ગુજરાત રાજ્યના શિક્ષણવિભાગના પત્ર-ક્રમાંક
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PHYSICS

PRACTICAL RECORD BOOK

(JOURNAL)

Standard XII

PLEDGE

India is my country.
All Indians are my brothers and sisters.
I love my country and I am proud of its rich and varied heritage.
I shall always strive to be worthy of it.
I shall respect my parents, teachers and all my elders and treat everyone with courtesy.
I pledge my devotion to my country and its people.
My happiness lies in their well-being and prosperity.

રાજ્ય સરકારની વિનામૂલ્યે યોજના હેઠળનું પુસ્તક

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PREFACE

In accordance with the Government's Policy to implement uniformed curriculum at national level, the Government of Gujarat and Secondary and Higher Secondary Board of Education, Gujarat State have decided to implement the NCERT textbooks at school level directly as per resolution No M.SH.B./1217/1036/CHH dated 25-10-17. With reference to that Gujarat State Board of School Textbooks is pleased to introduce this **Physics Practical Record Book (Journal)** prepared for **Standard XII** before the students.

Before publishing the Physics Practical Record Book (Journal), its manuscript has been fully reviewed by expert professors and teachers. According to their suggestions, we have made necessary changes in the manuscript before publishing the Physics Practical Record Book (Journal). The Board has taken special care to ensure that this Physics Practical Record Book (Journal) is made interesting, useful and free from errors. However, to improve the quality of the Physics Practical Record Book (Journal). We welcome suggestions, from people interested in education,

P. Bharathi (IAS)
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Date : 10-12-2019

Executive President
Gandhinagar

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FUNDAMENTAL DUTIES

It shall be the duty of every citizen of India :*

(a) To abide by the Constitution and respect its ideals and institutions, the National Flag and the National Anthem;

(b) To cherish and follow the noble ideals which inspired our national struggle for freedom;

(c) To uphold and protect the sovereignty, unity and integrity of India;

(d) To defend the country and render national service when called upon to do so;

(e) To promote harmony and the spirit of common brotherhood amongst all the people of India transcending religious, linguistic and regional or sectional diversities; to renounce practices derogatory to the dignity of women;

(f) To value and preserve the rich heritage of our composite culture;

(g) To protect and improve the natural environment including forests, lakes, rivers and wildlife, and to have compassion for living creatures;

(h) To develop the scientific temper, humanism and the spirit of inquiry and reforms;

(i) To safeguard public property and to abjure violence;

(j) To strive towards excellence in all spheres of individual and collective activity so that the nation constantly rises to higher levels of endeavour and achievement.

(k) Who is a parent or guardian to provide opportunities for education to his child or, as the case may be, ward between the age of six and fourteen years.

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* Constitution of India : Section 51-A

CERTIFICATE

Exam Seat No. : _____

PHYSICS PRACTICAL RECORD BOOK (JOURNAL)

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_____

has performed practical work of _____ physics practicals out of _____ practicals satisfactorily.

_____ _____

Sign of Subject teacher / Lab teacher **Principal**

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No.	Practical	Page No.	Date	Sign
10.	To find out the focal length of a convex lens by plotting graphs between u and υ or between $1/u$ and $1/\upsilon$.			
11.	To find out the focal length of a convex mirror using a convex lens.			
12.	To find out the focal length of a concave lens with the help of a convex lens.			
13.	To determine the angle of minimum deviation for a given glass prism by plotting a graph between the angle of incidence and the angle of deviation.			
14.	To determine refractive index of a glass slab using a travelling microscope.			
15.	To determine the refractive index of a liquid (water) using (i) concave mirror, (ii) convex lens and (iii) a plane mirror.			
16.	To draw the *I-V* characteristic curves of a p-n junction in forward bias and reverse bias.			
17.	To draw the characteristic curve of a Zener diode and to determine its reverse breakdown voltage.			
18.	To study the characteristics of a common emitter n-p-n (or p-n-p) transistor and to find out the values of current and voltage gains.			

●

Date : _____

EXPERIMENT 1

Aim :

To determine resistance per unit length of a given wire by plotting a graph of potential difference versus current.

Apparatus and materials required :

Procedure :

Circuit diagram :

Observations :

(1) Range of ammeter = 0 mA to ..... mA.

(2) Least count of ammeter = ... mA.

(3) Range of voltmeter = 0 V to ..... V.

(4) Least count of voltmeter = ... V.

(5) Least count of metre scale = ... m.

(6) Length of the given wire, l = ... m.

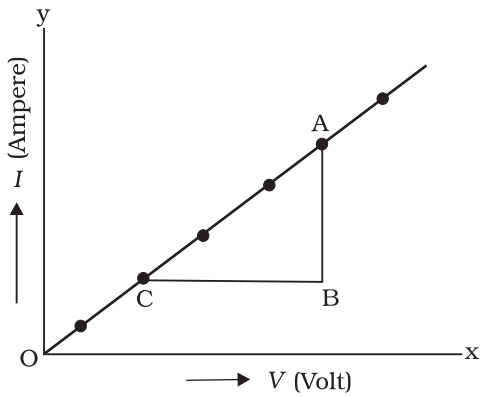
Observation table :

Voltmeter and milliammeter readings

S. No.	Applied potential difference [Voltmeter reading V] (V)	Current flowing through the wire [milliammeter reading]		Resistance $R = \frac{V}{I}$ Ω	Average R Ω
		I' (mA)	$I = I' \times 10^{-3}$ (A)		
(1)					
(2)					
(3)					
(4)					
(5)					
(6)					

Graph and Calculation :

Plot a graph between the current (I) flowing through wire and the potential difference across the wire (V)



Slope of the graph $= \frac{AB}{BC}\ \Omega^{-1}$

The resistance of the given wire is equal to the reciprocal of the slope.

The resistance of the wire $R = \frac{1}{\text{slope}} = \frac{BC}{AB}\ \Omega$

1. Resistance per unit length of the given wire $= \frac{R}{l} =$

Error :

$$\frac{\Delta R}{R} = \frac{\Delta V}{V} + \frac{\Delta I}{I} = ...$$

$$\therefore \quad \Delta R = R\left[\frac{\Delta V}{V} + \frac{\Delta I}{I}\right]\ \Omega$$

Result :

(1) The potential difference across the given wire varies linearly with the current.

(2) The resistance per unit length of the wire is $(R \pm \Delta R) = (..... \pm ..... \ \Omega m^{-1})$.

Self Assessment :

1. A voltmeter is always connected in parallel and an ammeter in series with the circuit. Why ? Will they record the respective parameters if connected in opposite manner ?

2. Why are copper wires normally used for connecting different components in an electric circuit ?

3. What happens if the current is allowed to flow through the circuit continuously for a long time ? Why ?

Signature of subject teacher / Lab teacher

Date : _____

EXPERIMENT 2

Aim :

To determine the resistance of a given wire using a metre bridge and hence determine the resistivity of the material of the wire.

Apparatus and materials required :

Procedure :

Circuit diagram :

Observations :

(1) Length of the wire of unknown resistance, L = ... cm.

(2) Measurement of diameter of the wire of unknown resistance.

Least count of the screw gauge (L.C.) = ... cm.

Zero error of the screw gauge = ... cm.

Zero correction of the screw gauge = ... cm.

Observation table :

1 : Diameter of Wire

S. No.	Reading along one direction			Reading along mutually perpendicular direction			Mean Diameter
	Main scale reading P (cm)	Coinciding circular scale division n	Diameter $d_1 = P + (n \times \text{L.C.})$ (cm)	Main scale reading P' (cm)	Coinciding circular scale division n'	Diameter $d_2 = P' + (n' \times \text{L.C.})$ (cm)	$d = \frac{d_1 + d_2}{2}$ (cm)
(1)							
(2)							
(3)							

Mean diameter (corrected for zero error) d = ... cm

Radius of wire $r = \frac{d}{2}$ = ... cm

Observation table :

2 : Unknown resistance

S. No.	S in the left gap				S in the right gap			Mean resistance $S = \frac{S_1 + S_2}{2}$ Ω	ρ Ω m	ΔS_1 Ω	ΔS_2 Ω	ΔS Ω	Δρ Ωm
	Resistance R Ω	Position of balance point $(AD=l)$ (cm)	Balancing length DC = 100 – l (cm)	$S_1 = R \times \frac{l}{100-l}$ Ω	Position of balance point AD′ = l' (cm)	Balancing length D′C = 100 – l' (cm)	$S_2 = R \times \frac{100-l'}{l'}$ Ω						
(1)													
(2)													
(3)													
(4)													
(5)													

Calculation :

Unknown resistance $S = R \frac{l}{100-l}$ Ω

Unknown resistance $S' = R \times \frac{100 - l'}{l'}$ Ω

Mean $S = \frac{S + S'}{2}$ Ω

The resistivity of the material of the wire is $\rho = \frac{S \pi r^2}{L}$ Ωm

Error :

$$\Delta S_1 = \left[\frac{\Delta l}{l} + \frac{\Delta l}{(100 - l)} \right] S_1 \ \Omega$$

The maximum values of ΔS_1 = ... Ω

$$\Delta S_2 = \left[\frac{\Delta l'}{l'} + \frac{\Delta l'}{(100 - l')} \right] S_2 \ \Omega$$

The maximum values of ΔS_2 = ... Ω

The maximum error of measurement of the resistance $\Delta S = \Delta S_1 + \Delta S_2 \Omega$

Therefore, resistivity maximum error is $\frac{\Delta\rho}{\rho} = \frac{\Delta S}{S} + \frac{2\Delta r}{r} + \frac{\Delta L}{L}$ Where Δr = L. C. of Screw gouge

ΔL = L. C. of Scale

$$\therefore \Delta\rho = \rho\left[\frac{\Delta S}{S} = \frac{2\Delta r}{r} + \frac{\Delta L}{L}\right] \Omega$$

Result :

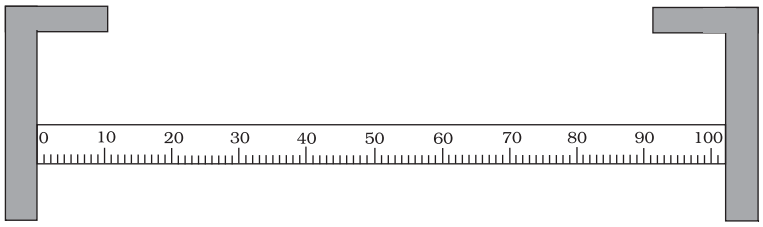
(1) The unknown resistance of the given wire is found to be $S \pm \Delta S$ = ... $\pm$ ..... Ω

(2) The resistivity of the material of the wire is $\rho \pm \Delta\rho$ = ... $\pm$ ..... Ωm

Self Assessment :

1. The bridge wire may not be exactly 100 cm long, so record its exact length and use this in the calculation.

2. If the metre bridge wire is not of uniform area of cross section, how will it affect the observations ?



Defective scale of a metre bridge

3. If the metre bridge wire is not made of a material of uniform density, how will it affect the observations ?

4. If the same experiment is performed with AC = 50 cm wire instead of 1 m, what changes would be there in the result ?

5. The scale attached along the wire may not indicate the exact length as shown in Q. 2 How would you minimise the error ?

6. Why is the metre bridge not suitable for measuring very high/very low resistances ?

7. Why is the metre bridge preferred for determining the resistance of a wire over the Ohm's law circuit ?

Signature of subject teacher / Lab teacher

Date : _____

EXPERIMENT 3

Aim :

To verify the laws of combination of resistances (series and parallel) using a metre bridge.

Apparatus and materials required :

Procedure :

Circuit diagram :

Observation table :

Resistance R_1= ..... Ω

Resistance R_2= ..... Ω

Series and Parallel combination of resistances

	S. No.	Resistance R (Ohm)	Length AD = l (cm)	Length DC, $l' = 100 - l$ (cm)	Unknown resistance X (R_S or R_P) = $\frac{R \times l}{l'}$ (Ohm)	ΔR_S or ΔR_P (Ohm)
R_1 and R_2 in series, R_S	(1)					
	(2)					
	(3)					
	(4)					
	(5)					
R_1 and R_2 in Parallel, R_P	(1)					
	(2)					
	(3)					
	(4)					
	(5)					

Calculation :

1. Series combination of R_1 and R_2 : $R_S = \frac{R \times l}{l'}\ \Omega$

Mean resistance of in series connection R_1 and R_2 : $R_S = \frac{R_{S_1} + R_{S_2} + R_{S_3} + R_{S_4} + R_{S_5}}{5}\ \Omega$

2. The theoretically expected value of the series connection of resistances R_1 and R_2 is

   $R_S = R_1 + R_2 =$ ..... = ... Ω

3. Parallel combination of R_1 and R_2 : $R_P = \frac{R \times l}{l'}\ \Omega$

Means resistance of in parallel connection R_1 and R_2 : $R_P = \frac{R_{P_1} + R_{P_2} + R_{P_3} + R_{P_4} + R_{P_5}}{5}\ \Omega$

4. The theoretically expected value of the parallel connection of resistances R_1 and R_2 is

$$R_p = \frac{R_1 R_2}{R_1 + R_2}\ \Omega$$

5. An error arising in the measurement of series connection of R_1 and R_2 Resistance is

$$\frac{\Delta R_s}{R_s} = \frac{\Delta l}{l} + \frac{\Delta l'}{l'}$$

$$\Delta R_S = R_S \left[\frac{\Delta l}{l} + \frac{\Delta l'}{l'}\right] \Omega$$

Maximum Value of ΔR_S = ... Ω

6. An error arising in the measurement of parallel connection of R_1 and R_2 Resistance is

$$\therefore\ \frac{\Delta R_P}{R_P} = \frac{\Delta l}{l} + \frac{\Delta l'}{l'}$$

$$\therefore\ \Delta R_p = R_p \left[\frac{\Delta l}{l} + \frac{\Delta l'}{l}\right] \Omega$$

Maximum value of ΔR_P = ... Ω

Result :

Theoretical and Experimental values of resistance

	Theoretically expected resistance (Ω)	Experimentally obtained resistance (Ω)
Series Combination	$R_s = R_1 + R_2 =$	$R_s \pm \Delta R_s =$
Parallel Combination	$R_P = \frac{R_1 R_2}{R_1 + R_2} =$	$R_P \pm \Delta R_P =$

Self Assessment :

1. Comment on the difference between theoretically expected and experimentally obtained values of the effective resistances.

