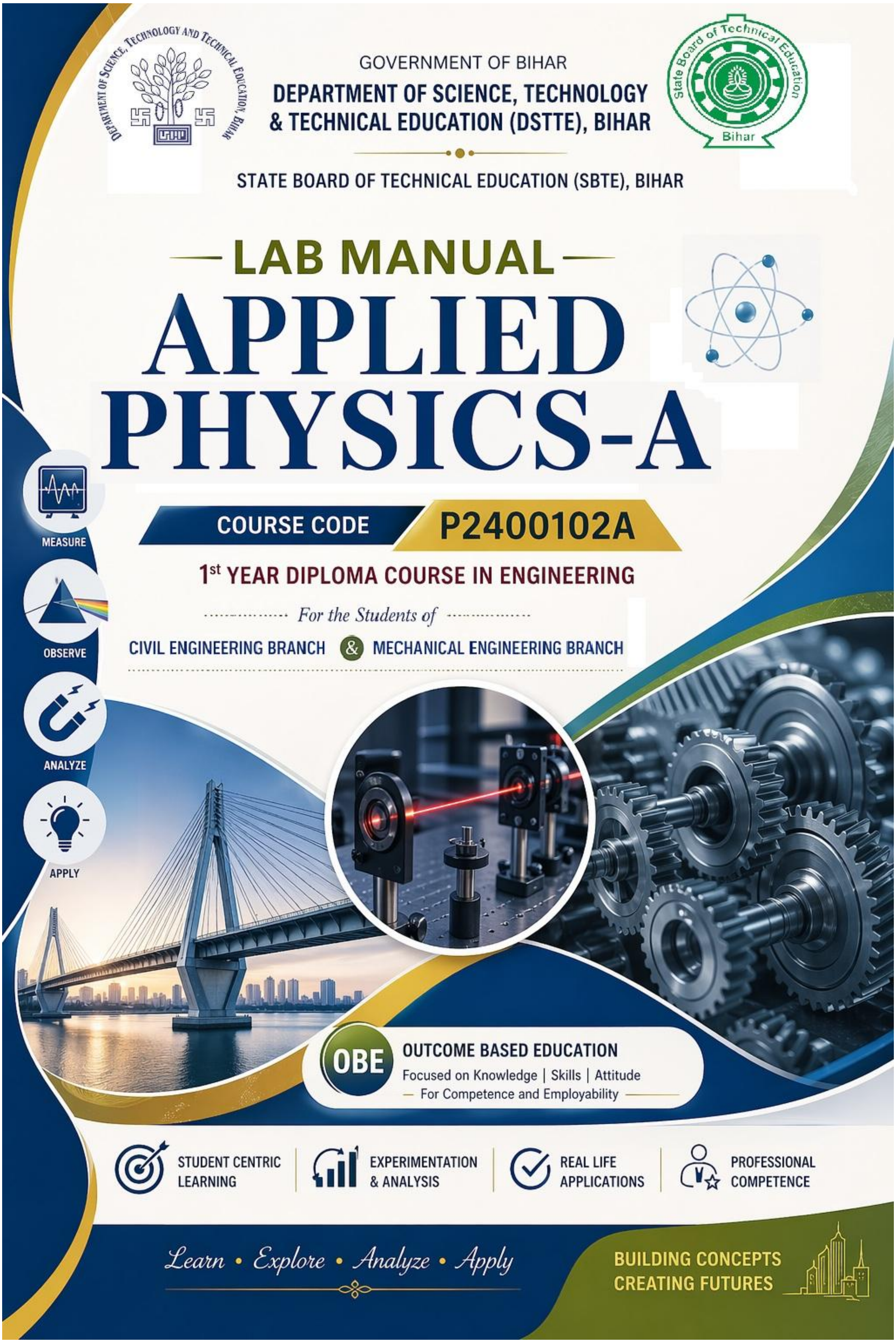
GOVERNMENT OF BIHAR
DEPARTMENT OF SCIENCE, TECHNOLOGY & TECHNICAL EDUCATION (DSTTE), BIHAR
STATE BOARD OF TECHNICAL EDUCATION (SBTE), BIHAR
LAB MANUAL
APPLIED PHYSICS-A
COURSE CODE P2400102A
1st YEAR DIPLOMA COURSE IN ENGINEERING
For the Students of
CIVIL ENGINEERING BRANCH & MECHANICAL ENGINEERING BRANCH
MEASURE
OBSERVE
ANALYZE
APPLY
OBE
OUTCOME BASED EDUCATION
Focused on Knowledge | Skills | Attitude
For Competence and Employability
STUDENT CENTRIC LEARNING
EXPERIMENTATION & ANALYSIS
REAL LIFE APPLICATIONS
PROFESSIONAL COMPETENCE
Learn • Explore • Analyze • Apply
BUILDING CONCEPTS CREATING FUTURES

PREFACE

This laboratory manual for Applied Physics–A (Course Code: P2400102A) has been carefully designed for the students of first-year Diploma in Engineering, particularly those belonging to Civil Engineering and Mechanical Engineering branches under the Department of Science, Technology & Technical Education (DSTTE), Bihar and the State Board of Technical Education (SBTE), Bihar.

The primary objective of this manual is to bridge the gap between theoretical concepts and practical understanding of physics. In alignment with the principles of Outcome Based Education (OBE), this manual emphasizes the development of knowledge, practical skills, analytical thinking, and professional attitude among students. Each experiment has been structured to encourage observation, measurement, analysis, and real-life application, thereby nurturing scientific temperament and problem-solving ability.

Special care has been taken to present experiments in a simple, systematic, and student-friendly manner. The manual includes clear objectives, apparatus details, theoretical background, procedural steps, observations, calculations, and result interpretation. It is expected that this structured approach will help students not only perform experiments effectively but also understand the underlying physical principles in depth.

I hope that this manual will serve as a useful resource for both students and instructors, facilitating effective laboratory learning and contributing to the overall academic development of diploma engineering students.

Constructive suggestions for further improvement of this manual will be highly appreciated.

Keshav Kumar Singh
CSIR-NET, GATE, SET
Lecturer (Physics)
Government Polytechnic, Sheohar, Bihar
Email: pranamamitubhyam@gmail.com
Email: keshav89.dstte@bihar.gov.in

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I express my sincere gratitude to the Department of Science, Technology & Technical Education (DSTTE), Bihar and the State Board of Technical Education (SBTE), Bihar for their continuous support and vision in strengthening technical education through Outcome Based Education.

I would like to place on record my deep sense of gratitude to **Dr. Anju Rawley** and **Dr. A. S. Walkey** for their invaluable role in conceptualising this initiative. Their vision, guidance, and dedication have been the key driving forces behind the development of this lab manual. I am especially thankful for their patience and mentorship during the **hands-on training at IUCTE, Varanasi**, which provided crucial insights into Lab Manual Development.

I also extend my sincere thanks to **SBTE, Bihar** for effectively translating this concept into practice and bringing it to the ground level for the benefit of students and educators.

I am deeply grateful to **Dr. Rajesh Niranjan, Lecturer in Physics, Government Polytechnic, Dehri-On-Sone**, for his valuable assistance in the development of the experiment on the Photoelectric Effect.

I express my sincere appreciation to **Mr. Ritesh Kumar Singh, Lecturer (Electronics), Government Polytechnic, Sheohar**, and **Mr. Kapil Deo Kumar, Lecturer (Mechanical), Government Polytechnic, Sheohar,** for his invaluable practical assistance and consistent technical support throughout the development of this lab manual.

I also extend my heartfelt thanks to **Mr. Anuj Kumar, Lab Assistant (Physics)**, for his dedicated support in laboratory arrangements, timely assistance during experiments, and ensuring the smooth functioning of all practical activities.

Lastly, I thank my students, whose curiosity and enthusiasm continue to inspire me to improve and innovate in teaching and learning.

Constructive suggestions for further improvement of this manual will always be welcome.

Keshav Kumar Singh
Lecturer (Physics)
Government Polytechnic, Sheohar, Bihar

Applied Physics-A

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Experiment No.- 01

Determination of Dimensions of Various Objects using Vernier Callipers

I. Practical Significance

Precision measurement is a cornerstone of experimental physics and engineering. Standard rulers are limited to a resolution of 1 mm, which is often insufficient for technical applications. The Vernier Calliper overcomes this by using a secondary sliding scale to achieve a much higher degree of accuracy. Mastering this tool is essential for:

- **Manufacturing Quality Control:** Ensuring machine parts fit together with tight tolerances.
- **Material Analysis:** Determining the volume and density of small components.
- **Engine Maintenance:** Measuring cylinder bores and piston diameters in mechanical engineering.

II. Relevant Program Outcomes (POs)

- **PO1: Basic and Discipline Specific Knowledge:** Apply knowledge of mathematics and physics to solve measurement problems.
- **PO4: Engineering Tools & Experimentation:** Use the Vernier Calliper as a modern tool to solve engineering problems with high precision.

III. Relevant Course Outcomes (COs)

- **CO1:** Demonstrate the ability to use precision measuring instruments and record observations with correct significant figures.

IV. Laboratory Session Outcomes (LSOs):

- Use Vernier Callipers to measure external and internal dimensions
- Determine least count and correct zero error

- Calculate volume of cylindrical objects using measured data

V. Description of the Measuring Device

The Vernier Calliper is a versatile instrument consisting of the following parts:

- **Main Scale:** This is the fixed scale graduated in centimeters (cm) and millimeters (mm), providing the primary reading of the measurement.

- **Vernier Scale:** This is the sliding scale that allows for precise measurements smaller than the smallest division (1 mm) on the main scale.

- **Lower Jaws (Outside Jaws):** These jaws are projected at right angles to the scale and are used to measure the external diameters and lengths of objects.

- **Upper Jaws (Inside Jaws):** These are specifically designed to be inserted into hollow objects to measure their internal diameters.

- **Metallic Strip (Depth Measuring Scale):** Located at the end of the instrument, this thin strip is used to measure the depth of objects like beakers or holes.

- **Knob (Fine Adjustment Screw) & Locking Screw:** The knob is used to slide the vernier scale smoothly, while the locking screw fixes the scale at a desired position to hold a reading.

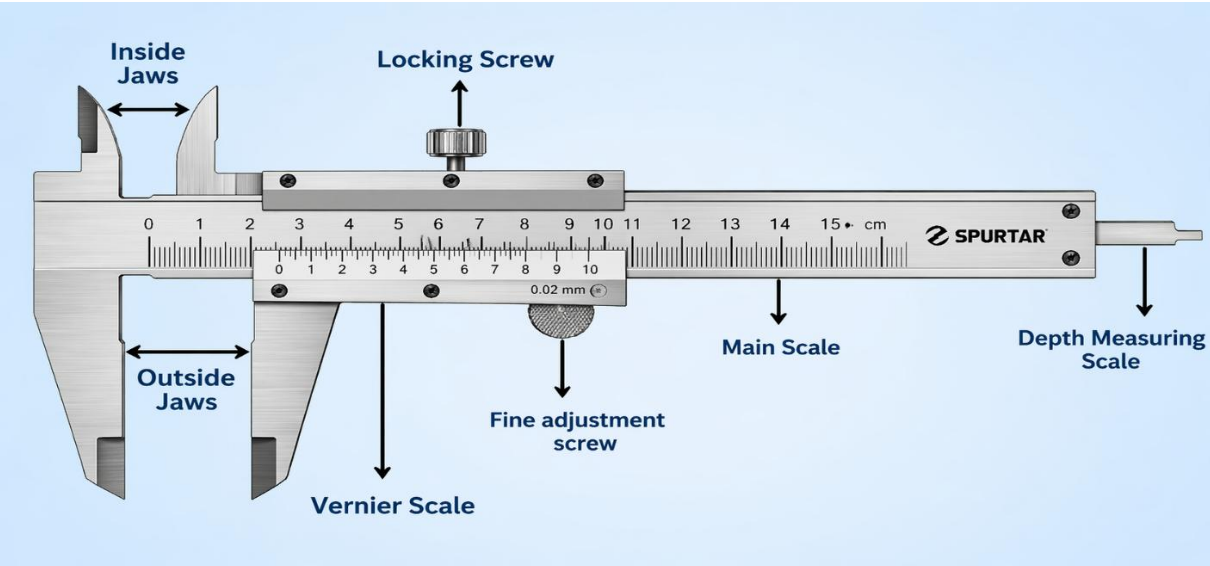


Fig: 01.01 Vernier Callipers

When jaws are closed, both zero marks should coincide; otherwise, zero error exists.

VI. Minimum Theoretical Background

1. Principle of Vernier Callipers :

The least count (LC), or Vernier Constant, is the difference between one Main Scale Division (MSD) and one Vernier Scale Division (VSD).

$$LC = 1\ MSD - 1\ VSD$$

Suppose **N** Vernier Scale Divisions coincide with **M** Main Scale Divisions.

Mathematically, this can be written as

$$(N)\ VSD = (M)\ MSD \quad \text{(where } M<N\text{)}$$

$$LC = 1\ MSD - \left(\frac{M}{N}\right) MSD = \left(1 - \frac{M}{N}\right) MSD$$

If $M = N - 1$, then $(N)\ VSD = (N-1)\ MSD$ and $LC = \frac{1 MSD}{N}$

$$\text{Least count of vernier callipers} = \frac{\text{the magnitude of the smallest division on the main scale}}{\text{the total number of small divisions on the vernier scale}}$$

It represents the smallest distance that can be measured using the instrument.

2. Formulas for Calculation:

Total Reading (TR): $TR = MSR + (N \times LC)$

Density (ρ): $\rho = m / V$

Volume of Cylinder (V): $V = \pi r^2 h = (\pi D^2 h) / 4$

3. Zero Error:

Sometimes due to mechanical error in vernier callipers, the zero mark of the vernier scale does not coincide with the zero mark on the main scale. Hence, the vernier callipers is said to have a zero error.

In order to find the zero error, we note the division of the vernier scale which coincides with any division of the main scale. The number of this vernier division when multiplied by the least count of the vernier gives the zero error.

(i) Zero Error (No Error Condition)

Zero error is present when the instrument shows a non-zero reading even when the jaws are fully closed.

Correct condition: Main scale zero coincides with Vernier scale zero.

In this case, no correction is required.

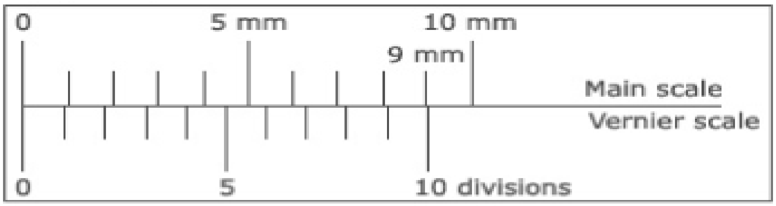


Fig:01.02 No Error

(ii) Positive Zero Error (+ve)

Condition: Vernier zero lies to the RIGHT of main scale zero.

The instrument shows a positive reading even when closed.

Example:

LC = 0.01 cm

3rd Vernier division coincides

Zero Error = +3 × 0.01 = +0.03 cm

Correction:

True Reading = Observed Reading – 0.03

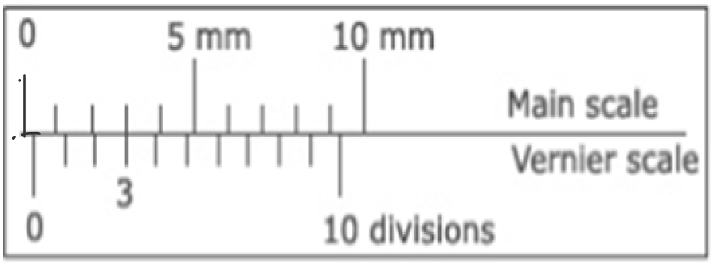


Fig: 01.03 Positive Zero Error

(iii) Negative Zero Error (−ve)

Condition: Vernier zero lies to the LEFT of main scale zero.

The instrument shows a negative reading when closed.

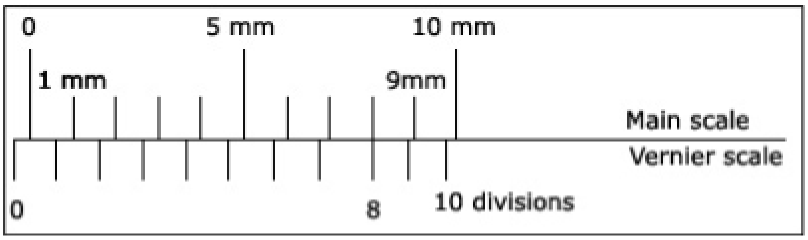


Fig: 01.04 Negative Zero Error

Example: LC = 0.01 cm

8th Vernier division coincides

Zero Error = −8 × 0.01 = −0.08 cm

Correction: True Reading = Observed Reading + 0.08 cm

VII. Resources Required: Table:01.01

Sr. No.	Item	Specification	Quantity	Remarks
1	**Vernier Callipers**	**LC = 0.01 cm**	**1**	**Checked**
2	**Steel Ball**	**Smooth surface**	**1**	**Clean**
3	**Beaker**	**Cylindrical**	**1**	**Dry**
4	**Cloth**	**Soft**	**1**	**Cleaning**

VIII. Experimental Setup

The setup involves:

- Vernier Callipers
- Small spherical/cylindrical object
- Cylindrical container (beaker/calorimeter)

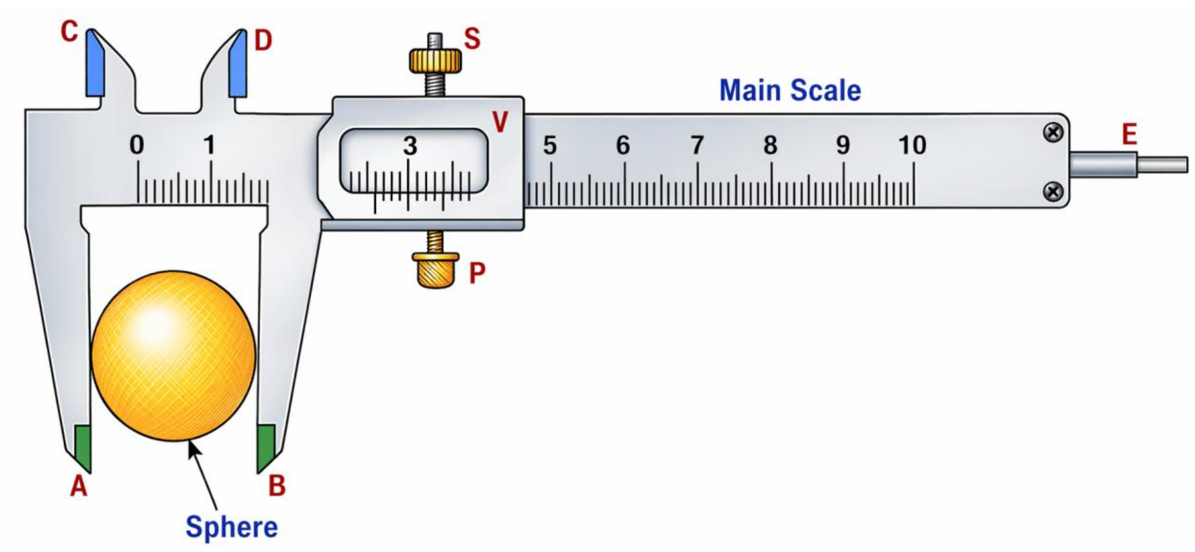


Fig.01.05 Vernier Callipers used to measure Outer diameter

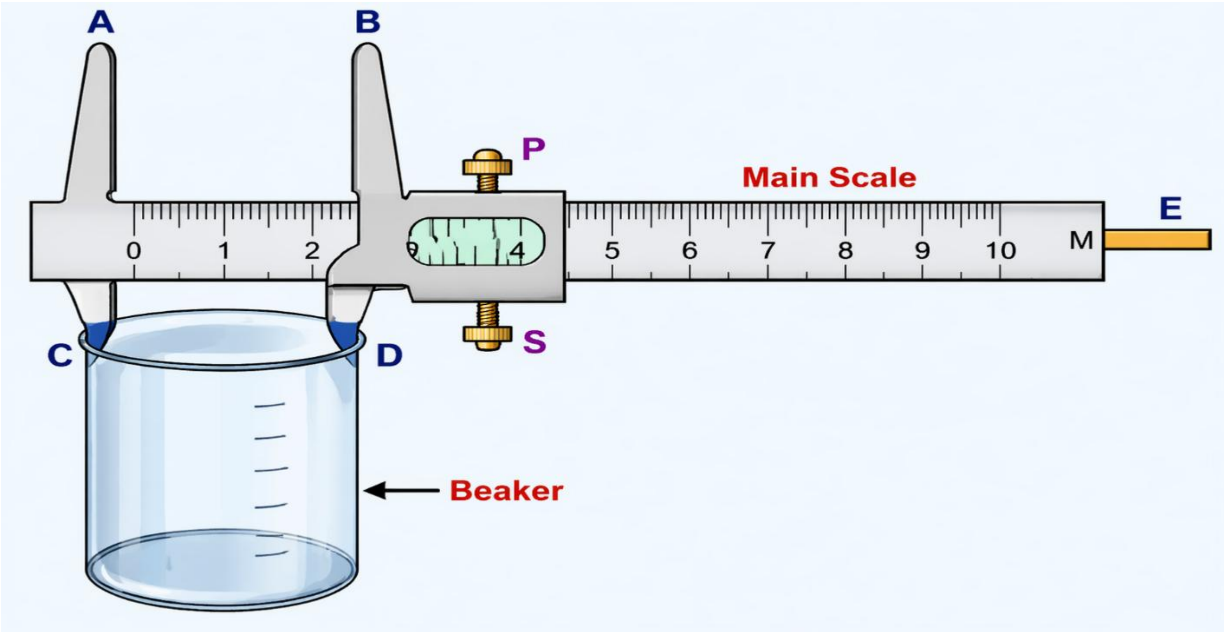


Fig 01.06 Vernier Callipers used to measure internal diameter of beaker

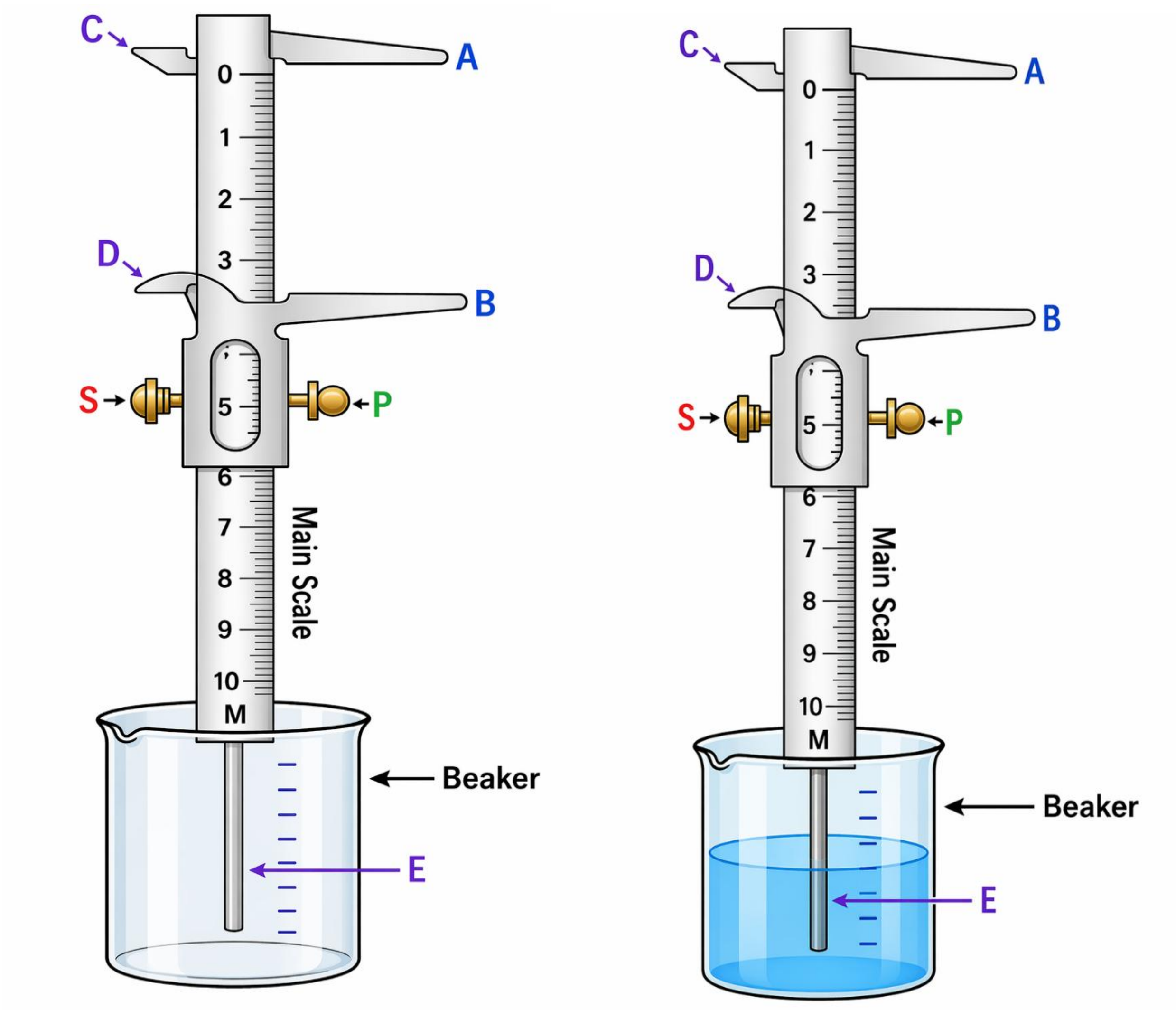


Fig 01.07 Vernier Callipers used to measure depth of beaker

IX. Precautions:

- Check zero error before use
- Keep jaws clean and dry
- Do not apply excessive force otherwise the threads of the screw may damage
- Keep the eye directly over the division mark to avoid any error due to parallax.
- Note down the measurements with accuracy while taking into account the correct significant digits and units

X. Procedure:

(a)Measurement of External Diameter/Dimensions of a Small Spherical/Cylindrical Body

1. **Zero Check**:
Close the jaws of the Vernier Callipers and ensure that the zero of the vernier scale coincides with the zero of the main scale. If not, determine and note the zero error.
2.Least Count Identification:
Identify the least count of the instrument and locate the vernier division that coincides with a main scale division.
3.Placement of Object:
Loosen the screw and gently place the given spherical/cylindrical body between the outer jaws. Ensure that the object is held without excessive pressure and that the jaws are perpendicular to its diameter. Tighten the screw lightly.
4. Main Scale Reading (MSR):
Note the main scale reading just to the left of the zero of the vernier scale.

5. Vernier Scale Reading (VSR):
Observe the vernier scale carefully and identify the division that exactly coincides with any main scale division. Record its number as N.

6. Calculation: Measure External diameter using

$$\text{Diameter} = \text{MSR} + (N \times \text{LC})$$

7. Repetition of Readings:
Repeat the measurement at least three times by rotating the object to different positions to ensure accuracy.

8. Recording Observations:
Tabulate all readings with proper units. Apply zero correction wherever necessary.

9. Final Result:
Calculate the mean of the corrected readings and express the diameter with appropriate significant digits.

(b) Measurement of Internal Diameter

1. **Positioning of Jaws:**
   Open the inner jaws of the Vernier Callipers and insert them inside the cylindrical object (beaker/calorimeter).
2. **Proper Contact:**
   Adjust the jaws gently until they just touch the inner walls without applying excessive force. Ensure the jaws remain horizontal and properly aligned.
3. **Main Scale Reading (MSR):**
   Note the main scale reading just to the left of the zero of the vernier scale.
4. **Vernier Scale Reading (VSR):**
   Identify the vernier division that coincides with a main scale division and record its number as N.
5. **Calculation:**
   Determine the internal diameter using:

$$D = \text{MSR} + (N \times \text{LC})$$

6. **Repetition:**
   Repeat the measurement at least three times at different angular positions of the object.
7. **Recording:**
   Tabulate all readings with proper units and apply zero correction, if required.
8. **Mean Value:**
   Calculate the mean of the corrected readings to obtain the final internal diameter.

(c) Measurement of Depth

1. **Placement of Instrument:**
   Place the Vernier Callipers vertically on the top edge of the cylindrical object.
2. **Use of Depth Rod:**
   Slide the movable jaw so that the depth rod extends inside and touches the bottom surface of the object.
3. **Proper Alignment:**
   Ensure that the depth rod is perpendicular to the base and just touches it without force.
4. **Main Scale Reading (MSR):**
   Note the main scale reading corresponding to the zero of the vernier scale.

5. **Vernier Scale Reading (VSR):**
   Observe the coinciding vernier division and record its number N.
6. **Calculation:**
   Calculate the depth using:

$$h = \text{MSR} + (N \times \text{LC})$$

7. **Repetition:**
   Take at least three readings at different positions for accuracy.
8. **Recording and Mean:**
   Record all readings in tabular form, apply zero correction if needed, and compute the mean depth.

XI. Observations and Calculations

(a) Least count of Vernier Callipers (Vernier Constant)

1 main scale division (MSD) = 1 mm = 0.1 cm

Number of vernier scale divisions, N = 10

10 vernier scale divisions = 9 main scale divisions = 9×0.1 cm =0.9 cm

1 vernier scale division = 0.09 cm

Least Count = 1 main scale division – 1 vernier scale division = 0.1 cm - 0.09 cm = 0.01 cm

***Alternatively*, Vernier constant or LC** $= \frac{\textit{Value of 1 MSD}}{\textit{Total Number OF Vernier Divisions}} = \frac{1\ mm}{10}$ **= 0.1 mm = 0.01 cm**

(b) External Diameter of a Small Spherical/Cylindrical Body

Table:01.02 Least Count (LC): 0.01 cm

Trial	MSR (cm)	N	VSR (cm) = LC×N	Diameter (cm)
1	2.1	6	0.06	2.16
2	2.1	7	0.07	2.17
3	2.1	6	0.06	2.16
4				
5				

Average/Mean Diameter $= \frac{D1+D2+D3+\cdots+Dn}{n}$ **=2.163 cm Error = ± e**

Average Diameter = [2.16 – (± e)] cm (Rounded up to 2 significant digits)

(c) Internal Diameter of Beaker: Table:01.03

Trial	MSR (cm)	N	VSR (cm) =LC×N	Diameter
1	6.0	5	0.05	6.05
2	6.0	6	0.06	6.06
3	6.0	5	0.05	6.05
4				
5				

Average Diameter $= \frac{D1+D2+D3+\cdots+Dn}{n}$ **= 6.053 cm** **Error = ± e**

Average Internal Diameter = [6.05 – (± e)] cm **(Rounded up to 2 significant digits)**

(d) Depth of Beaker: Table:01.04

Trial	MSR (cm)	N	VSR (cm) =LC ×N	Depth (cm)
1	8.2	3	0.03	8.23
2	8.2	4	0.04	8.24
3	8.2	3	0.03	8.23
4				
5				
6				

Mean Depth = 8.233 cm **Error = ± e**

Mean Depth = [8.23 – (± e)] cm **(Rounded up to 2 significant digits)**

(e) Volume of the beaker

$$V = 3.14\times 6.05^2\times 8.23/4 = 236.472282$$

$$V = 236.47\ cm^3$$

XII. Results

Average External Diameter = [2.16 – (± e)] cm **(Rounded up to 2 significant digits)**

Average Internal Diameter (or Depth) = [6.05 – (± e)] cm **(Up to 2 significant digits)**

Mean Depth = [8.23 – (± e)] cm **(Rounded up to 2 significant digits)**

Volume of the beaker V = 236.47 cm^3

XIII. Interpretation of Results and Conclusions:

The experiment shows that Vernier Callipers can measure small dimensions with high precision. The accuracy of volume depends on careful measurement of diameter and depth. Small observational errors can significantly affect final results.

XIV. Practical Related Questions:

1. What is least count?
2. Why is zero error correction necessary?
3. Why do we take average readings?
4. How does error affect volume calculation?
5. How does vernier scale improve precision?
6. How can you find the value of π using a given cylinder and a pair of Vernier Callipers?

