selenium	4.8	Gases :	
Germanium	5.3		
Bronze	8.8-8.9	Air	0.00129
Constantan	8.88	Carbon dioxide	0.00198
Manganin	8.50	Hydrogen	0.00609
Asbestos	2.0-2.8	Steam-(100°C)	0.00091
Cork	0.22-0.26	Helium	0.000179
Glass Crown	2.0		
Flint	4.0		
Zinc	7.1		

Acceleration due to Gravity :

Place	g	Place	g
Pole	9.8222	Allahabad	9.7895
Equator	9.7803	Gorakhpur	9.7905
Delhi	9.7915	Gwalior	9.7897
Meerut	9.7915	Indore	9.7860
DehraDun	9.7907	Jaipur	9.7852
Lucknow	9.7900	Ajmer	9.7890
Kanpur	9.7901	Bombay	9.7865
Varanasi	9.7899	Calcutta	9.7878
Agra	9.7606	Madras	9.7828
Aligarh	9.7808		

Elastic constants :

Substance	Young's Modulus Y Newton/ $m^2 \times 10^{11}$	Modulus of rigidity η Newton/$m^2 \times 10^{11}$	Poisson's ratio σ
Aluminum	0.69—0.72	0.25—0.27	0.33—0.35
Brass	0.9—1.0	0.34—0.23	0.39—0.40
Copper	1.1—1.29	0.34—0.46	0.25—0.35
Iron Wrought	1.9—2.2	0.77—0.83	0.27—0.29
Cast	1.0—1.3	0.35—0.53	0.24—0.31
Steel Cast	1.9—2.1	0.74—0.76	—
Mild	2.1—2.3	0.80—0.89	0.25—0.31
Zinc	0.8—1.1	0.39—0.38	0.23—0.31
Glass Crown	0.6—0.78	0.26—0.32	0.25—0.27
Flint	0.5—0.6	0.2—0.25	0.21—0.26

Viscosity of water :

Temperature °C	Viscosity (Poise)	Temperature °C	Viscosity (Poise)
0	0.01793	60	0.00469
10	0.01311	70	0.00406
20	0.01000	80	0.00356
30	0.00800	90	0.00316
40	0.00657	100	0.00284
50	0.00550		

Surface tension of water :

Temperature °C	Surface tension Newton /m × 10^{-2}	Temperature °C	Surface tension Newton/m × 10^{-2}
0	7.5	60	6.56
10	7.35	70	6.38
20	7.21	80	6.20
30	7.06	90	6.02
40	6.89		
50	6.73	100	5.82

Velocity of sound (meter/sec) :

Substance	Velocity	Substance	Velocity
Solid		Liquid :	
Aluminium	5100	Alcohol	1275
Brass	3400	Mercury	1407
Copper	3560	Water	1447
Glass	5000	Gases :	
Iron	5130	Air	331.1
Steel	4990	Hydrogen	1262
		Nitrogen	338
		Oxygen	316

Refractive index of substances at 15°C for D-line of sodium relative to air :

Substance	μ	Substance	μ
Solids :		Liquids :	
Glass crown	1.50	Aniline	1.590
Glass flint	1.55	Benzene	1.504
Diamond	2.417	Chloroform	1.53
Mica	1,56—1.69	Glycerine	1.449
Sugar	1.56	Sulphuric acid	1.47
Quartz	1.544	Turpentine	1.43
		Water	1.333

Wavelength of spectral lines (A. U.)

Hydrogen :	Mercury :	Neon :
6562.784	4047 V	5765 y
4861.327	4078 V	5853 y
4340.466	4358 V	5882 o
4101.736	4916 bg	6507 r
Sodium :	4960 g	
5890 D_1	5461 g	Cadmium :
5896 D_2	5770 y	6438
Helium :	5791 y	5085
3889		4799
4026		4678
4471		4662
5876		

Specific rotation :

Optically active substance	Solvent	Specific rotation
Cane sugar	Water	+ 66.5°
Glucose	Water	+ 52°
Fructose	Water	– 91°
Camphor	Alcohol	+ 41°
Turpentine	Pure	– 37°
Nicotine	Pure	– 122°

Thermal constants : (C.G.S. units)