2. Given n resistors of resistance R each, how will you combine them to get the maximum and the minimum effective resistance? Extend this experiment using filament of bulbs as resistors.

3. Identify some method(s) to reduce the effect of 'end-resistance' at connections between the wire and copper strip or because of the improper soldering of wire.

4. How will the sensitivity of metre bridge change under following condition?

   Rheostat head is moved from minimum resistance to maximum resistance positions.

Signature of subject teacher / Lab teacher

Date : _____

EXPERIMENT 4

Aim :

To compare the emf of two given primary cells (Daniel and Leclanche cells) using a potentiometer.

Apparatus and materials required :

Procedure :

Circuit diagram :

Observations :

(1) No. of wires on the Potentiometer board = ...

∴ length of wire L= Number of wires x Length of each wire = ...m

(2) Range of the voltmeter = 0 V to V

(3) Least count of the Voltmeter = ... V

(4) Potential drop across E = ... V

(5) Potential drop across E_1 = ... V

(6) Potential drop across E_2 = ... V

Observation table :

Balance length

S. No.	l_1 cm Leclanche cell (E_1) in the circuit			l_2 cm Daniel cell (E_2) in the circuit			Ratio $\frac{E_1}{E_2} = \frac{l_1}{l_2}$	$\Delta\left(\frac{E_1}{E_2}\right)$
	Jockey being moved in one direction (i)	Jockey being moved in another direction (ii)	Mean	Jockey being moved in one direction (i)	Jockey being moved in another direction (ii)	Mean		
(1)								
(2)								
(3)								
(4)								

Calculation :

$$\frac{E_1}{E_2} = \frac{l_1}{l_2}$$

$$\text{Mean} \quad \left(\frac{E_1}{E_2}\right) = \frac{\left(\frac{E_1}{E_2}\right)_1 + \left(\frac{E_1}{E_2}\right)_2 + \left(\frac{E_1}{E_2}\right)_3 + \left(\frac{E_1}{E_2}\right)_4}{4}$$

Error :

$$\frac{\Delta\left(\frac{E_1}{E_2}\right)}{\frac{E_1}{E_2}} = \frac{\Delta l_1}{l_1} + \frac{\Delta l_2}{l_2}$$

$$\therefore \Delta\left(\frac{E_1}{E_2}\right) = \left(\frac{\Delta l_1}{l_1} + \frac{\Delta l_2}{l_2}\right)\left(\frac{E_1}{E_2}\right)$$

Maximum value of $\Delta\left(\frac{E_1}{E_2}\right)$ = ...

Result :

The ratio of **emfs** E_1/E_2 for Leclanche cell to Daniel cell

$$= \frac{E_1}{E_2} \pm \Delta\left(\frac{E_1}{E_2}\right)_{max} = \text{.....} \pm \text{.....}$$

Self Assessment :

1. A voltmeter connected across the terminals of a battery measures the potential difference. How is it different from **emf** ?

2. What would you conclude if galvanometer needle keeps shaking (vibrating) in your experimental set up?

3. Use a voltmeter to obtain the ratio of potential difference of the two cells. Does it differ considerably from the ratio of their **emfs**? If not, what can you conclude?

Signature of subject teacher / Lab teacher

Date : _____

EXPERIMENT 5

Aim :

To determine the internal resistance of a given primary cell using a potentiometer.

Apparatus and materials required :

Procedure :

Circuit Diagram :

Observations :

l_0 = ... cm. (in the beginning of the experiment)

l_0 = ... cm. (at the end of the experiment)

Mean l_0 = ... cm

Observation table :

Balance length

S. No.	R Ω	l cm	$\frac{1}{R}$ Ω^{-1}	$\frac{1}{l}$ cm^{-1}	$r = \left(\frac{l_0 - l}{l}\right) R$ Ω
(1)					
(2)					
(3)					
(4)					
(5)					
(6)					

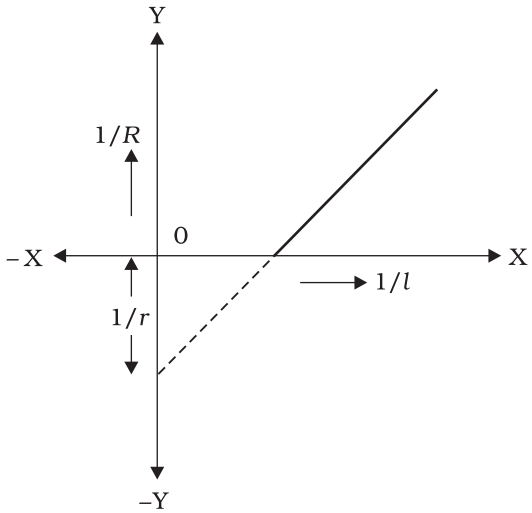
Graph and Calculation :

$$r = \left(\frac{l_0 - l}{l}\right) R \quad \Omega$$

The mean internal resistance of the cell

$$r = \frac{r_1 + r_2 + r_3 + r_4 + r_5 + r_6}{6} \ \Omega$$

Taking $\frac{1}{l}$ On X-axis and $\frac{1}{R}$ on Y-axis, plot a graph of $\frac{1}{R} \rightarrow \frac{1}{l}$



Graph between *1/R* and *1/l*

The negative intercept on the Y-axis gives the value of

$\frac{1}{r}$ = ... Ω

∴ The internal resistance of the cell r = ... Ω

Result :

The internal resistance of the given cell r

(1) by calculation ..... Ω

(2) by graph ..... Ω

Self Assessment :

1. All the positive terminals of sources of **emf** are joined at point A of potentiometer, but if all the negative terminals of sources of **emf** are joined at point A then how will the balance length be affected ?

2. Find the internal resistance of a freshly prepared Leclanche cell. Will its internal resistance change with R ?

3. State the factors on which the internal resistance of a cell depends.

Signature of subject teacher / Lab teacher

Date : _____

EXPERIMENT 6

Aim :

To determine the resistance of a galvanometer by half-deflection method and to find its figure of merit.

Apparatus and materials required :

Procedure :

Circuit diagram :

Observations :

Emf of the battery E = ... V

Number of divisions on full scale of galvanometer = ...

Observation table :

Resistance of galvanometer

Sl. No.	High resistance R (Ω)	Deflection in the galvano meter θ (division)	Half deflection in the galvanometer $\frac{\theta}{2}$ (division)	Shunt resistance S (Ω)	$G = \frac{RS}{R - S}$ (Ω)	$k = \left(\frac{E}{R+G}\right) \cdot \frac{1}{\theta}$ $\frac{\text{ampere}}{\text{division}}$
(1)						
(2)						
(3)						
(4)						
(5)						

Calculation :

Resistance of galvanometer

$$G = \frac{RS}{R - S} \ \Omega$$

Mean value of G (resistance of galvanometer) $= \frac{G_1 + G_2 + G_3 + G_4 + G_5}{5} = ...\Omega$

Figure of merit of galvanometer

$$k = \left(\frac{E}{R+G}\right)\frac{1}{\theta} \text{ ampere / division}$$

Mean value of k (figure of merit of galvanometer) $k = \frac{k_1 + k_2 + k_3 + k_4 + k_5}{5}$ ampere / division

Result :

(1) Resistance of galvanometer by half deflection method, G = ... Ω

(2) Figure of merit of galvanometer, k = ...ampere / division

Self Assessment :

1. How will you use a galvanometer for measuring current ?

2. (a) Out of Galvanometer, Ammeter and Voltmeter; which one has the highest resistance and which one has the lowest? Explain.

   (b) Which of the two meters has lower resistance – a milliammeter or a microammeter ?

3. What are the factors on which sensitivity of a galvanometer depends ?

4. Internal resistance of the cell is taken to be zero. This implies that we have to use a freshly charged accumulator in the experiment or use a good battery eliminator. If the internal resistance is finite, how will it affect the result ?

5. Is it possible to find the galvanometer resistance by taking $\frac{1}{3}$ deflection ? If so, what changes would be required in the formula for calculation of value of G ?

Signature of subject teacher / Lab teacher

Date : _____

EXPERIMENT 7

Aim :

To convert the given galvanometer (of known resistance and figure of merit) into (i) an ammeter of a desired range (say 0 to 30 mA) and (ii) a voltmeter of desired range (say 0 to 3 V) and to verify the same.

Apparatus and materials required :

(i) Conversion of Galvanometer into an Ammeter

Procedure :

Circuit diagram :

Observations :

(1) Galvanometer resistance, G (given) = ... Ω

(2) Figure of merit of the galvanometer, k (given) = ... ampere/division

(3) Number of divisions on either side of zero of the galvanometer scale, N = ... division

(4) Current required for producing full scale deflection of N divisions, $I_g = kN$ = ... ampere

(5) Radius of Wire :

Least count of the given Screw gauge = ... cm

Zero error = ... cm

Zero correction = ... cm

Observed diameter of the wire :

(i) ..... cm (ii) ..... cm (iii) ..... cm (iv) ..... cm

Mean observed diameter, D = ... cm

Radius of the wire $r = \frac{D}{2}$ = ... cm

Given value of specific resistance of the material of the wire ρ = ... Ω m

Calculation :

Shunt resistance $S = \frac{I_g \times G}{I_O - I_g}$ Ω

Where I_O = Desired range of ammeter =.....mA = ...A

Required length of the wire, $l = \frac{S\pi r^2}{\rho}$ cm

Observed length of the Shunt wire for the desired range l' = ... cm

Shunt resistance from the observed length of the Wire $S' = \frac{l' \times \rho}{\pi r^2}$ Ω

Result :

To convert the given galvanometer into an ammeter of the range, 0 to ..... ampere

(1) The calculated resistance of the Shunt wire S = ... Ω

(2) The observed resistance of the Shunt wire S' = ... Ω

(ii) Conversion of Galvanometer into a Voltmeter

Procedure :

Circuit diagram :

Observations :

(1) Resistance of the galvanometer, G (given) = ... Ω

(2) The Figure of merit of the galvanometer, k (given) = ...ampere/division

(3) Number of divisions on either side of zero of the galvanometer scale, N = ... division

(4) Current required for producing full scale deflection of N divisions, $I_g = kN$ = ... ampere

(5) Total resistance taken out from the resistance box R' = ... Ω

Calculation :

Resistance to be connected in series with the Galvanometer,

$$R = \frac{V_o}{I_g} - G\ \Omega$$ Where V_o = Desired range of voltmeter = ...V

Result :

To convert the given Galvanometer into a Voltmeter of the range, 0 to ..... Ω

(1) The value of the calculated series resistance, R = ... Ω

(2) The value of the observed series resistance, R' = ... Ω

(3) Current for full scale deflection, I_g = ... ampere

Self Assessment :

1. How can you increase the range of the converted Galvanometer to 0-60 mA ?

2. How can you decrease the range of the converted Galvanometer to 0-20 mA ?

3. If $S << G$, what is the order of resistance of converted Galvanometer ?

4. Why is an Ammeter always connected in series with the circuit ?

5. Why is a voltmeter always connected in parallel with the circuit ?

Signature of subject teacher / Lab teacher

Date : _____

EXPERIMENT 8

Aim :

To determine the frequency of alternating current using a Sonometer and an electromagnet.

Apparatus and materials required :

Procedure :

Observations :

(1) Length of the Wire = ... cm = ... m

(2) Mass of the wire = ... g = ... kg

(3) Mass per unit length, m = ... g / cm = ... kg/m

(4) Acceleration due to gravity, g = ... ms^{-2}

Observation table :

Resonant length

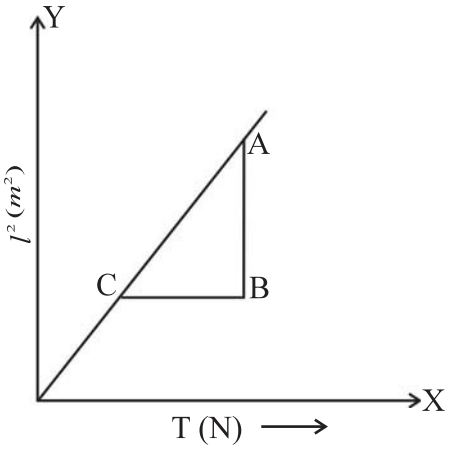
S. No.	Load including mass of hanger m' (kg)	Tension $T = m'g$ (N)	Resonant length l			Mean l in (m)	$\nu = \frac{1}{2l}\sqrt{\frac{T}{m}}$ (Hz)
			First trial (cm)	Second trial (cm)	Mean (cm)		
(1)							
(2)							
(3)							
(4)							

Calculations :

(1) $\nu = \frac{1}{2l}\sqrt{\frac{T}{m}}$ Hz

$$\nu = \frac{\nu_1 + \nu_2 + \nu_3 + \nu_4}{4} \text{ Hz}$$

(2) Graph



Slope of the graph $= \frac{AB}{BC} \frac{m^2}{N}$

Slope of the graph $= \frac{1}{4m\nu^2}$

$\therefore \quad \nu = \frac{1}{\sqrt{4m \times \text{Slope}}}$ Hz

Result :

(1) The graph between T and l^2 is a straight line.