XV. Suggested Activities:

1. Measure thickness of a book

2. Measure diameter of a pipe

3. Compare results with a ruler

XVI. References for Further Reading:

- Physics Laboratory Manual (Class XI). **NCERT**
- Arora S.L. *Practical Physics (Class XI & XII)*
- Halliday, Resnick, and Walker. *Fundamentals of Physics*. Wiley Pub.(10th Ed.)
- Bansal R.K. *A Text of Fluid Mechanics.* Laxmi Publication (P) Ltd (2nd Ed.)
- Sears, Zemansky, Young, Freedman. *University Physics.* Pearson Education Limited (2020)
- Verma H.C., *Concepts of Physics – Part I.* Bharati Bhawan (1st Ed.)

Online Educational Resources:

- https://n20.ncert.org.in/pdf/publication/sciencelaboratorymanuals/classXI/physics/kelm102.pdf

- www.studypage.in/physics/vernier-callipers-experiment
- www.studocu.com/in/document/amrita-vishwa-vidyapeetham/amrita-values-programme/calibration-of-vernier-caliper-experiment-no-1-met-2026/153377735
- www.vedantu.com/cbse/class-11-physics-to-measure-internal-diameter-and-depth-of-a-given-beaker-or-calorimeter-using-vernier-callipers-experiment

XVII. Rubric for Assessment:

Table:01.05

Sr. No.	Indicator	Excellent (4)	Good (3)	Basic (2)	Poor (1)
1	Concept	Clear	Good	Basic	Poor
2	Handling	Accurate	Minor error	Needs help	Incorrect
3	Procedure	Correct	Minor lapse	Weak	Unsafe
4	Data	Accurate	Minor error	Wrong	Not done
5	Conclusion	Logical	Partial	Weak	Incorrect

Experiment No.- 02

Determination of Dimensions of Small Objects using a Screw Gauge

I. Practical Significance

The screw gauge is a precision instrument capable of measuring lengths to an accuracy of 0.01 mm or even 0.001 mm. Unlike the Vernier calliper, the screw gauge works on the principle of a screw: one full rotation of the thimble advances the spindle by a fixed distance called the pitch. The proficiency and competency of this instrument develop the student's ability to work with precision tools, understand least count and zero error, and apply error analysis — skills that are directly transferable to mechanical engineering, industry, quality control, and research laboratories.

This instrument is indispensable for:

- **Mechanical Engineering:** Measuring the thickness of sheet metal, wire gauges, and bearing clearances.
- **Electronics Manufacturing:** Checking diameter of fine copper wire used in transformers and motors.
- **Optical Industry:** Measuring thickness of glass lenses and optical flats.
- **Quality Control:** Verifying that machined parts meet tight dimensional tolerances (±0.01 mm).
- **Medical Research:** Employed to measure the dimensions of surgical instruments and components for medical devices.

II. Relevant Program Outcomes (POs)

PO1: Basic and Discipline Specific Knowledge — Apply knowledge of physics and mathematics to perform precision measurements.

PO2: Problem Analysis — Identify sources of error, apply corrections, and analyse uncertainty.

PO4: Engineering Tools & Experimentation — Use precision measuring instruments in accordance with safe laboratory practices.

III. Relevant Course Outcomes (COs)

CO1: Demonstrate the use of precision measuring instruments and document observations systematically.

CO2: Apply principles of error analysis to evaluate and report experimental results.

IV. Laboratory Session Outcomes (LSOs)

LSO 2.1: Use a screw gauge to measure the diameter / thickness of a given object.

LSO 2.2: Estimate the mean absolute error, relative error, and percentage error up to three significant figures.

V. Description of the Device:

A screw gauge works on the principle of a screw. So, it is better to learn about screw before learning the functions of the screw gauge. We all have seen that the threads are engraved around the cylindrical portion of the screw (See Fig. 02.01). The main parts of the screw can be observed in the fig. The distance between any two consecutive threads is called Pitch.

The Pitch can be calculated using the formula: Pitch of the screw = $\frac{\textit{Thread Length}}{\textit{Total No.of Threads}}$.

As shown in Fig.02.02, thread length is 6.0 mm and is occupied by 12 threads. So, pitch is 0.5 mm.

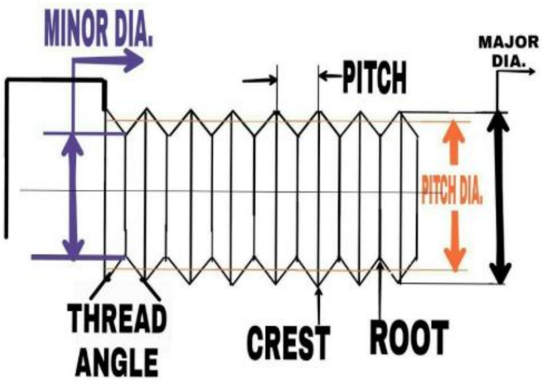


Fig.02.01: Parts of the Screw

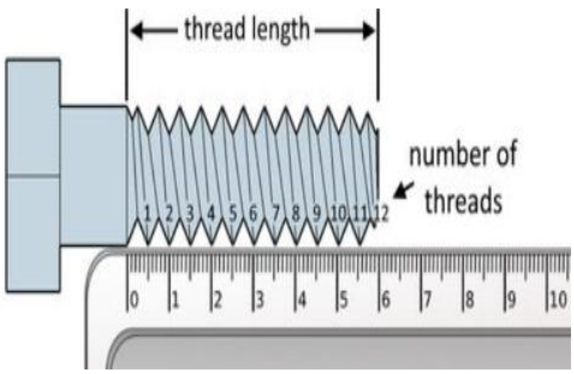


Fig. 02.02: Pitch measurement

A screw gauge (also called a micrometer screw gauge) is a precision measuring instrument that uses the principle of a screw to amplify small distances into larger, more readable rotations. It can measure dimensions to an accuracy of 0.01 mm (10 µm) or better.

Main Components:

- U-shaped metallic frame — provides rigidity and stability.
- Stud/ Anvil — fixed reference surface against which the object is held.
- Spindle — moveable rod that presses against the object.
- Sleeve (Barrel) — fixed cylindrical scale with main scale markings (1 mm divisions).
- Thimble — rotating drum with circular scale (100 divisions, each = 0.01 mm).
- Ratchet stop — ensures consistent measuring force and prevents over-tightening.
- Lock nut — locks the spindle in position for stable reading

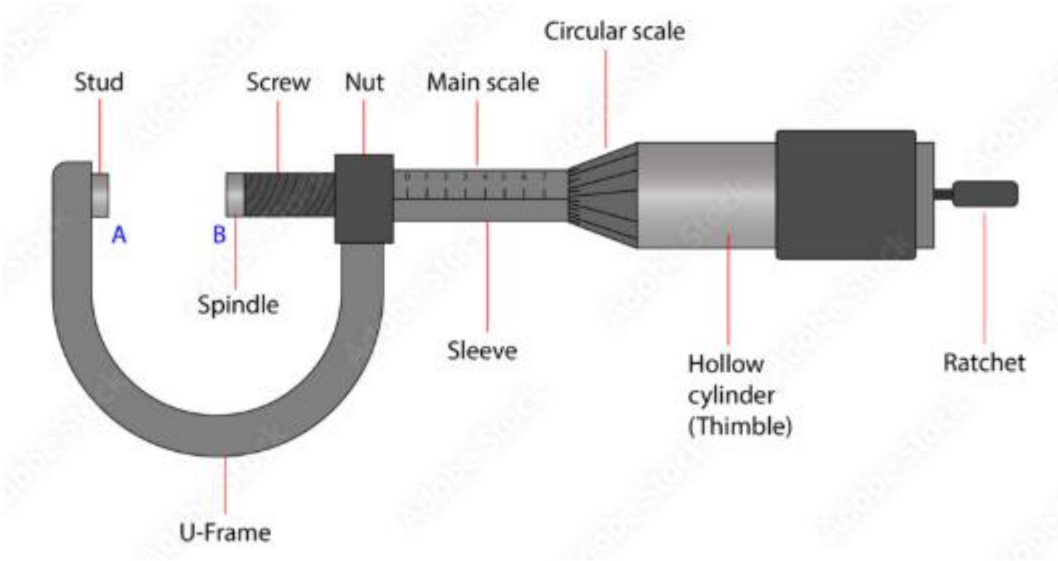


Fig. 02.03: Screw Gauge with its components

The smallest division on the main scale is 1 mm in one type of screw gauge (or 0.5 mm in another type). There is a circular scale on the head, which can be rotated. There are 100 divisions (or 50 in other type) on the circular scale. The distance moved by spindle on one complete rotation of the thimble = pitch =1mm for 100 div type (0.5 mm for 50 div type). When the end B of the screw touches the surface A of the stud, the zero marks on the main scale and the circular scale should coincide with each other. This represents that the screw gauge has no zero error.

VI. Minimum Theoretical Background:

6.1 Pitch and Least Count

Pitch (p) = Distance moved by spindle in one full rotation

Least Count (LC) = Pitch / Number of circular divisions on thimble

For a standard screw gauge: LC = 1 mm / 100 (=0.5 mm / 50) = 0.01 mm

6.2 Zero Error

When the left end surface B of the spindle and the right end surface A of the stud are in contact with each other, the zeroes of the linear (main) scale and the circular scale should coincide and align with the datum line. This is the situation of No Zero Error demonstrated in Fig. 02.04 (a).

In case this is not so, the screw gauge is said to have an error called zero error. Depending upon the position of zero mark of circular scale with datum line when A and B meet, zero error is categorised into Positive and Negative Zero errors.

Positive Zero Error: When the reading on the circular scale across the linear scale is more than zero (or positive), the instrument has Positive zero error as shown in Fig. E 2.4 (b). Note that zero mark of circular scale is below the datum line.

Here Zero of the circular scale is 2 units below the datum line, so,
Positive Zero Error= +2×LC = +2×0.01 mm = + 0.02 mm = + 0.002 cm

Negative Zero Error: When the reading of the circular scale across the linear scale is less than zero (or negative), the instrument is said to have negative zero error as shown in Fig. 02.04 (c). Note that zero mark of circular scale is above the datum line.

Here Zero of the circular scale is 4 units above the datum line, so,

Negative Zero Error= - 4×LC = - 4×0.01 mm = - 0.04 mm = - 0.002 cm

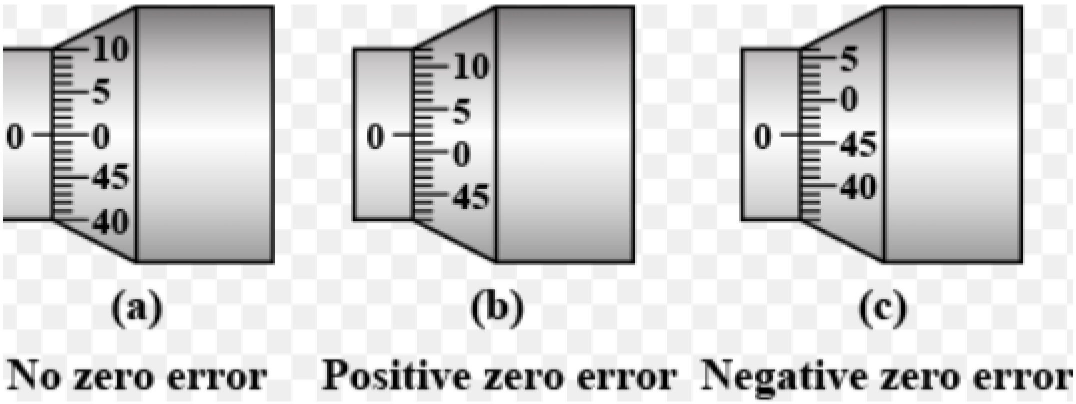


Fig. 02.04: Errors

6.3 Reading of the Screw Gauge

Total Reading = Main Scale Reading (MSR) + (Circular Scale Reading × LC) ± Zero Error Correction

TR = MSR + (CSR × LC) ± ZE

Volume of sphere $V = (4/3)\,\pi\, r^3 = \pi\, d^3 / 6$

Cross-sectional Area of wire $A = \pi\, d^2 / 4$

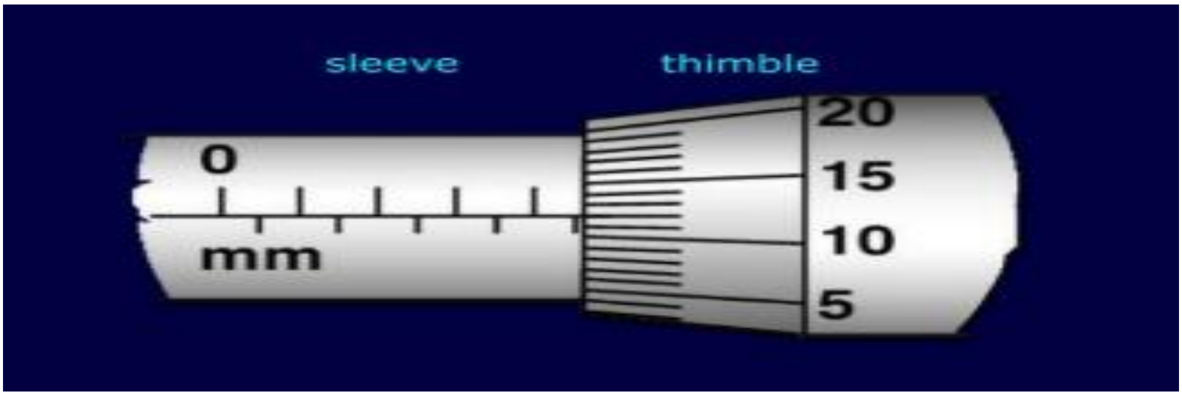


Fig. 02.05

In the Fig. 02.05, the reading of the Main scale engraved on the sleeve is 4.5 mm, and the Circular Scale Reading (CSR) is 12 units coinciding with the datum line.

$$\mathbf{TR = MSR + (CSR \times LC) \pm ZE}$$

$$\mathbf{= 4.5\ mm + 12 \times 0.01\ mm = 4.5\ mm + 0.12\ mm = 4.62\ mm}$$

6.4 Error Analysis

Mean Value ($\bar{x}$): $\bar{x} = (x_1 + x_2 + \ldots + x_n) / n$

Absolute Error ($|\Delta x_i|$): $|\Delta x_i| = |x_i - \bar{x}|$ (for each reading)

Mean Absolute Error ($\Delta\bar{x}$): $\Delta\bar{x} = (|\Delta x_1| + |\Delta x_2| + \ldots + |\Delta x_n|) / n$

Relative Error: $\delta = \Delta\bar{x} / \bar{x}$

Percentage Error: % error $= (\Delta\bar{x} / \bar{x}) \times 100\%$

Results are reported as: Measured value $= \bar{x} \pm \Delta\bar{x}$ (with unit) to three significant figures.

VII. Resources Required Table: 02.01

Sr. No.	Name of Resource / Item	Specifications	Quantity	Remarks
1	Screw Gauge (Micrometer)	Range: 0–25 mm; L.C. 0.01 mm	1	Check for zero error before use
2	Object — Metal wire	Diameter 0.5–3 mm	1	
3	Object — Glass / metal sphere	Diameter 5–15 mm	1	
4	Object — Sheet metal strip	Thickness 0.5–2 mm	1	

5	Cleaning cloth	Soft, lint-free	1	To clean measuring faces

VIII. Precautions

- Always check and record the zero error before taking readings.
- Never tighten the spindle directly; always use the ratchet stop.
- Clean the anvil and spindle faces with a soft cloth before use.
- Take measurements at a minimum of three different positions / orientations of the object.
- Avoid parallax error — read the thimble (circular) scale perpendicular to your line of sight.
- Do not apply excessive force — the ratchet will slip when the correct force is applied.
- Lock the spindle with the lock nut before removing the object for stable reading.
- Handle the instrument carefully; do not drop it.

IX. Procedure

1. Determine and record the Least Count of the screw gauge.
2. Check for zero error: close the jaws gently using the ratchet stop. If the zero of the thimble scale coincides with the main scale zero aligned with the datum line, zero error is nil. If not, record the zero error (positive or negative) and apply zero correction.
3. Clean the object and the measuring faces of the instrument with a soft cloth.
4. Place the object (wire / sphere / sheet) between the anvil and spindle; close using the ratchet stop.
5. Read the Main Scale Reading (MSR) — the last visible division on the sleeve.
6. Read the Circular Scale Reading (CSR) — the thimble division coinciding with the reference line on the sleeve.
7. Rotate the thimble in only one direction, say clockwise to avoid Backlash Error.
8. Compute: Total Reading = MSR + (CSR × L.C.) ± Zero Correction.
9. Repeat steps 4–7 for at least two different orientations (One orientation perpendicular to the other)
10. Repeat steps 4–7 for at least five different positions on the object.
11. Calculate $\bar{x}$, mean absolute error ($\Delta\bar{x}$), relative error, and percentage error.

X. Observations and Calculations

Pitch of Screw (P)	= ________ mm

Number of Circular Scale Divisions (N)	= ________

Least Count (L.C. = P/N)	= ________ mm

Zero Error (Z.E.)	= ________ mm Zero Correction (Z.C.) = ________ mm

Table 02.02: Observations for Diameter / Thickness

Sr. No.	MSR (mm)	CSR (div)	CSR × LC (mm)	Total (mm)	Mean (mm)
1					
2					
3					
4					
5					

Mean Diameter / Thickness ($\bar{x}$): $\bar{x}$ = ________________ mm

Table 02.03: Observations and Calculation of errors

Reading (x_i) mm	$\lvert\Delta x_i\rvert = \lvert x_i - \bar{x}\rvert$ mm	$\Delta\bar{x}$ (Mean Abs. Error) mm	Relative Error $\delta = \Delta\bar{x}/\bar{x}$	% Error	Result ($\bar{x} \pm \Delta\bar{x}$) mm
		↓	↓	↓	↓

XI. Results

The diameter / thickness of the given object is found to be:

Measured Value = __________ ± __________ **mm**

Relative Error: __________ **Percentage Error:** _________ %

XII. Sources of Error

1.The wire may not be of uniform cross-section.

2. Error due to backlash though can be minimised but cannot be completely eliminated.

Backlash Error: In a good instrument (either screw gauge or a spherometer) the thread on the screw and that on the nut (in which the screw moves), should tightly fit with each other. However, with repeated use, the threads of both the screw and the nut may get worn out. As a result, the screw slips a small linear distance without rotation. Sometimes it is observed that on reversing the direction of rotation of the thimble, the tip of the screw does not start moving in the opposite direction at once, but it remains stationary for a part of rotation. This causes error in the observation which is called backlash error. This happens because a gap develops between the two consecutive threads. To avoid the error, while taking the measurements, screw should be rotated in one direction only.

If it is required to change the direction of rotation of screw then do not change the direction of rotation at once. Move the screw still further, stop there for a while and then rotate it in the reverse direction.

3. The divisions on the linear scale and the circular scale may not be evenly spaced.

XIII. Interpretation of Results and Conclusions

Compare the measured value with the given / standard value if available. Comment on whether the error is within acceptable limits. Discuss the major sources of error (zero error, parallax error, Backlash error) and how they were minimised. Note that percentage error below 2–3% is generally acceptable in basic physics laboratories. If the percentage error is large, identify the probable cause and suggest corrective measures.

XIV. Practical Related Questions

1. What is the principle behind the working of a screw gauge? How is the least count related to the pitch of the screw?
2. Define zero error. How do you account for positive and negative zero errors? How to correct these errors?
3. Why is the ratchet stop used in a screw gauge? What would happen if the spindle were tightened directly?
4. If the zero of the thimble coincides with the 2nd division above the reference line when jaws are closed, what is the zero error and zero correction?

5. How do you calculate the mean absolute error? How does it differ from the relative error and the percentage error?
6. Why should readings be taken at different orientations of the object?
7. How will you avoid Backlash Error?

XV. References for Further Reading.

- Laboratory Manual (Physics Laboratory Class XI). **NCERT**
- Arora S.L. *Practical Physics (Class XI & XII)*
- Halliday, Resnick, and Walker. *Fundamentals of Physics*. Wiley Pub.(10th Ed.)
- Sears, Zemansky, Young, Freedman. *University Physics.* Pearson Education Limited (2020)
- Verma H.C., *Concepts of Physics – Part I*. Bharati Bhawan (1st Ed.)
- Online Lab Simulation: https://amrita.olabs.edu.in/?sub=1&brch=5&sim=16&cnt=1
- NPTEL Video Lecture on Measurement Uncertainty and Error Analysis.

XVI. Rubric for Assessment

Sr. No.	Performance Indicator (PI)	Level 4 Exemplary (4M)	Level 3 Proficient (3M)	Level 2 Developing (2M)	Level 1 Beginner (1M)
1	**Conceptual clarity of screw gauge principle, LC, zero error, and error types**	Explains principle, derives LC, explains all error types with examples	Explains principle & formula correctly with minor gaps	Knows formula but poor conceptual link between LC and pitch	No conceptual clarity
2	**Experimental setup, zero error check, and identification of components**	Accurate setup; checks zero error; correctly identifies all parts	Setup correctly with minor guidance; identifies most parts	Setup incomplete; cannot identify zero error	Wrong setup; unsafe handling
3	**Procedural rigor: correct use of ratchet, readings at multiple orientations**	Executes all steps independently; uses ratchet correctly; takes 5+ readings	Minor procedural lapse; takes minimum readings	Frequent assistance needed; fewer than 3 readings	Unsafe practices observed
4	**Data integrity: MSR, CSR, zero correction, error computation, significant figures**	Precise readings; correct calculations; proper units and significant figures; error discussed	Minor numerical/unit error; error computed	Data recorded but calculation errors	Data unreliable / not recorded
5	**Interpretation, conclusion, viva voce**	Interprets result; compares with standard;	Conclusion correct; partial reasoning	Conclusion stated	Incorrect conclusion; poor viva

		answers viva logically		without interpretation	

Experiment No.-03

Measurement of Radius of Curvature Using Spherometer

I. Practical Significance

The spherometer is a precision optical instrument that measures the radius of curvature of any spherical surface (convex or concave) to an accuracy of 0.01 mm. While a flat ruler cannot capture the curvature of a surface, the spherometer uses a central screw and three symmetrically placed legs to calculate the sagitta (depth of curve), from which the radius is derived mathematically.

Accurate knowledge of surface curvature is indispensable in optical manufacturing (lenses, telescopes, microscopes), ophthalmic lens grinding, precision engineering of ball bearings, quality control of curved glass components, curvature analysis in biomedical implant design and in astronomical instruments such as parabolic mirrors.

II. Relevant Program Outcomes (POs)

PO1: Basic and Discipline Specific Knowledge — Apply knowledge of geometry and physics to measure curved surfaces.

PO2: Problem Analysis — Analyse sources of error in curvature measurement and apply corrections.

PO4: Engineering Tools & Experimentation — Use spherometer as a precision tool to measure curved surface parameters.

III. Relevant Course Outcomes (COs)

CO1: Demonstrate the correct use of a spherometer and record observations systematically with correct significant figures.

IV. Laboratory Session Outcomes (LSOs)

LSO 3.1: Use a spherometer to measure the radius of curvature of a given convex and concave mirror / surface.
LSO 3.2: Estimate errors in the measurement.

V. Description of the Device

A spherometer is a precision instrument used to measure the radius of curvature of a spherical surface — either convex or concave. The word 'spherometer' is derived from the Greek word 'sphaira' (sphere) + 'metron' (measure). It operates on the principle of the micrometer screw and can measure curved surfaces to an accuracy of 0.01 mm.

The Spherometer consists of the following components:

- **Three Outer Legs (A, B, C):** Three equidistant pointed legs forming an equilateral triangle. They rest on the surface being measured. The distance between any two legs is denoted by 'l'.
- **Central Screw:** A vertically threaded screw that passes through the centre of the tripod frame. The screw advances by one pitch for every complete rotation.
- **Circular Scale (Thimble Scale):** Engraved on the drum of the central screw. A full rotation of the drum moves the tip by one pitch. It is divided into 50 or 100 equal divisions.
- **Main Scale or Pitch Scale (Vertical Scale):** A linear scale engraved on the vertical stem alongside the screw. Each division equals the pitch (usually 1 mm or 0.5 mm).
- **Knurled Knob/ Head:** Used to rotate the central screw smoothly for precise adjustment.
- **Spider (Frame):** Rigid metallic frame supporting the system. Holds the screw and three legs in fixed position

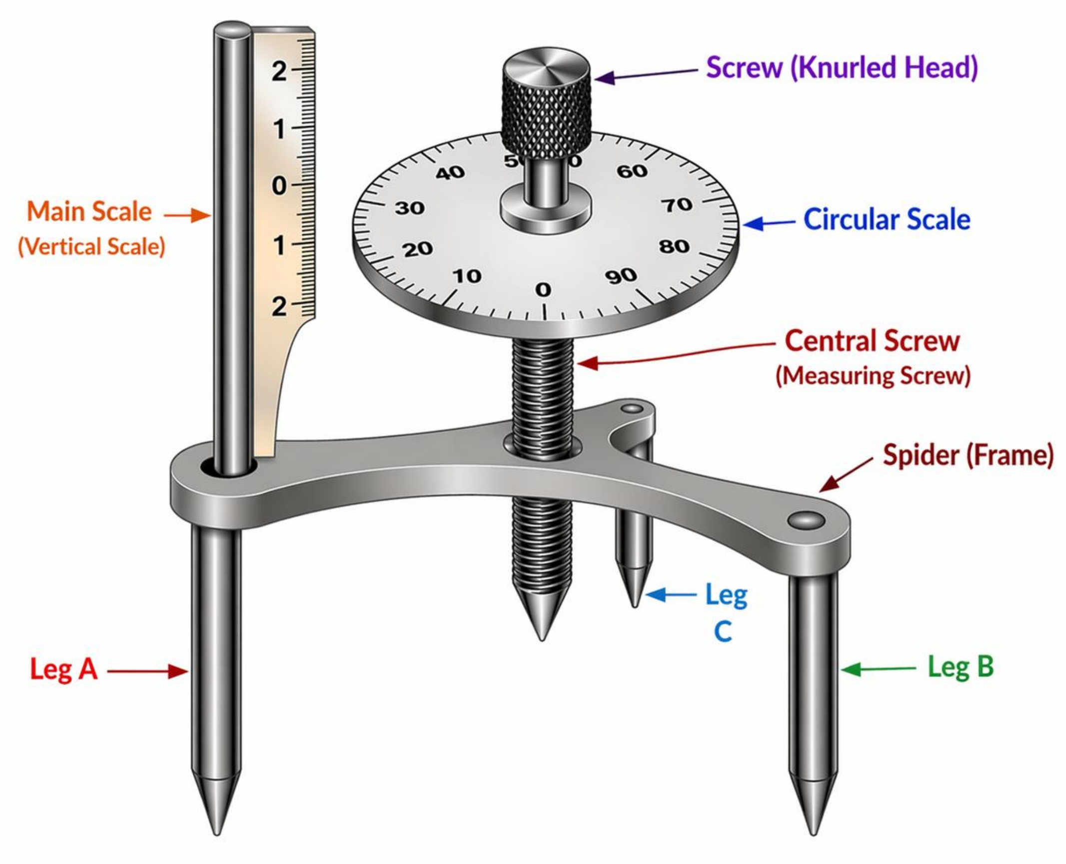


Fig. 03.01: Spherometer with its components

VI. Minimum Theoretical Background

When a spherometer with three legs rests on a flat surface, all three tips touch the surface and the central screw just touches it (reading = 0). When placed on a curved surface, the central screw must be adjusted until it also touches — the distance moved by the screw from the plane position to the curved surface is the sagitta (h).

1. **Pitch of a Spherometer:**

Pitch is the vertical distance moved by the central screw when one complete rotation is made by the circular scale.

$$\text{Pitch} = \frac{\text{Distance moved by central Screw on Main Scale}}{\text{Number of rotations done by Circular Scale}}$$

If the screw moves 1 mm in one full turn, then Pitch = 1 mm.

2. **Least Count of a Spherometer:**

Least Count (LC) is the smallest distance that the spherometer can measure accurately. Least Count is the distance moved by the spherometer screw when it is turned through one division on the circular scale.

$$\text{Least Count} = \frac{\text{Pitch}}{\text{Number of divisions on circular scale}}$$

If the pitch of the Spherometer screw is 1 mm and Circular scale divisions is 100, then

$$\text{LC} = \frac{1}{100} = 0.01 \text{ m}$$

3.Sagitta (h) — The Key Measurement:

The sagitta is the depth of curvature — the vertical distance between the central tip (P) and the plane defined by the three outer legs. It is measured as the difference in the screw readings on the flat surface and on the curved surface.

h = Reading on flat surface − Reading on curved surface (or vice versa, take the magnitude)

Sagitta (h): h = (number of complete rotations × pitch) + (circular scale reading × L.C.)

4. Mean Distance 'l' Between Outer Legs:

The three legs form an equilateral triangle. The side length 'l' is measured by placing the spherometer on graph paper and marking the three leg positions, then measuring the distance between any two marks with a ruler. Take the average of three such measurements.

5. Radius of Curvature:

For Convex and Concave Surfaces (General Formula):

$$\mathbf{R = l^2 / (6h) + h / 2}$$

where l = mean distance between any two tips of the spherometer legs (determined by imprinting on paper and measuring with a ruler)

h = sagitta = height of the curved surface above the plane of the three tips

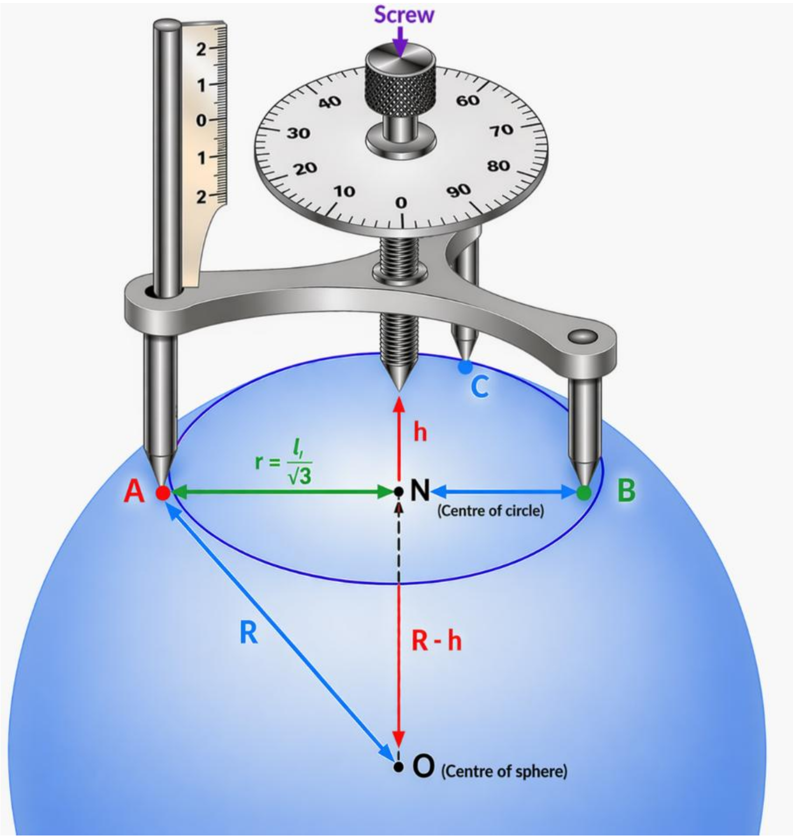


Fig. 03.02

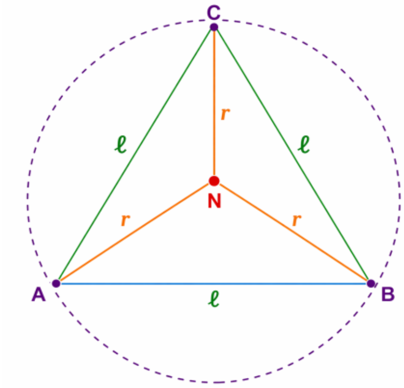


Fig. 03.04

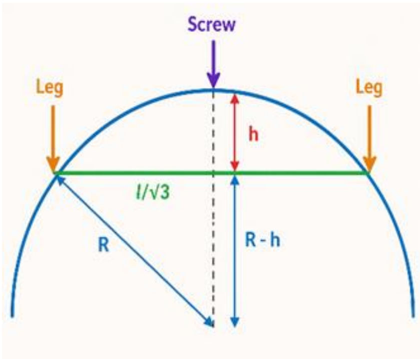


Fig. 03.03

Deduction of Radius of Curvature (R):

It is clear from the Fig. 03.02 and Fig. 03.03: In right-angled triangle ANO,

$$(AO)^2 = (NO)^2 + (NA)^2$$

$$(R)^2 = (R - h)^2 + (r)^2$$

$$R^2 = R^2 + h^2 - 2\text{Rh} + r^2$$

$$2\text{Rh} = h^2 + r^2$$

$$\mathbf{R} = \frac{h^2 + r^2}{2\text{h}} = \frac{r^2}{2\text{h}} + \frac{h}{2}$$

But, in equilateral triangle ABC (Fig. 03.04), $\mathbf{r} = \frac{\boldsymbol{l}}{\sqrt{3}}$

Hence, $\mathbf{R} = \frac{\boldsymbol{l}^2}{6\mathbf{h}} + \frac{\boldsymbol{h}}{2}$

Note: Although we have deduced the formula for a convex surface, it is equally applicable for concave surface.