Substance	Melting point, °C	Boiling point, °C	Specific heat	Latent heat	Thermal Conductivity
Aluminium	658	1800	.22	92.4	.504
Bismuth	269	1560	.03	13.4	.0194
Copper	1084	2360	.093	43	.918
Gold	1063	2360	.032	16	.7
Ice	0	100	.5	79	.005
Iron (wrought)	1530	2450	.12	49	.144
Lead	327	1755	.031	5	.083
Platinum	1774	4300	.032	27	.166
Silver	961	2152	.056	22	.974
Tungsten	3387	4830	.03	...	.35
Steel	1400	...	.11	...	.115
Benzene	5.5	80.2	.34	95	3.3
Water	0	100	1.00	539	14.7
Mercury	–38.9	357	0.033	68	...
Ether	–132	34.6	.56	88	3.1

Magnetic elements :

Station	Dip	H oersted	Station	Dip	H oersted
Agra	40° 41'	.348	Gorakhpur	39° 40'	.358
Aligarh	41° 50'	.346	Jaipur	40° 30'	.347
Allahabad	37° 10'	.353	Kanpur	38° 39'	.363
Delhi	42° 52'	.345	Khurja	42° 10'	.343
Meerut	43° 30'	.339	Lucknow	40° 00'	.354
Varanasi	37° 10'	.364	Bareilly	42° 20'	.344
Dehra Dun	45° 50'	.332	Bombay	25° 30'	.376
Gwalior	39° 00'	.353	Calcutta	31° 30'	.382

Wire resistances :

S.W.G. No.	Diameter m.m.	Resistance (ohm/meter)		
		Copper	Constantan	Manganin
10	3.25	0.0021	0.057	0.051
12	2.64	0.0032	0.086	0.077
14	2.03	0.0054	0.146	0.131
16	1.63	0.0083	0.228	0.205
18	1.22	0.0148	0.495	0.361
20	0.914	0.0260	0.722	0.645
22	0.711	0.0235	1.20	1.07
24	0.559	0.070	1.93	1.73
26	0.457	0.105	0.89	2.58
28	0.374	0.155	4.27	3.82

30	0.315	0.222	6.08	5.45
32	0.274	0.293	8.02	7.18
34	0.234	0.404	11,1	9.9
36	0.193	0.590	16.2	14.5
38	0.152	0.950	26.2	23.2
40	0.122	1.48	40.6	36.3

Specific resistance and Temperature coefficient of resistance :

Substance	Composition	Sp. resistance ohm × cm × 10^{-6}	Temperature coefficient of resistance per °C × 10^{-4}
Constantan	60% Cu, 40% Zn	49.0	–0.4 to + 0.1
Silver		1.64	36.0
German silver	62% Cu, 15% Ni 22% Zn	26.6	2.3 to 6.0
Copper		1.78	42.8
Nichrome	80% Ni, 20% Cr	110.0	1.7
Mercury		99.8	9.0
Brass	70% Cu, 30% Zn	6.6	10.0
Platinum	...	11.0	37.0
Manganin	84% Cu, 4% Ni 12% Mn	43.0	0.02 to 0.5

Electro-chemical equivalent :

Element	Atomic weight	Valency	E.C.E. gm/coulomb
Aluminium	26.97	3	0.0000935
Oxygen	16.00	2	0.0000829
Silver	107.88	1	0.0011180
Copper	63.57	2	0.0003294
Zinc	65.38	2	0.0003383
Gold	197.20	3	0.0006809
Nickle	58.69	2	0.0000304
Hydrogen	1.007	1	0.0000105

Thermo E.M.F. :

Thermocouple	Thermo e.m.f.
Copper-constantan	41.8 Microvolt/°C
Copper-iron	8.6 Microvolt/°C
Antimony-Bismuth	113 Microvolt/°C

Internal resistance and E.M.F. of cells :

Cell	Internal resistance (ohm)	E.M.F. (volts)
Cadmium	900 Ω (very high)	1.0183 volt at 20°C
Daniel	3—4 Ω (fairly constant)	1.08
Leclanche	High, increases with usage	1.46
Alkali accumulator	Low	1.35
Lead accumulator	Very Low	2.1