(2) Frequency of AC supply $= \frac{\nu}{2}$

(i) From calculation = ... Hz

(ii) From graph = ... Hz

Self Assessment :

1. How is AC different from DC ?

2. What is the meaning of frequency of AC ?

3. How does the wire vibrate? Identify and explain the rule with the help of which you can determine the direction of force acting on the wire.

4. What should be the property of the iron for making it a good electromagnet ?

5. Is there any relation between frequency and magnetism of the electromagnet, and frequency of the Alternating Current ?

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EXPERIMENT 9

Aim :

To find the value of 'v' for different values of 'u' in case of concave mirror and to find the focal length.

Apparatus and materials required :

Procedure :

Observations :

(1) Approximate focal length of the concave mirror = ... cm

(2) Actual distance of the object from the mirror using index needle, l_o = ... cm

(3) Observed distance of the object from the mirror l'_0 = position of mirror upright – position of object pin upright on the scale = ... cm

(4) Index correction for object distance, e = actual distance – observed distance.

$= l_0 - l'_0 =$ ..... cm

Similarly for image pin

$e_i = l_i - l_i^1 =$ ..... cm.

Observation table :

Determination of *u*, *v* and *f*

S. No.	Mirror M (cm)	Position of Object pin P_1 (cm)	Image pin P_2 (cm)	Observed u' (cm)	Observed υ' (cm)	Corrected $u = u' + e$ (cm)	Corrected $\upsilon = \upsilon' + e_i$ (cm)	$f = \frac{u\upsilon}{u+\upsilon}$ (cm)	Δf (cm)
(1)									
(2)									
(3)									
(4)									
(5)									
(6)									

Calculation :

(1) $\frac{1}{f} = \frac{1}{u} + \frac{1}{\upsilon}$

$\therefore f = \frac{u\upsilon}{u + \upsilon}$ cm

Mean of the focal length $f = \frac{f_1 + f_2 + f_3 + f_4 + f_5 + f_6}{6}$ cm

Error :

$\therefore \quad \frac{1}{f} = \frac{1}{u} + \frac{1}{\upsilon}$

$\frac{\Delta f}{f^2} = \frac{\Delta u}{u^2} + \frac{\Delta \upsilon}{\upsilon^2}$

or $\Delta f = f^2 \left[\frac{\Delta u}{u^2} + \frac{\Delta \upsilon}{\upsilon^2} \right]$ cm

The maximum value of Δf = ... cm

Result :

The focal length of the given concave (converging) mirror is

($f \pm \Delta f$) = ... $\pm$ ..... cm

Self Assessment :

1. A dentist uses concave mirror to see the tooth. In what way does it help the dentist ?

2. Can you determine the focal length of the concave mirror if $u < f$?

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EXPERIMENT 10

Aim :

To find the focal length of a convex lens by plotting graphs between u and v or between $\frac{1}{u}$ and $\frac{1}{v}$.

Apparatus and materials required :

Procedure :

Observations :

(1) Approximate focal length of the convex lens = ... cm

(2) Length of the index needle as measured by the metre scale, L_0 = ... cm

(3) Thickness of the thin convex lens (given), t = ... cm

(4) Actual length between the optical centre O of the lens and tip of the pin,

$l_0 = L_0 + t/2 =$ .... cm

(5) Observed length of the index needle, l'_0 = Distance between the centre of convex lens and tip of the object pin

= Position of lens upright – position of object pin upright on the scale.

= .... cm – .... cm = ... cm

(6) Index correction for object distance, $e_0 = l_0 - l'_0 =$ .... cm; similarly for image pin, $e_i = l_i - l'_i =$ .... cm.

Observation table :

Determination of *u*, *υ* and *f*

S. No.	Lens upright *a* (cm)	Object pin upright *b* (cm)	Image pin upright *c* (cm)	Observed $u = a - b$ (cm)	Observed $\upsilon = a - c$ (cm)	Corrected u = Observed $u + e_0$ (cm)	Corrected υ = Observed + e_i (cm)	$\frac{1}{u}$ cm^{-1}	$\frac{1}{\upsilon}$ cm^{-1}	$f = \frac{u\upsilon}{u+\upsilon}$ cm	Δf (cm)
(1)											
(2)											
(3)											
(4)											
(5)											
(6)											

Calculation :

(1) $\frac{1}{f} = \frac{1}{u} + \frac{1}{\upsilon}$

$\therefore f = \frac{u\upsilon}{u + \upsilon}$ cm

Mean of the focal length $f = \frac{f_1 + f_2 + f_3 + f_4 + f_5 + f_6}{6}$ cm

Error :

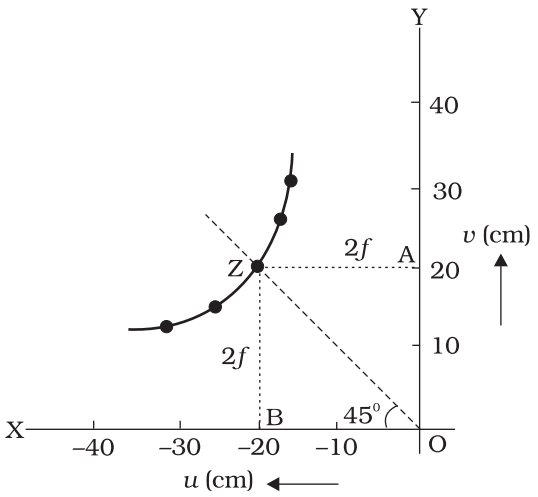
$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$

Or $\frac{\Delta f}{f^2} = \frac{\Delta u}{u^2} + \frac{\Delta v}{v^2}$

$\therefore \quad \Delta f = f^2 \left[\frac{\Delta u}{u^2} + \frac{\Delta v}{v^2} \right]$ cm

The maximum value of Δf = ... cm

(3) **Calculation of focal length by plotting graphs :**



u versus υ graph for convex lens

From the graph :

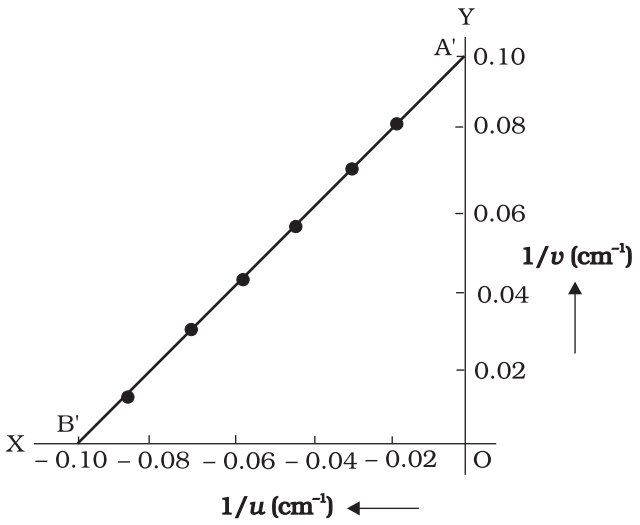
Distance OA (= $2f$) on Y-axis = ... cm

Distance OB (= $2f$) on X-axis = ... cm

Mean focal length of the convex lens,

$$f = \frac{OA + OB}{4} = \text{.....} = \text{.....cm}$$

(4) $\frac{1}{u} - \frac{1}{v}$ graph



$\frac{1}{u}$ versus $\frac{1}{\upsilon}$ graph for a convex lens (not to scale)

From the graph :

Intercept OA' $\left(=\frac{1}{f}\right)$ on Y-axis = ... cm^{-1}

Intercept OB' $\left(=\frac{1}{f}\right)$ on X-axis = ... cm^{-1}

Mean fo al length (f) of the convex lens,

$f = \frac{2}{OA' + OB'}$ = ...= .....cm

Result :

The focal length of the given converging thin convex lens :

(i) from calculations as shown in observation table $f \pm \Delta f$ = ... ± ..... cm. (Here f is mean value of the focal length.)

(ii) From $u - v$ graph = ... cm and

(iii) From $\frac{1}{u} - \frac{1}{\upsilon}$ graph = ... cm

Self Assessment :

1. Draw the ray diagram for image formation in case of a convex lens for position of object varying from infinity to optical centre.

2. What are the differences between the image formed by a convex lens and a concave lens ?

3. How does the focal length of a thick convex lens differ from that of a thin lens ?

4. How can you recognise a convex lens, a circular glass slab and a concave lens, without touching them ?

5. Where does the centre of curvature of the plane surface of a plano-convex lens lie ?

6. Define the principal axis of a plano-convex lens ?

7. How does the focal length of a convex lens change if it is dipped in water ?

8. What is the relation between focal length and radius of curvature of a plano-convex lens ?

9. Can a virtual image produced by a lens be inverted ?

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EXPERIMENT 11

Aim :

To find the focal length of a convex mirror using a convex lens.

Apparatus and materials required :

Procedure :

Observations :

(1) Focal length of the convex lens, f (estimated/given) = ... cm

(2) Actual length of the index needle, l = ... cm

(3) Observed length of the index needle l' = Position of mirror upright – Position of pin upright on the scale = ... cm

(4) Index correction, e = Actual length – Observed length ($l - l'$) = ... cm

Observation table :

Determination of radius of curvature of convex mirror, R

S. No.	Upright position of				Observed $R' = c-d$ (cm)	Corrected R = Observed $R' + e$ (cm)	Focal length f (cm)	Δf (cm)
	Object pin P_1 a (cm)	Convex lens LL′ b (cm)	Convex Mirror MM′ c (cm)	Image pin P_2 d (cm)				
(1)								
(2)								
(3)								
(4)								
(5)								

Calculation :

(1) Curvature of the convex mirror, R cm

(2) Focal length of the convex mirror, f cm

Mean of the focal length $f = \dfrac{f_1 + f_2 + f_3 + f_4 + f_5}{5}$ cm

Error :

$$f = \frac{R' + l}{2} = \frac{(c - d) + (l - l')}{2}$$

$$\therefore \frac{\Delta f}{f} = \frac{\Delta c}{c} + \frac{\Delta d}{d} + \frac{\Delta l}{l} + \frac{\Delta l'}{l'}$$

$$\therefore \Delta f = f \left[\frac{\Delta c}{c} + \frac{\Delta d}{d} + \frac{\Delta l}{l} + \frac{\Delta l'}{l} \right] \text{ cm}$$

Δf = ... cm (The maximum value from Δf_1, Δf_2, Δf_3, Δf_4, Δf_5)

Result :

The focal length of the given convex mirror ($f \pm \Delta f$) = ... $\pm$ ..... cm.

Self Assessment :

1. If focal length of the concave mirror is determined by using convex lenses of different focal lengths, do you expect any change in the result? If yes, what type of change? If not, why not ?

2. How will the result change if a convex lens of different refractive indices were used ?

3. If the convex lens selected for the experiment has focal length less than that of the convex mirror, how would this selection limit the experiment ?

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EXPERIMENT 12

Aim :

To find out the focal length of a concave lens with the help of a convex lens.

Apparatus and materials required :

Procedure :

Observations :

(1) Focal length of the convex lens, f_L = ... cm

(2) Length of the index needle as measured by the scale, s = ... cm

(3) Thickness of the thin concave lens (given) at its optical centre, t = ... cm

(4) Actual length between the optical centre O of the lens and tip of the pin, $l = s + \frac{t}{2}$ = ... cm

(5) Observed length of the index needle, l' = Distance between the pole of the lens and tip of the pin

= Position of lens upright - position of pin upright on the scale = ... cm

(6) Index correction, $e = l - l'$ = ... cm

Observation table :

Determination of u, v, and f of concave lens

S. No.	Object pin upright P_1, a (cm)	Convex lens L_1 upright, b (cm)	Image formed by L_1, (Point I_1) c (cm)	Concave lens L_2 upright, d (cm)	Image formed by L_1 and L_2, point I_2, g (cm)	Observed $u = c - d$ (cm)	Observed $v = g - d$ (cm)	Corrected u = Observed $u + e$ (cm)	Corrected v = Observed $v + e$ (cm)	$f = \frac{uv}{u-v}$ (cm)	Δf (cm)
(1)											
(2)											
(3)											
(4)											
(5)											

Calculation :

Focal length of concave lens $f = \frac{u\upsilon}{u - \upsilon}$ cm

Mean $f = \frac{f_1 + f_2 + f_3 + f_4 + f_5}{5}$ cm

Error :

$$\frac{1}{f} = \frac{1}{\upsilon} - \frac{1}{u}$$

$$\frac{\Delta f}{f^2} = \frac{\Delta \upsilon}{\upsilon^2} + \frac{\Delta u}{u^2}$$

$$\Delta f = f^2 \left[\frac{\Delta \upsilon}{\upsilon^2} + \frac{\Delta u}{u^2} \right] \text{ cm}$$

The maximum value of Δf = ... cm

Result :

The focal length of the given concave lens is $(f \pm \Delta f)$ = ... $\pm$ ..... cm.