Sign Convention: For a convex surface, the screw is raised (h is positive). For a concave surface, the screw is lowered into the surface (h is positive in magnitude but the surface curves away).

Error Analysis:

Mean h ($\bar{h}$): $\bar{h} = (h_1 + h_2 + h_3 + \ldots + h_n) / n$

Mean Absolute Error ($\Delta\bar{h}$): $\Delta\bar{h} = (|\Delta h_1| + |\Delta h_2| + \ldots + |\Delta h_n|) / n$

Relative Error in R: $\Delta R/R = 2\Delta l/l + \Delta h/h$ (propagated error)

Report: $R = \bar{R} \pm \Delta R$ (mm) to three significant figures.

VII. Resources Required Table 03.01

Sr. No.	Name of Resource / Item	Specifications	Quantity	Remarks
1	Spherometer	Pitch 1 mm; L.C. 0.01 mm; 100 divisions	1	Check for zero error before use
2	Convex mirror / lens	Radius of curvature 20–100 cm	1	Handle with care
3	Concave mirror / lens	Radius of curvature 20–100 cm	1	Handle with care
4	Plane glass slab	Flat surface for zero reading	1	Clean, dry
5	Millimetre graph paper	A4 size	2 sheets	To measure leg distance l
6	Pencil and ruler	30 cm steel ruler; L.C. 1 mm	1 each	

VIII. Experimental Setup:

The setup involves placing the spherometer on a flat glass slab to note the reference zero reading (flat surface reading). The spherometer is then transferred carefully to the curved surface. The central screw is adjusted until its tip just touches the curved surface. The new reading is noted. The difference gives the sagitta 'h'

IX. Precautions

- Determine the distance l between the legs carefully — press the legs on graph paper and measure the distance between imprinted dots with a millimetre scale.
- Ensure the glass / mirror surface is clean and free from dust before placing the spherometer.
- Always record the zero reading on the plane glass slab before placing on the curved surface.
- Take the reading only when the central tip just grazes the surface — not when pressed hard.
- Take readings for both clockwise and anticlockwise rotation to avoid backlash error. Also, note the direction of screw rotation (clockwise or anticlockwise).
- Repeat observations at least three times for each surface to ensure reliability.
- Keep the spherometer vertical while taking readings.
- Keep the eye level with the pitch scale to avoid parallax error during reading.
- Handle mirrors and lenses by the edges; never touch the optical surfaces.

X. Procedure

(a) Determination of Pitch and Least Count:

1. Place the spherometer on the flat glass slab. Rotate the central screw until its tip just touches the flat surface. Note this reading as the reference.
2. Give the central screw exactly 5 complete rotations. Count the number of divisions traversed on the pitch scale. Pitch = Total distance traversed / Number of rotations.
3. Count the total number of circular scale divisions (N). Calculate: LC = Pitch / N.

(b) Measurement of Sagitta for Convex Surface:

1. Place the spherometer on the flat glass plate. Rotate the central screw gently until its tip just touches the flat surface. Record this as reading R_1.
2. Lift the spherometer and carefully place it on the convex surface of the mirror/lens.
3. Rotate the central screw slowly downward until the central tip just touches the convex surface. Record this reading as R_2.
4. Compute sagitta: $h = R_1 - R_2$ (since the tip needs to go up on convex surface).
5. Repeat the measurement three times and calculate the mean sagitta.

(c) Measurement of Sagitta for Concave Surface:

1. Repeat steps (b1) to (b5) with the concave surface. Here the tip needs to go down: $h = R_2 - R_1$.
2. Record all readings carefully and compute sagitta for the concave surface.

(d) Measurement of Distance 'l' Between Legs:

1. Place the spherometer on graph paper and press lightly to mark the three leg positions as dots A, B, C.
2. Measure AB, BC, and CA using the ruler. Compute the mean: l = (AB + BC + CA) / 3.

X. Observations and Calculations

(a) Least Count:

Pitch of the screw = 1 mm (1 complete rotation = 1 mm advance)

Number of circular scale divisions = 100

Least Count (LC) = 1 mm / 100 = 0.01 mm

(b) Distance Between Outer Legs: Table: 03.02

Measurement	AB (cm)	BC (cm)	CA (cm)	Mean l (cm)
Trial 1	3.80	3.82	3.79	3.803
Trial 2	3.81	3.80	3.81	3.807
Trial 3				
Trial 4				
Trial 5				

(c) Sagitta for Convex Surface: Table: 03.03

Least Count (LC): 0.01 mm

Trial	Reading on Flat Surface R_1 (mm)	Reading on Convex R_2 (mm)	Sagitta $h = R_1 - R_2$ (mm)
1	0.00	−1.85	1.85
2	0.00	−1.87	1.87
3			
4			
5			

Mean Sagitta (convex): h = (1.85 + 1.87 + …) / 5 = 1.860 mm

(d) Sagitta for Concave Surface: **Table: 03.04**

Trial	Reading on Flat Surface R_1 (mm)	Reading on Concave R_2 (mm)	Sagitta $h = R_2 - R_1$ (mm)
1	0.00	2.12	2.12
2	0.00	2.14	2.14
3			
4			
5			

Mean Sagitta (concave): h = (2.12 + 2.14 + …) / 5 = 2.130 mm

(e) Radius of Curvature Calculation:

l (mean) = 3.805 cm = 38.05 mm

For Convex surface: $R\_convex = l^2 / (6h) + h/2 = (38.05)^2 / (6 \times 1.860) + 1.860/2$

$= 1447.8 / 11.16 + 0.93 = 129.73 + 0.93 \approx 130.66$ mm = 13.07 cm

For Concave surface: $R\_concave = (38.05)^2 / (6 \times 2.130) + 2.130/2 = 1447.8 / 12.78 + 1.065$

$= 113.29 + 1.065 \approx 114.36$ mm = 11.44 cm

(f) Error Calculation **Table: 03.04**

Surface	$\bar{l}$ (mm)	$\Delta\bar{l}$ (mm)	$\bar{h}$ (mm)	$\Delta\bar{h}$ (mm)	$\bar{R} = l^2/6\bar{h} + \bar{h}/2$ (mm)	$\bar{R} \pm \Delta R$ (mm)
Convex						
Concave						

XI. Results

Radius of Curvature of Convex Surface: R = ____ ± ____ mm = _____ ± _____ cm

Radius of Curvature of Concave Surface: R = _____ ± ___ mm = ______ ± ___ cm

Percentage Error (Convex): ________ % **Percentage Error (Concave):** _____ %

XII. Interpretation of Results and Conclusions:

Compare the measured radius of curvature with the standard / marked value (if available) on the mirror / lens. Comment on whether the percentage error is within acceptable limits (typically < 3% for diploma-level experiments).

The sagitta method used here is geometrically elegant — even a small depth measurement 'h' combined with the precisely known leg separation 'l' yields the full radius of a sphere with high precision. The difference between convex and concave readings confirms the instrument's ability to distinguish the nature (direction) of curvature. Repeated readings reduce random errors and increase reliability.

Discuss how the value of R is related to the focal length by the mirror formula $f = R/2$. Discrepancies may arise due to inaccurate measurement of l, improper levelling of the spherometer, or backlash error in the central screw.

Note: The formula $R = l^2/(6h) + h/2$ assumes a perfectly spherical surface. For surfaces that are not perfectly spherical, different readings at different positions will yield slightly different values of R.

XIII. Practical Related Questions

1. Derive the formula $R = l^2/(6h) + h/2$ using the geometry of a sphere and chord-sagitta relationship.
2. Define 'pitch' and 'least count' for a spherometer. How are they related?
3. In what situation does the formula $R = l^2/(6h) + h/2$ reduce approximately to $R \approx l^2/(6h)$?
4. A spherometer has a pitch of 0.5 mm and 50 circular divisions. Find its least count and the minimum measurable sagitta.
5. What is the sagitta of a curved surface? Explain with a diagram.
6. How does the radius of curvature of a surface relate to the focal length of a spherical mirror?
7. If $l = 40$ mm and $h = 2.5$ mm, calculate R. Show all steps.
8. What error would occur if the legs of the spherometer are not equidistant from each other?
9. Why is it important to first take a zero reading on a plane glass slab?
10. How would you distinguish between a convex and concave surface using the spherometer reading alone?

XIV. References for Further Reading

- Physics Laboratory Manual (Class XI). **NCERT**
- NCERT Physics Part I (Class XI) — Chapter 9: Ray Optics and Optical Instruments.
- Halliday, Resnick, and Walker. *Fundamentals of Physics*. Wiley Pub.(10th Ed.) — Optics and Curvature.

- Sears, Zemansky, Young, Freedman. *University Physics.* Pearson Education Limited (2020) — Geometric Optics.
- Verma H.C., *Concepts of Physics – Part I.* Bharati Bhawan (1st Ed.) — Chapter on Optics
- Arora S.L., Practical Physics (Class XI & XII).
- https://ncert.nic.in — Physics Lab Manual, Experiment on Spherometer
- Online Simulation — Spherometer Virtual Lab: https://amrita.olabs.edu.in

XV. Rubric for Assessment

Sr. No.	Performance Indicator (PI)	Level 4 Exemplary (4)	Level 3 Proficient (3)	Level 2 Developing (2)	Level 1 Beginner (1)
1	**Conceptual clarity: sagitta, radius of curvature, LC derivation, and formula**	Derives formula from geometry; explains sagitta; connects R to focal length	Explains principle & formula correctly with minor gaps	Knows formula but cannot explain sagitta or its geometric origin	No conceptual clarity
2	**Experimental setup: zero reading, leg distance l measurement, and surface identification**	Correct zero reading; precise l measurement from graph paper; identifies convex/concave correctly	Setup correctly with minor guidance; measures l adequately	Setup incomplete; cannot find zero reading	Wrong setup; unsafe handling of mirrors
3	**Procedural rigor, safety with optical components, and repetition**	Executes steps independently; takes 3+ readings per surface; no damage to optics	Minor procedural lapse; takes minimum readings	Frequent assistance; fewer than 3 readings	Unsafe practices; damages optical surfaces
4	**Data integrity: h values, error computation, propagated error in R, significant figures**	Precise readings; correct computation of R; error propagated and reported to 3 sig. figs.	Minor numerical/unit error; error computed	Data recorded but calculation errors; no error propagation	Data unreliable / not recorded
5	**Interpretation, comparison with standard value, conclusion, and viva voce**	Interprets result; compares with standard; derives f = R/2; answers viva logically	Conclusion correct; partial reasoning	Conclusion stated without interpretation	Incorrect conclusion; poor viva

Experiment No.- 04

Determination of the Spring Constant of a Given Helical Spring

I. Practical Significance:

This experiment determines the stiffness (spring constant) of a spring by studying its extension under applied load. It helps in understanding elastic behaviour of materials.

After performing this experiment, students will:

- Understand the relation between force and extension
- Verify linear elastic behaviour
- Calculate spring constant using experimental data

Applications:

- Design of shock absorbers and suspension systems in vehicles
- Measurement devices like spring balances
- Engineering structures involving elastic materials

II. Relevant Program Outcomes (POs):

PO1: Basic and Discipline Specific Knowledge - Apply physics principles in real systems
PO2 – Problem Analysis -Analyze experimental data and relationships
PO4 – Engineering Tools & Experimentation - Use laboratory instruments effectively

III. Relevant Course Outcomes (COs):

CO3: Apply physical laws to perform experiments and analyze results

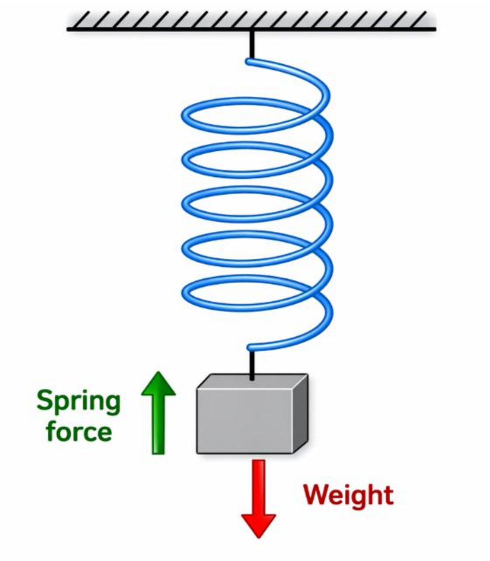
IV. Laboratory Session Outcomes (LSOs):

- Calculate the **spring constant (K)**, which defines the stiffness of the spring.
- Verify Hooke's law

V. Minimum Theoretical Background:

When a force (load) is applied to a spring, it undergoes an extension. According to Hooke's Law, for relatively small displacements, the extension (x) is directly proportional to the applied force (F).

Mathematically: F = - K . x



Where:

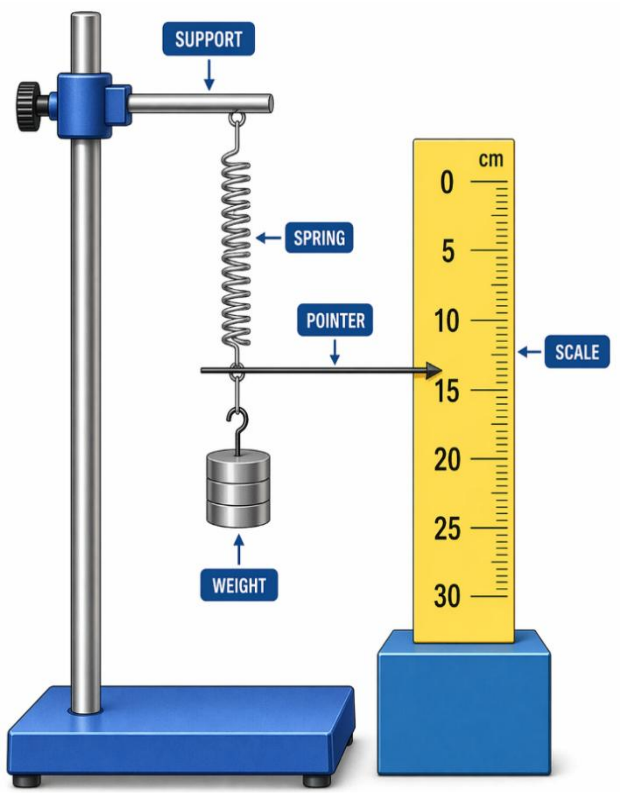
- **F** : The restoring /spring force (equal to the weight applied, mg.
- **K** : The spring constant (Force per unit extension/ compression).
- **x**: The change in length from the equilibrium position.

The spring constant represents the "stiffness" of the spring. A higher value of K indicates a stiffer spring that requires more force to stretch.

VI. Experimental Setup:

This setup is used to demonstrate **Hooke's Law**, which states that the force (F) needed to extend or compress a spring by some distance (x) varies linearly with that distance.

$$F = - K . x$$



Components of the Setup

- **Support:** A fixed horizontal arm that holds the spring in place so it can hang vertically.
- **Helical Spring:** The elastic object being tested. Its "stiffness" is known as the spring constant (K)
- **Pointer:** Attached to the bottom of the spring to show the exact position on the scale.

Meter Scale: A ruler (least count = 1 mm) used to measure the extension/ compression of the spring.

- **Weight Hanger & Slotted Weights (Load):** The mass added to the spring. Gravity pulls this mass down, creating a force (Load = mg).
- **Clamp Stand:** Holds the spring vertically

Fig.-01: Experimental Set-up for calculating Spring Constant

VII. Resources Required: Table:04.01

Sr. No.	Name of Resources	Specifications	Quantity
1	**Helical Spring**	Steel wire, uniform coils	1
2	**Slotted Weights**	50g or 100g increments with a hanger	1 set
3	**Rigid Support**	Heavy base stand with a horizontal clamp	1
4	**Vertical Scale**	0-50 cm or 0-100 cm, Least Count = 0.1 cm	1
5	**Pointer**	Lightweight needle or wire attached to the hanger	1

VIII. Precautions:

- Do not load the spring beyond its **elastic limit** (if it doesn't return to original length, it's ruined).
- The weights should be added and removed **gently** to avoid sudden jerks.
- The spring should not touch the scale or any surrounding objects during the experiment.
- Avoid oscillations before reading
- Take readings at eye level

IX. Procedure:

1. **Setup:** Hang the helical spring from the rigid clamp and attach the weight hanger and pointer to the lower end.
2. **Zero Reading:** Ensure the pointer is not touching the scale. Note the initial position of the pointer (L_0)with only the hanger attached.
3. **Loading:** Add a weight (e.g., 50g) to the hanger. Wait for the spring to stop oscillating. Note the new position (L_1).
4. **Incremental Steps:** Continue adding weights in equal increments, recording the position for each load.

5. **Unloading:** Gradually remove the weights one by one and record the pointer positions during unloading to check for elastic hysteresis or permanent deformation.
6. **Mean Extension:** Calculate the mean position for each load and determine the extension (x = Mean Position - L_0)

X. Observations and Calculations:

- Acceleration due to gravity (g) = 9.8 ms^{-2}
- Least Count of Measuring Scale = 0.1 cm
- Initial Reading (Hanger only): L_0 = 10.0 cm

Observation Table - Loading **Table:04.02**

Load (g)	Force F (N)	Initial (cm)	Final (cm)	Extension x (cm)	x (m)	K = F/x (N/m)
50	0.49	10.0	11.0	1.0	0.01	49
100	0.98	10.0	12.0	2.0	0.02	49
150	1.47	10.0	13.0	3.0	0.03	49

Average Value of K based on this observation table:04.02

$$< K >= \frac{K_1+K_2+K_3}{3} = \mathbf{49\ N/m}$$

Observation Table- Unloading **Table:04.03**

Load (g)	Force (N)	Initial (cm)	Final (cm)	Compression (cm)	x (m)	K (N/m)
150	1.47	9.8	12.9	3.1	0.031	47.4
100	0.98	9.8	11.9	2.1	0.021	46.7
50	0.49	9.8	10.9	1.1	0.011	44.5

Average Value of K based on the observation table:04.03

$$< K >= \frac{K_1+K_2+K_3}{3} = \mathbf{46.2\ N/m}$$

Average Spring Constant = (49+46.2)/2 = 47.6 N/m ≈48N/m

XI. Results:

The spring constant of the given helical spring is found to be:

$$\boldsymbol{k} = \mathbf{48\ N/m\ (approx.)}$$

XII. Interpretation of Results and Conclusions:

The results show a nearly constant ratio of force to extension, confirming Hooke's law. Minor deviations occur due to observational and alignment errors.

XIII. Practical Related Questions:

1. What is Hooke's law?
2. What is elastic limit?
3. Why should oscillations be avoided?
4. What happens beyond elastic limit?
5. How does stiffness affect extension?
6. What is the physical significance of spring constant 20.5 N/m?

XIV. References for Further Reading:

- Halliday, Resnick, and Walker. *Fundamentals of Physics*. Wiley Pub.(10th Ed.)
- Bansal R.K. *A Text of Fluid Mechanics.* Laxmi Publication (P) Ltd (2nd Ed.)
- Sears, Zemansky, Young, Freedman. *University Physics.* Pearson Education Limited (2020)
- Verma H.C., *Concepts of Physics – Part I.* Bharati Bhawan(1st Ed.)

Online Educational Resources:

www.sciencing.com/spring-constant-hookes-law-what-is-it-how-to-calculate-w-units-formula-13720806/

ncert.nic.in/pdf/publication/sciencelaboratorymanuals/classXI/physics/kelm105.pdf

2.7: Spring Force- Hooke's Law - Physics LibreTexts

www.sciencefacts.net/spring-force.html

XV. Rubric for Assessment:

Sr. No.	Performance Indicator	Level 4 (4 M)	Level 3 (3 M)	Level 2 (2 M)	Level 1 (1 M)

1	**Concept clarity**	Excellent	Good	Basic	Poor
2	**Setup**	Accurate	Minor error	Needs help	Incorrect
3	**Procedure**	Correct	Minor lapse	Weak	Unsafe
4	**Data**	Accurate	Minor error	Incorrect	Not done
5	**Conclusion**	Logical	Partial	Weak	Incorrect

Experiment No.- 05

Determination of g and Radius of Gyration using Bar Pendulum

I. Practical Significance A bar pendulum is a physical (compound) pendulum — a rigid extended body oscillating about a fixed horizontal knife-edge pivot. Unlike the simple pendulum (which is an idealization), the bar pendulum accounts for the actual distribution of mass along its length. By varying the pivot position along the bar and measuring the time period at each position, one can determine both the local acceleration due to gravity 'g' and the radius of gyration K_G of the bar about its centre of mass.

Bar pendulum principles underlie the calibration of precision time standards, the design of clock escapements, the analysis of rotating machinery, the calculation of moments of inertia in structural engineering, and the determination of g in geophysical surveys.

II. Relevant Program Outcomes (POs)

- **PO1: Basic and Discipline Specific Knowledge:** Apply rotational dynamics and oscillation theory to physical pendulums.
- **PO2: Problem Analysis:** Analyse T vs L data graphically to extract g and K_G.
- **PO4: Engineering Tools:** Use measuring instruments and experimental methods effectively
- **PO6: Project Management:** Conduct experiments systematically and interpret results

III. Relevant Course Outcomes (COs)

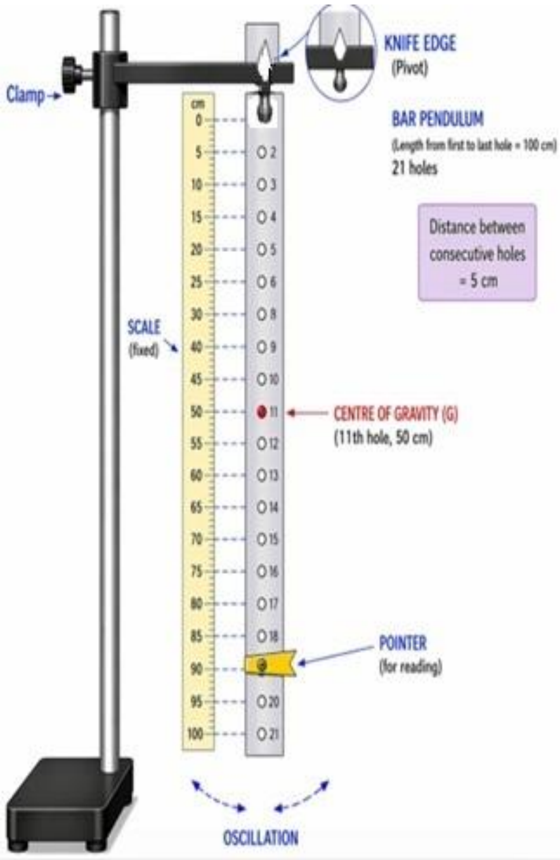
CO2: Apply principles of mechanics to solve physical problems
CO4: Determine g and moment of inertia parameters using the bar pendulum experiment.

IV. Laboratory Session Outcomes (LSOs)

- **LSO 5.1:** Determine the time period of oscillation of given bar pendulum.
- **LSO 5.2:** Determine the radius of gyration and moment of inertia about an axis perpendicular to the plane of oscillation and passing through its centre of mass of given bar pendulum.

V. Description of the Apparatus

- **Bar (Metallic Rod):** A uniform metallic bar about 80–100 cm long with evenly spaced holes (typically 5 cm apart).These holes allow the bar to be suspended from different points to study oscillations about various axes.
- **Knife Edge:** A **hardened steel wedge-shaped knife edge** is inserted into one of the holes of the bar. It acts as the **pivot point** about which the bar oscillates. Its sharp edge ensures **minimum friction**, allowing accurate time measurements.
- **Support Bracket:** A **rigid bracket** (often wall-mounted or stand-mounted) provides stable and fixed support during oscillations. It has a **grooved surface** where the knife edge rests securely.
- **Stopwatch:** Measures the time period for oscillations at each pivot position.



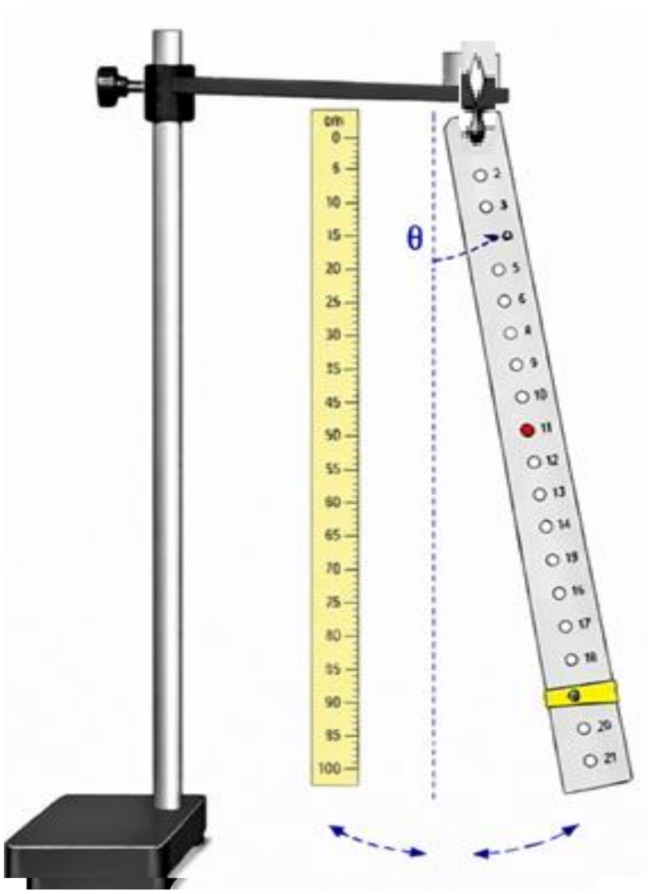


Fig. 05.01: Bar Pendulum in vertical stable position

Fig. 05.02: Bar Pendulum under oscillation

VI. Minimum Theoretical Background

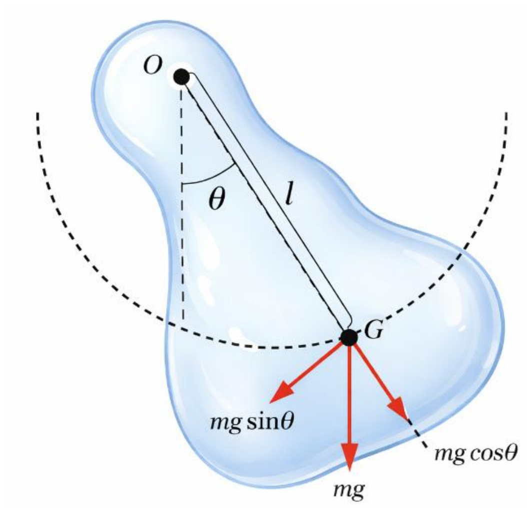


Fig. 05.03 : The Compound Pendulum

A compound pendulum (also known as a physical pendulum) consists of a rigid body suspended in the vertical plane on a horizontal axis through a point other than its centre of mass, and is free to oscillate about the point of suspension (pivot). A bar pendulum is the simplest form of compound pendulum. It is in the form of a rectangular bar (with its length much larger than the breadth and the thickness) with holes (for fixing the knife edges) drilled along its length at equal separation (see Fig. 05.01).

In Fig. 05.03 a body of irregular shape is pivoted about a horizontal frictionless axis through O and is displaced from its equilibrium position by an angle θ. In the equilibrium position the centre of mass G of the body is vertically below O. The distance of the centre of mass G from O is l and the mass of the body is m.

At an angular displacement θ, the pendulum experiences a restoring torque:

$$\tau = -mgl\sin(\theta) \approx -mgl\theta \quad \text{if angle } \theta \text{ is very small.}$$

This restoring torque produces an angular acceleration $\alpha = \frac{d^2\theta}{d^2t}$.

Using Newton's 2nd law for rotating mass system:

Net restoring torque = moment of inertia × angular acceleration

$$\tau = I\alpha = I\frac{d^2\theta}{d^2t}.$$

We can therefore write: $I\frac{d^2\theta}{d^2t} = -mgl\theta \Rightarrow I\frac{d^2\theta}{d^2t} + mgl\theta = 0$ … Eq. (05.01)

(Using Eq. 05.01 and 05.02)

Moment of inertia I about the point of suspension, $I = I_G + ml^2$ (Parallel axes theorem)

where I_G = Moment of inertia about the centre of mass G = mK^2 (K = radius of gyration about G)

Hence, Moment of inertia I about the point of suspension, $I = mK^2 + ml^2 = m(K^2 + l^2)$

Using this value of I in Eq. (05.01), $m(K^2 + l^2)\frac{d^2\theta}{d^2t} + mgl\theta = 0$

$$\frac{d^2\theta}{d^2t} + \frac{gl}{(K^2 + l^2)}\theta = 0 \qquad \text{... Eq. (05.02)}$$

Standard equation of Angular Simple Harmonic Motion: $\frac{d^2\theta}{d^2t} + \omega^2\theta = 0$ ... Eq. (05.03)

On comparison Eq. (05.02) and Eq. (05.02), $\omega^2 = \frac{gl}{(K^2 + l^2)} \Rightarrow \omega = \sqrt{\frac{gl}{(K^2 + l^2)}}$

Therefore Time-period $\mathbf{T = 2\pi\sqrt{\frac{(K^2 + l^2)}{gl}} = 2\pi\sqrt{\frac{[(\frac{K^2}{l}) + l]}{g}}}$ … Eq. (05.04)

$$\mathbf{T = 2\pi\sqrt{\frac{L}{g}}} \qquad \text{… Eq. (05.05)}$$

where L is the equivalent length of a Simple Pendulum given by,

$$L = \frac{K^2}{l} + l \qquad \text{… Eq. (05.06)}$$

From Eq. (05.05), we get $\boldsymbol{g = 4\pi^2\frac{L}{T^2}}$ … Eq. (05.07)

The point at a distance L from the centre of suspension O along a line passing through the centre of suspension O and the centre of mass G is known as the **centre of oscillation**. Time period T will have minimum value when $l^2 = K^2$ or, $l = \pm K$ (using Eq. (05.04).

Then EF = L = 2K (see Fig. 05.05) and the Minimum Time Period $T_0 = 2\pi\sqrt{\frac{2K}{g}}$ … Eq. (05.08)

The acceleration due to gravity **g** from Eq. (05.08) can be found to be, $\boldsymbol{g = 8\pi^2\frac{K}{T_0^2}}$ …Eq. (05.09)

Simplifying Eq. (05.06), we get $l^2 - lL + K^2 = 0$ … Eq. (05.10)

Since Eq. (05.08) is a quadratic equation in l, this equation has two roots. Suppose l_1 and l_2 are the two values of l, then by the theory of quadratic equations:

If $ax^2 + bx + c = 0$ is a quadratic eq. in x, then Sum of Roots = -b/a, and Product of Roots = c/a

$$l_1 + l_2 = L \qquad \text{... Eq. (05.11)}$$

$$l_1 l_2 = K^2 \quad \text{...Eq. (05.12)}$$

Therefore, we can write solutions as $l = l_1$, and $l = l_2 = \frac{K^2}{l_1}$ ...Eq. (05.13)

As both the sum and the product of the two roots are positive, for any particular value of l, there is a second point on the same side of centre of mass G and at a distance of $\frac{K^2}{l}$ from it, about which the pendulum will have the same time-period.

From Eq. (05.12), we can calculate **Radius of Gyration** $\mathbf{K = \sqrt{l_1 l_2}}$ ...Eq. (05.14)

By determining L, l_1 and l_2 graphically for a particular value of T, the acceleration due to gravity $\boldsymbol{g}$ at that place and the radius of gyration **K** of the compound pendulum can be determined.

If a graph is plotted with the time period on Y-axis and the distance of the point of suspension O from the centre of mass G on X-axis, the graph should take the shape as shown in Fig. (05.05), having two curves symmetrical about the CM of the bar.