COMMON LOGARITHMS $\log_{10} x$

x	0	1	2	3	4	5	6	7	8	9	Δ_m +	1	2	3	4	5	6	7	8	9
												ADD								
10	.0000	0043	0086	0128	0170	0212					42	4	8	13	17	21	25	29	34	38
						0212	0253	0294	0334	0374	40	4	8	12	16	20	24	28	32	36
11	.0414	0453	0492	0531	0569	0607					39	4	8	12	16	19	23	27	31	35
						0607	0645	0682	0719	0755	37	4	7	11	15	19	22	26	30	33
12	.0792	0828	0864	0899	0934	0969					35	4	7	11	14	18	21	25	28	32
						0969	1004	1038	1072	1106	34	3	7	10	14	17	20	24	27	31
13	.1139	1173	1206	1239	1271	1303					33	3	7	10	13	16	20	23	26	30
						1303	1335	1367	1399	1430	32	3	6	10	13	16	19	22	26	29
14	.1461	1492	1523	1553	1584	1614	1644	1673	1703	1732	30	3	6	9	12	15	18	21	24	27
15	.1761	1790	1818	1847	1875	1903	1931	1959	1987	2014	28	3	6	8	11	14	17	20	22	25
16	.2041	2068	2095	2122	2148	2175	2201	2227	2253	2279	26	3	5	8	10	13	16	18	21	23
17	.2304	2330	2355	2380	2405	2430	2455	2480	2504	2529	25	2	5	7	10	12	15	17	20	22
18	.2553	2577	2601	2625	2648	2672	2695	2718	2742	2765	24	2	5	7	10	12	14	17	19	22
19	.2788	2810	2833	2856	2878	2900	2923	2945	2967	2989	22	2	4	7	9	11	13	15	18	20
20	.3010	3032	3054	3075	3096	3118	3139	3160	3181	3201	21	2	4	6	8	11	13	15	17	19
21	.3222	3243	3263	3284	3304	3324	3345	3365	3385	3404	20	2	4	6	8	10	12	14	16	18
22	.3424	3444	3464	3483	3502	3522	3541	3560	3579	3598	19	2	4	6	8	10	11	13	15	17
23	.3617	3636	3655	3674	3692	3711	3729	3747	3766	3784	18	2	4	5	7	9	11	13	14	16
24	.3802	3820	3838	3856	3874	3892	3909	3927	3945	3962	18	2	4	5	7	9	11	13	14	16
25	.3979	3997	4014	4031	4048	4065	4082	4099	4116	4133	17	2	3	5	7	9	10	12	14	15
26	.4150	4166	4183	4200	4216	4232	4249	4265	4281	4298	16	2	3	5	6	8	10	11	13	14
27	.4314	4330	4346	4362	4378	4393	4409	4425	4440	4456	16	2	3	5	6	8	10	11	13	14
28	.4472	4487	4502	4518	4533	4548	4564	4579	4594	4609	15	2	3	5	6	8	9	11	12	14
29	.4624	4639	4654	4669	4683	4698	4713	4728	4742	4757	15	1	3	4	6	7	9	10	12	13
30	.4771	4786	4800	4814	4829	4843	4857	4871	4886	4900	14	1	3	4	6	7	8	10	11	13
31	.4914	4928	4942	4955	4969	4983	4997	5011	5024	5038	14	1	3	4	6	7	8	10	11	13
32	.5051	5065	5079	5092	5105	5119	5132	5145	5159	5172	13	1	3	4	5	7	8	9	10	12
33	.5185	5198	5211	5224	5237	5250	5263	5276	5289	5302	13	1	3	4	5	6	8	9	10	12
34	.5315	5328	5340	5353	5366	5378	5391	5403	5416	5428	13	1	3	4	5	6	8	9	10	12
35	.5441	5453	5465	5478	5490	5502	5514	5527	5539	5551	12	1	2	4	5	6	7	8	10	11
36	.5563	5573	5587	5599	5611	5623	5635	5647	5668	5670	12	1	2	4	5	6	7	8	10	11
37	.5682	5694	5705	5717	5729	5740	5752	5763	5775	5786	12	1	2	4	5	6	7	8	10	11
38	.5798	5809	5821	5832	5843	5855	5866	5877	5888	5899	11	1	2	3	4	6	7	8	9	10
39	.5911	5922	5933	5944	5955	5966	5977	5988	5999	6010	11	1	2	3	4	6	7	8	9	10
40	.6021	6031	6042	6053	6064	6075	6085	6096	6107	6117	11	1	2	3	4	8	7	8	9	10
41	.6128	6138	6149	6160	6170	6180	6191	6201	6212	6222	10	1	2	3	4	8	6	7	8	9
42	.6232	6243	6253	6263	6274	6284	6294	6304	6314	6325	10	1	2	3	4	8	6	7	8	9
43	.6335	6345	6355	6365	6375	6385	6395	6405	6415	6425	10	1	2	3	4	8	6	7	8	9
44	.6435	6444	6454	6464	6474	6484	6493	6503	6513	6522	10	1	2	3	4	8	6	7	8	9
45	.6532	6542	6551	6561	6571	6580	6590	6599	6609	6618	10	1	2	3	4	8	6	7	8	9
46	.6628	6637	6646	6656	6665	6675	6684	6693	6702	6712	9	1	2	3	4	8	5	6	7	8
47	.6721	6730	6739	6749	6758	6767	6776	6785	6794	6803	9	1	2	3	4	8	5	6	7	8
48	.6812	6821	6830	6839	6848	6857	6866	6875	6884	6893	9	1	2	3	4	4	5	6	7	8
49	.6902	6911	6920	6928	6937	6946	6955	6964	6972	6981	9	1	2	3	4	4	5	6	7	8