Self Assessment :

1. In this experimental setup the combination of concave lens and convex lens separated by a distance d behaves as a single lens of focal length f. Check the relation $\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{d}{f_1 f_2}$ for any one of the observations.

2. Calculate f by interchanging the value of u and v and compare it with the experimentally determined value of f.

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EXPERIMENT 13

Aim :

To determine the angle of minimum deviation for a given glass prism by plotting a graph between the angle of incidence and the angle of deviation.

Apparatus and materials required :

Procedure :

Observations :

Least count of the protractor = ... (degree)

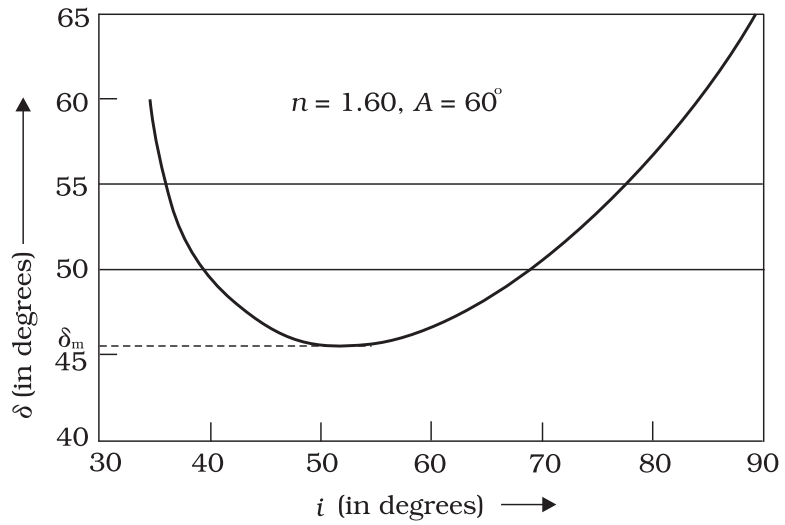
Angle of the prism, (A) = ... (degree)

Observation table :

Measuring the angle of incidence, *i* and angle of deviation δ for a prism

S. No.	Angle of incidence, i (degrees)	Angle of deviation, δ (degrees)
(1)		
(2)		
(3)		
(4)		
(5)		
(6)		
(7)		
(8)		
(9)		
(10)		

Plotting the graph between *i* and δ for the prism



Graph between angle of incidence and angle of deviation

Calculation :

Draw tangent on the lowest point of a graph parallel to X-axis, and read the angle of minimum deviation δ_m on the Y-axis of the graph = ...

RESULT :

Angle of minimum deviation, δ_m = ... (degree)

Self Assessment :

1. Interpret the graph between *i* and δ

2. If the experiment is performed with angle of emergence taken as angle of incidence, will there be any change in the values? If yes, why? If not, why ?

3. What will happen if you go on decreasing the angle of incidence? If you think there is a munimum, try to find its expression theoretically. What happens when *i* is less than the minimum angle of incidence ?

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EXPERIMENT 14

Aim :

To determine refractive index of a glass slab using a travelling microscope.

Apparatus and materials required :

Procedure :

Observations :

Least count (LC) of the travelling microscope :

$$\text{Least Count (LC) of the travelling microscope} = \frac{\text{Value of one division on main scale (MSD)}}{\text{Total division on vernier scale (VSD)}}$$

= ..... cm

= ..... cm

Observation table :

Refractive Index of Glass Slab

S. No.	Reading of the microscope when focused on								
	Mark made on paper			Mark on paper through the slab			Particles on top of the glass surface		
	M.S.R. M (cm)	V.S.R. (N×L.C.) (cm)	a_1 = M+ (N×L.C.) (cm)	M.S.R. M (cm)	V.S.R. (N×L.C.) (cm)	a_2 = M+ (N×L.C.) (cm)	M.S.R. M (cm)	V.S.R. (N×L.C.) (cm)	a_3 = M+ (N×L.C.) (cm)
(1)									
(2)									
(3)									

Calculation :

1. The refractive index $n_{ga} = \frac{\text{real thickness of the slab}}{\text{apparent thickness of the slab}} = \frac{a_1 - a_3}{a_3 - a_2}$

$$\text{Mean } n_{ga} = \frac{n_{ga_1} + n_{ga_2} + n_{ga_3}}{3}$$

Error :

The estimated uncertainty in the measurement of n_{ga} is

$$\frac{\Delta n_{ga}}{n_{ga}} = \left(\frac{\Delta b}{b} + \frac{\Delta c}{c} \right) \quad \ldots \quad \ldots \quad \ldots \quad (1)$$

Where $\frac{\Delta b}{b} = \left(\frac{\Delta a_1}{a_1} + \frac{\Delta a_3}{a_3} \right) = \left(\frac{\Delta a}{a_1} + \frac{\Delta a}{a_3} \right)$ = ...

and $\frac{\Delta c}{c} = \left(\frac{\Delta a_1}{a_1} + \frac{\Delta a_2}{a_2} \right) = \left(\frac{\Delta a}{a_1} + \frac{\Delta a}{a_2} \right)$ = ... Where Δa is L. C. of microscope.

From eq. (1) $\frac{\Delta n_{ga}}{n_{ga}}$ = ... + ...

Δn_{ga_1} = Δn_{ga_2} = Δn_{ga_3} =

Maximum value of Δn_{ga} = ...

Result :

The refractive index of glass of the slab

$n_{ga} \pm \Delta n_{ga}$ = ... $\pm$ ..... .

Self Assessment :

1. Will a colourless slab be visible if immersed in a transparent liquid of the same refractive index as that of the slab ? State the reason for it.

2. You have three slabs of same dimensions – the first one is hollow and completely filled with water, the second one is made of crown glass and the third flint glass. If each of them has a coloured mark at the bottom, in which case will it appear to have risen the most ? Given its $n_{\text{flint}} > n_{\text{crown}} > n_{\text{water}}$

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EXPERIMENT 15

Aim :

To determine the refractive index of a liquid (water) using (i) concave mirror, (ii) Convex lens and a plane mirror.

(i) Refractive index of water using concave mirror

Apparatus and materials required :

Procedure :

Observations :

(1) Approximate value of the focal length of the concave mirror, f = ... cm

(2) Approximate value of the radius of curvature, $R = 2f$ = ... cm

Observation table :

Observations for R, R' and n_{wa}

S. No.	Position of pin with respect to pole P		$n_{wa} = R/R'$	Δn_{Wa}
	For empty concave mirror, distance PC, R (cm)	For water-filled mirror, distance PC', R' (cm)		
(1)				
(2)				
(3)				

Calculation :

$$n_{wa} = \frac{R}{R'}$$

$$\text{Mean } n_{wa} = \frac{n_{wa_1} + n_{wa_2} + n_{wa_3}}{3}$$

Error :

$$\frac{\Delta n_{wa}}{n_{wa}} = \frac{\Delta R}{R} + \frac{\Delta R'}{R'}$$

$$\therefore \Delta n_{wa} = \left[\frac{\Delta R}{R} + \frac{\Delta R'}{R'}\right] n_{wa}$$

Where ΔR, $\Delta R'$ = L. C. of Scale.

Result :

The refractive index of water with respect to air is

$n_{wa} \pm \Delta n_{wa} =$ ..... $\pm$ .....

Self Assessment :

1. Find the refractive index of water from this experiment considering that a concave mirror filled with water behaves as a combination of concave mirror and a plano-convex lens.

2. If you gradually increase the quantity of water in the mirror, starting with a few drops, do you expect any change in the position or brightness of the image ?

3. If colours are added to water keeping its transparency, would this alter the value of refractive index and intensity of the image ?

4. If a small quantity of some transparent liquid (like kerosene) lighter than water is added such that it forms a thin film on the water surface, can the experiment still be performed? If so, would the value of refractive index be changed ?

Aim :

(ii) Refractive index of water using convex lens and a plane mirror

Apparatus and materials required :

Procedure :

Observations :

(1) Mean value of distance between the two legs of the spherometer l = ... cm

(2) Mean value of sagitta (bulge of the lens) h = ... cm

(3) Mean value of the radius of curvature of the lens R = ... cm

Observation table :

Focal length of convex lens, OF (= f) and water plano-convex lens (OF′) = f'

S. No.	Position of pin with respect to optical centre O						$f_w = \frac{f\,f'}{f - f'}$	Δf_w	n_{wa}	Δn_{wa}
	Without water (OF = f)			With water (OF′ = f')						
	Distance of the pin from			Distance of the pin from						
	Upper surface of the lens d_1 (cm)	Plane Mirror d_2 (cm)	$f = \frac{d_1 + d_2}{2}$ f (cm)	Upper surface of the lens d_3 (cm)	Plane mirror d_4 (cm)	$f' = \frac{d_3 + d_4}{2}$ f (cm)				
(1)										
(2)										
(3)										

Calculation :

$$f_w = \frac{f\,f'}{f - f'} \text{ cm}$$

Value of the radius of curvature of the lens R = $\frac{l^2}{6h} + \frac{h}{2}$

$$n_{wa} = \left(1 + \frac{R}{f_w}\right)$$

Mean $n_{wa} = \frac{n_{wa_1} + n_{wa_2} + n_{wa_3}}{3}$

= .....

Error :

$$\frac{\Delta f_W}{f_W{}^2} = \frac{\Delta f}{f^2} + \frac{\Delta f'}{f^{12}}$$ Where Δf, $\Delta f'$ = L. C. of Scale

Or $\Delta f_w = f_w{}^2 \left[\frac{\Delta f}{f^2} + \frac{\Delta f'}{f'^2}\right]$ cm

$$\Delta R = R\left[\frac{2\Delta l}{l} + \frac{2\Delta h}{h}\right] \text{cm}$$ Where Δl, Δh = L. C. of Scale

$$\frac{\Delta n_{wa}}{n_{wa}} = \frac{\Delta R}{R} + \frac{\Delta f_w}{f_w}$$

or $\Delta n_{wa} = n_{wa}\left[\frac{\Delta R}{R} + \frac{\Delta f_w}{f_w}\right]$

The maximum value of Δn_{wa} = ...

Result :

The refractive index of a given liquid (say water) with respect to air is $n_{wa} \pm \Delta n_{wa}$ = ... $\pm$ .....

Self Assessment :

1. What will happen if you are given a convex lens of small focal length ?

2. What are the basic assumptions you have made in performing this experiment ?

3. Why do we have to raise the object pin upward after filling water between the lens and the mirror ?

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EXPERIMENT 16

Aim :

To draw the *I - V* characteristic curves of a p-n junction in forward bias and reverse bias.

Apparatus and materials required :

Procedure :

Circuit Diagram : (For Forward bias and Reverse bias)

Observations :

(1) p-n junction diode used (diode no.) = ...

(2) For forward biasing :

(i) Range of the Voltmeter = 0 V to V

(ii) Least count of the Voltmeter scale = ... V

(iii) Range of the Milliammeter = 0 mA to ..... mA

(iv) Least count of the Milliammeter scale = ... mA

(3) For reverse biasing :

(i) Range of the Voltmeter = 0 V to V

(ii) Least count of the Voltmeter scale = ... V

(iii) Range of the Microammeter = 0 μA to ..... μA

(iv) Least count of the Microammeter = ... μA

Observation table [1] :

Variation of forward current with voltage across the diode (forward bias)

S. No.	Forward voltage V_f (V)	Forward current I_f (mA)
(1)		
(2)		
(3)		
(4)		
(5)		
(6)		
(7)		
(8)		
(9)		
(10)		
(11)		
(12)		
(13)		
(14)		
(15)		
(16)		
(17)		
(18)		
(19)		
(20)		

Observation table [2] :

Variation of reverse current with voltage across the diode (reverse bias)

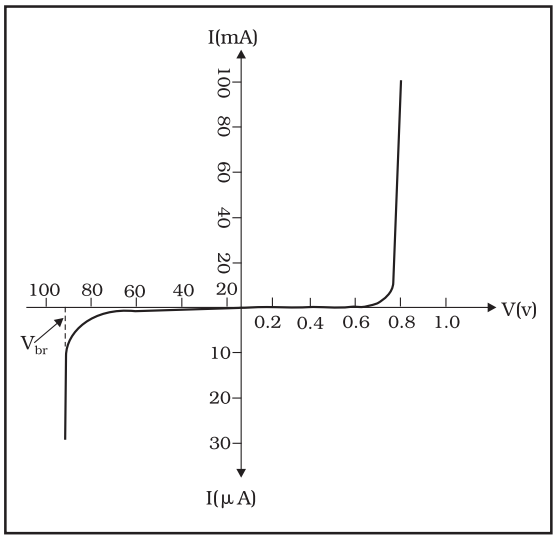
S. No.	Reverse voltage V_r (V)	Reverse current I_r (μA)
(1)		
(2)		
(3)		
(4)		
(5)		
(6)		
(7)		
(8)		
(9)		
(10)		
(11)		
(12)		
(13)		
(14)		
(15)		
(16)		
(17)		
(18)		
(19)		
(20)		

Plotting graph :

(1) Plot a graph between forward voltage across the diode (V_f) along the positive x-axis and current flowing through the diode (I) along the positive y-axis. The graph as shown in figure represents a typical I-V characteristic of a silicon diode used.