To find the equivalent length L of a simple pendulum with the same period, a horizontal line ABPCD can be drawn which cuts the graph at points A, B, C and D, all of which read the same time period. For A as the centre of suspension, C is the centre of oscillation (the position of the centre of oscillation C from the centre of suspension A is at $L = l_1 + l_2$). Similarly, for B as the centre of suspension, D is the centre of oscillation ($BD = L = l_1 + l_2$).

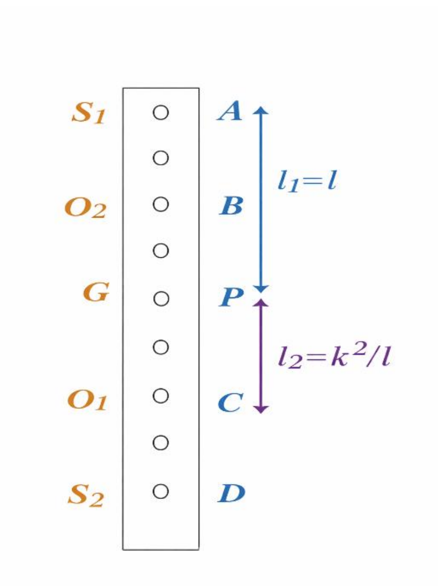


Fig. 05.04: Bar Pendulum

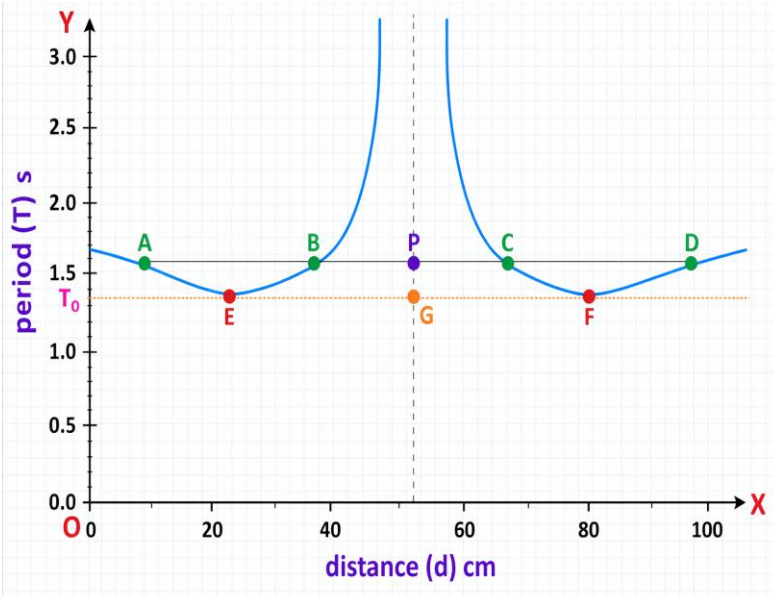


Fig. 05.05: Time-Distance Graph

Theory Summarisation:

1. Time Period of a Physical Pendulum:

For a rigid body oscillating about a pivot at distance l from the centre of mass G:

$$T = 2\pi\sqrt{\frac{[(\frac{K^2}{l}) + l]}{g}} = 2\pi\sqrt{\frac{L}{g}} \quad \text{where } L = \frac{K^2}{l} + l \text{ is the equivalent length of a Simple Pendulum}$$

Time period T will have minimum value when $l^2 = K^2$ or, $l = \pm K$

Then EF = L = 2K (see Fig. 05.05) and the Minimum Time Period $T_0 = 2\pi\sqrt{\frac{2K}{g}}$

2.Acceleration due to gravity:

In terms of L and Time-period T: $\boldsymbol{g = 4\pi^2 \frac{L}{T^2}}$

In terms of radius of gyration K and the minimum time period T_0: $\boldsymbol{g = 8\pi^2 \frac{K}{T_0^2}}$

3. Radius of Gyration:

$\mathbf{K = \sqrt{(l_1 \times l_2)}}$

l_1 and l_2 are two pivot distances giving the same T (from graph)

Ferguson's method for determination of *g*

Using Eq. 05.05 and Eq. 05.10 we get
$l^2 = (g / 4\pi^2)\, lT^2 - K^2$.
A graph between l^2 and lT^2 should therefore be a straight line with slope $g / 4\pi^2$, as shown in (Fig. 05.06). The intercept on the y-axis is $-K^2$.

Acceleration due to gravity, $\boldsymbol{g = 4\pi^2 \times}$ **slope**

Radius of gyration, **K = √(intercept)**

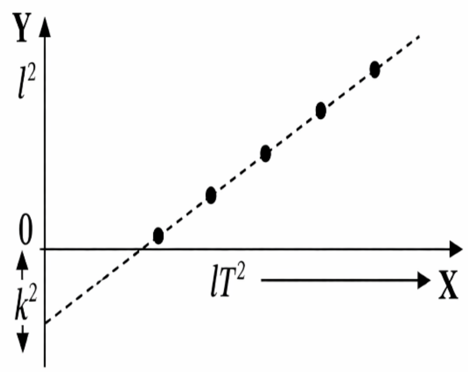


Fig. 05.06

VII. Resources Required

Table: 05.01

Sr. No.	Item	Specification	Quantity	Remarks
1	Bar Pendulum	Metallic bar ~100 cm, holes every 5 cm	1	Uniform, defect-free
2	Knife Edge	Hardened steel, sharp edge	1	Fits bar holes
3	Support Bracket	Wall-mounted, grooved	1	Rigidly fixed to wall / Stand
4	Stopwatch	Least count 0.1 s	1	Calibrated
5	Metre Scale	100 cm	1	For measuring l

VIII. Experimental Setup

Mount the support bracket firmly on the wall or stand (Fig. 05.01). Insert the knife edge through the first hole (nearest to one end) of the bar. Rest the knife edge on the bracket groove. The bar should swing freely in a vertical plane. Use a metre scale to measure the distance d of the knife edge (pivot) to the centre of mass of the bar (midpoint of the bar).

IX. Precautions

- Ensure the bar swings in a single vertical plane — avoid any rotational or lateral motion.
- Keep the amplitude of oscillation small (< 5°) to satisfy the small-angle approximation.
- The knife edge must be sharp and the groove must be smooth to minimize friction at the pivot.
- Start the stopwatch when the bar passes through the mean (equilibrium) position.
- Measure the distance l from the pivot to the exact centre of mass of the bar (not one end).
- Take time for at least 20 oscillations to reduce percentage error in T.
- Avoid parallax error while measuring distance.

X. Procedure

1. Balance the bar on a sharp wedge and mark the position of its centre of mass G.
2. Suspend the bar pendulum using a knife edge through a hole close to one end of the bar.
3. Displace the bar slightly (Fig. 05.02) and allow it to oscillate freely in a vertical plane with a small amplitude (not exceeding 5°).
4. Using a stopwatch, record the time taken for 20 complete oscillations. Repeat this measurement three times and calculate the mean time t. Then determine the time period using

$$T = \frac{t}{20}.$$

5. Measure the distance $d$of the point of suspension (hole) from one end of the bar using a meter scale.
6. Move the knife edge to the next hole (5 cm further). Repeat steps 3–5 to record new distance and corresponding time-period.
7. Repeat the above steps for different holes along the bar, moving towards the centre of gravity (G), where the time period becomes maximum.
8. Invert the bar and again repeat the same set of observations for all the holes, starting from the opposite end.
9. Plot a graph between distance d (along X-axis) and time period T (along Y-axis). The graph obtained will be symmetrical in nature.
10. Draw a horizontal line (constant T) cutting the curve at points A, B, C, and D. The midpoint P of this line corresponds to the position of the centre of gravity (G).

11. Measure the distances AC and BD and calculate the effective length L of the equivalent simple pendulum using their average (L = $\frac{AC+BD}{2}$). Note the corresponding time period T and calculate the value of acceleration due to gravity g.
12. Draw several such horizontal lines and repeat the above process to obtain multiple values of $\boldsymbol{g}$, then calculate their mean.
13. Alternatively, plot a graph between T^2(X-axis) and l(Y-axis). This graph will be a straight line. From its slope, determine the value of $\boldsymbol{g}$ (see Fig. 05.06).
14. To find the radius of gyration K, measure lengths of the line segments AP, BP, PC and PD of line ABPCD from the graph and compute $\sqrt{AP \times BP}$ or $\sqrt{PC \times PD}$. Repeat the procedure for each horizontal line and calculate the mean value of K.

XI. Observations and Calculations

(a) Distance between holes = 5 cm; Length of bar = 100 cm

(b) Time Period vs Pivot Distance (T-l):

Table: 05.02: Observation Table for T and l

Sr. No.	Hole No.	Distance l (cm)of pivot / hole from centre of mass G	Distance d (cm) from one end (A) hole	Time for 20 Osc. (s)	Mean t (s)	T = t/20 (s)
One side of C.M.						
1	3	-40	10	33.2, 33.0, 33.1	33.1	1.655
2	5	-30	20	30.8, 30.6, 30.7	30.7	1.535
3	9	-10	40	31.2, 31.0, 31.1	31.1	1.555
4						
5						
Other side of C.M						
6	13	+10	60	31.3, 31.1, 31.2	31.2	1.560
7	17	+30	80	30.9, 30.7, 30.8	30.8	1.540
8	21	+50	100	33.3, 33.1, 33.2	33.2	1.660
9						
10						

(c) From T vs d graph (Horizontal Line Method):

Consider the horizontal line ABPCD drawn in Fig. 05.05, we observe that

A ≈ 10 cm, B ≈ 40 cm, C ≈ 60 cm, D ≈ 100 cm

AC = 60 – 10 = 50 cm

BD = 100 – 40 = 60 cm

Equivalent length, L = (AD + BE)/2 = (50 + 60)/2 = 55 cm

Table: 05.03 Calculation of g and K

Obs. No.	L (cm)	T (s)	$g = 4\pi^2\frac{L}{T^2}$ (cm/s²)	K = $\sqrt{l_1 \times l_2}$ (cm)
1	55	1.55	905	28.3
2	58	1.56	940	29.5
3	60	1.54	998	31.0

Mean g = (905 + 940 + 998)/3 = 947.7 cm/s²

Mean K = (28.3 + 29.5 + 31.0)/3 = 29.6 cm

For a pendulum of mass 1.5 kg, Moment of Inertia about CM, I_G = mK² (K = radius of gyration about G) = 1.50 kg × $(29.6\ cm)^2$ = 1314.24 kg cm^2 = 0.131424 kg-m^2 = 0.131 kg-m^2

Standard value of g = 980 cm/s²

Percentage Error = |980 – 947.7| / 980 × 100 = 3.29%

XII. Results

The acceleration due to gravity determined using bar pendulum is 947.7 cm/s² with an error of 3.29%.

The radius of gyration of the bar pendulum is 29.6 cm.

For a pendulum of mass 1.5 kg, Moment of Inertia about CM is 0.131 kg-m^2

XIII. Interpretation of Results and Conclusions

The experiment successfully demonstrates the concept of equivalent simple pendulum length. The T vs d (T vs l) graph has a characteristic U-shape with a clear minimum, confirming that T is minimum when l = ± K. By reading conjugate lengths (equal T) from the graph, both g and K are determined with high accuracy. The result g ≈ 947.7 cm/s² is very close to the standard value (980 cm/s²), validating the experimental method.

XIV. Practical Related Questions

1. What is a physical (compound) pendulum? How does it differ from a simple pendulum?
2. Explain why the T vs l (or T vs d) graph has a minimum. At what value of L does Time-period become minimum?
3. Define the 'centre of oscillation'. What is the relationship between centre of suspension and centre of oscillation?

4.What happens to T if the bar is made of denser material but the same dimensions?

5. A bar pendulum has K = 20 cm. If suspended at l = 20 cm from G, what type of pendulum does it resemble?

6. Why is the experiment done on both sides of the centre of mass?

XV. Suggested Activities

1. Determine the moment of inertia of the bar about one end using the bar pendulum data.
2. Compare the experimentally determined g with the local value of g from a geophysical database.

XVI. References for Further Reading

- H.C. Verma, Concepts of Physics – Part I, Bharati Bhawan.
- Halliday, Resnick & Walker, Fundamentals of Physics, 10th Ed., Wiley.
- Sears, Zemansky, Young & Freedman, University Physics, Pearson.
- R.K. Shukla, Anchal Srivatsav, Practical physics, New Age International (P) Ltd, New Delhi
- NCERT Physics Lab Manual — Oscillations.

XVII. Rubric for Assessment **Table: 05.04**

Sr. No.	Indicator	Excellent (4)	Good (3)	Basic (2)	Poor (1)
1	Concept	Explains compound pendulum and radius of gyration K clearly	Good, minor gaps	Partial	Cannot explain
2	Handling	Correct knife-edge placement, timing	Minor positional error	Needs help	Incorrect placement
3	Procedure	All steps followed, graph plotted	Minor lapse, graph adequate	Weak procedure	Absent/unsafe
4	Data	T vs l table correct, smooth curve	Minor graph error	Errors present	Data absent
5	Conclusion	g and K found with % error	Partial — one value found	Only T values found	Absent/wrong

Experiment No. -06

Determination of Moment of Inertia of a Flywheel

I. Practical Significance

A flywheel is a heavy rotating disc that stores rotational kinetic energy. Its ability to resist changes in angular speed — quantified by its Moment of Inertia 'I' — is the key property that makes it useful. The flywheel experiment is a classic method to measure 'I' by converting the potential energy of a falling mass (via a wrapped string) into rotational kinetic energy and dissipating it against bearing friction.

Flywheel moments of inertia are critical in engine design (smoothing power delivery), gyroscopes (navigation systems), energy storage flywheels (hybrid vehicles), industrial machinery (punch presses), and precision instruments. Accurately knowing 'I' helps in calculating rotational kinetic energy, angular momentum, and rotational dynamics.

II. Relevant Program Outcomes (POs)

- **PO1: Basic and Discipline Specific Knowledge:** Apply rotational energy and angular momentum concepts to flywheel dynamics.
- **PO4: Engineering Tools and Experimentation:** Use the energy method with a flywheel to determine moment of inertia.

III. Relevant Course Outcomes (COs)

- **CO2:** Determine the moment of inertia of a flywheel experimentally using the energy method.

IV. Laboratory Session Outcomes (LSOs)

- **LSO 6.1:** Find the moment of inertia of a given flywheel.

V. Description of the Apparatus

- **Flywheel:** A heavy metallic disc (cast iron/steel) mounted on a horizontal axle supported by bearings. The flywheel rotates freely with minimal friction. Its axle has a small radius 'r'.
- **Axle:** A cylindrical rod (radius r) on which the string is wound. The effective radius of the axle determines the velocity relationship between the falling mass and the flywheel.
- **String and Mass:** A light, inextensible string wrapped around the axle with a mass 'm' attached. When released, the mass falls through height 'h', unwraps the string, and sets the flywheel spinning.
- **Metre Scale:** To measure the height 'h' through which the mass falls before the string detaches.

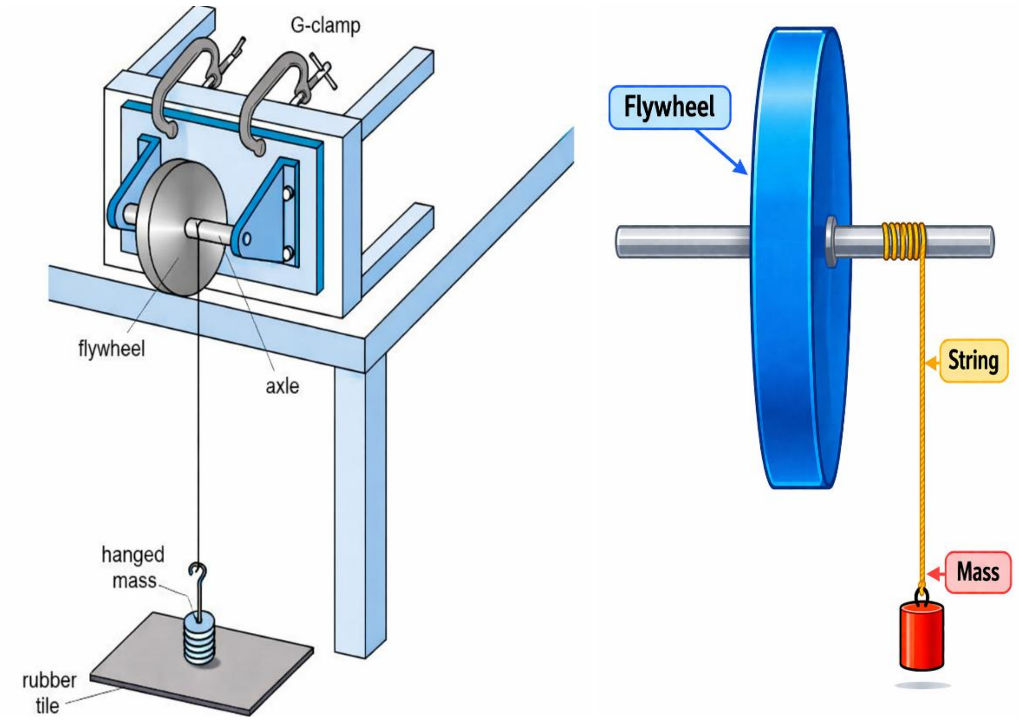


Fig. 06.01: Flywheel Experiment — Setup Showing Axle, String, Falling Mass

VI. Minimum Theoretical Background (Energy Method):

Consider a flywheel mounted on an axle with a light string wound around it. A mass m is attached to the free end of the string. When the mass is released, it falls through a height h, causing the flywheel to rotate.
As the mass descends through a height h, it loses potential energy U = mgh.

This loss in potential energy is converted into:

1. Rotational kinetic energy of the flywheel

2. Translational kinetic energy of the falling mass

3. Work done against friction

Rotational kinetic energy of flywheel: $\frac{1}{2} I\,\omega^2$

Translational kinetic energy of falling mass: $\frac{1}{2} m\,v^2$

Work done against friction is given by: $W_{friction} = n\,W_f$

where n is the number of rotations and W_f is work done per rotation

Applying conservation of energy:

$$m\,g\,h = \frac{1}{2} I\,\omega^2 + \frac{1}{2} m\,v^2 + n\,W_f \qquad \text{...Eq. (06.01)}$$

After the string detaches from the axle, the flywheel continues to rotate and comes to rest after N more rotations due to friction, then the the rotational kinetic energy finally gained is used up in working against friction, hence $N\,W_f = \frac{1}{2} I\,\omega^2$ … Eq. (06.02)

Therefore, $W_f = \frac{1}{2N} I\,\omega^2$ … Eq. (06.03)

Also, linear velocity v is related to angular velocity by:
$v = \omega r$

Substituting in energy equation:
$m\,g\,h = \frac{1}{2} I\,\omega^2 + \frac{1}{2} m\,\omega^2 r^2 + n\,\frac{1}{2N} I\,\omega^2$ … Eq. (06.04)

Solving for moment of inertia I: $I = \frac{2mgh - m\omega^2 r^2}{\omega^2\,(1+\frac{n}{N})}$

$$I = \frac{N\,m}{N+n}\left(\frac{2gh-\omega^2 r^2}{\omega^2}\right) = \frac{N\,m}{N+n}\left(\frac{2gh}{\omega^2} - r^2\right) \quad \text{… Eq. (06.05)}$$

If the fly wheel takes time t for N number of rotations (till it stops rotating after the detachment of the string), then the average angular velocity of the wheel $\omega_{average}$ in radians per second,

$$\omega_{average} = \frac{\textit{Total angular displacement}}{\textit{Total time taken}} = \frac{2\pi N}{t}$$

Since we are assuming that the torsional friction is constant over time, so the relation between angular velocity of the wheel (ω) , final velocity (0) of the wheel and $\omega_{average}$ is,

$$\omega_{average} = \frac{\textit{initial ang.velocity} + \textit{final ang.velocity}}{2} = \frac{\omega+0}{2}$$

$$\text{Therefore, } \omega = 2\,\omega_{average} = \frac{4\pi N}{t} \quad \text{… Eq. (06.06)}$$

Now, ‘h’ is the height through which mass ‘m’ falls until the string detaches itself, then ‘h’ may be calculated as:

h = circumference of the axle × No. of turns of the string wrapped over the axle

$$h = (2\pi r)\,n \quad \text{… Eq. (06.07)}$$

Substituting the value of ω from Eq. (06.06) and the value of h from Eq. (06.07) in Eq. (06.05),

$$\mathbf{I} = \frac{N\,m}{N+n}\left(\frac{nrgt^2}{4\pi N^2} - \mathbf{r^2}\right) \quad \text{… Eq. (06.08)}$$

Neglecting $\mathbf{r^2}$, $\mathbf{I} = \frac{m}{N+n}\left(\frac{nrgt^2}{4\pi N}\right)$ … Eq. (06.09)

The moment of inertia of flywheel may be found using Eq. (06.08) or Eq. (06.09), Preferably Eq. (06.09) for our laboratory purposes.

VII. Resources Required

Table: 06.01

Sr. No.	Item	Specification	Quantity	Remarks
1	Flywheel with axle	Cast iron disc, axle radius r ≈ 1 cm	1	Bearing lubricated
2	String	Light, inextensible cord	1 m	Non-elastic
3	Slotted masses	50 g to 200 g, with hanger	4–6	Standard weights
4	Metre Scale	100 cm, mm graduations	1	Vertical measuring
5	Stopwatch	LC = 0.1 s	1	For counting N
6	Vernier Calliper	LC = 0.01 cm	1	For measuring diameter of the axle
7	Chalk/Marker	To mark initial string position on axle	1	

VIII. Experimental Setup

Mount the flywheel on its axle support (see Fig. 06.01). Wind the string (attached to mass m) around the axle for n turns, noting the winding height. Measure the height 'h' from the bottom of the mass to the floor. Release the mass. When the string fully unwinds (n turns), it detaches from the axle and the flywheel continues spinning freely. Count N = number of complete revolutions after string detachment until the flywheel stops.

IX. Precautions

- Wind the string neatly in a single layer around the axle — overlapping increases effective radius error.
- Mark the exact starting position of the string on the axle to count ‘n’ accurately.
- Ensure the mass falls freely without swinging — maintain vertical fall.
- Count N carefully from the instant the string detaches (mass hits floor) until flywheel stops.
- Oil the bearings lightly but do not over-lubricate — excess oil changes frictional characteristics.
- Perform the experiment in a draught-free environment to avoid air resistance effects on the flywheel.

X. Procedure

1. Measure the radius of the axle using a vernier calliper (see Experiment N0.- 01). Calculate radius as half of the mean diameter.

2. Mark a point on the rim of the flywheel to help count the number of rotations accurately.

3. Wind the string around the axle neatly without overlapping. Take different values of initial turns n (such as 10, 11, 12 and 13) for observations. Count the turns carefully.

4. Hold the mass gently and release it from rest. Observe the mass fall and the flywheel accelerate.

5. When the string fully unwinds and the mass hits the floor (or string detaches), start counting flywheel rotations immediately.

6. Count the number of full rotations N of the flywheel from string detachment until it completely stops. Use chalk marks if needed. If the last rotation is incomplete, measure its fraction using arc length and circumference.

7. Record n (winding turns) and N (free rotation turns after detachment).

8. Release the mass and start the stopwatch immediately after the string leaves the axle. Stop the stopwatch when the flywheel stops rotating.

9. Repeat the experiment 3 times with the same mass and height. Record n and N each time.

10. Repeat for two more different masses (e.g., m_2 and m_3). Record all readings.

11. Use the formula, $\mathbf{I} = \frac{m}{N+n}\left(\frac{nrgt^2}{4\pi N}\right)$ to calculate I for each trial.

12. Find the mean value of I and compare with the theoretical value $I = MR^2/2$ (for a solid disc).

13. Use a suitable slotted weight with hanger as the falling mass attached to the string.

XI. Observations and Calculations

Axle radius r = 2.00 cm = 0.02 m

Formula Used: $\mathbf{I} = \frac{m}{N+n}\left(\frac{nrgt^2}{4\pi N}\right)$

S.No	m (kg)	N	n	r (m)	t (s)	I (kg·m²)
1	0.1	20	10	0.02	5	0.000650
2	0.1	22	11	0.02	5.5	0.000715
3	0.1	25	12	0.02	6	0.000728
4	0.1	28	14	0.02	6.5	0.000785

Mean Moment of Inertia: I = (0.000650 + 0.000715+ 0.000728+0.000785) / 4

= (0.002878/4) kg·m² = 0.0007195 kg·m²

XII. Results

Average moment of inertia of flywheel = $7.19 \times 10^{-4}\ kg \cdot m^2$

XIII. Interpretation of Results and Conclusions

The energy method provides an effective means to measure the moment of inertia without direct knowledge of the mass distribution within the flywheel. The method inherently accounts for bearing friction through the 'N' measurement. The result $I = 7.19 \times 10^{-4}$ kg·m² is physically reasonable for a small laboratory flywheel. The experiment highlights the conversion chain: gravitational PE → translational KE of mass + rotational KE of flywheel and rotational KE of flywheel→ heat (friction).

XIV. Practical Related Questions

1. Define moment of inertia. On what factors does it depend for a given body?
2. Why does a flywheel have most of its mass concentrated at the rim rather than at the centre?
3. Explain the role of the friction couple 'f' in this experiment. How is it determined?
4. If the axle radius is doubled but all other parameters remain the same, how does I change?
5. What is the significance of 'N' being large? What physical property of the flywheel does it indicate?
6. Compare the experimental value of I with the theoretical solid disc formula $I = MR^2/2$ for your flywheel.

XV. Suggested Activities

1. Compare moment of inertia for the flywheel with and without additional rim weights and discuss the change.
2. Calculate angular momentum $L = I\omega$ at the moment the string detaches from the axle.

XVI. References for Further Reading

- H.C. Verma, Concepts of Physics – Part I, Bharati Bhawan.
- Halliday, Resnick & Walker, Fundamentals of Physics, 10th Ed., Wiley.
- Bansal R.K., A Text of Fluid Mechanics, Laxmi Publications.
- Arora S.L., Practical Physics, Class XI & XII.
- Mina Talati, Vinod Kumar Yadav Applied Physics-I Khanna Book Publishing Pvt Ltd.
- Moment of Inertia of Flywheel (Theory) : Mechanics Virtual Lab (Pilot) : Physical Sciences : Amrita Vishwa Vidyapeetham Virtual Lab
- Experiment: Determination of Moment of Inertia of a Fly Wheel - QS Study
- Moment of Inertia of Flywheel Calculator | Calculate Moment of Inertia of Flywheel

XVII. Rubric for Assessment

Table: 06.03

Sr. No.	Indicator	Excellent (4)	Good (3)	Basic (2)	Poor (1)
1	Concept	Energy equation and I formula clearly explained	Good — minor gaps	Partial	Cannot explain
2	Handling	String winding, n and N counting accurate	Minor counting error	Needs assistance	Wrong method
3	Procedure	All 10 steps correctly executed	Minor lapse	Weak execution	Unsafe/absent
4	Data	n, N table correct, I calculated	Minor arithmetic error	Errors in table	Data missing
5	Conclusion	I found, physical interpretation given	Partial conclusion	Only I value stated	Absent/wrong

Experiment No.- 07

Determination of Coefficient of Linear Expansion using Pullinger's Apparatus

I. Practical Significance

All solid materials expand when heated and contract when cooled. This thermal expansion is predictable, measurable, and engineered into countless applications. The coefficient of linear expansion (α) quantifies how much a material expands per unit length for each degree of temperature rise. Pullinger's apparatus provides a simple, direct, and highly accurate method to measure this tiny fractional elongation using a dial gauge (micrometre indicator).

Knowledge of α is essential in: railway track design (expansion gaps), bridge construction (expansion joints), pipeline engineering (thermal stress relief loops), bimetallic thermostats, precision instruments (Invar in clocks), dental fillings, and the choice of materials for aircraft and spacecraft structures where thermal cycling is extreme.

II. Relevant Program Outcomes (POs)

- **PO1: Basic and Discipline Specific Knowledge:** Apply thermal expansion equations to determine material coefficients experimentally.
- **PO3: Design and Development of Solutions:** Use thermal expansion data in material selection for engineering applications.

III. Relevant Course Outcomes (COs)

- **CO3:** Determine the coefficient of linear expansion of a given material and express results with proper error analysis.

IV. Laboratory Session Outcomes (LSOs)

- **LSO 7.1:** Determine the coefficient of linear expansion of material of a given rod.

V. Description of the Apparatus

- **Metal Rod (Specimen):** A rod of known original length L_0 (typically 50–70 cm) of the material under study (copper, steel, aluminium, or brass), enclosed in a steam jacket.
- **Steam Jacket:** A cylindrical metallic tube surrounding the specimen rod. Steam flows through the jacket to heat the rod uniformly from room temperature to ~100°C.
- **Dial Gauge (Indicator):** A precision mechanical gauge with a resolution of 0.01 mm, mounted at the free (expanding) end of the rod. It measures the linear expansion ΔL directly.
- **Thermometer:** A mercury-in-glass or digital thermometer inserted into the steam jacket to measure $T_{initial}$ and T_{final} of the rod.
- **Steam Generator (Boiler):** A small boiler connected to the steam jacket via rubber tubing. Generates steam at ~100°C for uniform heating.

Linear Expansion Coefficient (α):

$\Delta L = L_0 \times \alpha \times \Delta T$

$\alpha = \Delta L / (L_0 \times \Delta T)$

Unit: per °C or per K ($°C^{-1}$)

ΔT = T_final - T_initial

Typical Values of α:

Copper: 17×10^{-6} /°C

Steel: 12×10^{-6} /°C

Aluminium: 23×10^{-6} /°C

Brass: 19×10^{-6} /°C

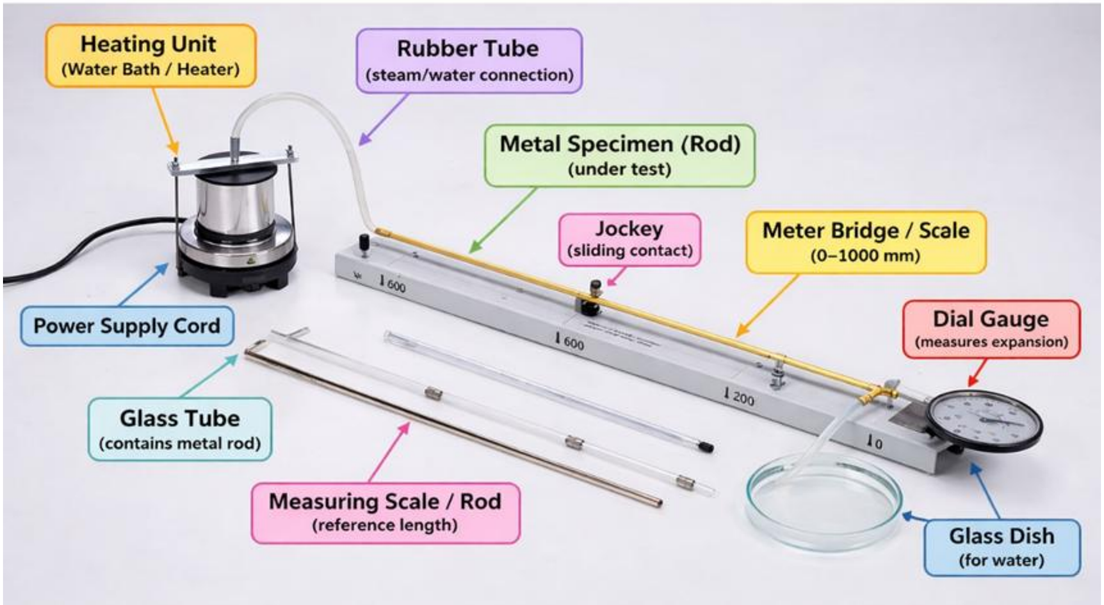


Fig:07.01 Pullinger's apparatus for measurement of Coefficient of Linear Expansion

VI. Minimum Theoretical Background

1. Thermal Expansion:

When a solid rod of original length L_0 is heated by ΔT degrees, it expands by ΔL:

Linear Expansion Law: $\Delta L = L_0 \times \alpha \times \Delta T$

α = coefficient of linear expansion (per °C or per K)

Therefore:

Coefficient of Linear Expansion:

$$\alpha = \Delta L / (L_0 \times \Delta T)$$

Units: $°C^{-1}$ or K^{-1} (same numerical value)

2. Temperature Change:

Temperature rise:

$$\Delta T = T_{final} - T_{initial}$$

$T_{initial}$ = room temperature, T_{final} = temperature with steam

3. Typical Values (for reference):

Copper: $\alpha \approx 17\times10^{-6}$ /°C | Steel: $\alpha \approx 12\times10^{-6}$ /°C | Aluminium: $\alpha \approx 23\times10^{-6}$ /°C | Brass: $\alpha \approx 19\times10^{-6}$ /°C

VII. Resources Required

Table: 07.01

Sr. No.	Item	Specification	Quantity	Remarks
1	Pullinger's Apparatus	Complete set: steam jacket, dial gauge, rod	1	Leakage-free joints
2	Metal Rod (specimen)	Copper/Aluminium/Steel, $L_0 \approx 50$ cm	1	Measure L_0 carefully
3	Steam Generator (Boiler)	Small boiler, 500 mL capacity	1	Safety-tested
4	Thermometer	0–110°C, mercury-in-glass	2	Initial & final temp
5	Dial Gauge	Resolution 0.01 mm	1	Zeroed before use
6	Rubber Tubing	Steam-resistant, for steam connection	50 cm	Tight joints
7	Metre Scale	100 cm	1	For L_0 measurement

VIII. Experimental Setup

The metal rod is placed inside the steam jacket with one end fixed rigidly against a stop and the other end (free end) in contact with the plunger of the dial gauge. The dial gauge is zeroed at room temperature. The boiler is connected to the steam inlet of the jacket. Steam flows in and heats the rod. The expansion of the rod pushes the dial gauge plunger, and the reading increases. The final steady-state reading minus the initial zero reading gives ΔL.