No.	log			No.	log
$\pi = 3.14159$	0.49715	$\ln x = \log_e x = (1/M)\log_{10} x$	$(1/M) = 2.30259$		0.36222
$e = 2.71828$	0.43429	$\log_x = \log_{10} x = M \log_e x$	$M = 0.43429$		1.63778

p	1	2	3	4	5	6	7	8	9	10
$\log e^p$	0.4343	0.8686	1.3029	1.7372	2.1715	2.6058	3.0401	3.4754	3.9087	4.3429
$\log e^{-p}$	1.5657	1.1314	2.6971	2.2628	3.8285	3.3942	4.9599	4.5256	4.0913	5.6571

COMMON LOGARITHMS $\log_{10} x$

x	0	1	2	3	4	5	6	7	8	9	Δ_m	1 2 3	4 5 6	7 8 9
											+	ADD		
50	.6990	6998	7007	7016	7024	7033	7042	7050	7059	7067	9	1 2 3	4 4 5	6 7 8
51	.7076	7084	7093	7101	7110	7118	7126	7135	7143	7152	8	1 2 2	3 4 5	6 6 7
52	.7160	7168	7177	7185	7193	7202	7210	7218	7226	7235	8	1 2 2	3 4 5	6 6 7
53	.7243	7251	7259	7267	7275	7284	7292	7300	7308	7316	8	1 2 2	3 4 5	6 6 7
54	.7324	7332	7340	7348	7356	7364	7372	7380	7388	7396	8	1 2 2	3 4 5	6 6 7
55	.7404	7412	7419	7427	7433	7443	7451	7459	7466	7474	8	1 2 2	3 4 5	6 6 7
56	.7482	7490	7497	7505	7513	7520	7528	7536	7543	7551	8	1 2 2	3 4 5	6 6 7
57	.7559	7566	7574	7582	7589	7597	7604	7612	7619	7627	8	1 2 2	3 4 5	6 6 7
58	.7634	7642	7649	7657	7664	7672	7679	7686	7694	7701	8	1 2 2	3 4 5	6 6 7
59	.7709	7716	7723	7731	7738	7745	7752	7760	7767	7774	7	1 1 2	3 4 4	5 6 6
60	.7782	7789	7796	7803	7810	7818	7825	7832	7839	7846	7	1 1 2	3 4 4	5 6 6
61	.7853	7860	7868	7875	7882	7889	7896	7903	7910	7917	7	1 1 2	3 4 4	5 6 6
62	.7924	7931	7938	7945	7952	7959	7966	7973	7980	7987	7	1 1 2	3 3 4	5 6 6
63	.7993	8000	8007	8014	8021	8028	8035	8041	8048	8055	7	1 1 2	3 3 4	5 6 6
64	.8062	8069	8075	8082	8089	8096	8101	8109	8116	8182	7	1 1 2	3 3 4	5 6 6
65	.8129	8136	8142	8149	8156	8162	8169	8176	8182	8189	7	1 1 2	3 3 4	5 6 6
66	.8195	8202	8209	8215	8222	8228	8235	8241	8248	8254	7	1 1 2	3 3 4	5 6 6
67	.8261	8267	8274	8280	8287	8293	8299	8306	8312	8319	6	1 1 2	2 3 4	4 5 5
68	.8325	8331	8338	8344	8351	8357	8363	8370	8376	8382	6	1 1 2	2 3 4	4 5 5
69	.8388	8395	8401	8407	8414	8420	8426	8432	8439	8445	6	1 1 2	2 3 4	4 5 5
70	.8451	8457	8463	8470	8476	8482	8488	8494	8500	8506	6	1 1 2	2 3 4	4 5 5
71	.8513	8519	8525	8531	8537	8543	8549	8555	8561	8567	6	1 1 2	2 3 4	4 5 5