Locate the knee and determine the cut-in voltage.

(2) Now plot the reverse voltage (V_r) along the negative x-axis and the corresponding current (in μA) along the negative y-axis as shown in figure Determine the reverse saturation current.



Typical I–V characteristies of a silicon diode in forward biasing and reverse biasing

Result :

(A) The value of cut-in voltage for the given diode is = ... V.

(B) The reverse saturation current for the given diode is = ... μA.

Self Assessment :

1. How can you operate diode as a switch or as a rectifier ?

2. What is the difference between a diode and a resistor ?

3. If a resistor of higher value (greater than the resistor connected in the circuit) is connected in series with diode, then comment on the slope of linear region of I - V characteristics.

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EXPERIMENT 17

Aim :

To draw the characteristic curve of a Zener diode and to determine its reverse breakdown voltage.

Apparatus and materials required :

Procedure :

Circuit Diagram :

Observations :

(1) Range of the voltmeter = 0 V to V

(2) Least count of the voltmeter = ... V

(3) Range of the microammeter = 0 μA to ..... μA

(4) Least count of the microammeter = ... μA

(5) Specification of Zener diode used (code no.) = ...

(6) To calculate the value of protective resistance R_p, following data is required.

Maximum permissible power (power rating) of the Zener diode specified by the manufacturer, P_z = ...W

Maximum permissible voltage (voltage rating) of the Zener diode as specified by the manufacturer, V_z = ...V

Value of the protective resistor to be used in series with the Zener diode,

R_p = ... Ω $R_p = \frac{(V - V_z)V_z}{P_z}$ = ... Ω

(7) Note down the reading of the voltmeter and microammeter in Table.

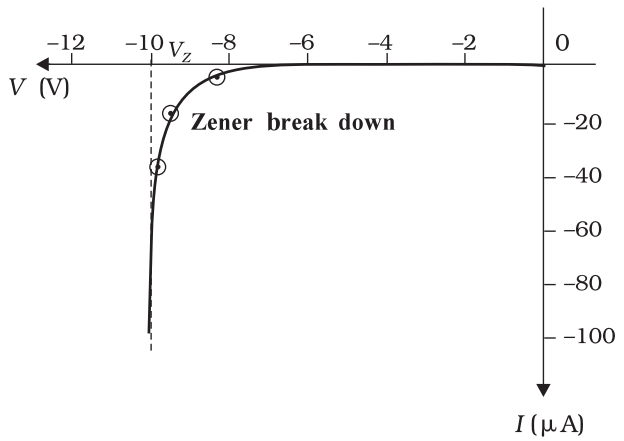
Observation table :

Variation of reverse current I_r with reverse voltage V_r across the Zener diode

S. No.	For Zener diode	
	Voltmeter reading V_r (V)	**Microammeter I_r (μA)**
(1)		
(2)		
(3)		
(4)		
(5)		
(6)		
(7)		
(8)		
(9)		
(10)		

Graph :

(i) Plot a graph between reverse voltage, V_r and reverse current, I_r taking V_r along x-axis and I_r along y-axis by using the readings from observation table.



Result :

The breakdown voltage of the Zener diode obtained from the graph is V_Z = ... V

Self Assessment :

1. What is the principle of Zener diode ?

2. How is reverse current obtained ?

3. What happens at Zener breakdown ?

4. What is meant by internal field emission ?

5. How can you use a Zener diode as a voltage regulator ?

Signature of subject teacher / Lab teacher

Date : _____

EXPERIMENT - 18

Aim :

To study the characteristics of a common emitter n-p-n (or p-n-p) transistor and to find out the values of current and voltage gains.

Apparatus and materials required :

Procedure :

Circuit diagram :

Observations :

(1) Range of the voltmeter used in the input circuit = 0 V to V

(2) Least count of the voltmeter used in the input circuit = ... V

(3) Range of the voltmeter used in the output circuit = 0 V to ..... V.

(4) Least count of the voltmeter used in the output circuit = ... V

(5) Range of the microammeter used in the input circuit = 0 μA to ..... μA

(6) Least count of the microammeter used in the input circuit = ... μA

(7) Range of the milliammeter used in the output circuit = 0 mA to ..... mA

(8) Least count of the milliammeter used in the output circuit = ... mA

(9) Specification of the transistor used = ...

Observation table [1] :

Variation in input current I_B with input voltage V_{BE} for fixed value of V_{CE}

S. No.	Input voltage V_{BE} (V)	Input current, I_B (μA) at			
		V_{CE} = ... V	V_{CE} = ... V	V_{CE} = ... V	V_{CE} = ... V
(1)					
(2)					
(3)					
(4)					
(5)					
(6)					
(7)					
(8)					
(9)					
(10)					

Observation table [2] :

Variation in output current I_C with output voltage V_{CE} for fixed value of I_B

S. No.	Output voltage V_{CE} V_{CE} (V)	Output current I_C (mA) at			
		I_B = ... μA	I_B = ... μA	I_B = ... μA	I_B = ... μA
(1)					
(2)					
(3)					
(4)					
(5)					
(6)					
(7)					
(8)					
(9)					
(10)					

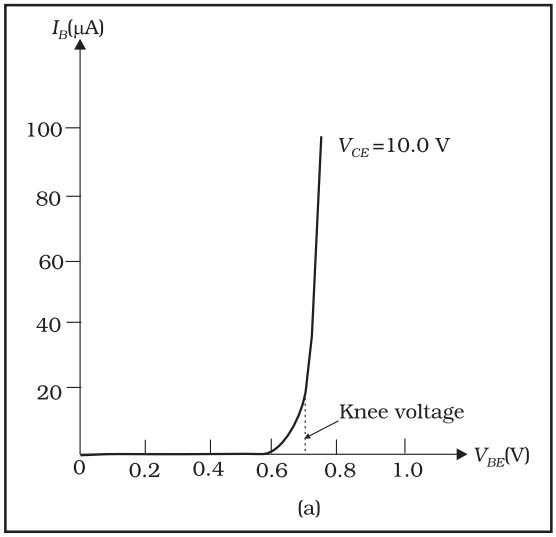
Observation table [3] :

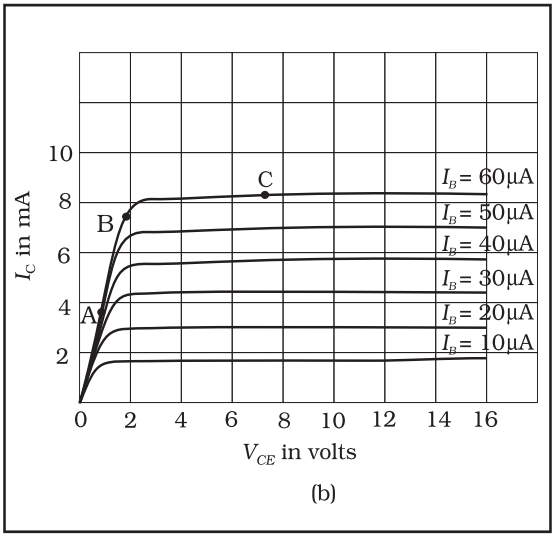
Variation in output current I_C with input current I_B for fixed value of V_{CE}

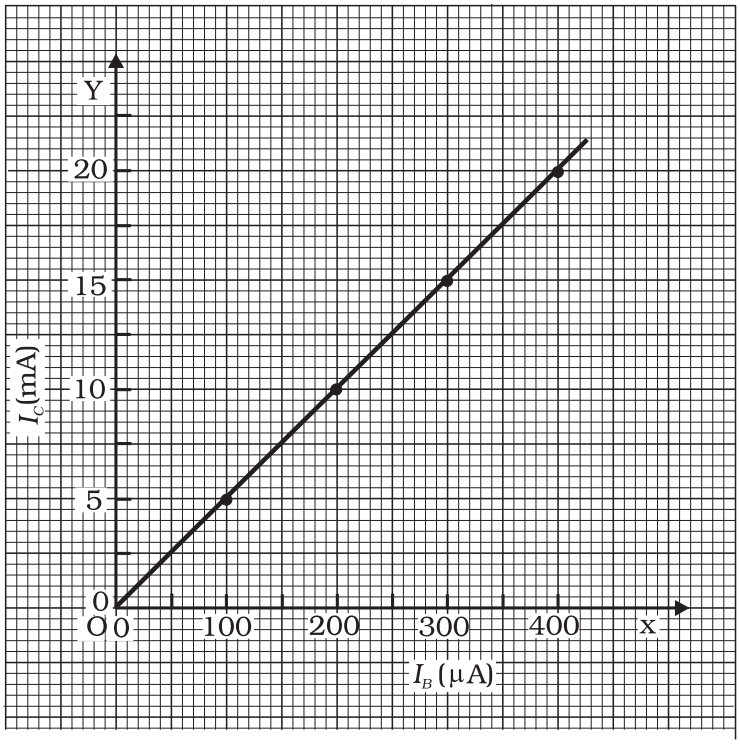
S. No.	Input current I_B (μA)	Output current I_C (mA)			
		V_{CE} = V	V_{CE} = V	V_{CE} = V	V_{CE} = V
(1)					
(2)					
(3)					
(4)					
(5)					
(6)					
(7)					
(8)					
(9)					
(10)					

Plotting graph :

(i) For input characteristics, plot the graph between input voltage V_{BE} and input current I_B for fixed value of V_{CE} taking V_{BE} along x-axis I_B along y-axis, using observation table 1.







(c)

(ii) For output characteristics, plot the graph between input voltage V_{CE} and output current I_C for fixed value I_B, taking V_{CE} along x-axis and I_C along y-axis, by using observation Table 2.

(iii) For output characteristics, plot the graph between input current I_B and output current I_C for fixed value of V_{CE}, taking I_B along x-axis and I_C along y-axis, by using Observation Table 3.

Calculation :

(i) Draw a tangent on the input characteristics curve at a point on the rapid rising portion graph (a), and from it, determine the reciprocal of slope of the curve at that point. This gives the dynamic input resistance of the transistor

$$r_i = \left(\frac{\Delta V_{BE}}{\Delta I_B}\right)_{V_{CE} = \text{ constant}} \qquad \therefore\ r_i = \text{.....}$$

$$= \text{.....}\ \Omega$$

(ii) Draw tangents on the output characteristics curve (at linearly rising part A, at turning point B and nearly horizontal part C) (Graph (b)).

Measure the reciprocal of slopes which will give the dynamic output resistances, at operating points A, B and C (Graph (b)). Note that the dynamic output resistance depends on the operating point.

$$r_o = \left(\frac{\Delta V_{CE}}{\Delta I_C} \right)_{I_B = \text{constant}} \quad \Omega$$

Note : That dynamic output resistance depends on operating point.

(iii) Find the slope on the transfer characteristics of the transistor to obtain current gain (β) of the transistor as

$$\beta = \left(\frac{\Delta I_C}{\Delta I_B} \right)_{V_{CE} = \text{constant}}$$

(iv) Take the values of input resistance r_i, output resistance r_0 and current gain β and calculate the value of voltage gain A_V of the transistor by using the relation

$$A_V = \beta \left(\frac{r_o}{r_i} \right)$$

Result :

For the given transistor in the common emitter (CE) configuration

(1) The characteristics of the transistor are shown in the graphs drawn.

(2) At V_{CE} = ... V input resistance = ... Ω

(3) At V_{BE} = ... V output resistance = ... Ω

(4) Current gain, β = ...

(5) Voltage gain, A_V = ...

Self Assessment :

1. What do you mean by dynamic input resistance and why is it called dynamic ?

2. For CE configuration, I_C is not cut-off even for $I_B = 0$. For determination of the cut-off voltage in CE mode, how will you reduce I_C to zero ?

3. Is I_C almost independent of V_{CE} for $V_{CE} > V_{BE}$ in CE configuration ?

Signature of subject teacher / Lab teacher

Experiment No:.....

Date:.....

Scale Value

X - axis : .....

Y - axis : .....

Experiment No:.....

Date:.....

Scale Value

X - axis : .....

Y - axis : .....

Experiment No:.....

Date:.....

Scale Value

X - axis : .....

Y - axis : .....

Experiment No:.....

Date:.....

Scale Value

X - axis : .....

Y - axis : .....

Experiment No:.....

Date:.....

Scale Value

X - axis : .....

Y - axis : .....

Experiment No:.....

Date:.....

Scale Value

X - axis : .....

Y - axis : .....

Experiment No:.....

Date:.....

Scale Value

X - axis : .....

Y - axis : .....

Experiment No:.....

Date:.....

Scale Value

X - axis : .....

Y - axis : .....

Experiment No:.....

Date:.....

Scale Value

X - axis : .....

Y - axis : .....

Experiment No:.....

Date:.....

Scale Value

X - axis : .....

Y - axis : .....

Experiment No:.....

Date:.....

Scale Value

X - axis : .....