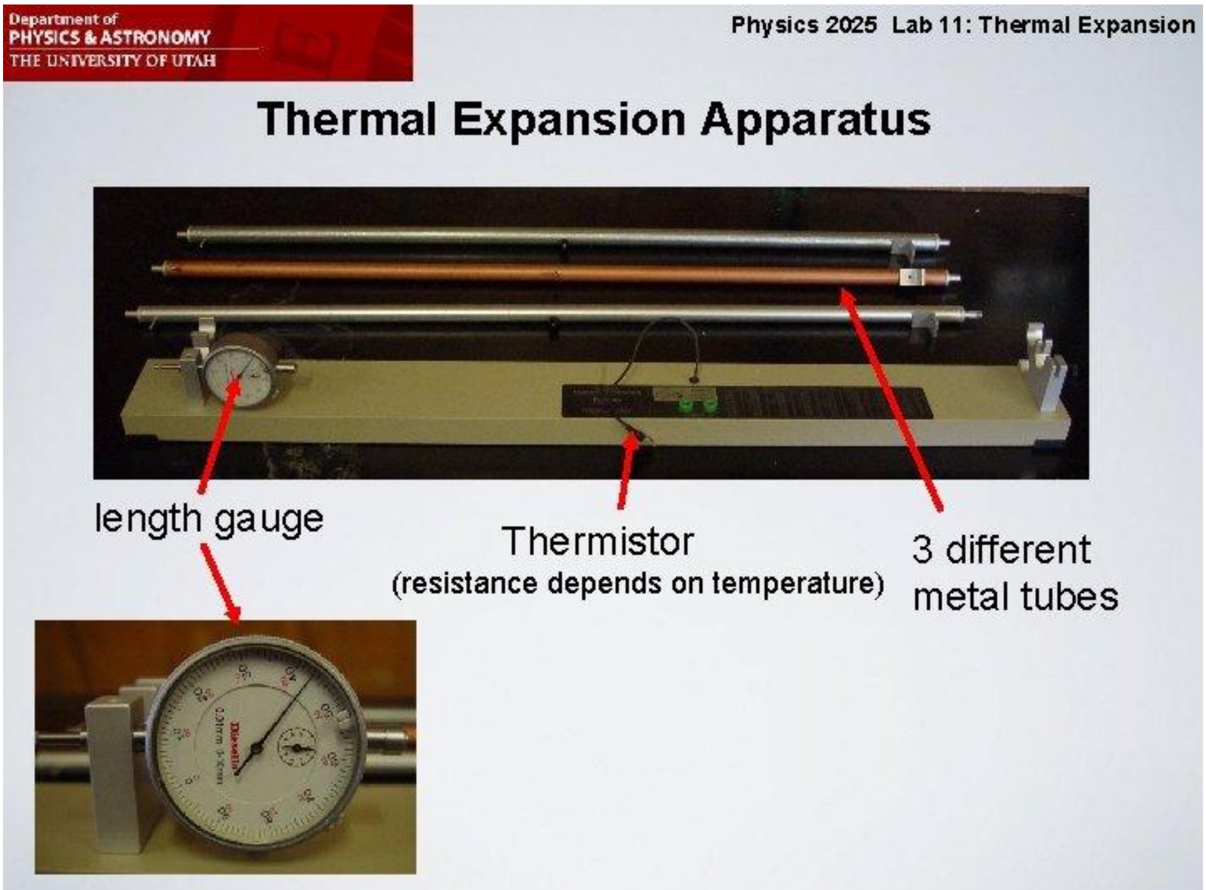


Photo Cedit: Department of Physics and Astronomy, The University of Utah(Physics 2025)

Fig. 07.02: Pullinger's apparatus for measurement of linear thermal expansion

IX. Precautions

- Do not touch the steam jacket, steam generator, rubber tubes, hot plates and linear expansion apparatus with bare hands during the experiment — use heat-resistant gloves.
- Keep your face away from the opening of steam outlets.
- Ensure steam outlet is open to prevent pressure buildup in the jacket.
- Measure the original length L_0 at room temperature before starting the experiment.
- Ensure the fixed end of the rod is truly fixed — any slippage underestimates ΔL.
- Zero (set to zero) the dial gauge at room temperature with the rod in place, before steam is introduced.
- Wait for the dial gauge reading to become steady before recording T_{final} (5–8 minutes after steam flow stabilises).

X. Procedure

1. Measure the original length L_0 of the metal rod at room temperature using the metre scale. Record $T_{initial}$ using the thermometer.
2. Insert the rod into the steam jacket. Fix one end firmly against the metal stop. Position the dial gauge tip against the free end and zero it.
3. Fill the steam generator or boiler with water up to its two-third level and then turn on.
4. Next, connect the outlet of steam generator to the steam inlet of the jacket using rubber tubing. Open the steam outlet valve of the jacket.
5. Heat the boiler. Allow steam to flow through the jacket until the dial gauge reading stabilises (approximately 5–7 minutes).
6. Record the steady final dial gauge reading as ΔL in mm. Record T_{final} using the thermometer inside the jacket.
7. Switch off the boiler. Allow the apparatus to cool. Repeat the experiment two more times for accuracy.
8. For each trial, calculate: $\Delta T = T_{final} - T_{initial}$ and $\alpha = \Delta L / (L_0 \times \Delta T)$.
9. Calculate the mean value of α and then estimate error.

XI. Observations and Calculations

Material of rod: Aluminium | Original Length: L_0 = 50.0 cm = 0.500 m

Table: 07.02

Trial	$T_{initial}$ (°C)	T_{final} (°C)	ΔT (°C)	ΔL (mm)	$\alpha = \Delta L/(L_0 \times \Delta T)$ ($\times 10^{-5}$/°C)
1	28	96	68	0.78	2.294
2	29	97	68	0.79	2.324

3	28	95	67	0.77	2.299

Mean $\alpha = (2.294 + 2.324 + 2.299) \times 10^{-5} / 3 = 2.306 \times 10^{-5}$ /°C $= 23.06 \times 10^{-6}$ /°C

Standard value for Aluminium: $\alpha = 23 \times 10^{-6}$ /°C

$$\% \text{ error} = \frac{Observed\ \ Value - Standard\ Value}{Standard\ value} = \frac{(23.06-23)10^{-6}\ /°C}{23 \times 10^{-6}\ /°C} = 0.26\ \%$$

XII. Results

Mean value of coefficient of linear expansion α is 23.06×10^{-6} /°C.

XIII. Interpretation of Results and Conclusions

The experiment accurately determines α using the simple, direct relationship between measured length change and temperature rise. The excellent agreement with the standard value (23×10^{-6} /°C) validates the method. The dial gauge provides sub-millimetre resolution (0.01 mm), making it sensitive enough to detect the tiny expansion (< 1 mm) of a 50 cm rod over a ~70°C temperature rise. The Pullinger's apparatus is particularly suitable for materials with α in the range 10–30 $\times 10^{-6}$ /°C.

XIV. Practical Related Questions

1. Why are expansion gaps provided in railway tracks and concrete bridges? Illustrate with a calculation.

2. Define the coefficient of linear expansion. Why does it have units of per degree (°C^{-1})?

3. Two rods of the same material and original length are heated through the same ΔT. Will the longer rod or shorter rod expand more? Justify.

4. What is a bimetallic strip? How does the difference in α between two metals make it useful as a thermostat?

5. If ΔL is measured as 0.75 mm for $L_0 = 60$ cm and $\Delta T = 70$°C, calculate α.

6. Why is Invar (an iron-nickel alloy with $\alpha \approx 0.9 \times 10^{-6}$ /°C) preferred for precision pendulum clocks?

XV. Suggested Activities

1. Repeat the experiment with a copper rod and compare α with the standard value.

2. Research the coefficient of volumetric expansion $\gamma = 3\alpha$ and verify for a known material.

XVI. References for Further Reading

- *H.C. Verma*, Concepts of Physics – Part II, Bharati Bhawan.
- *Halliday, Resnick & Walker*, Fundamentals of Physics, 10th Ed., Wiley.

- *Sears, Zemansky, Young & Freedman*, University Physics, Pearson (2020).
- *H.K. Malik & A.K. Singh Engineering Physics*
- *S.L. Gupta Applied Physics*

XVII. Rubric for Assessment

Table: 07.03

Sr. No.	Indicator	Excellent (4)	Good (3)	Basic (2)	Poor (1)
1	Concept	α formula and thermal expansion clearly explained	Good — minor gaps	Partial	Cannot explain
2	Handling	Dial gauge zeroed, steam steady, correct readings	Minor reading error	Needs assistance	Wrong setup
3	Procedure	All 8 steps correctly followed, safety observed	Minor lapse	Weak	Unsafe/absent
4	Data	ΔL, ΔT table and α calculation correct	Minor arithmetic error	Errors present	Data absent
5	Conclusion	α found with % error vs standard value	Partial — no comparison	Only α stated	Absent/wrong

Experiment No.- 08

Determination of Young's Modulus of a Wire using Searle's Apparatus

I. Practical Significance

Young's Modulus (Y) is the most fundamental elastic constant of a solid material. It quantifies the stiffness of a material under tension or compression- how much stress is required to produce a given strain. Searle's apparatus is the standard laboratory method for measuring Y of a metallic wire with great precision.

Young's Modulus data is used in: structural engineering (beam design, deflection calculations), machine design (spring design, shaft sizing), materials science (characterising new alloys), cable engineering (suspension bridges, elevator cables), aerospace (airframe material qualification), and civil engineering (bridges and buildings).

II. Relevant Program Outcomes (POs)

- **PO1: Basic and Discipline Specific Knowledge:** Apply stress-strain concepts and Hooke's law to determine elastic modulus experimentally.
- **PO4: Engineering Tools and Experimentation:** Use Searle's apparatus with micrometer and spirit level as precision measurement tools.

III. Relevant Course Outcomes (COs)

- **CO3:** Measure material properties (Young's Modulus) with precision instruments and express results with error analysis.

IV. Laboratory Session Outcomes (LSOs)

- **LSO 8.1:** Use Searle's apparatus to determine the Young's modulus of a given wire.

V. Description of the Apparatus

- **Two Identical Wires (Reference R and Experimental E):** Both wires are made of the same material (e.g. steel), have the same original length L (typically 1.5–2 m), and are hung from the same rigid support. This twin-wire design eliminates the effect of temperature changes and support vibrations.
- **Crossbar (Stirrup/Frame):** A rigid horizontal bar connecting the lower ends of both wires. The frame ensures both wires are loaded symmetrically.
- **Dead Weight on Reference Wire:** A constant load (e.g., 0.5 kg) on the reference wire to keep it taut at all times.
- **Variable Loads on Experimental Wire:** Slotted masses added progressively to the experimental wire to produce controlled extensions.
- **Micrometre Screw Gauge on Crossbar:** Measures the relative extension (x) between the two wires by restoring the spirit level bubble to the centre after each load addition.
- **Spirit Level:** Mounted on the crossbar. The crossbar tilts when the experimental wire extends. The micrometre is adjusted to restore the level — this reading gives x.

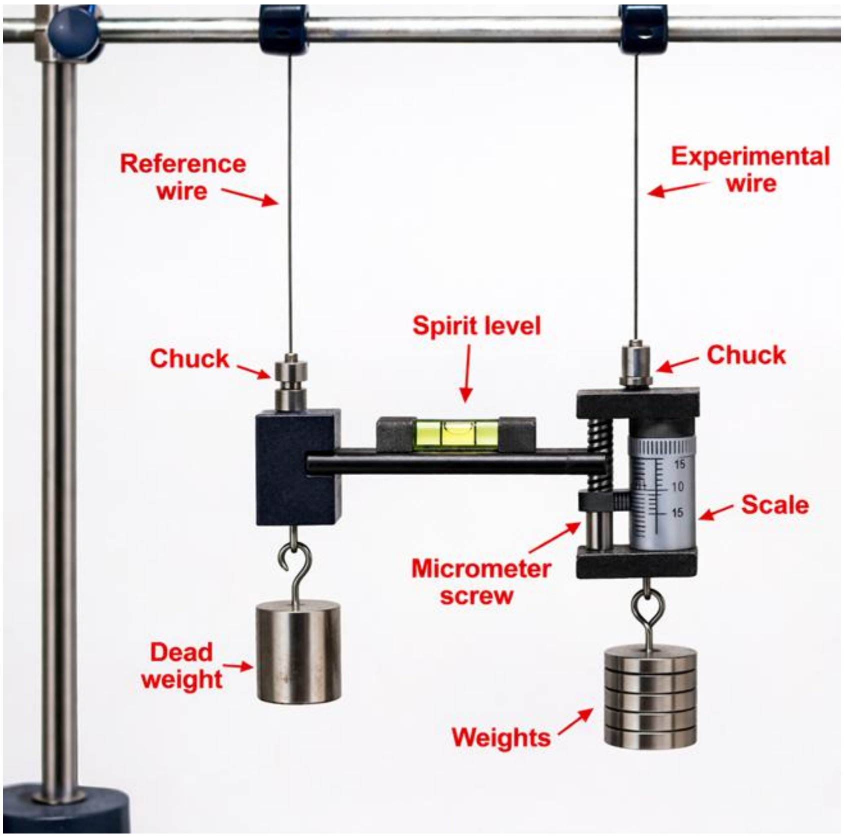


Fig. 08.01: Searle's Apparatus — Twin Wire Setup with Micrometre and Spirit Level

VI. Minimum Theoretical Background

1. Stress, Strain, and Young's Modulus:

- **Stress:** $\sigma = F/A$ (in $N/m^2 = Pa$) where F = applied force, A = cross-sectional area of wire
- **Strain:** $\varepsilon = x/L$ (dimensionless) where x = extension, L = original length
- **Young's Modulus:** Y = Stress / Strain = (F/A) / (x/L)

Young's Modulus Formula:

$$Y = (F \times L) / (A \times x) = (mgL) / (\pi d^2 x/4)$$

d = diameter of wire, m = added mass, g = 9.8 m/s^2

2. Slope Method (from graph):

Plot x (extension) vs F (load). The slope of this straight line = L/(AY). Therefore:

$$Y = L / (A \times \text{slope})$$

slope = $\Delta x / \Delta F$ from best-fit line of x vs F graph

VII. Resources Required

Table: 08.01

Sr. No.	Item	Specification	Quantity	Remarks
1	Searle's Apparatus	Two wires, stirrup, spirit level, micrometre	1	Checked alignment
2	Steel/Brass Wire	Length L = 1.5–2 m, Diameter d ≈ 0.4–0.6 mm	2 (same)	Identical material & diameter
3	Slotted Masses	0.5 kg to 3 kg in 0.5 kg steps	6	Standard weights
4	Screw Gauge	LC = 0.01 mm	1	For wire diameter
5	Metre Scale	200 cm (measuring tape)	1	For wire length L

VIII. Experimental Setup

Clamp both wires firmly to the same rigid support (ceiling, iron rod, or support frame). Ensure both wires hang parallel (Fig. 08.01). Attach the rigid crossbar to both wire ends. Add the dead weight (0.5 kg) to the reference wire. Mount the spirit level and micrometre screw on the crossbar. Adjust the micrometre until the spirit level bubble is exactly at the centre position. Record this as the zero reading. Measure the original length L of the experimental wire and its diameter d (with micrometre gauge at 6 different positions along length).

IX. Precautions

- Both wires must be free from kinks, bends, or surface defects — uniform cross-section throughout.
- Add loads slowly and steadily — jerks cause oscillations and inaccurate readings.
- After adding each load, wait 1–2 minutes for the extension to stabilise before restoring the spirit level.
- Restore the spirit level bubble to exactly the centre for every reading — off-centre gives wrong x.
- Measure the wire diameter at several positions and orientations — use the mean to compute A.
- Do not exceed the elastic limit of the wire — remove loads in the same order as added for return readings.

X. Procedure

1. Suspend weights from the hooks of the frame so that both wires- Experimental and Reference get stretched.
2. Suspend a dead weight W_1 of about 1 kg from the hook of reference wire.
3. Measure original length L of the experimental wire using metre tape (from support to lower end).
4. Measure wire diameter d using micrometre screw gauge at 6 positions (3 along length, 2 perpendicular orientations each). Compute mean d and area $A = \pi d^2/4$.

5. Suspend Set the micrometre to its reference (zero) reading with the spirit level bubble centred. Record as x_0.
6. Add first load m_1 = 0.5 kg to the experimental wire. The crossbar tilts. Adjust the micrometre to restore the spirit level to centre. Record new micrometre reading. Extension x_1 = new reading − x_0.
7. Add second load m_2 = 1.0 kg. Restore spirit level. Record micrometre reading and extension x_2.
8. Continue adding loads in 0.5 kg steps up to 3.0 kg. Record extension for each.
9. Tabulate F = mg (N) and corresponding extension x (mm).
10. Plot x vs F graph. Draw best-fit straight line. Calculate slope = $\Delta x/\Delta F$.
11. Calculate Y = L / (A × slope). Write the value in units of N/m² (Pa).
12. Now unload the wights on by one and take the micrometre reading each time, in the same way as it is done when loading.

XI. Observations and Calculations

Wire Material: Steel | Original Length L = 175.0 cm = 1.750 m

(a) Wire Diameter Measurement: Least Count of Screw gauge: 0.01 mm

Table: 08.02

S. No.	Reading in one direction			Reading in perpendicular direction			Mean d = $(d_1+d_2)/2$
	MSR (mm)	CSR (mm)	d_1 (mm)	MSR (mm)	CSR (mm)	d_2 (mm)	Mean (mm)
1	0.5	2	0.52	0.5	3	0.53	0.525
2	0.5	1	0.51	0.5	2	0.52	0.515
3	0.5	3	0.53	0.5	2	0.52	0.525
4	0.5	2	0.52	0.5	3	0.53	0.525

Mean diameter d = (0.525+0.515+0.525+0.525)/4 = 0.5225 mm ≈ 0.523 mm

$= 5.22 \times 10^{-4}$ m

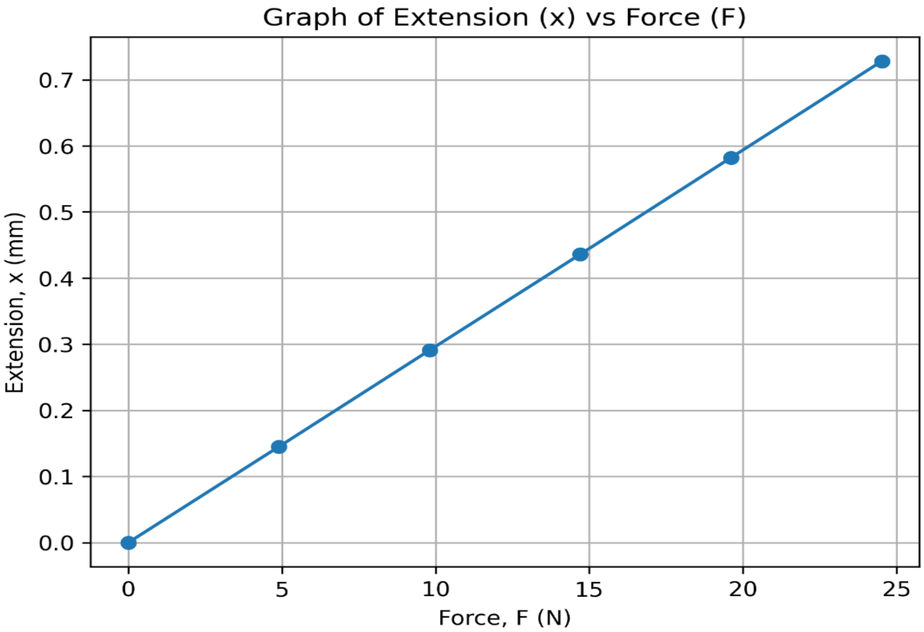
Radius $r = 2.61 \times 10^{-4}$ m

Cross-sectional area $A = \pi(d/2)^2 = \pi \times (2.61 \times 10^{-4})^2 = 2.139 \times 10^{-7}$ m²

(b) Extension vs Load:

Table: 08.03

Load m (kg)	Force F= mg (N)	Micrometre Reading (mm)	Extension x (mm) (Loading)	Compression (Unloading) (mm)	Mean (mm)	x/F (mm/N)
0	0	0.0	0.0	0.0	0.0	-
0.5	4.9	0.145	0.145	0.145	0.145	0.0296
1.0	9.81	0.291	0.291	0.291	0.291	0.0297
1.5	14.71	0.436	0.436	0.436	0.436	0.0296
2.0	19.61	0.582	0.582	0.582	0.582	0.0297
2.5	24.52	0.728	0.728	0.728	0.728	0.0297



Slope of x vs F = Δx/ΔF = 0.728/(24.52) = 0.02969 mm/N = 2.969×10^{-5} m/N

Young's Modulus: Y = L / (A × slope) = 1.750 / ($2.139 \times 10^{-7} \times 2.969 \times 10^{-5}$)

Y = 1.750 / (6.351×10^{-12}) = 2.756×10^{11} N/m²

Y ≈ 2.76×10^{11} Pa = 276 GPa (Standard value of Y for Steel: 200–210 GPa)

XII. Results

The experimental value of Young’s modulus of elasticity comes out to be 2.76×10^{11} Pa = 276 GPa

XIII. Interpretation of Results and Conclusions

The experiment demonstrates Hooke's law in practice — the extension x is perfectly proportional to the applied load F (demonstrated by constant x/F ratio in the table or, straight line x-F graph). The twin-wire Searle's design is highly effective in eliminating systematic errors from temperature changes and support vibrations. The measured Y = 276 GPa is within the expected range for steel (200–220 GPa from standard data); the slightly higher value may reflect the specific alloy composition or a systematic error in wire diameter measurement (small d errors affect $A = \pi d^2/4$ significantly). The experiment reinforces the concept that elastic modulus is a material property, independent of specimen dimensions.

XIV. Practical Related Questions

1. Define Young's Modulus, stress, and strain. Give their SI units.
2. Why does the Searle's apparatus use two wires instead of one? What errors does this eliminate?
3. The diameter of the wire is the most critical measurement. If d has a 5% error, what is the resulting error in Y?

4. A steel wire (Y = 200 GPa) of length 2 m and diameter 0.5 mm is loaded with 5 kg. Find the extension.

5. Why is the elastic limit of the wire not to be exceeded? What happens if it is?

6. Compare the Young's moduli of steel, copper, aluminium, and rubber. Which is stiffest? Which most flexible?

XV. Suggested Activities

1. Repeat the experiment with a copper wire and compare Y with the standard value (120 GPa).

2. Investigate how the wire diameter measurement accuracy affects the final Young's Modulus calculation — perform a sensitivity analysis.

XVI. References for Further Reading

- H.C. Verma, Concepts of Physics – Part I, Bharati Bhawan.
- Halliday, Resnick & Walker, Fundamentals of Physics, 10th Ed., Wiley.
- Sears, Zemansky, Young & Freedman, University Physics, Pearson (2020).
- NCERT Physics Lab Manual — Mechanical Properties of Solids.
- Arora S.L., Practical Physics (Class XI & XII).
- https://ncert.nic.in — Physics Lab Manual, Experiment on Searle's Apparatus

XVII. Rubric for Assessment

Table: 08.04

Sr. No.	Indicator	Excellent (4)	Good (3)	Basic (2)	Poor (1)
1	Concept	Y, stress-strain and Searle's design clearly explained	Good — minor gaps	Partial	Cannot explain
2	Handling	Micrometer, spirit level, wire diameter measured accurately	Minor error	Needs assistance	Wrong technique
3	Procedure	All 10 steps correctly followed, graph plotted	Minor lapse, adequate graph	Weak	Unsafe/absent
4	Data	Extension table, slope, Y calculation all correct	Minor arithmetic error	Table errors	Data missing
5	Conclusion	Y found, % error vs standard discussed	Partial — no comparison	Only Y value stated	Absent/wrong

Experiment No.- 09

Determination of the coefficient of viscosity using Stokes Law

I. Practical Significance:

This experiment measures the viscosity of a liquid by observing the motion of a spherical ball falling through it under gravity. After performing this experiment, students will be able to distinguish between laminar and turbulent flow, understand the concept of terminal velocity, and apply fluid mechanics principles to calculate physical constants.

This has a number of applications in day-to-day life such as, ensuring the consistency of paints, syrups, and cosmetics; measurement of Blood Viscosity (Haematology) to diagnose cardiovascular risks; and designing engine oils that maintain a specific flow rate at different temperatures.

II. Relevant Program Outcomes (POs):

PO1: Basic and Discipline Specific Knowledge - Apply knowledge of physics and mathematics to find fluid properties.

PO2 – Problem Analysis **-Identify and analyze well-defined engineering problems using scientific principles.**

PO4 – Engineering Tools & Experimentation - Use appropriate techniques, tools, and modern engineering tools to solve problems.

III. Relevant Course Outcomes (COs):

CO3: Apply basic principles of physics to perform experiments and analyze results.

IV. Laboratory Session Outcomes (LSOs):

Apply Stokes' Law to experimentally determine the coefficient of viscosity of a given viscous liquid using standard laboratory apparatus and safe practices.

V. Relevant Theory:

According to **Stokes' Law**, the viscous drag force acting on a small sphere moving with uniform velocity in a viscous fluid is directly proportional to the radius of the sphere, the velocity of the sphere, and the coefficient of viscosity of the liquid.

When the sphere falls in a liquid, it initially accelerates and then attains a constant speed called **terminal velocity**. At terminal velocity, the downward gravitational force(W) is balanced by the upward buoyant force(U), and viscous drag(F).

$$W = U + F \qquad \text{..................(1)}$$

. Stokes' formula for viscosity is given by,

$$\eta = \frac{2r^2(\rho - \sigma)}{9v} \qquad \ldots\ldots\ldots\ldots\ldots\ldots..(2)$$

where,

η : co-efficient of viscosity

r: radius of the ball

ρ : density of the ball

σ : density of the liquid

v : terminal velocity

VI. Experimental Setup:

The setup consists of a tall glass cylinder marked with graduations. The liquid should be transparent and highly viscous to ensure the ball reaches terminal velocity quickly.

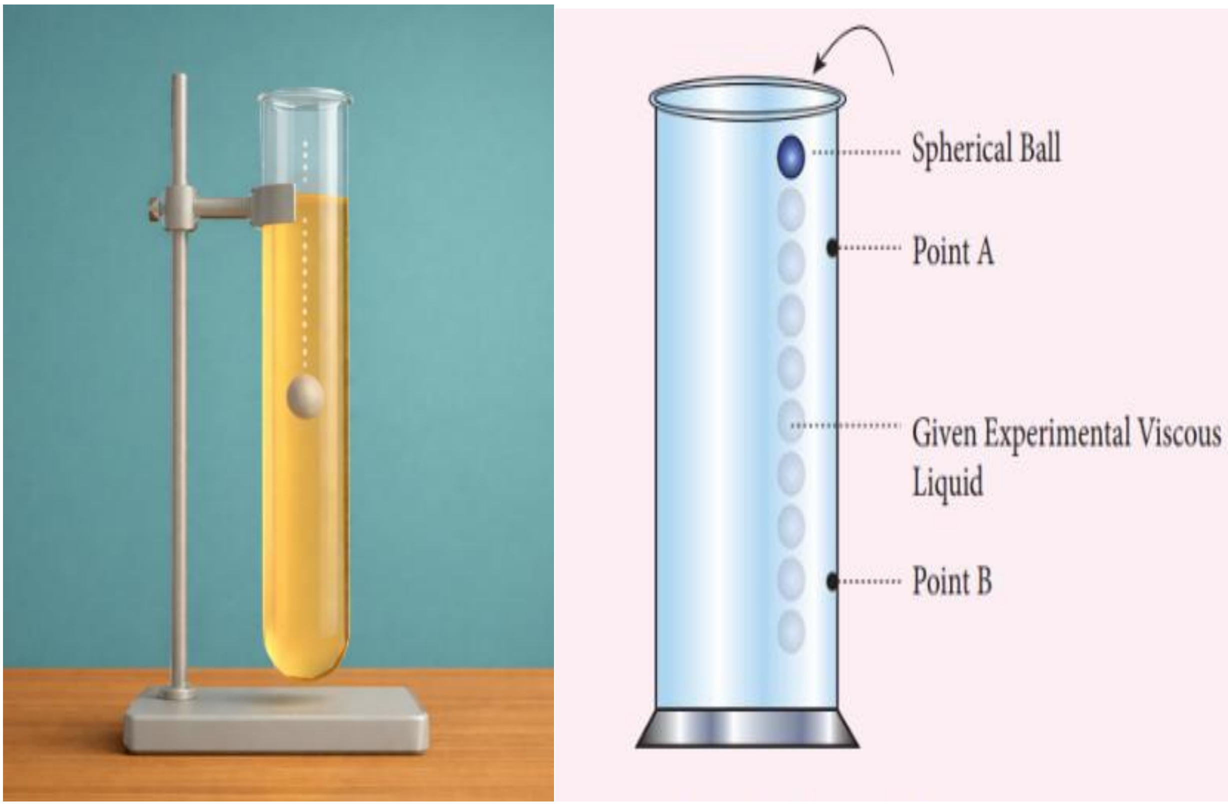


Fig.-01: Viscometer for measurement of Coefficient of viscosity

VII. Resources Required: Table:01

Sr. No.	Name of Resources/Items	Specifications	Quantity	Remarks
1	Glass Jar / Tall Cylinder	Transparent, height ≥ 50 cm	1	Clean and dry
2	Viscous liquid	Glycerine / Castor oil of known density	Sufficient	Free from bubbles
3	Spherical balls	Steel / glass balls (uniform size) of known density	3–5	
4	Micrometre screw gauge	Least count 0.01 mm	1	
5	Meter scale	Least count 1 mm	1	
6	Stopwatch	Least count 0.01 s	1	
7	Thermometer	Range 0–50 °C	1	
8	Stand and clamp	To hold cylinder	1	

VIII. Precautions:

- The cylinder must be broad enough to avoid **Wall Effects** (which increase drag).
- The liquid must be free from air bubbles.
- The ball should be clean, dry, polished and spherical.
- Release the ball gently without initial push.
- The ball must be dropped exactly in the centre of the cylinder Keep the cylinder vertical.
- Avoid parallax error while measuring distances.
- Measurements should begin only after the ball has reached terminal velocity (well below the liquid surface).
- Perform readings at room temperature.

IX. Procedure:

Preparation: Clean the cylinder and fill it with the viscous liquid of known density (σ).

Measurement: Measure the diameter of the ball using a screw gauge at 3 or more than 3 different orientations and find the average radius(r).

Marking: Mark two points A and B on the cylinder. Ensure point A is at least 15 cm below the surface.

Drop: Drop the ball gently into the liquid.

Timing: Start the stopwatch when the ball crosses mark A and stop it when it crosses mark B.

Repeating: Repeat the process for three (more than three) different balls of the same size, then repeat with balls of different radii.