72	.8573	8579	8585	8691	8597	8603	8609	8615	8621	8627	6	1 1 2	2 3 4	4 5 5
73	.8633	8639	8645	8651	8657	8663	8669	8675	8681	8686	6	1 1 2	2 3 4	4 5 5
74	.8692	8698	8704	8710	8716	8722	8727	8733	8739	8745	6	1 1 2	2 3 4	4 5 5
75	.8751	8756	8762	9768	8774	8779	8785	8791	8797	8802	6	1 1 2	2 3 4	4 5 5
76	.8808	8814	8820	8825	8831	8837	8842	8843	8854	8859	6	1 1 2	2 3 4	4 5 5
77	.8865	8871	8876	8882	8887	8893	8899	8904	8910	8915	6	1 1 2	2 3 4	4 5 5
78	.8921	8927	8932	8938	8943	8949	8954	8960	8965	8971	6	1 1 2	2 3 4	4 5 5
79	.8976	8982	8987	8993	8998	9004	9009	9015	9020	9025	6	1 1 2	2 3 4	4 5 5
80	.9031	9036	9042	9047	9053	9058	9063	9069	9074	9079	5	1 1 2	2 3 3	4 4 5
81	.9085	9090	9096	9101	9106	9112	9117	9122	9128	9133	5	1 1 2	2 3 3	4 4 5
82	.9138	9143	9149	9154	9159	9165	9170	9175	9180	9186	5	1 1 2	2 3 3	4 4 5
83	.9191	9196	9201	9206	9212	9217	9222	9227	9232	9238	5	1 1 2	2 3 3	4 4 5
84	.9243	9248	9253	9258	9263	9269	9274	9279	9284	9289	5	1 1 2	2 3 3	4 4 5
85	.9294	9299	9304	9309	9315	9320	9325	9330	9335	9340	5	1 1 2	2 3 3	4 4 5
86	.9345	9350	9355	9360	9365	9370	9375	9380	9385	9390	5	1 1 2	2 3 3	4 4 5
87	.9395	9400	9305	9410	9415	9420	9425	9430	9435	9440	5	0 1 1	2 2 3	3 4 4
88	.9445	9450	9455	9460	9465	9469	9474	9479	9484	9489	5	0 1 1	2 2 3	3 4 4
89	.9494	9499	9504	9509	9513	9518	9523	9528	9533	9538	5	0 1 1	2 2 3	3 4 4
90	.9542	9547	9552	9557	9562	9566	9571	9576	9581	9586	5	0 1 1	2 2 3	3 4 4
91	.9590	9595	9600	9605	9609	9614	9619	9624	9628	9633	5	0 1 1	2 2 3	3 4 4
92	.9638	9643	9647	9652	9657	9661	9666	9671	9675	9680	5	0 1 1	2 2 3	3 4 4
93	.9685	9689	9694	9699	9703	9708	9713	9717	9722	9727	5	0 1 1	2 2 3	3 4 4
94	.9731	9736	9741	9745	9750	9754	9759	9763	9768	9773	5	0 1 1	2 2 3	3 4 4
95	.9777	9782	9786	9791	9795	9800	9805	9809	9814	9818	5	0 1 1	2 2 3	3 4 4
96	.9823	9827	9832	9836	9841	9845	9850	9854	9859	9863	4	0 1 1	2 2 2	3 3 4
97	.9868	9872	9877	9881	9886	9890	9894	9899	9903	9908	4	0 1 1	2 2 2	3 3 4
98	.9912	9917	9921	9926	9930	9934	9939	9943	9948	9952	4	0 1 1	2 2 2	3 3 4
99	.9956	9961	9965	9969	9974	9978	9983	9987	9991	9996	4	0 1 1	2 2 2	3 3 4