Y - axis : .....

Experiment No:.....

Date:.....

Scale Value

X - axis : .....

Y - axis : .....

Experiment No:.....

Date:.....

Scale Value

X - axis : .....

Y - axis : .....

Experiment No:.....

Date:.....

Scale Value

X - axis : .....

Y - axis : .....

Experiment No:.....

Date:.....

Scale Value

X - axis : .....

Y - axis : .....

Experiment No:.....

Date:.....

Scale Value

X - axis : .....

Y - axis : .....

Experiment No:.....

Date:.....

Scale Value

X - axis : .....

Y - axis : .....

LOGARITHMS

	0	1	2	3	4	5	6	7	8	9	Mean Difference								
											1	2	3	4	5	6	7	8	9
10	0000	0043	0086	0128	0170	0212	0253	0294	0334	0374	4	8	12	17	21	25	29	33	37
11	0414	0453	0492	0531	0569	0607	0645	0682	0719	0755	4	8	11	15	19	23	26	30	34
12	0792	0828	0864	0899	0934	0969	1004	1038	1072	1106	3	7	10	14	17	21	24	28	31
13	1139	1173	1206	1239	1271	1303	1335	1367	1399	1430	3	6	10	13	16	19	23	26	29
14	1461	1492	1523	1553	1584	1614	1644	1673	1703	1732	3	6	9	12	15	18	21	24	27
15	1761	1790	1818	1847	1875	1903	1931	1959	1987	2014	3	6	8	11	14	17	20	22	25
16	2041	2068	2095	2122	2148	2175	2201	2227	2253	2279	3	5	8	11	13	16	18	21	24
17	2304	2330	2355	2380	2405	2430	2455	2480	2504	2529	2	5	7	10	12	15	17	20	22
18	2553	2577	2601	2625	2648	2672	2695	2718	2742	2765	2	5	7	9	12	14	16	19	21
19	2788	2810	2833	2856	2878	2900	2923	2945	2967	2989	2	4	7	9	11	13	16	18	20
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201	2	4	6	8	11	13	15	17	19
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404	2	4	6	8	10	12	14	16	18
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598	2	4	6	8	10	12	14	15	17
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784	2	4	6	7	9	11	13	15	17
24	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962	2	4	5	7	9	11	12	14	16
25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133	2	3	5	7	9	10	12	14	15
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298	2	3	5	7	8	10	11	13	15
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456	2	3	5	6	8	9	11	13	14
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609	2	3	5	6	8	9	11	12	14
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757	1	3	4	6	7	9	10	12	13
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900	1	3	4	6	7	9	10	11	13
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038	1	3	4	6	7	8	10	11	12
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172	1	3	4	5	7	8	9	11	12
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302	1	3	4	5	6	8	9	10	12
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428	1	3	4	5	6	8	9	10	11
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551	1	2	4	5	6	7	9	10	11
36	5563	5575	5587	5566	5611	5623	5635	5647	5658	5670	1	2	4	5	6	7	8	10	11
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786	1	2	3	5	6	7	8	9	10
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899	1	2	3	5	6	7	8	9	10
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010	1	2	3	4	5	7	8	9	10
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117	1	2	3	4	5	6	8	9	10
41	6128	6238	6149	6160	6170	6180	6191	6201	6212	6222	1	2	3	4	5	6	7	8	9
42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325	1	2	3	4	5	6	7	8	9
43	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425	1	2	3	4	5	6	7	8	9
44	6435	6345	6454	6464	6474	6484	6494	6503	6513	6522	1	2	3	4	5	6	7	8	9
45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618	1	2	3	4	5	6	7	8	9
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712	1	2	3	4	5	6	7	7	8
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803	1	2	3	4	5	5	6	7	8
48	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893	1	2	3	4	4	5	6	7	8
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981	1	2	3	4	4	5	6	7	8
50	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067	1	2	3	3	4	5	6	7	8
51	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152	1	2	3	3	4	5	6	7	8
52	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235	1	2	2	3	4	5	6	7	7
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316	1	2	2	3	4	5	6	6	7
54	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396	1	2	2	3	4	5	6	6	7
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**

	0	1	2	3	4	5	6	7	8	9	Mean Difference								
											1	2	3	4	5	6	7	8	9
55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474	1	2	2	3	4	5	5	6	7
56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551	1	2	2	3	4	5	5	6	7
57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627	1	2	2	3	4	5	5	6	7
58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701	1	1	2	3	4	4	5	6	7
59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774	1	1	2	3	4	4	5	6	7
60	7782	7789	7769	7803	7810	7818	7825	7832	7839	7846	1	1	2	3	4	4	5	6	6
61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917	1	1	2	3	4	4	5	6	6
62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987	1	1	2	3	3	4	5	6	6
63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055	1	1	2	3	3	4	5	5	6
64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122	1	1	2	3	3	4	5	5	6
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189	1	1	2	3	3	4	5	5	6
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254	1	1	2	3	3	4	5	5	6
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319	1	1	2	3	3	4	5	5	6
68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382	1	1	2	3	3	4	4	5	6
69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445	1	1	2	2	3	4	4	5	6
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506	1	1	2	2	3	4	4	5	6
71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567	1	1	2	2	3	4	4	5	5
72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627	1	1	2	2	3	4	4	5	5
73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686	1	1	2	2	3	4	4	5	5
74	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745	1	1	2	2	3	4	4	5	5
75	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802	1	1	2	2	3	3	4	5	5
76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859	1	1	2	2	3	3	4	5	5
77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915	1	1	2	2	3	3	4	4	5
78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971	1	1	2	2	3	3	4	4	5
79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025	1	1	2	2	3	3	4	4	5
80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079	1	1	2	2	3	3	4	4	5
81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133	1	1	2	2	3	3	4	4	5
82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186	1	1	2	2	3	3	4	4	5
83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238	1	1	2	2	3	3	4	4	5
84	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289	1	1	2	2	3	3	4	4	5
85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340	1	1	2	2	3	3	4	4	5
86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390	1	1	2	2	3	3	4	4	5
87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440	0	1	1	2	2	3	3	4	4
88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489	0	1	1	2	2	3	3	4	4
89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538	0	1	1	2	2	3	3	4	4
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586	0	1	1	2	2	3	3	4	4
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633	0	1	1	2	2	3	3	4	4
92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680	0	1	1	2	2	3	3	4	4
93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727	0	1	1	2	2	3	3	4	4
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773	0	1	1	2	2	3	3	4	4
95	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818	0	1	1	2	2	3	3	4	4
96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863	0	1	1	2	2	3	3	4	4
97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908	0	1	1	2	2	3	3	4	4
98	9912	9917	9921	9926	9930	9934	9939	9843	9948	9952	0	1	1	2	2	3	3	4	4
99	9956	9961	9965	9969	9974	9978	9983	9987	9991	9996	0	1	1	2	2	3	3	3	4
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**

ANTILOGARITHMS

	0	1	2	3	4	5	6	7	8	9	Mean Difference								
											1	2	3	4	5	6	7	8	9
.00	1000	1002	1005	1007	1009	1012	1014	1016	1019	1021	0	0	1	1	1	1	2	2	2
.01	1023	1026	1028	1030	1033	1035	1038	1040	1042	1045	0	0	1	1	1	1	2	2	2
.02	1047	1050	1052	1054	1057	1059	1062	1064	1067	1069	0	0	1	1	1	1	2	2	2
.03	1072	1074	1076	1079	1081	1084	1086	1089	1091	1094	0	0	1	1	1	1	2	2	2
.04	1096	1099	1102	1104	1107	1109	1112	1114	1117	1119	0	1	1	1	1	2	2	2	2
.05	1122	1125	1127	1130	1132	1135	1138	1140	1143	1146	0	1	1	1	1	2	2	2	2
.06	1148	1151	1153	1156	1159	1161	1164	1167	1169	1172	0	1	1	1	1	2	2	2	2
.07	1175	1178	1180	1183	1186	1189	1191	1194	1197	1199	0	1	1	1	1	2	2	2	2
.08	1202	1205	1208	1211	1213	1216	1219	1222	1225	1227	0	1	1	1	1	2	2	2	3
.09	1230	1233	1236	1239	1242	1245	1247	1250	1253	1256	0	1	1	1	1	2	2	2	3
.10	1259	1262	1265	1268	1271	1274	1276	1279	1282	1285	0	1	1	1	1	2	2	2	3
.11	1288	1291	1294	1297	1300	1303	1306	1309	1312	1315	0	1	1	1	2	2	2	3	3
.12	1318	1321	1324	1327	1330	1334	1337	1340	1343	1346	0	1	1	1	2	2	2	2	3
.13	1349	1352	1355	1358	1361	1365	1368	1371	1374	1377	0	1	1	1	2	2	2	3	3
.14	1380	1384	1387	1390	1393	1396	1400	1403	1406	1409	0	1	1	1	2	2	2	3	3
.15	1413	1416	1419	1422	1426	1429	1432	1435	1439	1442	0	1	1	1	2	2	2	3	3
.16	1445	1449	1452	1455	1459	1462	1466	1469	1472	1476	0	1	1	1	2	2	2	3	3
.17	1479	1483	1486	1489	1493	1496	1500	1503	1507	1510	0	1	1	1	2	2	2	3	3
.18	1514	1517	1521	1524	1528	1531	1535	1538	1542	1545	0	1	1	1	2	2	2	3	3
.19	1549	1552	1556	1560	1563	1567	1570	1574	1578	1581	0	1	1	1	2	2	3	3	3
.20	1585	1289	1592	1596	1600	1603	1607	1611	1614	1618	0	1	1	1	2	2	3	3	3
.21	1622	1626	1629	1633	1637	1641	1644	1648	1652	1656	0	1	1	2	2	2	3	3	3
.22	1660	1663	1667	1671	1675	1679	1683	1687	1690	1694	0	1	1	2	2	2	3	3	3
.23	1698	1702	1706	1710	1714	1718	1722	1726	1730	1734	0	1	1	2	2	2	3	3	4
.24	1738	1742	1746	1750	1754	1758	1762	1766	1770	1774	0	1	1	2	2	2	3	3	4
.25	1778	1782	1786	1791	1795	1799	1803	1807	1811	1816	0	1	1	2	2	2	3	3	4
.26	1820	1824	1828	1832	1837	1841	1845	1849	1854	1858	0	1	1	2	2	3	3	3	4
.27	1862	1866	1871	1875	1879	1884	1888	1892	1897	1901	0	1	1	2	2	3	3	3	4
.28	1905	1910	1914	1919	1923	1928	1932	1936	1941	1945	0	1	1	2	2	3	3	4	4
.29	1950	1954	1959	1963	1968	1972	1977	1982	1986	1991	0	1	1	2	2	3	3	4	4
.30	1995	2000	2004	2009	2014	2018	2023	2028	2032	2037	0	1	1	2	2	3	3	4	4
.31	2042	2046	2051	2056	2061	2065	2070	2075	2080	2084	0	1	1	2	2	3	3	4	4
.32	2089	2094	2099	2104	2109	2113	2118	2123	2128	2133	0	1	1	2	2	3	3	4	4
.33	2138	2143	2148	2153	2158	2163	2168	2173	2178	2183	0	1	1	2	2	3	3	4	4
.34	2188	2193	2198	2203	2208	2213	2218	2223	2228	2234	1	1	2	2	3	3	4	4	5
.35	2239	2244	2249	2254	2259	2265	2270	2275	2280	2286	1	1	2	2	3	3	4	4	5
.36	2291	2296	2301	2307	2312	2317	2323	2328	2333	2339	1	1	2	2	3	3	4	4	5
.37	2344	2350	2355	2360	2366	2371	2377	2380	2388	2393	1	1	2	2	3	3	4	4	5
.38	2399	2404	2410	2415	2421	2427	2432	2438	2443	2449	1	1	2	2	3	3	4	4	5
.39	2455	2460	2466	2472	2477	2483	2489	2495	2500	2506	1	1	2	2	3	3	4	5	5
.40	2512	2518	2523	2529	2535	2541	2547	2553	2559	2564	1	1	2	2	3	4	4	5	5
.41	2570	2576	2582	2588	2594	2600	2606	2612	2618	2624	1	1	2	2	3	4	4	5	5
.42	2630	2636	2642	2649	2655	2661	2667	2673	2679	2685	1	1	2	2	3	4	4	5	6
.43	2692	2698	2704	2710	2716	2723	2729	2735	2742	2748	1	1	2	3	3	4	4	5	6
.44	2754	2761	2767	2773	2780	2786	2793	2799	2805	2812	1	1	2	3	3	4	4	5	6
.45	2818	2825	2831	2838	2844	2851	2858	2864	2871	2877	1	1	2	3	3	4	5	5	6
.46	2884	2891	2897	2904	2911	2917	2924	2931	2938	2944	1	1	2	3	3	4	5	5	6
.47	2951	2958	2965	2972	2979	2985	2992	2999	3006	3013	1	1	2	3	3	4	5	5	6
.48	3020	3027	3034	3041	3048	3055	3062	3069	3076	3083	1	1	2	3	4	4	5	6	6
.49	3090	3097	3105	3112	3119	3126	3133	3141	3148	3155	1	1	2	3	4	4	5	6	6
	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9