Calculation: Calculate velocity v = Distance / Time =AB / t = s /t

X. Observations and Calculations:

Density of Ball (ρ)_______ kg/m^3 | **Density of Liquid (σ)**_____ kg/m^3

Trial	Radius r (m)	Dist. s (m)	Time t (s)	Velocity v (m/s)	η (Pa·s)
1					
2					
3					
4					
Avg.					

Calculation:

Average Radius: $< r >= \frac{r_1+r_2+r_3+\cdots+r_n}{n}$,

Average velocity in first trial, $v_1 = \frac{s_1}{t_1}$,

Average velocity in second trial, $v_2 = \frac{s_2}{t_2}$, and so on.

Average velocity: $< v >= \frac{v_1+v_2+v_3+\cdots+v_n}{n}$

Use the above values in Eq. (2) and calculate η.

$$\eta = \frac{2r^2(\rho-\sigma)}{9v} \quad \ldots\ldots\ldots\ldots\ldots (2)$$

XI. Results:

The coefficient of viscosity for the given liquid is found to be _______ at room temperature.

XII. Interpretation of Results and Conclusions:

If the calculated η is close to the standard value (e.g., 1.412 Pa.s) for Glycerin at 20°C, the flow is laminar. Discrepancies may arise due to temperature fluctuations or wall effects.

Viscosity remains constant for a specific fluid at a constant temperature, regardless of the size of the sphere used (within experimental limits).

Perform the experiment at different temperatures to observe how viscosity decreases as temperature increases.

XIII. Practical Related Questions:

1. Why do we use a high-viscosity liquid for this experiment instead of water?
2. What is the effect of the container walls on the terminal velocity?
3. If the ball is not perfectly spherical, how will it affect the results?
4. What will happen if the liquid contains air bubbles?
5. Why is it necessary to take the time only after the ball attains uniform speed?

XIV. References for Further Reading:

- Halliday, Resnick, and Walker. *Fundamentals of Physics*. Wiley Pub.(10th Ed.)
- Bansal R.K. *A Text of Fluid Mechanics.* Laxmi Publication (P) Ltd (2nd Ed.)
- Sears, Zemansky, Young, Freedman. *University Physics.* Pearson Education Limited (2020)
- Verma H.C., *Concepts of Physics – Part I.* Bharati Bhawan(1st Ed.)

Online Educational Resources:

https://ph1-nitk.vlabs.ac.in/exp/viscosity-stokes/theory.html

https://www.youtube.com/watch?v=6JB89KCKkiA

https://myphysicsclassroom.in/to-determine-the-coefficient-of-viscosity-of-glycerin-by-stokes-method-lab-manual/

https://iitr.ac.in/Academics/static/Department/Physics/BTech%201st%20year%20lab/8_Stokes_Law.pdf

XV. Rubric for Assessment:

Sr. No.	Performance Indicator (PI)	Level 4 Exemplary (4)	Level 3 Proficient (3)	Level 2 Developing (2)	Level 1 Beginner (1)
1	Conceptual clarity of viscosity, terminal velocity & governing law	Explains principle, assumptions, limitations; derives formula	Explains principle & formula correctly	Knows formula but poor conceptual link	No conceptual clarity
2	Experimental setup, calibration & identification of components	Accurate setup; checks zero error & alignment	Setup correctly with minor guidance	Setup incomplete	Wrong setup; unsafe handling
3	Procedural rigor, safety compliance & lab discipline	Executes steps independently; follows all precautions	Minor procedural lapse	Frequent assistance needed	Unsafe practices observed

4	Data integrity: observation, uncertainty, computation & units	Precise readings; correct calculation; units & error discussed	Minor numerical/unit error	Data recorded but wrong calculation	Data unreliable / not recorded
5	Interpretation, conclusion, communication & viva voce	Interprets result; compares with standard; answers viva logically	Conclusion correct; partial reasoning	Conclusion stated without interpretation	Incorrect conclusion; poor viva

Experiment No.- 10

Inverse Square Law of Light using a Photo-Electric Cell

I. Practical Significance

Light behaves as both a wave and a particle (photon). When light emitted from a point source travels outward, its intensity decreases in proportion to the square of the distance from the source. This is the Inverse Square Law of Light. A photo-electric cell converts incident light energy into an electrical current, making it an ideal detector for justifying this relationship. The photocurrent (I) is directly proportional to the intensity ($I \propto 1/d^2$). This principle is fundamental to:

- **Astronomy & Photometry:** Estimating the brightness and distance of stars and galaxies using stellar luminosity.
- **Optical Instrumentation:** Designing light sensors, and photometric systems with precise calibration.
- **Safety Systems:** Smoke detectors, burglar alarms, and automatic street lights rely on photo-electric sensing.
- **Solar Energy:** Understanding irradiance variation with distance for optimal panel placement and efficiency.

II. Relevant Program Outcomes (POs)

- **PO1: Basic and Discipline Specific Knowledge:** Apply principles of physics, particularly the wave-particle duality of light and electrostatics, to analyse photo-electric behaviour.
- **PO3: Experiments and Practice:** Plan, execute, and critically analyse laboratory experiments to verify physical laws with systematic error control.
- **PO4: Engineering Tools & Experimentation:** Operate precision instruments (photo-electric cell, microammeter, optical bench) to collect quantitative data.

III. Relevant Course Outcomes (COs)

- **CO5:** Demonstrate experimental verification of electromagnetic radiation properties and their interaction with matter, including photoelectric emission.

IV. Laboratory Session Outcomes (LSOs)

- **LSO 10.1:** Determine the inverse square law relation between the distance of a photocell and light source versus the intensity of light (measured as photocurrent).
- **LSO 10.2:** Plot the graph of photocurrent (I) versus $1/d^2$ and verify the linear relationship confirming the inverse square law.

- **LSO 10.3:** Calculate the constant of proportionality and assess experimental accuracy through comparison with theoretical predictions.

V. Description of the Apparatus

The experimental setup consists of an optical bench on which all components are mounted coaxially. The key components are:

- **Light Source (Tungsten/Halogen Lamp):** Acts as an approximate point source of white light. Mounted on one end of the optical bench. Power: typically 40–100 W.
- **Colour Filters:** Interchangeable coloured glass filters (red, green, yellow, blue) placed in front of the source to select specific wavelength ranges for extended experimentation.
- **Photo-Electric Cell (Photocell):** A vacuum tube containing a photosensitive cathode. When illuminated, it emits electrons (photoelectric effect), generating a measurable photocurrent. The cell is mounted in a light-tight housing with an aperture.

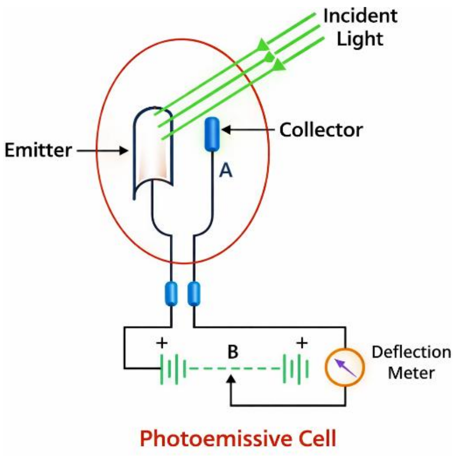


Fig. 10.01

- **Microammeter (μA):** A highly sensitive current-measuring instrument connected in series with the photocell to measure the very small photocurrent (typically 0–100 μA).
- **DC Power Supply / Battery:** Provides a small polarising voltage across the photocell to ensure all emitted electrons reach the anode.
- **Optical Bench with Scale:** A rigid, graduated rail (0–100 cm) for accurately setting and reading the distance (d) between the lamp and the photocell.

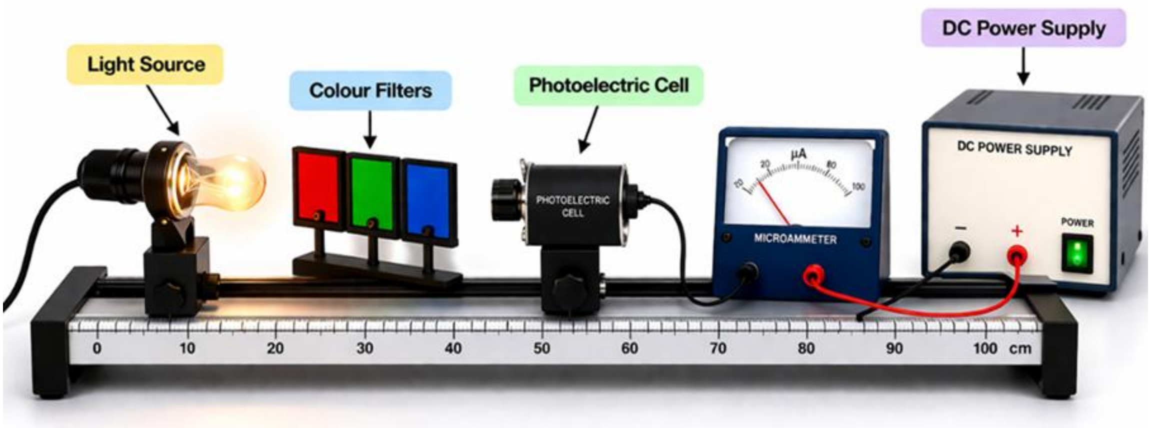


Fig. 10.02: Photo-Electric Cell Experimental Setup

VI. Minimum Theoretical Background

1. **The Inverse Square Law of Light:**

When light radiates uniformly in all directions from a point source of power P, it spreads over a spherical surface of area $4\pi d^2$ at distance d. Hence, intensity (energy per unit area per unit time) is given by:

$$I = P / (4\pi d^2) \implies I \propto 1/d^2$$

Since the photocurrent (i) generated by the photocell is directly proportional to the incident light intensity ($i \propto I$), we have:

$$i = k / d^2 \quad \text{or} \quad i \times d^2 = \text{constant } (k)$$

2. Graphical Verification:

A graph of photocurrent i (y-axis) against $1/d^2$ (x-axis) should yield a straight line passing through the origin. The slope of this line gives the constant k (= $P/4\pi$), which is a measure of the effective luminous power of the source. Deviation from linearity indicates stray light or instrument saturation.

3. Important Quantities:

- **Photocurrent (i):** The electric current produced in the photocell circuit due to photoelectric emission (unit: μA).
- **Distance (d):** The separation between the light source and the photocell aperture (unit: cm or m).
- **$1/d^2$:** Reciprocal of the square of distance; proportional to incident light intensity (unit: m^{-2} or cm^{-2}).

VII. Resources Required: Table 10.01

Sr. No.	Item	Specification	Quantity	Remarks
1	Photo-electric Cell Kit	Vacuum type, sensitivity: 0.1 μA/lux	1	Calibrated
2	Light Source (Lamp)	Tungsten, 60 W, 230 V	1	Clean bulb
3	Optical Bench	Graduated, 100 cm, with riders	1	Levelled
4	Microammeter	Range: 0–100 μA, LC = 0.5 μA	1	Zero checked
5	DC Power Supply	0–6 V, regulated	1	Stable output
6	Colour Filters (optional)	Red, Green, Blue glass	3	Clean glass
7	Connecting Wires	Insulated, crocodile clips	As req.	No loose connections
8	Graph Paper & Ruler	Millimetre ruled, 30 cm	1 each	Sharp pencil

VIII. Safety Precautions

1. **Eye Safety:** Never look directly at the light source. Keep the source hooded except for the directed beam aperture.
2. **Electrical Safety:** Ensure all connections are secure before switching on the power supply. The photocell polarising voltage should not exceed the rated value.
3. **Heat Precaution:** The lamp becomes very hot during operation. Allow a 5-minute warm-up for stable output and avoid touching the lamp housing.
4. **Instrument Care:** Handle the photocell gently; mechanical shock can damage the photosensitive surface. Store in a dark box when not in use.
5. **Stray Light:** Conduct the experiment in a darkened room or use a blackout curtain around the bench to eliminate ambient light interference.
6. **Meter Protection:** Start with the microammeter on its highest range and progressively reduce to avoid meter needle damage.

IX. Experimental Procedure

1. Initial Setup: Mount the lamp and photocell on the optical bench. Align them coaxially so the photocell aperture faces the lamp directly. Level the bench.

2. Circuit Connections: Connect the photocell anode to the positive terminal of the battery, and the cathode circuit through the microammeter. Double-check polarity.

3. Warm-up: Switch on the lamp and allow it to stabilise for at least 5 minutes to achieve constant light output.

4. Zero Adjustment: With the photocell shielded from all light, set the microammeter to zero using its zero-adjust knob.

5. Distance Setting: Set the distance d between the lamp and photocell aperture to the first value (e.g., $d = 10$ cm). Record the microammeter reading (i) in μA.

6. Vary Distance: Increase d in steps of 5 cm (up to 50 cm or until the reading becomes too small to measure accurately). Record i at each distance.

7. Repeat Readings: Take three readings at each distance, keeping the lamp at constant power. Average the readings to minimise random error.

8. Calculations: For each distance d, compute $1/d^2$ (in cm^{-2}). Plot the graph of i vs. $1/d^2$. Verify linearity using least-squares fit or best-fit straight line.

X. Observations and Calculations

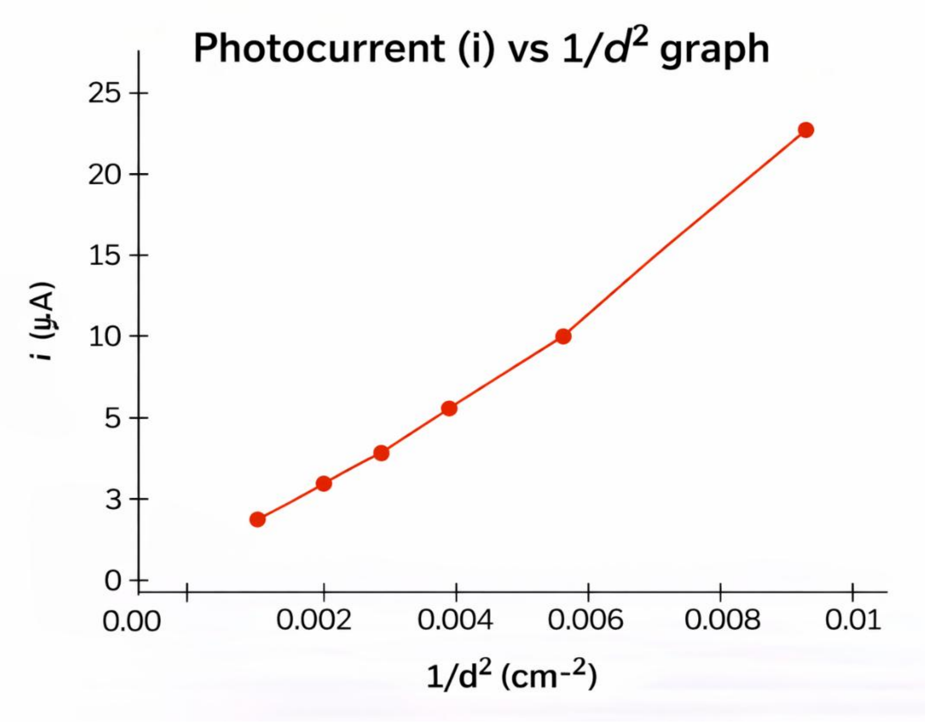
Table 10.02: Variation of Photocurrent with Distance

S. No.	Distance d (cm)	$1/d^2$ (cm^{-2})	Trial 1 i (μA)	Trial 2 i (μA)	Mean i (μA)	$i \times d^2$
1	10.0	0.0100	24.5	24.8	24.65	2465
2	15.0	0.0044	10.8	11.0	10.90	2452
3	20.0	0.0025	6.1	6.2	6.15	2460
4	25.0	0.0016	3.9	4.0	3.95	2469
5	30.0	0.0011	2.7	2.8	2.75	2475

Verification: The product $i \times d^2$ remains nearly constant (≈ 2464 μA·cm²), confirming the inverse square law.

Mean value of $k = i \times d^2$ = 2464.2 μA·cm² (Standard Deviation: ± 8.3 μA·cm²)

XI. Graph: Photocurrent (i) vs 1/d



(The graph has been drawn based on the data of Table 10.02)

Fig. 10.03: Graph showing $i \propto 1/d^2$ — Straight line through origin verifies Inverse Square Law

XII. Results

- The photocurrent (i) is inversely proportional to the square of the distance (d) from the light source, confirming the Inverse Square Law: $i \propto 1/d^2$.
- **Constant of proportionality:** $k = i \times d^2 = 2464.2 \pm 8.3$ μA·cm²

- **Graph verification:** The i vs. $1/d^2$ graph is a straight line through the origin, slope = k = 2464.2 μA·cm².

XIII. Interpretation of Results and Conclusions

The experiment conclusively demonstrates that as the distance between the light source and the photocell doubles, the photocurrent reduces to one-quarter of its original value — a hallmark of the inverse square law. The constant product $i \times d^2 \approx 2464$ μA·cm² across all distances confirms that the photocell current is a faithful measure of light intensity. The small variation in $i \times d^2$ (±0.34%) is attributable to minor lamp instability and stray reflections from the optical bench. The linear graph of i vs. $1/d^2$ with the regression line passing through (or very close to) the origin validates both the theory and the photocell response.

XIV. Practical Related Questions

1. State the inverse square law of light. How does it differ from the inverse law?
2. Why does the photocurrent not reduce to zero at very large distances? What are the limiting factors?
3. If the power of the light source is doubled, how does the photocurrent change at the same distance?
4. Explain the role of the polarising voltage in the photocell circuit. What happens without it?
5. Why is it necessary to conduct this experiment in a darkened room? How do stray photons affect the result?
6. Derive the expected slope of the i vs. $1/d^2$ graph in terms of the source power P.

XV. Suggested Activities

- Repeat the experiment using different colour filters and compare the constants k for each colour (related to spectral sensitivity of the photocell).
- Verify the law using an LED source and compare results with the tungsten lamp to discuss spectral differences.
- Use a smartphone lux meter app to independently measure intensity at each distance and compare with photocurrent readings.

XVI. References for Further Reading

- Halliday, Resnick, and Walker. Fundamentals of Physics (10th Ed.). Wiley Publications. Chapter 38: Photons and Matter Waves.
- Verma, H.C. Concepts of Physics – Part II. Bharati Bhawan. Chapter on Photo-Electric Effect.
- Arora, S.L. Practical Physics (Class XII). S. Chand & Company.

- **Online Resource:** https://ncert.nic.in — NCERT Physics Laboratory Manual, Class XII.
- **Online Resource:** https://vlab.amrita.edu — Amrita Virtual Lab: Photo-electric Effect Simulation.

XVII. Rubric for Assessment: Table 10.03

Sr. No.	Indicator	Excellent (4)	Good (3)	Basic (2)	Poor (1)
1	Conceptual Understanding	Explains law clearly with derivation	Good explanation, minor gaps	Basic understanding only	Unable to explain
2	Apparatus Setup & Handling	Perfect alignment, safe operation	Minor misalignment corrected	Needs assistance	Incorrect setup
3	Procedure & Data Recording	Systematic, all steps followed	Minor procedural lapse	Incomplete steps	Unsafe / not done
4	Data Accuracy & Calculations	Correct $i \times d^2$ constant, error <1%	Minor calculation error	Major error present	Not calculated
5	Graph & Interpretation	Linear graph, correct slope cited	Graph plotted, minor error	Graph incomplete	No graph drawn

Experiment No.- 11

Determination of Numerical Aperture (NA) of a Step-Index Optical Fiber

I. Practical Significance

Optical fibres are the backbone of modern communication networks, carrying data at nearly the speed of light over vast distances with negligible loss. The Numerical Aperture (NA) is a fundamental parameter that defines the light-gathering efficiency of a fibre — essentially, how wide an angle of light it can accept and guide. A higher NA means the fibre can accept light from a wider cone. Understanding and measuring NA is critical for:

- **Telecommunication Systems:** Selecting the correct fibre type (single-mode vs. multi-mode) for high-speed data transmission over long distances.
- **Fiber-Optic Sensors:** Designing displacement, pressure, and chemical sensors used in civil and structural engineering.
- **Medical Endoscopy:** Engineering flexible light guides for minimally invasive diagnostic procedures.
- **Laser Coupling:** Ensuring efficient coupling of laser beams into fibre systems in optical instruments and industrial lasers.

II. Relevant Program Outcomes (POs)

- **PO1: Basic Knowledge:** Apply physics of total internal reflection and wave optics to analyse optical fibre behaviour.
- **PO3: Experiments & Practice:** Execute precision optical experiments and interpret results to determine material/structural properties.
- **PO4: Engineering Tools:** Use laser sources, optical mounts, and measurement screens as modern engineering instruments.

III. Relevant Course Outcomes (COs)

CO5: Demonstrate experimental determination of optical parameters and link them to communication engineering applications.

IV. Laboratory Session Outcomes (LSOs)

- **LSO 11.1:** Determine the Numerical Aperture (NA) of a given step-index optical fibre by measuring the radius of the output light cone and the distance from the fibre end to the screen.
- **LSO 11.2:** Calculate the acceptance angle and verify the relation:

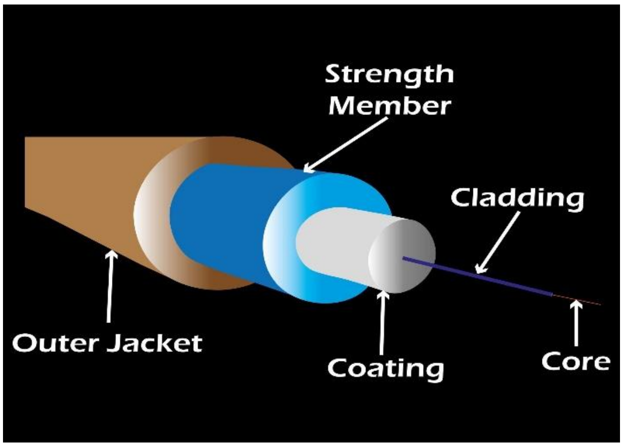
$$NA = \sin(\theta max) = r/\sqrt{(r^2 + L^2)}.$$

- **LSO 11.3:** Compare the experimentally obtained NA with the manufacturer's specified value and assess experimental accuracy.

V. Description of the Apparatus

The experiment employs the following components arranged on an optical bench:

- **Laser Source (He-Ne or Diode Laser):** Provides a coherent, monochromatic, collimated beam that is efficiently coupled into the fibre. Typical wavelength: 632.8 nm (He-Ne) or 650 nm (diode).
- **Step-Index Optical Fiber:** A multi-mode fibre with a high-refractive-index glass or plastic core surrounded by a lower-index cladding. The abrupt boundary causes total internal reflection. Typical NA: 0.40–0.50.



- **Graduated Screen / White Card:** Placed at a measured distance L from the fibre output end to capture the circular output cone. The cone radius r is measured using a ruler or millimetre scale.
- **Fiber Holder/Coupler:** A precision mount that aligns the fibre end with the laser beam for maximum light injection. Uses a micropositioner for x-y-z adjustment.

- **Optical Bench:** A rigid rail with graduated scale for precise placement of all components.

Fig. 11.01: Experimental Setup for Numerical Aperture Measurement

VI. Minimum Theoretical Background

1. Total Internal Reflection (TIR): When light travels from a denser medium (core, refractive index n_1) to a rarer medium (cladding, n_2), and the angle of incidence exceeds the critical angle $\theta c = \arcsin(n_2/n_1)$, the light is totally reflected back into the core. This is the mechanism that guides light along an optical fibre.

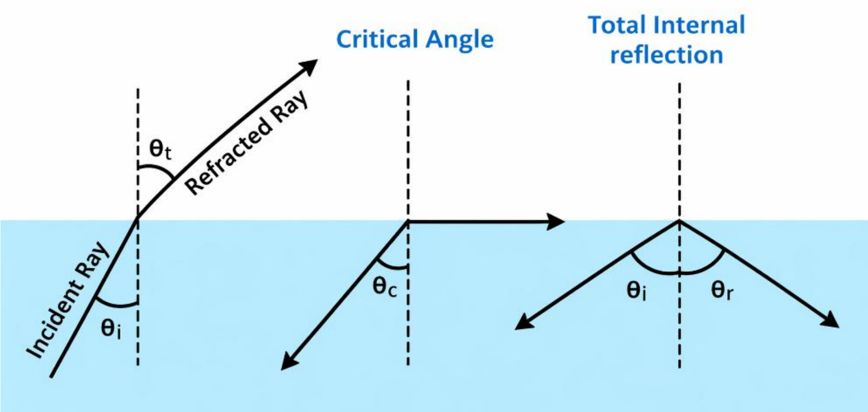


Fig. 11.02

2. Acceptance Angle (θmax): The maximum angle at which light entering the fibre end-face (from air) is totally internally reflected within the core. Light entering at angles greater than θmax leaks out of the cladding and is lost.

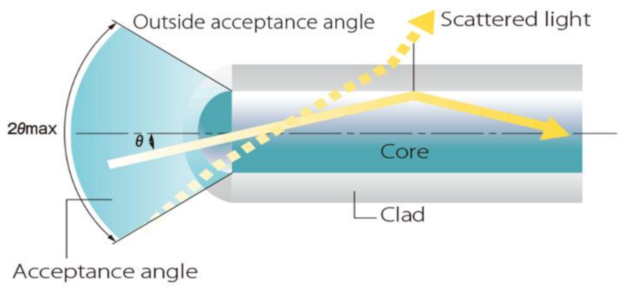


Fig. 11.03

$$NA = n_0 \cdot \sin(\theta max) = \sqrt{(n_1^2 - n_2^2)}$$

where $n_0 = 1$ (refractive index of air). For measurement from the output cone:

$$NA = \sin(\theta max) = r / \sqrt{(r^2 + L^2)}$$

where r = radius of the output light circle on the screen, and L = distance from fibre end to screen.

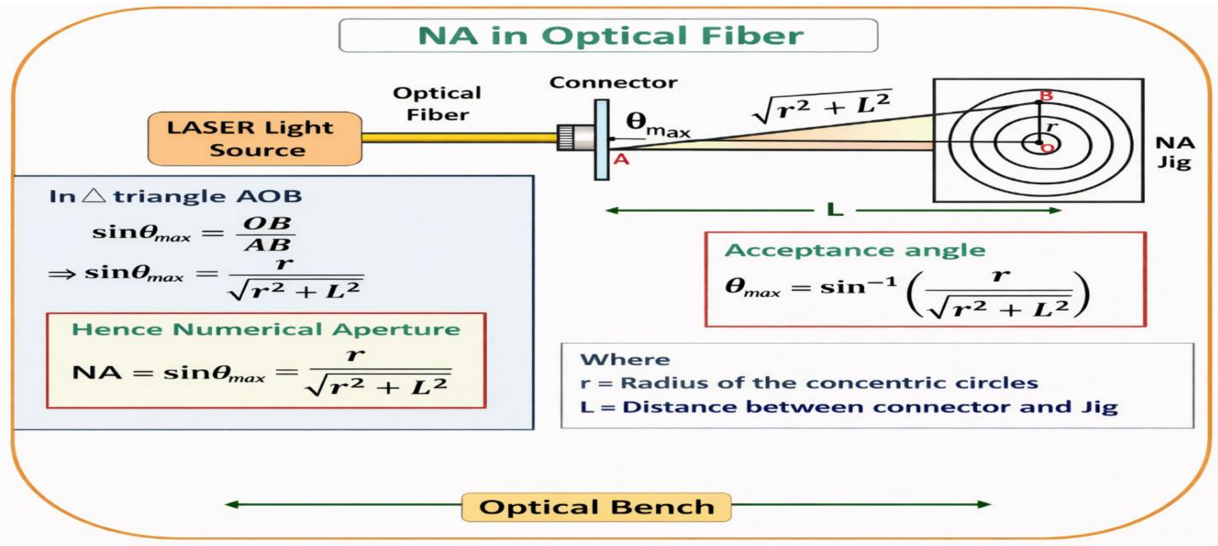


Fig. 11.04: Geometry for Calculating Acceptance Angle and NA

3. Key Formulas:

- **Acceptance Angle:** 2θmax (full cone angle; NA is based on the half-angle θmax)

- **NA from core/cladding indices:** $NA = \sqrt{n_1^2 - n_2^2}$ (theoretical)
- **NA from experiment:** $NA = r / \sqrt{r^2 + L^2}$ (practical measurement)

VII. Resources Required: *Table 11.01*

Sr. No.	Item	Specification	Quantity	Remarks
1	Step-Index Optical Fiber	Multi-mode, length 1–2 m, NA ≈ 0.46	1	Ends cleaved cleanly
2	He-Ne Laser / Diode Laser	632.8 nm / 650 nm, <5 mW	1	Safety goggles required
3	Fiber Coupler / Holder	Precision 3-axis micropositioner	1	Aligned to beam
4	Graduated Screen	White card with mm scale	1	Perpendicular to fibre axis
5	Optical Bench	Graduated, 60 cm	1	Levelled and stable
6	Millimetre Scale / Ruler	Resolution: 0.5 mm	1	For measuring r and L

VIII. Safety Precautions

1. **Laser Safety:** Never look directly into the laser beam or the fibre output end. Use the screen to observe the output cone. A Class IIIb laser can cause permanent retinal damage.
2. **Fiber Handling:** Do not bend the fibre sharply (minimum bend radius: 3 cm) as this causes micro-cracks and signal loss. Always store the fibre coiled loosely.
3. **Cleaving:** The fibre ends must be cleaved cleanly (flat, perpendicular cut) for uniform light output. Use a proper fibre cleaver. Handle fibre fragments with care as they are nearly invisible and extremely sharp.
4. **Electrical Safety:** The laser power supply is low voltage, but avoid touching terminals with wet hands. Switch off when not in use.
5. **Ambient Light:** Perform the experiment in a room with reduced ambient light to see the output cone clearly and measure r accurately.

IX. Experimental Procedure

1. **Fiber Preparation:** Inspect both ends of the fibre under a magnifier. Ensure the ends are cleanly cleaved and free from dust. Clean gently with an optical tissue if needed.
2. **Coupling:** Mount the fibre in the coupler and align the input end with the laser beam using the micropositioner. Adjust until the output end shows a bright, circular spot on the screen.
3. **Screen Positioning:** Place the screen at a measured distance L = 5 cm from the fiber output end. Record L precisely.

4. **Measure Output Spot:** Observe the circular patch of light on the screen. Using a millimeter scale, measure the diameter of the bright circle. Divide by 2 to get radius r. Repeat three times and take the mean.
5. **Vary Distance:** Move the screen to distances L = 8, 10, 12 cm. Record the corresponding radius r at each distance.
6. **Calculate NA:** For each (r, L) pair, compute $NA = r / \sqrt{r^2 + L^2}$. Average all values of NA.
7. **Acceptance Angle:** Compute $\theta max = \arcsin(NA)$ in degrees. The total acceptance cone is $2\theta max$.

X. Observations and Calculations

Table 11.02: Measurement of Output Cone Radius at Different Distances

S. No.	L (cm)	Diameter 2r (cm)	Radius r (cm)	$NA = r/\sqrt{r^2+L^2}$	θmax (degrees)
1	5.0	4.80	2.40	0.433	25.66
2	8.0	7.56	3.78	0.428	25.35
3	10.0	9.40	4.70	0.425	25.18
4	12.0	11.24	5.62	0.424	25.09

Mean Numerical Aperture (NA) = (0.433 + 0.428 + 0.425 + 0.424) / 4 = 0.428

Mean Acceptance Angle (θmax) = arcsin(0.428) = 25.35° ⟹ Full Acceptance Cone = 2 × 25.35° = 50.70°

XI. Results

- **Measured Numerical Aperture (NA):** 0.428 ± 0.005
- **Manufacturer Specified NA:** 0.46 (Step-index multi-mode fiber)
- **Percentage Error:** [(0.46 − 0.428) / 0.46] × 100 = 6.95% (within acceptable experimental limits)
- **Acceptance Angle (2θmax):** 50.70° (full cone angle)

XII. Interpretation of Results and Conclusions

The experimentally measured NA of 0.428 is in close agreement with the manufacturer's specified value of 0.46. The small discrepancy (< 7%) arises from fibre end imperfections (non-flat cleave), measurement of the penumbral region of the output spot, and ambient light scatter. The NA determines the fibre's light-gathering power: a higher NA collects from a wider angle, but suffers from greater modal dispersion. This experiment confirms that the output cone method is a reliable, non-destructive method for NA characterisation.