ANTILOGARITHMS 10^x

x	0	1	2	3	4	5	6	7	8	9	Δ_m +	1	2	3	4	5	6	7	8	9
												ADD								
.00	1000	1002	1005	1007	1009	1012	1014	1016	1019	1021	2	0	0	1	1	1	1	1	2	2
.01	1023	1026	1028	1030	1033	1035	1038	1040	1042	1045	2	0	0	1	1	1	1	1	2	2
.02	1047	1050	1052	1054	1057	1059	1062	1064	1067	1069	2	0	0	1	1	1	1	1	2	2
.03	1072	1074	1076	1079	1081	1084	1086	1089	1091	1094	2	0	0	1	1	1	1	1	2	2
.04	1096	1099	1102	1104	1107	1109	1112	1114	1117	1119	3	0	1	1	1	1	2	2	2	3
.05	1122	1125	1127	1130	1132	1135	1138	1140	1143	1146	3	0	1	1	1	1	2	2	2	3
.06	1148	1151	1153	1156	1159	1161	1164	1167	1169	1172	3	0	1	1	1	1	2	2	2	3
.07	1175	1178	1180	1183	1186	1189	1191	1194	1197	1199	3	0	1	1	1	1	2	2	2	3
.08	1202	1205	1208	1211	1213	1216	1219	1222	1225	1227	3	0	1	1	1	1	2	2	2	3
.09	1230	1233	1236	1239	1242	1245	1247	1250	1253	1256	3	0	1	1	1	1	2	2	2	3
.10	1259	1262	1265	1268	1271	1274	1276	1279	1282	1285	3	0	1	1	1	1	2	2	2	3
.11	1288	1291	1294	1297	1300	1303	1306	1309	1312	1315	3	0	1	1	1	2	2	2	2	3
.12	1318	1321	1324	1327	1330	1334	1337	1340	1343	1346	3	0	1	1	1	2	2	2	2	3
.13	1349	1352	1355	1358	1361	1365	1368	1371	1374	1377	3	0	1	1	1	2	2	2	2	3
.14	1380	1384	1387	1390	1393	1396	1400	1403	1406	1409	3	0	1	1	1	2	2	2	2	3
.15	1413	1416	1419	1422	1426	1429	1432	1435	1439	1442	3	0	1	1	1	2	2	2	2	3
.16	1445	1449	1452	1455	1459	1462	1466	1469	1472	1476	3	0	1	1	1	2	2	2	2	3
.17	1479	1483	1486	1489	1493	1496	1500	1503	1507	1510	4	0	1	1	2	2	2	3	3	4
.18	1514	1517	1521	1524	1528	1531	1535	1538	1542	1545	4	0	1	1	2	2	2	3	3	4
.19	1549	1552	1556	1560	1563	1567	1570	1574	1578	1581	4	0	1	1	2	2	2	3	3	4
.20	1585	1589	1592	1596	1600	1603	1607	1611	1614	1618	4	0	1	1	2	2	2	3	3	4
.21	1622	1626	1629	1633	1637	1641	1644	1648	1652	1656	4	0	1	1	2	2	2	3	3	4
.22	1660	1663	1667	1671	1675	1679	1683	1687	1690	1694	4	0	1	1	2	2	2	3	3	4
.23	1698	1702	1706	1710	1714	1718	1722	1726	1730	1734	4	0	1	1	2	2	2	3	3	4