ANTILOGARITHMS

	0	1	2	3	4	5	6	7	8	9	Mean Difference								
											1	2	3	4	5	6	7	8	9
.50	3162	3170	3177	3184	3192	3199	3206	3214	3221	3228	1	1	2	3	4	4	5	6	7
.51	3236	3243	3251	3258	3266	3273	3281	3289	3296	3304	1	2	2	3	4	5	5	6	7
.52	3311	3319	3327	3334	3342	3350	3357	3365	3373	3381	1	2	2	3	4	5	5	6	7
.53	3388	3396	3404	3412	3420	3428	3436	3443	3451	3459	1	2	2	3	4	5	6	6	7
.54	3467	3475	3483	3491	3499	3508	3516	3524	3532	3540	1	2	2	3	4	5	6	6	7
.55	3548	3556	3565	3573	3581	3589	3597	3606	3614	3622	1	2	2	3	4	5	6	7	7
.56	3631	3639	3648	3656	3664	3673	3681	3690	3698	3707	1	2	3	3	4	5	6	7	8
.57	3715	3724	3733	3741	3750	3758	3767	3776	3784	3793	1	2	3	3	4	5	6	7	8
.58	3802	3811	3819	3828	3837	3846	3855	3864	3873	3882	1	2	3	4	4	5	6	7	8
.59	3890	3899	3908	3917	3926	3936	3945	3954	3963	3972	1	2	3	4	5	5	6	7	8
.60	3981	3990	3999	4009	4018	4027	4036	4046	4055	4064	1	2	3	4	5	6	6	7	8
.61	4074	4083	4093	4102	4111	4121	4130	4140	4150	4159	1	2	3	4	5	6	7	8	9
.62	4169	4178	4188	4198	4207	4217	4227	4236	4246	4256	1	2	3	4	5	6	7	8	9
.63	4266	4276	4285	4295	4305	4315	4325	4335	4345	4355	1	2	3	4	5	6	7	8	9
.64	4365	4375	4385	4395	4406	4416	4426	4436	4446	4457	1	2	3	4	5	6	7	8	9
.65	4467	4477	4487	4498	4508	4519	4529	4539	4550	4560	1	2	3	4	5	6	7	8	9
.66	4571	4581	4592	4603	4613	4624	4634	4645	4656	4667	1	2	3	4	5	6	7	9	10
.67	4677	4688	4699	4710	4721	4732	4742	4753	4764	4775	1	2	3	4	5	7	8	9	10
.68	4786	4797	4808	4819	4831	4842	4853	4864	4875	4887	1	2	3	4	6	7	8	9	10
.69	4898	4909	4920	4932	4943	4955	4966	4977	4989	5000	1	2	3	5	6	7	8	9	10
.70	5012	5023	5035	5047	5058	5070	5082	5093	5105	5117	1	2	4	5	6	7	8	9	11
.71	5129	5140	5152	5164	5176	5188	5200	5212	5224	5236	1	2	4	5	6	7	8	10	11
.72	5248	5260	5272	5284	5297	5309	5321	5333	5346	5358	1	2	4	5	6	7	9	10	11
.73	5370	5383	5395	5408	5420	5433	5445	5458	5470	5483	1	3	4	5	6	8	9	10	11
.74	5495	5508	5521	5534	5546	5559	5572	5585	5598	5610	1	3	4	5	6	8	9	10	12
.75	5623	5636	5649	5662	5675	5689	5702	5715	5728	5741	1	3	4	5	7	8	9	10	12
.76	5754	5768	5781	5794	5808	5821	5834	5848	5861	5875	1	3	4	5	7	8	9	11	12
.77	5888	5902	5916	5929	5943	5957	5970	5984	5998	6012	1	3	4	5	7	8	10	11	12
.78	6026	6039	6053	6067	6081	6095	6109	6124	6138	6152	1	3	4	6	7	8	10	11	13
.79	6166	6180	6194	6209	6223	6237	6252	6266	6281	6295	1	3	4	6	7	9	10	11	13
.80	6310	6324	6339	6353	6368	6383	6397	6412	6427	6442	1	3	4	6	7	9	10	12	13
.81	6457	6471	6486	6501	6516	6531	6546	6561	6577	6592	2	3	5	6	8	9	11	12	14
.82	6607	6622	6637	6653	6668	6683	6699	6715	6730	6745	2	3	5	6	8	9	11	12	14
.83	6761	6776	6792	6808	6823	6839	6855	6871	6887	6902	2	3	5	6	8	9	11	13	14
.84	6918	6934	6950	6966	6982	6998	7015	7031	7047	7063	2	3	5	6	8	10	11	13	15
.85	7079	7096	7112	7129	7145	7161	7178	7194	7211	7228	2	3	5	7	8	10	12	13	15
.86	7244	7261	7278	7295	7311	7328	7345	7362	7379	7396	2	3	5	7	8	10	12	13	15
.87	7413	7430	7447	7464	7482	7499	7516	7534	7551	7568	2	3	5	7	9	10	12	14	16
.88	7586	7603	7621	7638	7656	7674	7691	7709	7727	7745	2	4	5	7	9	11	112	14	16
.89	7762	7780	7798	7816	7834	7852	7870	7889	7907	7925	2	4	5	7	9	11	12	14	16
.90	7943	7962	7980	7998	8017	8035	8054	8072	8091	8110	2	4	5	7	9	11	13	15	17
.91	8128	8147	8166	8185	8204	8222	8241	8260	8279	8299	2	4	6	8	9	11	13	15	17
.92	8318	8337	8356	8375	8395	8414	8433	8453	8472	8492	2	4	6	8	10	12	14	15	17
.93	8511	8531	8551	8570	8590	8610	8630	8650	8670	8690	2	4	6	8	10	12	14	16	18
.94	8710	8730	8750	8770	8790	8810	8831	8851	8872	8892	2	4	6	8	10	12	14	16	18
.95	8913	8933	8954	8974	8995	9016	9036	9057	9078	9099	2	4	6	8	10	12	15	17	19
.96	9120	9141	9162	9183	9204	9226	9247	9268	9290	9311	2	4	6	8	11	13	15	17	19
.97	9333	9354	9376	9397	9419	9441	9462	9484	9506	9528	2	4	7	9	11	13	15	17	20
.98	9550	9572	9594	9616	9638	9661	9683	9705	9727	9750	2	4	7	9	11	13	16	18	20
.99	9772	9795	9817	9840	9863	9886	9908	9931	9954	9977	2	5	7	9	11	14	16	18	20
	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9

NATURAL SINES

Degree	0’	6’	12’	18’	24’	30’	36’	42’	48’	54’	Mean Differences				
	0.0°	0.1°	0.2°	0.3°	0.4°	0.5°	0.6°	0.7°	0.8°	0.9°	1’	2’	3’	4’	5’
0	.0000	0017	0035	0052	0070	0087	0105	0122	0140	0157	3	6	9	12	15
1	.0175	0192	0209	0227	0244	0262	0279	0297	0314	0332	3	6	9	12	15
2	.0349	0366	0384	0401	0419	0436	0454	0471	0488	0506	3	6	9	12	15
3	.0523	0541	0558	0576	0593	0610	0628	0645	0663	0680	3	6	9	12	15
4	.0698	0715	0732	0750	0767	0785	0802	0819	0837	0854	3	6	9	12	14
5	.0872	0889	0906	0924	0941	0958	0976	0993	1011	1028	3	6	9	12	14
6	.1045	1063	1080	1197	1115	1132	1149	1167	1184	1201	3	6	9	12	14
7	.1219	1236	1253	1271	1288	1305	1323	1340	1357	1374	3	6	9	12	14
8	.1392	1409	1426	1444	1461	1478	1495	1513	1530	1547	3	6	9	12	14
9	.1564	1582	1599	1616	1633	1650	1668	1685	1702	1719	3	6	9	12	14
10	.1736	1754	1771	1788	1805	1822	1840	1857	1874	1891	3	6	9	11	14
11	.1908	1925	1942	1959	1977	1994	2011	2028	2045	2062	3	6	9	11	14
12	.2079	2096	2113	2130	2147	2164	2181	2198	2215	2233	3	6	9	11	14
13	.2250	2267	2284	2300	2317	2334	2351	2368	2385	2402	3	6	8	11	14
14	.2419	2436	2453	2470	2487	2504	2521	2538	2554	2571	3	6	8	11	14
15	.2588	2605	2622	2639	2656	2672	2689	2706	2723	2740	3	6	8	11	14
16	.2756	2773	2790	2807	2823	2840	2857	2874	2890	2907	3	6	8	11	14
17	.2924	2940	2957	2974	2990	3007	3024	3040	3057	3074	3	6	8	11	14
18	.3090	3107	3123	3140	3156	3173	3190	3206	3223	3239	3	6	8	11	14
19	.3256	3272	3289	3305	3322	3338	3355	3371	3387	3404	3	5	8	11	14
20	.3420	3437	3453	3469	3486	3502	3518	3535	3551	3567	3	5	8	11	14
21	.3584	3600	3616	3633	3649	3665	3681	3697	3714	3730	3	5	8	11	14
22	.3746	3762	3778	3795	3811	3827	3843	3859	3875	3891	3	5	8	11	14
23	.3907	3923	3939	3955	3971	3987	4003	4019	4035	4051	3	5	8	11	14
24	.4067	4083	4099	4115	4131	4147	4163	4179	4195	4210	3	5	8	11	13
25	.4226	4242	4258	4274	4289	4305	4321	4337	4352	4368	3	5	8	11	13
26	.4384	4399	4415	4431	4446	4462	4478	4493	4509	4524	3	5	8	10	13
27	.4540	4555	4571	4586	4602	4617	4633	4648	4664	4679	3	5	8	10	13
28	.4695	4710	4726	4741	4756	4772	4787	4802	4818	4833	3	5	8	10	13
29	.4848	4863	4879	4894	4909	4924	4939	4955	4970	4985	3	5	8	10	13
30	.5000	5015	5030	5045	5060	5075	5090	5105	5120	5135	3	5	8	10	13
31	.5150	5165	5180	5195	5210	5225	5240	5255	5270	5284	2	5	7	10	12
32	.5299	5314	5329	5344	5358	5373	5388	5402	5417	5432	2	5	7	10	12
33	.5446	5461	5476	5490	5505	5519	5534	5548	5563	5577	2	5	7	10	12
34	.5592	5606	5621	5635	5650	5664	5678	5693	5707	5721	2	5	7	10	12
35	.5736	5750	5764	5779	5793	5807	5821	5835	5850	5864	2	5	7	9	12
36	.5878	5892	5906	5920	5934	5948	5962	5976	5990	6004	2	5	7	9	12
37	.6018	6032	6046	6060	6074	6088	6101	6115	6129	6143	2	5	7	9	12
38	.6157	6170	6784	6198	6211	6225	6239	6252	6266	6280	2	5	7	9	11
39	.6293	3607	6320	6334	6347	6361	6374	6388	6401	6414	2	4	7	9	11
40	.6428	6441	6455	6468	6481	6494	6508	6521	6534	6547	2	4	7	9	11
41	.6561	6574	6587	6600	6613	6626	6639	6652	6665	6678	2	4	7	9	11
42	.6691	6704	6717	6730	6743	6756	6769	6782	6794	6807	2	4	6	9	11
43	.6820	6833	6845	6858	6871	6884	6896	6909	6921	6934	2	4	6	8	11
44	.6947	6959	6972	6984	6997	7009	7022	7034	7046	7059	2	4	6	8	10