XIII. Practical Related Questions

1. What is total internal reflection? How does it enable light guiding in an optical fibre?
2. Define Numerical Aperture and explain its physical significance in fibre-optic communication.
3. What is the difference between single-mode and multi-mode fibres in terms of NA and applications?
4. If the cladding refractive index is increased (approaching the core index), what happens to the NA? Explain.
5. Why must the fibre end be cleaved cleanly for this experiment? How does an imperfect end-face affect NA measurement?
6. Calculate the critical angle for a fibre with $n_1 = 1.50$ and $n_2 = 1.46$. What is the value of corresponding NA?

XIV. Suggested Activities

- Measure NA at two different wavelengths (red and green laser) and compare. Discuss chromatic dispersion effects.
- Bend the fibre at different radii and observe the change in output cone — note the effect on NA and signal loss.
- Use a single-mode fibre (NA ≈ 0.12) and compare its output cone with the multi-mode fiber used in this experiment.

XV. References for Further Reading

- Hecht, E. Optics (5th Ed.). Pearson Education. Chapter 5: Geometrical Optics and Fiber Optics.
- Ghatak, Ajay Optics McGraw hill Education India
- Keiser, G. Optical Fiber Communications (4th Ed.). McGraw-Hill. Chapter 2: Optical Fibers.
- Verma, H.C. Concepts of Physics – Part II. Bharati Bhawan. Chapter on Wave Optics.
- **Online:** https://vlab.amrita.edu — Virtual Labs: Optical Fiber NA Experiment.
- Microsoft Word - Fiber Optic Apparatus-NA (NITTTR Chandigarh)
- Determine Numerical Aperture of Optical Fiber (www.engineeringbyte.com)

XVI. Rubric for Assessment

Table 11.03: Assessment Rubric

Sr. No.	Indicator	Excellent (4)	Good (3)	Basic (2)	Poor (1)
1	Conceptual Clarity	Full explanation with derivation	Good, minor gap	Basic understanding	Unable to explain

Sr. No.	Indicator	Excellent (4)	Good (3)	Basic (2)	Poor (1)
2	Apparatus Handling	Perfect, safe, accurate	Minor error, self-corrected	Needs assistance	Incorrect handling
3	Procedure Followed	All steps, systematic	Minor lapse	Incomplete	Not done / unsafe
4	Data & Calculations	Accurate, error < 2%	Minor computation error	Major error	Not calculated
5	Graph / Conclusion	Correct graph, valid inference	Partial graph/inference	Weak conclusion	No graph/conclusion

Experiment No.- 12

Measurement of Wavelength of He-Ne/Diode Laser using a Plane Diffraction Grating

I. Practical Significance

Light waves exhibit diffraction — the bending and spreading of waves around obstacles — most pronounced when the obstacle or slit size is comparable to the wavelength of light. A plane diffraction grating exploits this phenomenon using thousands of precisely ruled parallel slits to disperse light into its component wavelengths. Measuring laser wavelength with a grating is a cornerstone technique with applications in:

- **Spectroscopy:** Identifying chemical elements and compounds by their unique spectral fingerprints in analytical chemistry and astrophysics.
- **Laser Technology:** Characterising and calibrating laser sources used in telecommunications, medical equipment, and research.
- **Metrology:** The metre itself is defined using laser wavelengths; grating spectroscopy underpins the most precise length measurements.
- **Holography & Optical Computing:** Designing gratings for beam-splitting and wavelength-division multiplexing (WDM) in fiber networks.

II. Relevant Program Outcomes (POs)

- **PO1: Basic Knowledge:** Apply wave optics principles (Huygens' principle, superposition) to explain diffraction grating operation.
- **PO3: Experiments & Practice:** Precisely measure angular positions of diffraction orders and calculate wavelengths with uncertainty analysis.
- **PO4: Engineering Tools:** Operate laser sources, optical benches, and diffraction gratings as professional optical instruments.

III. Relevant Course Outcomes (COs)

- **CO5:** Demonstrate experimental determination of laser wavelength and link the result to electromagnetic wave theory.

IV. Laboratory Session Outcomes (LSOs)

- **LSO 12.1:** Measure the wavelength of a He-Ne or diode laser by using a plane diffraction grating and measuring the positions of diffraction maxima.
- **LSO 12.2:** Apply the grating equation $d \cdot \sin(\theta) = n\lambda$ to compute the wavelength for each observable order.
- **LSO 12.3:** Compare the measured wavelength with the standard value and compute the percentage error.

V. Description of the Apparatus

- **He-Ne Laser:** Gas discharge tube containing helium and neon; emits intense red light at 632.8 nm. Highly collimated and coherent. Power: 1–5 mW.
- **Diode Laser (alternative):** Semiconductor laser, compact, emitting at 650 nm (red). Simpler and cheaper than He-Ne.
- **Plane Transmission Diffraction Grating:** A glass or plastic plate with 300, 500, or 600 lines/mm ruled on it. Slits are transparent and the rulings opaque. The grating constant d = 1/N (N = lines per mm, d in mm).
- **Optical Bench with Scale:** Holds the laser, grating holder, and screen in precise alignment.
- **Screen / Metre Scale:** White screen placed at distance D from the grating; a metre scale measures the positions of diffraction spots.

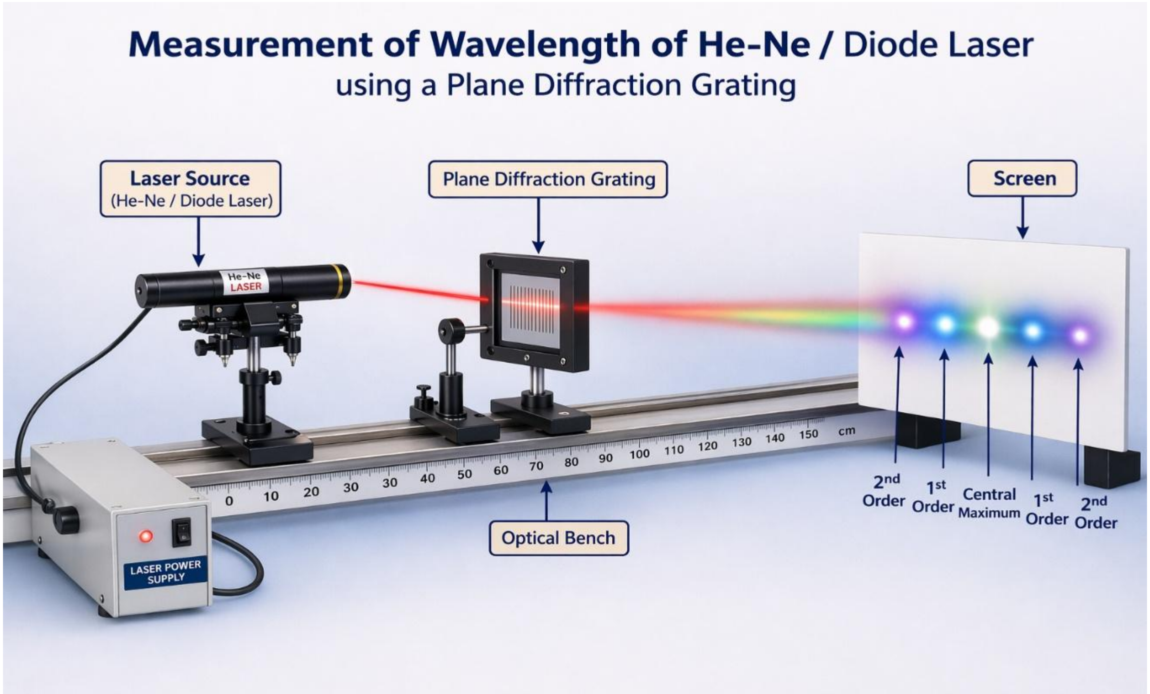


Fig. 12.01: Diffraction Pattern on Screen showing multiple colours

VI. Minimum Theoretical Background

1. Diffraction Grating Equation: When monochromatic light of wavelength **λ** falls normally on a grating of slit spacing **d** (grating constant), constructive interference (bright maxima) occurs at angles **θ** satisfying:

$$d \cdot \sin(\theta_n) = n\,\lambda \quad (n = 0, \pm1, \pm2, \pm3, \ldots)$$

Here n is the order of diffraction, **d** = 1/N (N = grating lines per mm, giving d in mm), and θ_n is the angular position of the n-th order maximum.

2. Measurement Strategy: The diffraction spots appear on a screen at distance D from the grating. If the n-th order spot is at a horizontal distance x from the central maximum (n = 0), then:

$$\tan(\theta_n) = x_n / D \quad \Longrightarrow \quad \theta_n = \arctan(x_n / D)$$

Substituting this value of θ_n into the grating equation, we can find λ

$$\lambda = d \cdot \sin(\theta_n) / n$$

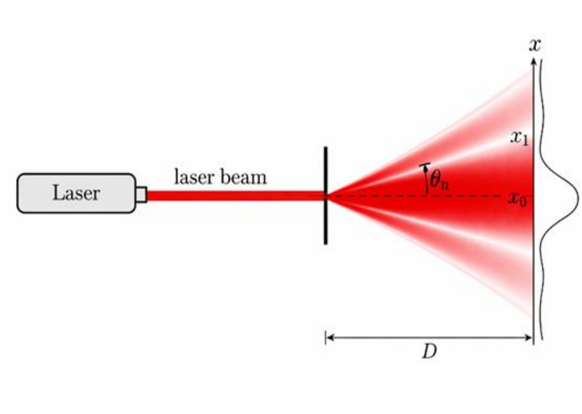


Fig. 12.02

3. Standard Values:

- **He-Ne Laser:** 632.8 nm (standard NIST value)
- **Red Diode Laser:** 650 nm (typical; may vary 640–660 nm)

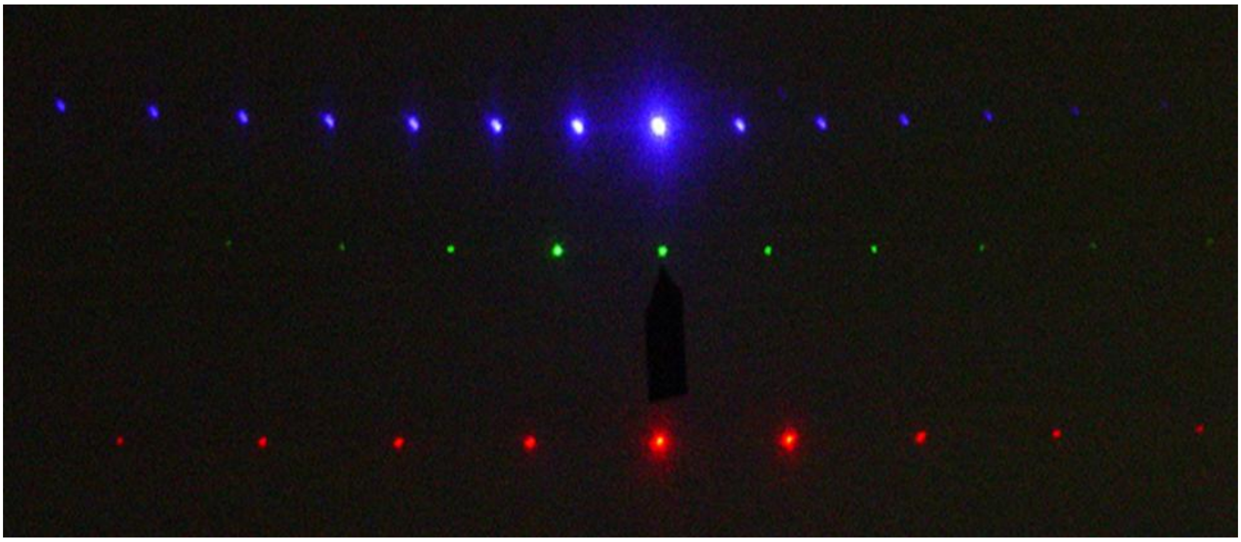


Photo Credit: UCLA Physics and Astronomy

Fig. 12.03: Laser Diffraction Pattern — Central maximum and higher orders

VII. Resources Required: Table 12.01

Sr. No.	Item	Specification	Quantity	Remarks
1	He-Ne Laser	Wavelength: 632.8 nm, Power: 2 mW	1	Safety goggles mandatory
2	Plane Diffraction Grating	500 lines/mm (d = 0.002 mm = 2000 nm)	1	Handle by edges only
3	Grating Holder	Precision mount, rotatable	1	Normal incidence set
4	White Screen	Minimum 30 cm wide	1	Perpendicular to laser

Sr. No.	Item	Specification	Quantity	Remarks
5	Optical Bench	Graduated, 150 cm	1	Levelled
6	Metre Scale	Least Count: 1 mm	1	Fixed to screen
7	Graph Paper & Calculator	For tabulation and analysis	1 each	For λ calculation

VIII. Safety Precautions

1. **Laser Eye Safety:** A Class IIIa/IIIb laser can permanently damage eyesight. Never look into the laser beam or into any specular reflection. Wear laser safety goggles rated for 633 nm / 650 nm.
2. **Normal Incidence:** Ensure the laser beam strikes the grating perpendicularly (normal incidence) before beginning measurements. A slight tilt changes all readings systematically.
3. **Grating Care:** Never touch the ruled surface of the grating. Hold by the edges only. Dust particles cause scattering and false readings.
4. **Screen Distance:** The screen must be fixed and perpendicular to the laser axis. Any slant introduces a cosine error in x measurements.
5. **Higher Orders:** For gratings of 500–600 lines/mm, second or third orders may not exist ($\sin\theta > 1$). Only measure orders that produce clear, well-separated spots.

IX. Experimental Procedure

6. **Setup:** Place the laser on one end of the optical bench. Mount the grating holder at a distance of 30–60 cm from the laser, perpendicular to the beam. Place the screen at distance D = 40–80 cm from the grating.
7. **Normal Incidence:** Switch on the laser. Adjust the grating until the reflected spot from its front surface coincides with the laser aperture (autocollimation method). This confirms normal incidence.
8. **Observe Orders:** On the screen, note the bright central spot (0th order, n = 0) and the symmetrically placed 1st order spots (±1) on either side. Note any 2nd order spots (±2) if visible.
9. **Measure Positions:** Using a metre scale fixed to the screen, measure the distance x_1 from the 0th order spot to the +1st order spot and x_1' to the −1st order spot. Take the average: $x_1 = (x_1 + x_1') / 2$.
10. **Repeat for D:** Change D to two more values (e.g., D = 50 cm and 70 cm). Record x_1 and x_2 at each distance.
11. **Calculate λ:** For each set: compute $\theta = \arctan(x/D)$, then $\lambda = d\cdot\sin(\theta)/n$. Average all values.

X. Observations and Calculations

Grating constant: N = 500 lines/mm ⟹ $d = 1/500$ mm $= 2.000 \times 10^{-3}$ mm = 2000 nm

Table 12.02: Measurement of Diffraction Angle and Wavelength

S. No.	D (cm)	x_+ (cm)	$-x_+$ (cm)	Mean x (cm)	θ = arctan(x/D)	sin θ	λ = d sinθ/n (nm)
1	40.0	13.2	13.0	13.10	18.14°	0.3113	622.6
2	50.0	16.5	16.3	16.40	18.17°	0.3118	623.7
3	60.0	19.8	19.6	19.70	18.17°	0.3118	623.7

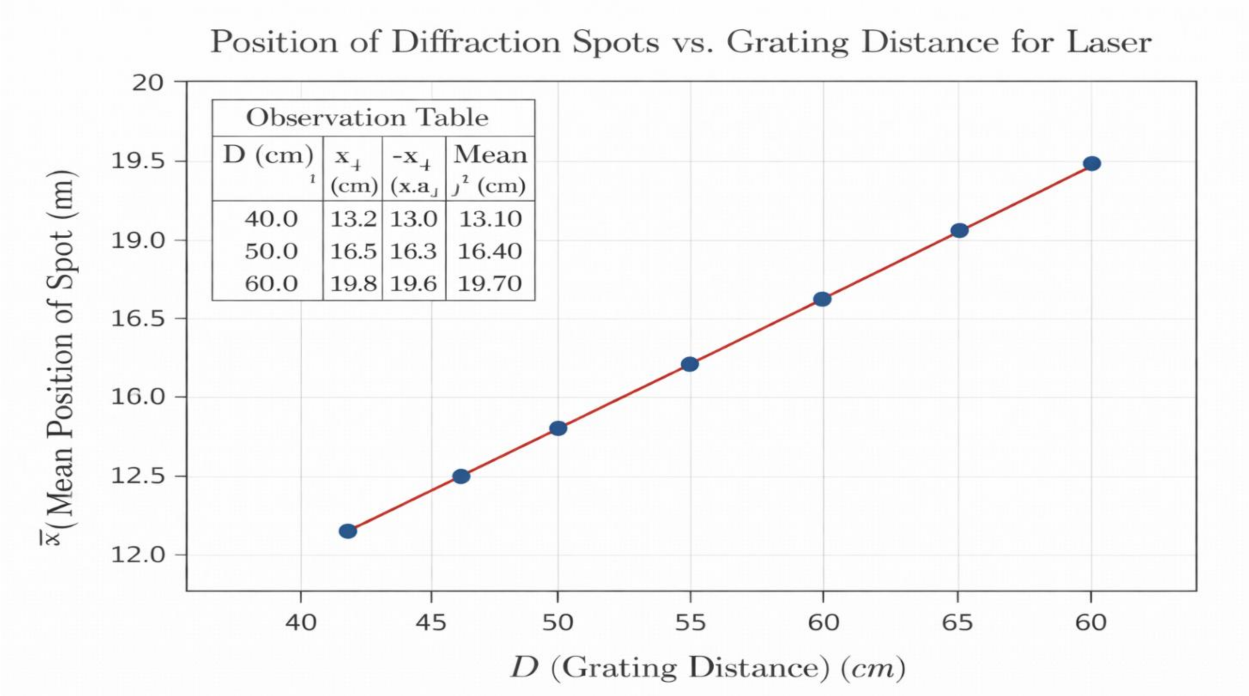
Mean wavelength (λ) = (622.6 + 623.7 + 623.7) / 3 = 623.3 nm

Standard value for He-Ne laser = 632.8 nm

Percentage Error = |(632.8 − 623.3) / 632.8| × 100 = 1.50%

XI. Graph: Position of Diffraction Spots vs. Grating Distance

The graph drawn (see below) between ***x*** and ***θ*** (based upon the data of Table 12.02) is a straight line. This confirms that the displacement is directly proportional to diffraction angle (for small angles).



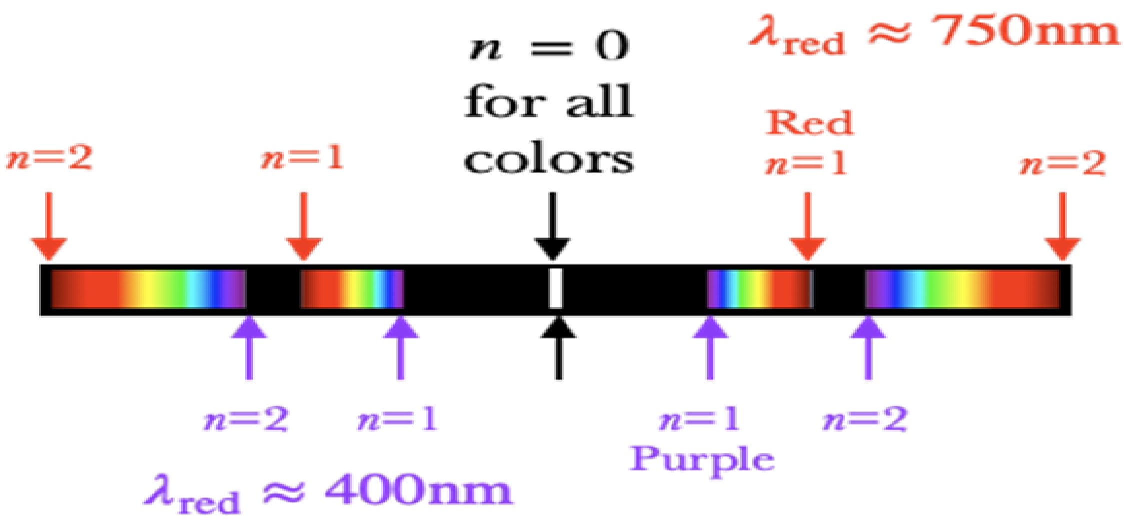


Fig. 12.04: Laser Diffraction Pattern — Central maximum and ±1st and ±2ndOrder Spots

XII. Results

- **Measured Wavelength of He-Ne Laser:** 623.3 ± 1.0 nm
- **Standard Wavelength:** 632.8 nm
- **Percentage Error:** 1.50 % (within acceptable limits for this setup)
- **Source of Error:** Slight non-normal incidence, parallax in reading screen positions, finite spot size.

XIII. Interpretation of Results and Conclusions

The experiment successfully determines the wavelength of the He-Ne laser as 623.3 nm, with a small deviation of 1.5% from the accepted value of 632.8 nm. This discrepancy is attributable to slight misalignment of normal incidence, manual measurement of spot positions, and finite width of the laser spot. The use of a 500 lines/mm grating provides well-separated first-order spots, making measurement practical. The experiment validates the grating equation and demonstrates the wave nature of laser light through interference and diffraction.

XIV. Practical Related Questions

12. Derive the diffraction grating equation d·sinθ = nλ from first principles (superposition of waves from N slits).
13. Why does a grating with more lines per mm give better resolution? What is the resolving power of a grating?
14. How would the diffraction pattern change if white light were used instead of the laser? Describe qualitatively.
15. Why is normal incidence important in this experiment? What systematic error arises from non-normal incidence?
16. A grating has 600 lines/mm. For the He-Ne laser (632.8 nm), what is the maximum order of diffraction visible?

17. How does the wavelength change if the experiment is repeated with a green diode laser (532 nm)? Predict x_1 for D = 50 cm.

XV. Suggested Activities

- Repeat with a green (532 nm) and violet (405 nm) laser pointer and compare results to build a mini wavelength calibration table.
- Use different grating densities (300, 500, 600 lines/mm) and compare the angular separations of orders.
- Photograph the diffraction pattern and use image analysis software to measure spot positions for greater precision.

XVI. References for Further Reading

- Hecht, E. Optics (5th Ed.). Pearson. Chapter 10: Diffraction.
- Halliday, Resnick & Walker. Fundamentals of Physics (10th Ed.). Wiley. Chapter 36: Diffraction.
- Verma, H.C. Concepts of Physics – Part II. Bharati Bhawan.
- **Online:** https://phet.colorado.edu — Wave Interference and Diffraction Simulation.

XVII. Rubric for Assessment

Table 12.03: Assessment Rubric for Experiment 12

Sr. No.	Indicator	Excellent (4)	Good (3)	Basic (2)	Poor (1)
1	Conceptual Clarity	Full explanation with derivation	Good, minor gap	Basic understanding	Unable to explain
2	Apparatus Handling	Perfect, safe, accurate	Minor error, self-corrected	Needs assistance	Incorrect handling
3	Procedure Followed	All steps, systematic	Minor lapse	Incomplete	Not done / unsafe
4	Data & Calculations	Accurate, error < 2%	Minor computation error	Major error	Not calculated
5	Graph / Conclusion	Correct graph, valid inference	Partial graph/inference	Weak conclusion	No graph/conclusion

Experiment No.- 13

Photoelectric Effect (Virtual Lab Experiment)

I. Practical Significance

The photoelectric effect — the emission of electrons from a metal surface when illuminated by light of sufficient frequency — played a pivotal role in the development of modern physics. Albert Einstein's 1905 explanation of this phenomenon, for which he was awarded the Nobel Prize in Physics (1921), demonstrated that light is quantised into discrete energy packets called photons. This finding is foundational to:

- **Quantum Mechanics:** Establishing the dual wave-particle nature of light and the concept of photon energy $E = h\nu$.
- **Solar Cells & Photodetectors:** The working principle of photovoltaic cells, camera sensors (CCD/CMOS), and light meters.
- **X-ray Imaging:** X-ray photoelectron spectroscopy (XPS) for surface analysis in materials science and forensics.
- **Night Vision Devices:** Image intensifiers and photomultiplier tubes used in astronomy and security systems.

II. Relevant Program Outcomes (POs)

- **PO1: Basic Knowledge:** Apply quantum theory — photon model of light, work function, and Einstein's equation — to explain photoelectric observations.
- **PO3: Experiments & Practice:** Use virtual lab platforms to perform controlled experiments, record data systematically, and draw valid scientific conclusions.
- **PO5: Individual and Team Work:** Operate simulation software and interpret results collaboratively.

III. Relevant Course Outcomes (COs)

- **CO5:** Demonstrate understanding of quantum properties of light through virtual experimentation on the photoelectric effect.

IV. Laboratory Session Outcomes (LSOs)

- LSO 1 Determine the threshold frequency of incident photon for different metal.
- LSO 2 Plot the graph between photo current v/s variation of intensity of threshold frequency of incident photon.
- LSO 3 Plot the graph between KE of Photo electron v/s frequency of incident light.
- LSO 4 Determine the value of Plank's Constant (h) from the graph between KE v/s frequency of incident light.
- LSO 5 Determine the variation of stopping potential w.r.t frequency of incident photon.
- LSO 6 Determine the work function of metal used for photoelectric effect.

V. Virtual Lab Platform

Recommended Simulation:

- **PhET Interactive Simulations (University of Colorado):** https://phet.colorado.edu/en/simulations/photoelectric
- **Amrita Virtual Labs:** https://vlab.amrita.edu/index.php?sub=1&brch=195&sim=335

The simulation allows the student to vary: (a) frequency of incident light, (b) intensity of light, (c) target metal (sodium, zinc, calcium, etc.), and observe: photocurrent, stopping potential, and KE of ejected electrons

VI. Relevant Theory

1. The Photoelectric Effect

The photoelectric effect is the phenomenon where electrons are emitted from the surface of a metal when light (electromagnetic radiation) of a sufficiently high frequency falls upon it. The emitted electrons are called photoelectrons.

2. Einstein's Photoelectric Equation

According to Einstein's quantum theory of light, energy is carried in discrete packets called photons. The energy of a photon is given by $E = h\nu$, where h is Planck's constant and ν is the frequency of light.

When a photon hits a metal surface, its energy is used in two ways:

1. Overcoming the surface barrier of the metal (Work Function, Φ).
2. Imparting maximum kinetic energy (K_{max}) to the ejected electron.

   Therefore, the photoelectric equation is:

$$K_{max} = h\nu - \Phi$$

3. Stopping Potential

If a negative (retarding) potential V is applied to the anode, it repels the photoelectrons. The minimum negative potential at which even the most energetic photoelectrons are stopped, and the photocurrent becomes zero, is called the stopping potential (V_S). At this point, the maximum kinetic energy is completely converted into electrostatic potential energy:

$$K_{max} = eV_S$$

Substituting this into Einstein's equation gives:

$$eV_S = h\nu - \Phi$$

$$V_S = \frac{(h\nu - \Phi)}{e}$$

4. Determining Planck's Constant

The equation $K_{max} = h\nu - \Phi$ represents a straight line ($y = mx + c$). By plotting a graph of K_{max} (on the y-axis) versus frequency ν (on the x-axis), a straight line is obtained.

- The slope of this line directly yields the value of Planck's constant (h).

The x-intercept gives the threshold frequency (ν_o).

VII. Experimental Simulator Setup

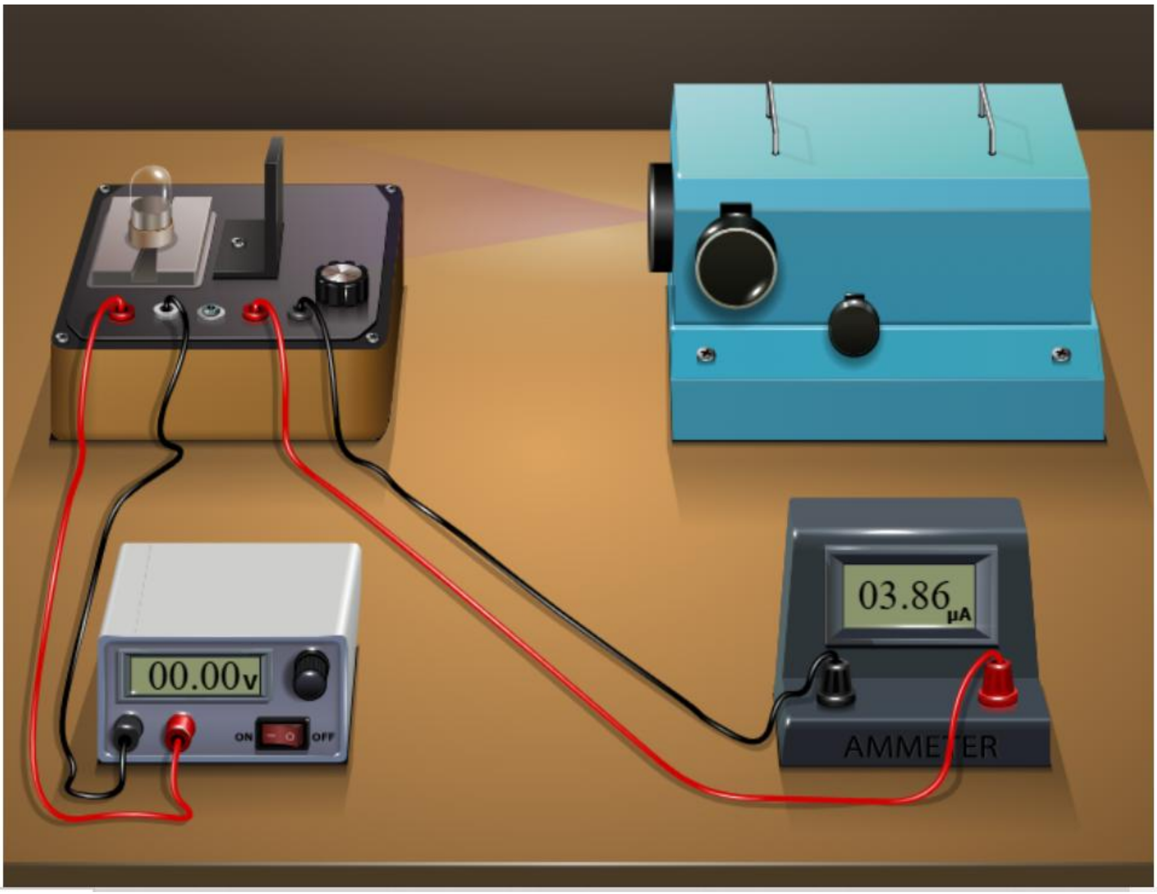


Photo Credit: PhET Interactive Simulations

Fig. 13.01: Vlab Simulator circuit diagram for photoelectric effect

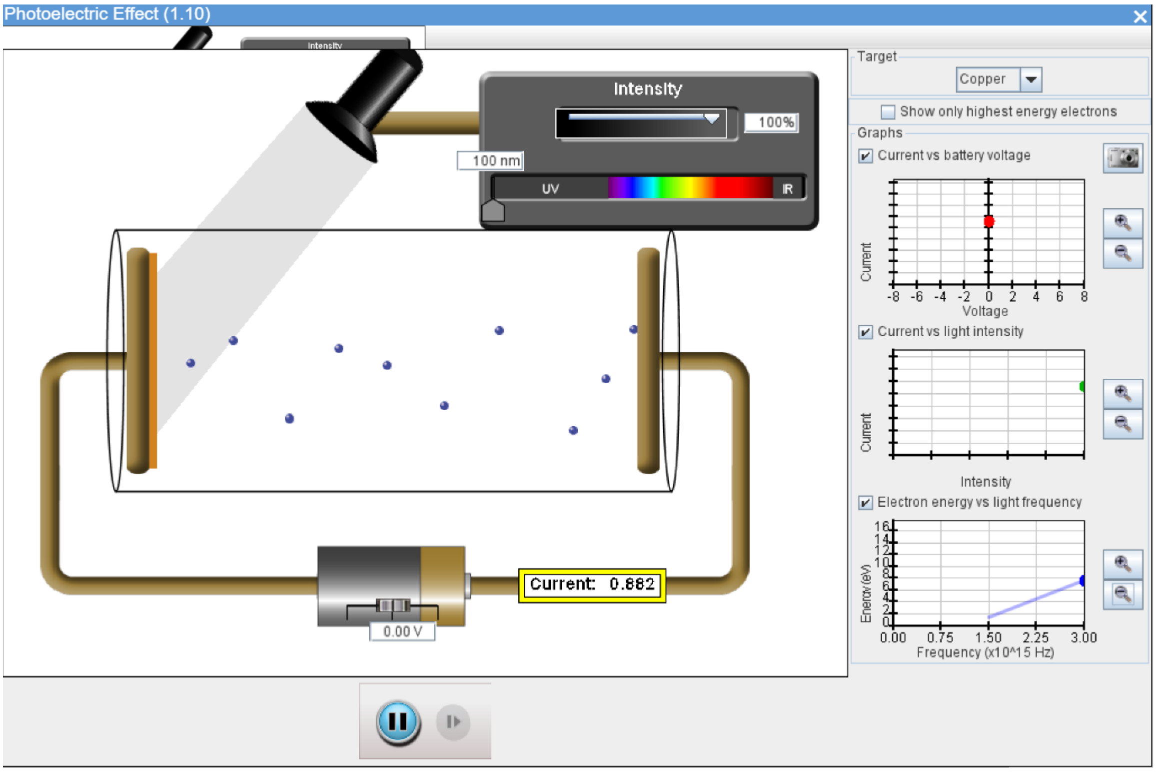


Fig. 13.02: PhET Simulation set up for photoelectric effect with graphical plot of (a) current v/s battery voltage (b) Intensity v/s light intensity (c) electron energy v/s light frequency.