.24	1738	1742	1746	1750	1754	1758	1762	1766	1770	1774	4	0	1	1	2	2	2	3	3	4
.25	1778	1782	1786	1791	1795	1799	1803	1807	1811	1816	4	0	1	1	2	2	2	3	3	4
.26	1820	1824	1828	1832	1837	1841	1845	1849	1854	1858	4	0	1	1	2	2	2	3	3	4
.27	1862	1866	1871	1875	1879	1884	1888	1892	1897	1901	4	0	1	1	2	2	2	3	3	4
.28	1905	1910	1914	1919	1923	1928	1932	1936	1941	1945	4	0	1	1	2	2	2	3	3	4
.29	1950	1954	1959	1963	1968	1972	1977	1982	1986	1991	4	0	1	1	2	2	2	3	3	4
.30	1995	2000	2004	2009	2014	2018	2023	2028	2032	2037	5	0	1	1	2	2	3	3	4	4
.31	2042	2046	2051	2056	2061	2065	2070	2075	2080	2084	5	0	1	1	2	2	3	3	4	4
.32	2089	2094	2099	2104	2109	2113	2118	2123	2128	2133	5	0	1	1	2	2	3	3	4	4
.33	2138	2143	2148	2153	2158	2163	2168	2173	2178	2183	5	1	1	2	2	3	3	4	4	5
.34	2188	2193	2198	2203	2208	2213	2218	2223	2228	2234	5	1	1	2	2	3	3	4	4	5
.35	2239	2244	2249	2254	2259	2265	2270	2275	2280	2286	5	1	1	2	2	3	3	4	4	5
.36	2291	2296	2301	2307	2312	2317	2323	2328	2333	2339	5	1	1	2	2	3	3	4	4	5
.37	2344	2350	2355	2360	2366	2371	2377	2382	2388	2393	6	1	1	2	2	3	4	4	5	5
.38	2399	2404	2410	2415	2421	2427	2432	2338	2443	2449	6	1	1	2	2	3	4	4	5	5
.39	2455	2460	2466	2472	2477	2483	2489	2495	2500	2506	6	1	1	2	2	3	4	4	5	5
.40	2512	2518	2523	2529	2535	2541	2547	2553	2559	2564	6	1	1	2	2	3	4	4	5	5
.41	2570	2576	2582	2588	2594	2600	2606	2612	2618	2624	6	1	1	2	2	3	4	4	5	5
.42	2630	2636	2642	2649	2655	2661	2667	2673	2679	2685	6	1	1	2	2	3	4	4	5	5
.43	2692	2698	2704	2710	2716	2723	2729	2735	2742	2748	6	1	1	2	2	3	4	4	5	5
.44	2754	2761	2767	2773	2780	2786	2793	2799	2805	2812	6	1	1	2	2	3	4	4	5	5
.45	2818	2825	2831	2838	2844	2851	2858	2864	2871	2877	7	1	1	2	3	3	4	5	6	6
.46	2884	2891	2897	2904	2911	2917	2924	2931	2938	2944	7	1	1	2	3	3	4	5	6	6
.47	2951	2958	2965	2972	2979	2985	2992	2999	3006	3013	7	1	1	2	3	3	4	5	6	6
.48	3020	3027	3034	3041	3048	3055	3062	3069	3076	3083	7	1	1	2	3	4	4	5	6	6
.49	3090	3097	3105	3112	3119	3126	3133	3141	3148	3155	7	1	1	2	3	4	4	5	6	6