NATURAL SINES

Degree	0’	6’	12’	18’	24’	30’	36’	42’	48’	54’	Mean Differences				
	0.0°	0.1°	0.2°	0.3°	0.4°	0.5°	0.6°	0.7°	0.8°	0.9°	1’	2’	3’	4’	5’
45	.7071	7083	7096	7108	7120	7133	7145	7457	7169	7181	2	4	6	8	10
46	.7193	7206	7218	7230	7242	7254	7266	7278	7290	7302	2	4	6	8	10
47	.7314	7325	7337	7349	7361	7373	7385	7396	7408	7420	2	4	6	8	10
48	.7431	7443	7455	7466	7478	7490	7501	7513	7524	7536	2	4	6	8	10
49	.7547	7559	7570	7581	7593	7604	7615	7627	7638	7649	2	4	6	8	9
50	.7660	7672	7683	7694	7705	7716	7727	7738	7749	7760	2	4	6	7	9
51	.7771	7782	7793	7804	7815	7826	7837	7848	7859	7869	2	4	5	7	9
52	.7880	7891	7902	7912	7923	7934	7944	7955	7965	7976	2	4	5	7	9
53	.7986	7997	8007	8018	8028	8039	8049	8059	8070	8080	2	3	5	7	9
54	.8090	8100	8111	8121	8131	8141	8151	8161	8171	8181	2	3	5	7	8
55	.8192	8202	8211	8221	8231	8241	8251	8261	8271	8281	2	3	5	7	8
56	.8290	8300	8310	8320	8329	8339	8348	8358	8368	8377	2	3	5	6	8
57	.8387	8396	8406	8415	8425	8434	8443	8453	8462	8471	2	3	5	6	8
58	.8480	8490	8499	8508	8517	8526	8536	8545	8554	8563	2	3	5	6	8
59	.8572	8581	8590	8599	8607	8616	8625	8634	8643	8652	1	3	4	6	7
60	.8660	8669	8678	8686	8695	8704	8712	8721	8729	8738	1	3	4	6	7
61	.8746	8755	8763	8771	8780	8788	8796	8805	8813	8821	1	3	4	6	7
62	.8829	8838	8846	8854	8862	8870	8878	8886	8894	8902	1	3	4	5	7
63	.8910	8918	8926	8934	8942	8949	8957	8965	8973	8980	1	3	4	5	6
64	.8988	8996	9003	9011	9018	9026	9033	9041	9048	9056	1	3	4	5	6
65	.9063	9070	9078	9085	9092	9100	9107	9114	9121	9128	1	2	4	5	6
66	.9135	9143	9150	9157	9164	9171	9178	9184	9191	9198	1	2	3	5	6
67	.9205	9212	9219	9225	9232	9239	9245	9252	9259	9265	1	2	3	4	6
68	.9272	9278	9285	9291	9298	9304	9311	9317	9323	9330	1	2	3	4	5
69	.9336	9342	9348	9354	9361	9367	9373	9379	9385	9391	1	2	3	4	5
70	.9397	9403	9409	9415	9421	9426	9432	9438	9444	9449	1	2	3	4	5
71	.9455	9461	9466	9472	9478	9483	9489	9494	9500	9505	1	2	3	4	5
72	.9511	9516	9521	9527	9532	9537	9542	9548	9553	9558	1	2	3	3	4
73	.9563	9568	9573	9578	9583	9588	9593	9598	9603	9608	1	2	2	3	4
74	.9613	9617	9622	9627	9632	9636	9641	9646	9650	9655	1	2	2	3	4
75	.9659	9664	9668	9673	9677	9681	9686	9690	9694	9699	1	1	2	3	4
76	.9703	9707	9711	9715	9720	9724	9728	9732	9736	9740	1	1	2	3	3
77	.9744	9748	9751	9755	9759	9763	9767	9770	9774	9778	1	1	2	3	3
78	.9781	9785	9789	9792	9796	9799	9803	9806	9810	9813	1	1	2	2	3
79	.9816	9820	9823	9826	9829	9833	9836	9839	9842	9845	1	1	2	2	3
80	.9848	9851	9854	9857	9860	9863	9866	9869	9871	9874	0	1	1	2	2
81	.9877	9880	9882	9885	9888	9890	9893	9895	9898	9900	0	1	1	2	2
82	.9903	9905	9907	9910	9912	9914	9917	9919	9921	9923	0	1	1	2	2
83	.9925	9928	9930	9932	9934	9936	9938	9940	9942	9943	0	1	1	1	2
84	.9945	9947	9949	9951	9952	9954	9956	9957	9959	9960	0	1	1	1	2
85	.9962	9963	9965	9966	9968	9969	9971	9972	9973	9974	0	0	1	1	1
86	.9976	9977	9978	9979	9980	9981	9982	9983	9984	9985	0	0	1	1	1
87	.9986	9987	9988	9989	9990	9990	9991	9992	9993	9993	0	0	0	1	1
88	.9994	9995	9995	9996	9996	9997	9997	9997	9998	9998	0	0	0	0	0
89	.9998	9999	9999	9999	9999	1.000	1.000	1.000	1.000	1.000	0	0	0	0	0

NATURAL TANGNTS

Degree	0’	6’	12’	18’	24’	30’	36’	42’	48’	54’	Mean Differences				
	0.0°	0.1°	0.2°	0.3°	0.4°	0.5°	0.6°	0.7°	0.8°	0.9°	1’	2’	3’	4’	5’
0	.0000	0017	0035	0052	0070	0087	0105	0122	0140	0157	3	6	9	12	15
1	.0175	0192	0209	0227	0244	0262	0279	0297	0314	0332	3	6	9	12	15
2	.0349	0367	0384	0402	0419	0437	0454	0472	0489	0507	3	6	9	12	15
3	.0524	0542	0559	0577	0594	0612	0629	0647	0664	0682	3	6	9	12	15
4	.0699	0717	0734	0752	0769	0787	0805	0822	0840	0857	3	6	9	12	15
5	.0875	0892	0910	0928	0945	0963	0981	0998	1016	1033	3	6	9	12	15
6	.1051	1069	1086	1104	1122	1139	1157	1175	1192	1210	3	6	9	12	15
7	.1228	1246	1263	1281	1299	1317	1334	1352	1370	1388	3	6	9	12	15
8	.1405	1423	1441	1459	1477	1495	1512	1530	1548	1566	3	6	9	12	15
9	.1584	1602	1620	1638	1655	1673	1691	1709	1727	1745	3	6	9	12	15
10	.1763	1781	1799	1817	1835	1853	1871	1890	1908	1926	3	6	9	12	15
11	.1944	1962	1980	1998	2016	2035	2053	2071	2089	2107	3	6	9	12	15
12	.2126	2144	2162	2180	2199	2217	2235	2254	2272	2290	3	6	9	12	15
13	.2309	2327	2345	2364	2382	2401	2419	2438	2456	2475	3	6	9	12	15
14	.2493	2512	2530	2549	2568	2686	2605	2623	2642	2661	3	6	9	12	16
15	.2679	2698	2717	2736	2754	2773	2792	2811	2830	2849	3	6	9	13	16
16	.2867	2886	2905	2924	2943	2962	2981	3000	3019	3038	3	6	9	13	16
17	.3057	3076	3096	3115	3134	3153	3172	3191	3211	3230	3	6	10	13	16
18	.3249	3269	3288	3307	3327	3346	3365	3385	3404	3424	3	6	10	13	16
19	.3443	3463	3482	3502	3522	3541	3561	3581	3600	3620	3	7	10	13	16
20	.3640	3659	3679	3699	3719	3739	3759	3779	3799	3819	3	7	10	13	17
21	.3839	3859	3879	3899	3919	3939	3959	3979	4000	4020	3	7	10	13	17
22	.4040	4061	4081	4101	4122	4142	4163	4183	4204	4224	3	7	10	14	17
23	.4245	4265	8286	4307	4327	4748	4369	4390	4411	4431	3	7	10	14	17
24	.4452	4473	4494	4515	4536	4557	4578	4599	4621	4642	4	7	11	14	18
25	.4663	4684	4706	4727	4748	4770	4791	4813	4834	4856	4	7	11	14	18
26	.4877	4899	4921	4842	4964	4986	5008	5029	5051	5073	4	7	11	15	18
27	.5095	5117	5139	5161	5184	5206	5228	5250	5272	5295	4	7	11	15	18
28	.5317	5340	5362	5384	5407	5430	5452	5475	5498	5520	4	8	11	15	19
29	.5543	5566	5589	5612	5635	5658	5681	5704	5727	5750	4	8	12	15	19
30	.5774	5797	5820	5844	5867	5890	5914	5938	5961	5985	4	8	12	16	20
31	.6009	6032	6056	6080	6104	6128	6152	6176	6200	6224	4	8	12	16	20
32	.6249	6273	6297	6322	6346	6371	6395	6420	6445	6469	4	8	12	16	20
33	.6494	6519	6544	6569	6594	6619	6644	6669	6694	6720	4	8	13	17	21
34	.6745	6771	6796	6822	6847	6873	6899	6924	6950	6976	4	9	13	17	21
35	.7002	7028	7054	7080	7107	7133	7159	7186	7212	7239	4	9	13	18	22
36	.7265	7292	7319	7346	7373	7400	7427	7454	7481	7508	5	9	14	18	23
37	.7536	7563	7590	7618	7646	7673	7701	7729	7757	7785	5	9	14	18	23
38	.7813	7841	7869	7898	7926	7954	7983	8012	8040	8069	5	9	14	19	24
39	.8098	8127	8156	8185	8214	8243	8273	8302	8332	8361	5	10	15	20	24
40	.8391	8421	8451	8481	8511	8541	8571	8601	8632	8662	5	10	15	20	25
41	.8693	8724	8754	8785	8816	8847	8878	8910	8941	8972	5	10	16	21	26
42	.9004	9036	9067	9099	9131	9163	9195	9228	9260	9293	5	11	16	21	27
43	.9325	9358	9391	9424	9457	9490	9523	9556	9590	9623	6	11	17	22	28
44	.9657	9691	9725	9759	9793	9827	9861	9896	9930	9965	6	11	17	23	29

NATURAL TANGNTS

Degree	0	6	12	18	24	30	36	42	48	54'	Mean Differences				
	0.0^0	0.1^0	0.2^0	0.3^0	0.4^0	0.5^0	0.6^0	0.7^0	0.8^0	0.9^O	1	2	3	4	5
45	1.0000	0035	0070	0105	0141	0176	0212	0247	0283	0319	6	12	18	24	30
46	1.0355	0392	0428	0464	0501	0538	0575	0612	0649	0686	6	12	18	25	31
47	1.0724	0761	0799	0837	0875	0913	0951	0990	1028	1067	6	13	19	25	32
48	1.1106	1145	1184	1224	1263	1303	1343	1383	1423	1463	7	13	20	27	33
49	1.1504	1544	1585	1626	1667	1708	1750	1792	1833	1875	7	14	21	28	34
50	1.1918	1960	2002	2045	2088	2131	2174	2218	2261	2305	7	14	22	29	36
51	1.2349	2393	2437	2482	2527	2572	2617	2662	2708	2753	8	15	23	30	38
52	1.2799	2846	2892	2938	2985	3032	3079	3127	3175	3222	8	16	24	31	39
53	1.3270	3319	3367	3416	3465	3514	3564	3613	3663	3713	8	16	25	33	41
54	1.3764	3814	3865	3916	3968	4019	4071	4124	4176	4229	9	17	26	34	43
55	1.4281	4335	4388	4442	4496	4550	4605	4659	4715	4770	9	18	27	36	45
56	1.4826	4882	4938	4994	5051	5108	5166	5224	5282	5340	10	19	29	38	48
57	1.5399	5458	5517	5577	5637	5697	5757	5818	5880	5941	10	20	30	40	50
58	1.6003	6066	6128	6191	6255	6319	6383	6447	6512	6577	11	21	32	43	53
59	1.6643	6709	6775	6842	6909	6977	7045	7113	7182	7251	11	23	34	45	56
60	1.7321	7391	7461	7532	7603	7675	7747	7820	7893	7966	12	24	36	48	60
61	1.8040	8115	8190	8265	8341	8418	8495	8572	8650	8728	13	26	38	51	64
62	1.8807	8887	8967	9047	9128	9210	9292	9375	9458	9542	14	27	41	55	68
63	1.9626	9711	9797	9883	9970	2.0057	2.0145	2.0233	2.0323	2.413	15	29	44	58	73
64	2.0503	0594	0686	0778	0872	0965	1060	1155	1251	1348	16	31	47	63	78
65	2.1445	1543	1642	1742	1842	1943	2045	2148	2251	2355	17	34	51	68	85
66	2.2460	2566	2673	2781	2889	2998	3109	3220	3332	3445	18	37	55	73	92
67	2.3559	3673	3789	3906	4023	4142	4262	4383	4504	4627	20	40	60	79	99
68	2.4751	4876	5002	5129	5257	5386	5517	5649	5782	5916	22	43	65	87	108
69	2.6051	6187	6325	6464	6605	6746	6889	7034	7179	7326	24	47	71	95	119
70	2.7475	7625	7776	7929	8083	8239	8397	8556	8716	8878	26	52	78	104	131
71	2.9042	9208	9375	9544	9714	9878	3.0061	3.0237	3.0415	3.0595	29	58	87	116	145
72	3.0777	0961	1146	1334	1524	1716	1910	2106	2305	2506	32	64	96	129	161
73	3.2709	2914	3122	3332	3544	3759	3977	4197	4420	4646	36	72	108	144	180
74	3.4824	5105	5339	5576	5816	6059	6305	6554	6806	7062	41	81	122	163	204
75	3.7321	7583	7848	8118	8391	8667	8947	9232	9520	9812	46	93	139	186	232
76	4.0108	0408	0713	1022	1335	1653	1976	2303	2635	2972	53	107	160	213	267
77	4.3315	3662	4015	4374	4737	5107	5483	5864	6252	6646					
78	4.7046	7453	7867	8288	8716	9152	9594	5.0045	5.0504	5.0970					
79	5.1446	1929	2422	2924	3465	3955	4486	5026	5578	6140					
80	5.6713	7297	7894	8502	9124	9758	6.0405	6.1066	6.1742	6.2432					
81	6.3138	3859	4596	5350	6122	6912	7720	8548	9395	7.0264					
82	7.1154	2066	3002	3962	4997	5958	6996	8062	9158	8.0285					
83	8.1443	2636	3863	5126	6427	7769	9152	9.0579	9.2052	9.3572					
84	9.514	9.677	9.845	10.02	10.20	10.39	10.58	10.78	10.99	11.20					
85	11.43	11.66	11.91	12.16	12.43	12.71	13.00	13.30	13.62	13.95					
86	14.30	14.67	15.06	15.46	15.89	16.35	16.83	17.34	17.89	18.46					
87	19.08	19.74	20.45	21.20	22.02	22.90	23.86	24.90	26.03	27.27					
88	28.64	30.14	31.82	33.69	35.80	38.19	40.92	44.07	47.74	52.08					
89	57.29	63.66	71.62	81.85	95.49	114.6	143.2	191.0	286.5	573.0					

Mean Differences no longer sufficiently accurate

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