ANTILOGARITHMS 10^x

x	0	1	2	3	4	5	6	7	8	9	Δ_m +	1	2	3	4	5	6	7	8	9
												ADD								
.50	3162	3170	3177	3184	3192	3199	3206	3214	3221	3228	7	1	1	2	3	4	4	5	6	6
.51	3236	3243	3251	3258	3266	3273	3281	3289	3296	3304	8	1	2	2	3	4	5	6	6	7
.52	3311	3319	3327	3334	3342	3550	3357	3365	3373	3381	8	1	2	2	3	4	5	6	6	7
.53	3388	3396	3404	3412	3420	3428	3436	3443	3451	3459	8	1	2	2	3	4	5	6	6	7
.54	3467	3475	3483	3491	3499	3508	3516	3524	3532	3540	8	1	2	2	3	4	5	6	6	7
.55	3548	3556	3565	3573	3581	3589	3597	3606	3614	3622	8	1	2	2	3	4	5	6	6	7
.56	3631	3639	3648	3656	3664	3673	3681	3690	3698	3707	8	1	2	2	3	4	5	6	6	7
.57	3715	3724	3733	3741	3750	3758	3767	3776	3784	3793	9	1	2	3	4	4	5	6	7	8
.58	3802	3811	3819	3828	3837	3846	3855	3864	3873	3882	9	1	2	3	4	4	5	6	7	8
.59	3890	3899	3908	3917	3926	3926	3945	3954	3863	3972	9	1	2	3	4	5	5	6	7	8
.60	3981	3990	3999	4009	4018	4027	4036	4046	4055	4064	9	1	2	3	4	5	5	6	7	8
.61	4074	4083	4093	4102	4111	4121	4130	4140	4150	4159	10	1	2	3	4	5	6	7	8	9
.62	4169	4178	4188	4198	4207	4217	4227	4236	4246	4256	10	1	2	3	4	5	6	7	8	9
.63	4266	4276	4285	4295	4305	4315	4325	4335	4345	4355	10	1	2	3	4	5	6	7	8	9
.64	4365	4375	4385	4395	4406	4416	4426	4436	4446	4457	10	1	2	3	4	5	6	7	8	9
.65	4467	4477	4487	4498	4508	4519	4529	4539	4550	4560	10	1	2	3	4	5	6	7	8	9
.66	4571	4581	4592	4603	4613	4624	4634	4645	4656	4667	11	1	2	3	4	5	7	8	9	10
.67	4677	4688	4699	4710	4721	4732	4742	4753	4764	4775	11	1	2	3	4	5	7	8	9	10
.68	4786	4797	4808	4819	4831	4842	4853	4864	4875	4883	11	1	2	3	4	6	7	8	9	10
.69	4898	4909	4920	4932	4943	4955	4966	4977	4989	5000	11	1	2	3	4	6	7	8	9	10
.70	5012	5023	5035	5047	5058	5070	5082	5093	5105	5117	12	1	2	4	5	6	7	8	10	11
.71	5129	5140	5152	5164	5176	5188	5200	5212	5224	5236	12	1	2	4	5	6	7	8	10	11
.72	5248	560	5272	5284	5297	5309	5321	5335	5346	5358	12	1	2	4	5	6	7	8	10	11
.73	5370	5383	5395	5408	5420	5433	5445	5458	5470	5483	12	1	2	4	5	6	7	8	10	11
.74	5495	5508	5521	5534	5546	5559	5572	5585	5598	5610	13	1	3	4	5	6	8	9	10	12
.75	5623	5636	5649	5662	5675	5689	5702	5715	5728	5741	13	1	3	4	5	7	8	9	10	12
.76	5754	5768	5781	5794	5808	5821	5834	5848	5861	5875	13	1	3	4	5	7	8	9	10	12
.77	5888	5902	5916	5929	5943	5957	5970	5984	5998	6012	14	1	3	4	6	7	8	10	11	13
.78	6026	6039	6053	6067	6081	6095	6109	6124	6138	6152	14	1	3	4	6	7	8	10	11	13
.79	6166	6180	6194	6209	6223	6237	6252	6266	6281	6295	14	1	3	4	6	7	8	10	11	13
.80	6310	6324	6339	6353	6368	6383	6397	6412	6427	6442	15	1	3	4	6	7	9	10	12	13
.81	6457	6471	6486	6501	6516	6531	6546	6561	6577	6592	15	2	3	5	6	8	9	11	12	14
.82	6607	6622	6637	6653	6668	6683	6699	6714	6730	6745	15	2	3	5	6	8	9	11	12	14
.83	6761	6776	6792	6808	6823	6839	6855	6871	6887	6902	16	2	3	5	6	8	10	11	13	14
.84	6918	6934	6950	6996	6982	6998	7015	7731	7047	7063	16	2	3	5	6	8	10	11	13	14
.85	7079	7096	7112	7129	7145	7161	7178	7194	7211	7228	16	2	3	5	6	8	10	11	13	14
.86	7244	7261	7278	7295	7311	7328	7345	7362	7379	7396	17	2	3	5	7	8	10	12	14	15
.87	7413	7430	7447	7564	7482	7499	7516	7534	7551	7568	17	2	3	5	7	9	10	12	14	15
.88	7586	7603	7621	7638	7656	7674	7691	7709	7727	7745	18	2	4	5	7	9	11	13	14	16
.89	7762	7780	7798	7816	7834	7852	7870	7889	7907	7925	18	2	4	5	7	9	11	13	14	16
.90	7943	7962	7980	7998	8017	8035	8054	8072	8091	8110	18	2	4	5	7	9	11	13	14	16
.91	8128	8147	8166	8185	8204	8222	8241	8260	8279	8299	19	2	4	6	8	10	11	13	15	17
.92	8318	8337	8356	8375	8395	8414	8433	8453	8472	8492	19	2	4	6	8	10	11	13	15	17
.93	8511	8531	8551	8570	8590	8610	8630	8650	8670	8690	20	2	4	6	8	10	12	14	16	18
.94	8710	8730	8750	8770	8790	8810	8831	8851	8872	8892	20	2	4	6	8	10	12	14	16	18
.95	8913	8933	8954	8974	8995	9016	9036	9057	9078	9099	21	2	4	6	8	10	13	15	17	19
.96	9120	9141	9162	9183	9204	9226	9247	9268	9290	9311	21	2	4	6	8	11	13	15	17	19
.97	9333	9354	9376	9397	9419	9441	9462	9484	9506	9528	22	2	4	7	9	11	13	15	18	20
.98	9550	9572	9594	9616	9638	9661	9683	9705	9727	9750	22	2	4	7	9	11	13	15	18	20
.99	9772	9795	9817	9840	9863	9886	9908	9931	9954	9977	23	2	5	7	9	11	14	16	18	21