VIII. Resources Required

- Computer or Laptop with an active internet connection.
- Modern web browser with HTML5 support.
- Access to an open-source Virtual Lab simulator for the Photoelectric Effect (e.g., PhET Interactive Simulations or Amrita OLABS).
- Spreadsheet software (Excel/Google Sheets) or Graph paper for plotting.
- Calculator.
- Graphing tool may also be utilized by the students for plotting the graphs so that the input - output parameters can easily be obtained.

IX. Precaution

- **Before switching on the system ensure that it is connected with uninterrupted power supply (UPS) to avoid immediate shutdown of the system.**
- **Ensure key board and mouse are working properly.**
- **Check availability of network connection.**
- Ensure the browser is updated to prevent lag or simulation freezing during readings.
- **Ensure that valid Id and password are available for log in the vlab.**
- After log in, place the required model instruments as per specified features.

- When measuring the effect of frequency, ensure the intensity of light remains constant.
- Adjust the retarding voltage slider very slowly to find the exact stopping potential (Vs) where the current reads exactly 0.00 A.
- Be meticulous when converting wavelength from nanometres (nm) to metres (m), and frequency in Hertz (Hz) to avoid errors in calculation.
- Be cautious in determining the exact point where the photocurrent becomes zero due to the finite step resolution of the virtual voltage slider.
- Be careful while converting units e.g. joule to eV and vice-versa, and changing wave-length into frequency ($c = f\lambda$).
- Human error in plotting the best-fit line on the graph and extracting the slope.
- After completion of experiment shut down the system properly.

X. Suggested Procedure

1. For Performing the Simulation Setup and Initialisation

- Switch on the system**.**
- **Go to Browser**
- **Click on link any one of the** following links :

  link 1:` https://mpv-au.vlabs.ac.in/modern-physics/Photo_Electric_Effect/
  link 2: https://phet.colorado.edu/en/simulations/photoelectric
- **Log on to Vlab using valid Id and password.**
- **Start the experiment by switching on the experiment model.**
- After completion of experiment shut down the system properly.

2. Finding Threshold Wavelength/Frequency for Various Metals

1. Select the metal from the relevant material tab.
2. Select area of the material.
3. Adjust the battery voltage to zero.
4. Switch on the light source.
5. Adjust the wavelength (λ) slider to the lowest available value (highest frequency, usually in the UV region) where electron emission is observed.
6. Observe the microammeter for photo current to start.

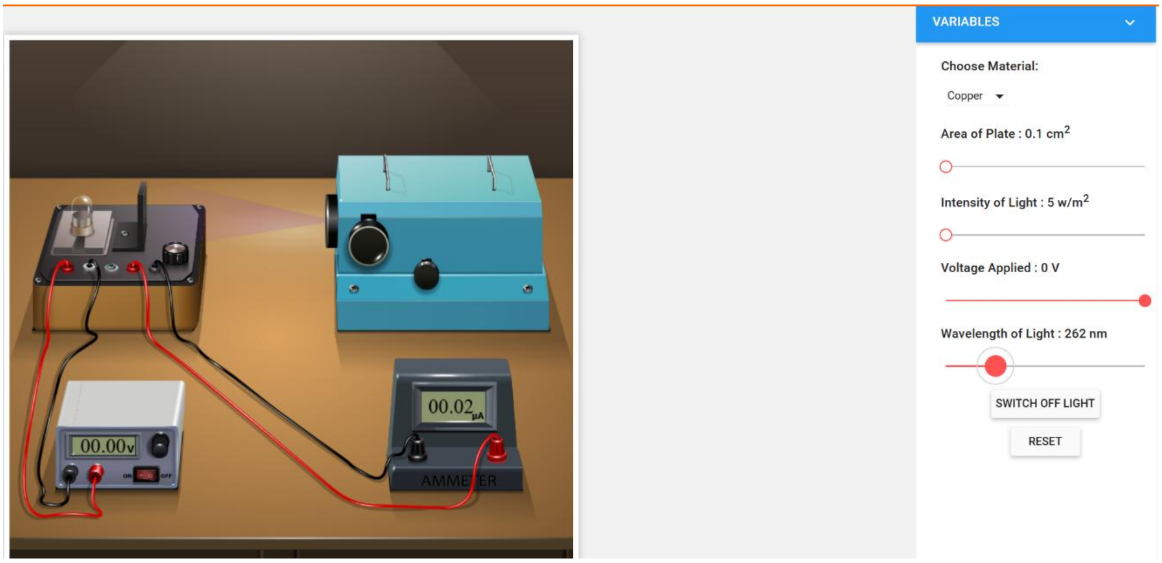


Photo Credit: PhET Interactive Simulations

Fig. 13.03: Simulator shows threshold frequency/wavelength of incident photon for copper.

7. Record this wavelength and convert to frequency using formula:

$$\nu = \frac{c}{\lambda}$$

Where, ν is frequency, c= 3 x 10^8 m/s, λ= wavelength

3. Finding Photo Current V/S Variation of Intensity of Threshold Frequency of Incident Photon for Various Metals

1. Select the metal from choose material tab.

2. Select area of the material.

3. Adjust the battery voltage to zero.

4. Switch on the light source.

5. Adjust the wavelength (λ) slider to the lowest available value (highest frequency, usually in the UV region) where electron emission is observed.

6. Observe the microammeter for photo current.

7. Adjust the intensity of threshold frequency of incident photon slider to at interval of 5 mW/m^2.

8. Repeat step 6.

9. Record the values of photo current at different intensity for selected material.

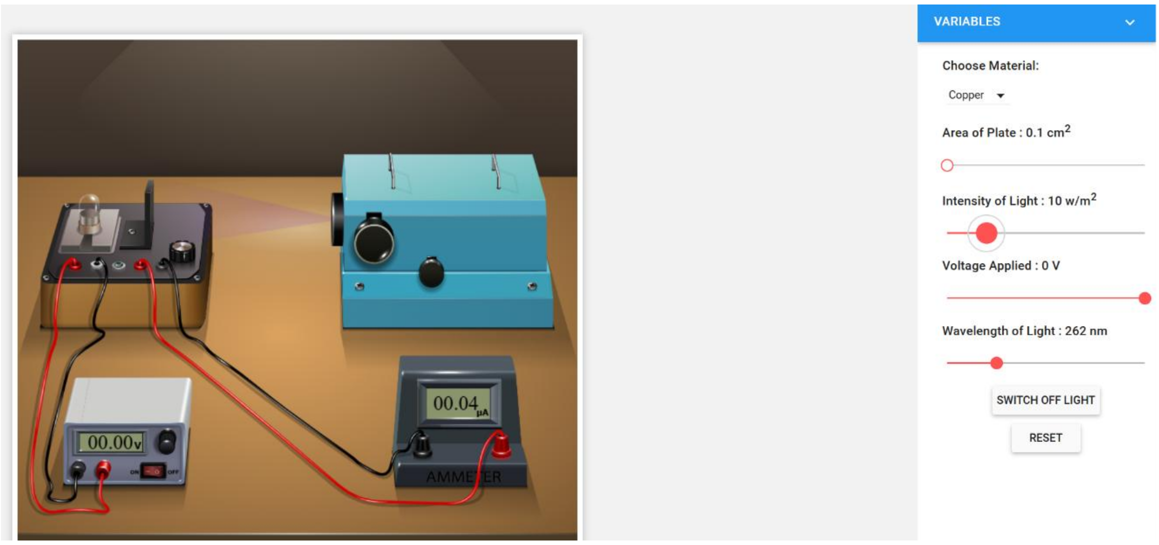


Photo Credit: PhET Interactive Simulations

Fig. 13.04: Simulator shows variation in photo current v/s variation of intensity of threshold frequency of incident photon of copper.

10. Plot the graphs between intensity of threshold frequency of incident photon versus photocurrent.

4. Finding Stopping Potential for Different Metals

1. Select the metal from the relevant material tab.

2. Select area of the material.

3. Switch on the light source.

4. Adjust the wavelength (λ) slider to the lowest available value (highest frequency, usually in the UV region) where electron emission is observed.

5. Adjust the battery voltage slider to negative values till micro ammeter shows photocurrent value to zero to confirm stopping of ejected electrons at cathode.

6. Record the applied negative potential.

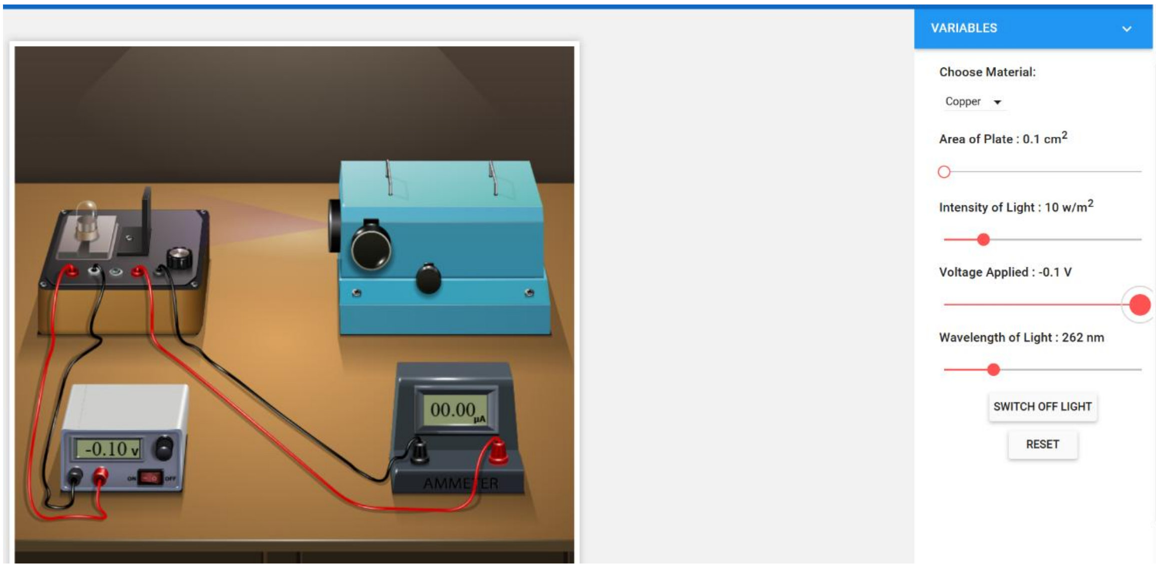


Photo Credit: PhET Interactive Simulations

Fig. 13.05: Simulator shows stopping potential v/s threshold frequency of incident photon for copper

7. Adjust the intensity of threshold frequency of incident photon slider at interval of 5 mW/m^2.

8. Increase the wavelength by a fixed interval (e.g., 20 nm) to decrease the frequency.

9. Repeat steps 3–5 to find the new stopping potential for the new wavelength.

10. Take at least 5 to 6 readings for different wavelengths until you approach the threshold frequency (where no emission occurs even at zero voltage).

11. Plot the graphs for current versus negative applied potential at different frequencies to determine stopping potential.

5. Finding Maximum Kinetic Energy of Photoelectrons Versus Frequency of Incident Radiation

1. Select the metal from relevant material tab.

2. Select area of the material.

3. Note down the work function of selected metal.

4. Adjust the wavelength (λ) slider to the threshold wavelength/frequency for selected metal.

5. Adjust the battery voltage slider to negative values till micro ammeter shows photocurrent value to zero to confirm stopping of ejected electrons at cathode.

6. Record the applied negative potential.

7. Decrease the wavelength by a fixed interval (e.g., 20 nm) to increase the frequency.

6. Adjust the battery voltage slider to negative values till micro ammeter shows photocurrent value to zero to confirm stopping of ejected electrons at cathode.

6. Record the applied negative potential.

7. Increase the wavelength by a fixed interval (e.g., 20 nm) to decrease the frequency.

8. Repeat steps 3–5 to find the new stopping potential for the new wavelength.

9. Take at least 5 to 6 readings for different wavelengths until you approach the threshold frequency (where no emission occurs even at zero voltage).

10. Calculate the value of $K_{max} = eVs$

11. Plot the graph for maximum kinetic energy of photoelectrons versus frequency of incident radiation graph.

XI. Graphical Method

After completing the various parameters simulations and recording the data in observation tables, you will be able to:

1. Plot the graph between photo current v/s variation of intensity of threshold frequency of incident photon.

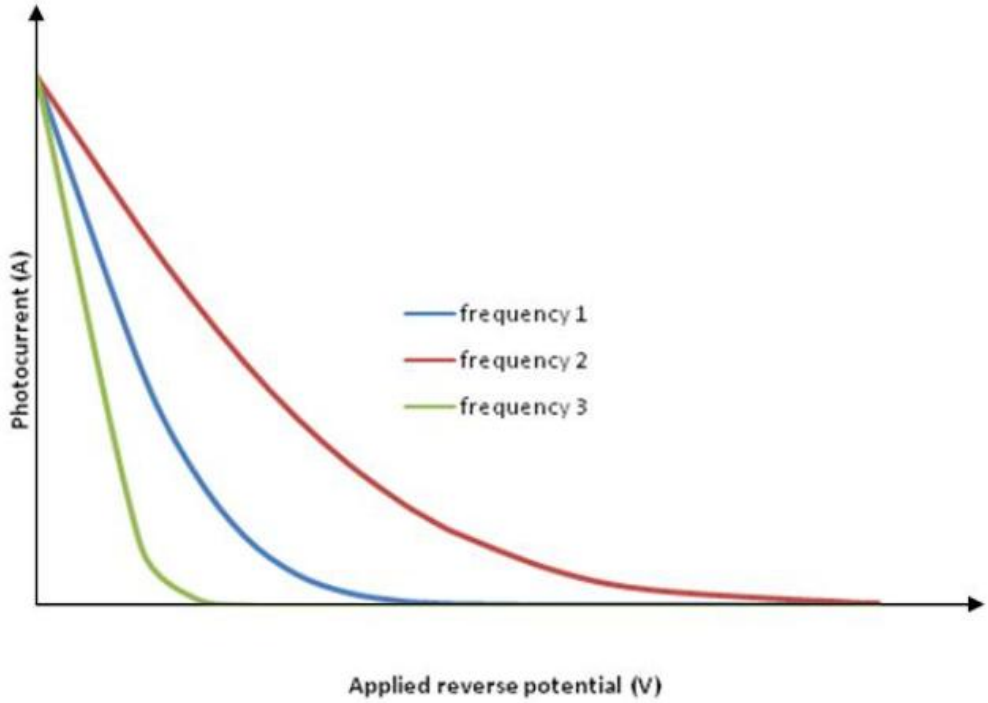


Fig. 13.06. Expected graphical plot: photocurrent versus applied reverse potential at constant light intensity with different frequencies

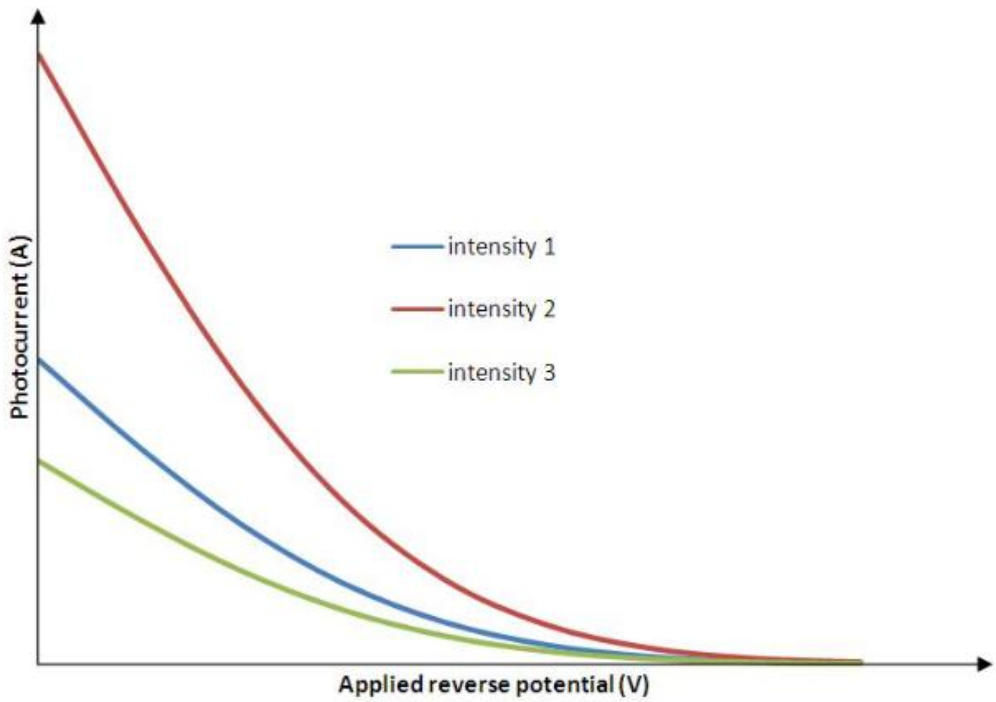


Fig. 13.07: Expected graphical plot photocurrent versus applied reverse potential at constant frequency with different intensities.

2. Plot the graph between KE of Photo electron v/s frequency of incident light.

(1) Plot a graph with Frequency (ν) on the X-axis and Kmax (in Joules) on the Y-axis.

(2) Draw the best-fit straight line through the data points.

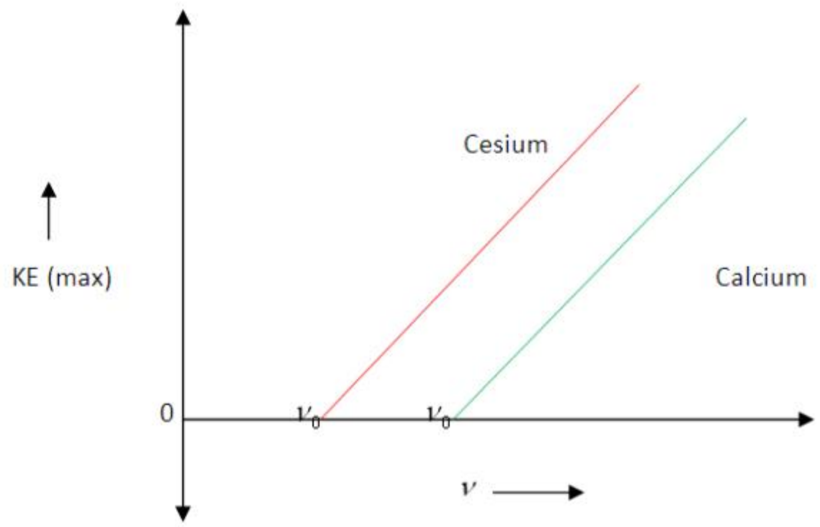


Fig. 8: Expected graphical plot for maximum kinetic energy of photoelectrons versus frequency of incident radiation graph.

XII. Observations and Calculations Observation Table:13.01

Target Metal: Sodium (Na) **Work Function φ = 2.3 eV**

Threshold Frequency $\nu_0 \approx 5.55 \times 10^{14}$ Hz

S. No.	Wavelength λ (nm)	Frequency ν ($\times 10^{14}$ Hz)	$(\nu - \nu_0)$ ($\times 10^{14}$ Hz)	Applied Potential (V)	Photo Current (mA)	Stopping Potential Vs (V)	Kmax (eV)	
1	155	19.35	13.8	0.0	0.309	-5.6	5.6	
2	182	16.48	10.93	0.0	0.363	-4.4	4.4	
3	226	13.27	7.72	0.0	0.286	-3.2	3.2	
4	265	11.32	5.77	0.0	0.187	-2.2	2.2	
5								
6								

1.1 Calculations

1. Convert each wavelength (λ) into frequency (ν) using the formula $\nu = c/\lambda$, where,

$c = 3 \times 10^8$ m/s.

2. Calculate the maximum kinetic energy for each reading using Kmax = eVs (where $e = 1.6 \times 10^{-19}$C). Note: If plotting Kmax in electron-volts (eV), Kmax is numerically equal to Vs.

Using: $\mathbf{h} = \frac{\mathbf{K_{max}}}{\boldsymbol{\nu - \nu_0}}$

$h_1 = \frac{5.60}{13.80\times10^{14}} = 4.06 \times 10^{-15}$ eV-s , $h_2 = \frac{4.40}{10.93\times10^{14}} = 4.02 \times 10^{-15}$ eV-s

$h_3 = \frac{3.20}{7.72\times10^{14}} = 4.14 \times 10^{-15}$ eV-s , $h_4 = \frac{2.20}{5.77\times10^{14}} = 3.81 \times 10^{-15}$ eV-s

Mean value of Planck's constant: $h_{mean} = \frac{4.06+4.02+4.14+3.81+}{4} \times 10^{-15}$ eV-s

Experimental Mean Value, $h_{mean} = 4.008 \times 10^{-15}$ eV-s

Theoretical Value: $h = 4.136 \times 10^{-15}$ eV-s

Percentage Error = $\frac{(4.136-4.008)\times10^{-15}\ \text{eV-s}}{4.136\times10^{-15}\ \text{eV-s}} \times 100\ \% = 3.09\ \% = 3.1\ \%$

The calculated value of Planck's constant is reasonably close to the standard value, confirming the validity of the experiment.

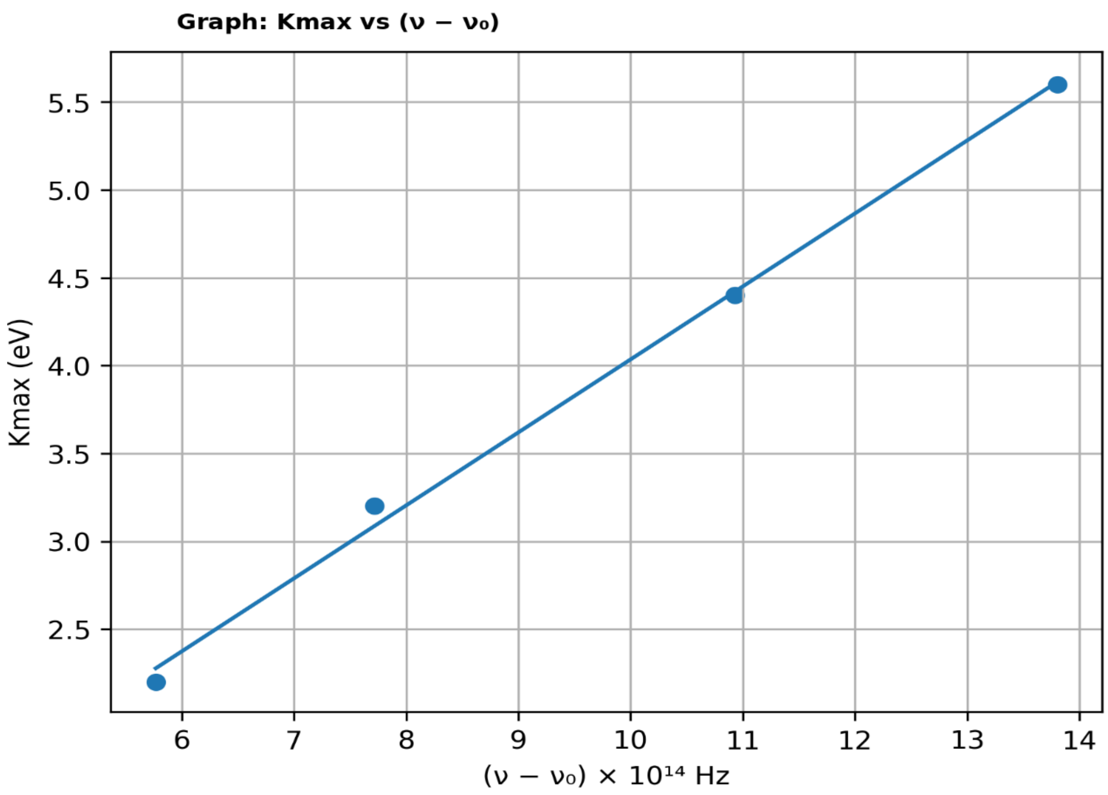
1.2 Calculation of Slope (Planck's Constant, h)

(1) Calculate the slope of this line Kmax -$\Delta\nu$.

(2) Points selected from the best-fit line: P_1 (ν_1, K_1) and P_2 (ν_2, K_2)

$$h = \frac{K_2 - K_1}{\nu_2 - \nu_1} = \text{.......eV-s}$$

(3) The slope represents Planck's constant (h).



Graph: 13.01

From the graph: $h \approx 4.05 \times 10^{-15}$ eV-s

This value of Planck's Constant is very much close to the Standard value $h = 4.136 \times 10^{-15}$ eV-s.

The graph between maximum kinetic energy and $(\nu - \nu_0)$ is linear, verifying Einstein's photoelectric equation.

XIII. Result

Parameter	**Calculated Value**	**Standard Value**	**Relative % Error**
Planck's Constant (h)	________ eV-s	4.136×10^{-15} eV-s.	3.1 %
Threshold Frequency (ν_0)	________ Hz	Material Dependent	N/A

XIV. Interpretation of Result

In this virtual experiment, the linear relationship between the maximum kinetic energy of photoelectrons and the frequency of incident light was verified. The stopping potential was found to increase linearly with the incident frequency. From the slope of the Kmax versus ν- ν_0 graph, Planck's constant was determined to be 4.008×10^{-15} eV-s. The relative error compared to the standard value is 3.1 %, validating Einstein's quantum theory of light and the particle nature of electromagnetic radiation.

XV. Practical Related Questions

1. Define threshold frequency and work function. How are they related?
2. What would the microammeter display if the incident light has a frequency lower than the threshold frequency, even if the intensity is set to maximum?
3. Determine the minimum frequency required to observe the Photoelectric Effect for an EM radiation incident on a zinc metal surface.
4. Why does the maximum kinetic energy of the emitted electrons depend on the frequency of the incident light but not on its intensity?
5. If the virtual target material is changed from Sodium to Platinum, how would the Kmax vs ν graph shift? Would the slope change? Justify your answer.
6. Two identical metal plates are illuminated with light of same frequency but different intensities. Compare their stopping potentials and photocurrents

XVI. Suggested Assessment Scheme/Rubrics

Sr. No.	Indicator	Excellent (4)	Good (3)	Basic (2)	Poor (1)
1	Conceptual Clarity	Clear explanation	Good, minor gap	Basic understanding	Unable to explain
2	System Handling	Perfect, safe, accurate	Minor error, self-corrected	Needs assistance	Incorrect handling
3	Procedure Followed	All steps in systematic order	Minor lapse	Incomplete	Not done / unsafe
4	Data & Calculations	Accurate, error < 2%	Minor computation error	Major error	Not calculated
5	Graph / Conclusion	Correct graph, valid inference	Partial graph/inference	Weak conclusion	No graph/conclusion

Experiment No.- 14

Emission Spectra of Hydrogen

(Virtual Lab Experiment)

I. Practical Significance

The hydrogen atom, being the simplest atom with one proton and one electron, has served as the 'hydrogen model' that underpins all of modern atomic physics. Its emission spectrum — a set of discrete, coloured lines rather than a continuous band — provided the first direct experimental evidence that atomic energy levels are quantized. Understanding the hydrogen spectrum is fundamental to:

- **Astrophysics:** Hydrogen is the most abundant element in the universe. Hydrogen spectral lines are used to determine the composition, temperature, and velocity (via Doppler shift) of stars and galaxies.
- **Atomic Physics:** The Rydberg formula, Bohr's model, and quantum mechanics were all developed to explain hydrogen's spectrum, laying the groundwork for quantum chemistry.
- **Laser Technology:** Hydrogen lasers and deuterium lamps are used as UV calibration sources in spectroscopy.
- **Nuclear Energy:** Understanding hydrogen's energy levels is essential in plasma physics and nuclear fusion research.

II. Relevant Program Outcomes (POs)

- **PO1: Basic Knowledge:** Apply Bohr's atomic model and quantum mechanical principles to explain the origin of discrete spectral lines.
- **PO3: Experiments & Practice:** Analyse spectral data (virtual) to identify spectral series and calculate Rydberg's constant.
- **PO5: Individual & Team Work:** Use online simulation platforms for systematic experimental investigation.

III. Relevant Course Outcomes (COs)

- **CO5:** Demonstrate experimental understanding of atomic emission spectra and their connection to quantum energy level theory.

IV. Laboratory Session Outcomes (LSOs)

- **LSO 14.1:** Determine the wavelength of different spectral lines of the Hydrogen spectrum (Balmer series) using the virtual spectroscope simulation.
- **LSO 14.2:** Verify the Rydberg formula: $1/\lambda = R_H (1/n_1^2 - 1/n_2^2)$ for the observed lines.
- **LSO 14.3:** Calculate the value of Rydberg's constant R_H from experimental data and compare with the standard value.

VI. Relevant Theoretical Concepts

1. Bohr's Model of the Hydrogen Atom: Niels Bohr (1913) proposed that electrons revolve around the nucleus in discrete circular orbits of fixed energy. The energy of the n^{th} orbit is:

$$E_n = -13.6 / n^2 \quad \text{eV} \quad (n = 1, 2, 3, \ldots)$$

When an electron transitions from a higher orbit n_2 to a lower orbit n_1, a photon is emitted with energy:

$$\Delta E = E_{n2} - E_{n1} = h\nu = hc/\lambda$$

2. Rydberg Formula: The wavelength of emitted light is given by:

$$1/\lambda = R_H \times (1/n_1^2 - 1/n_2^2)$$

where $R_H = 1.097 \times 10^7$ m^{-1} is Rydberg's constant, n_1 and n_2 are the lower and upper quantum numbers ($n_2 > n_1$).

3. Spectral Series of Hydrogen:

- **Lyman Series:** $n_1 = 1$ (transitions to ground state) — Ultraviolet region
- **Balmer Series:** $n_1 = 2$ (transitions to n= 2) — Visible region (observed in this experiment)
- **Paschen Series:** $n_1 = 3$ (transitions to n= 3) — Infrared region
- **Brackett Series:** $n_1 = 4$ (transitions to n= 4) — Far infrared
- **Pfund Series:** $n_1 = 5$ (transitions to n= 5) — Far infrared

4. Balmer Series Lines (Visible):

- **H_α (n=3→2):** 656.3 nm (Red)
- **H_β (n=4→2):** 486.1 nm (Blue-Green / Cyan)`
- **H_γ (n=5→2):** 434.0 nm (Violet)
- **H_δ (n=6→2):** 410.2 nm (Deep Violet / UV edge)

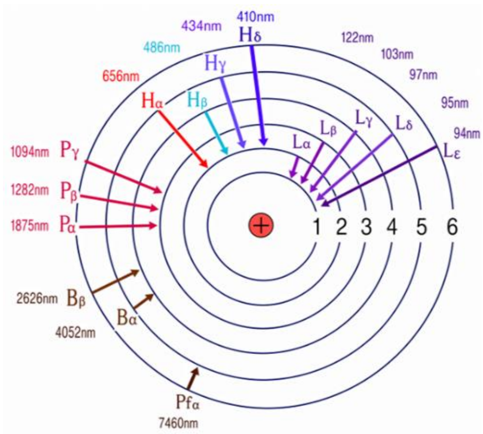


Fig. 14.00: Atomic transition

VII. Experimental Set-up

1. An Overview of Original Experimental set-up

(*The two descriptive figures 14.01 and 14.02 added here, though not necessarily to be part of this VLAB section, in view to introduce you about the operational story taking place behind the VLAB***).**

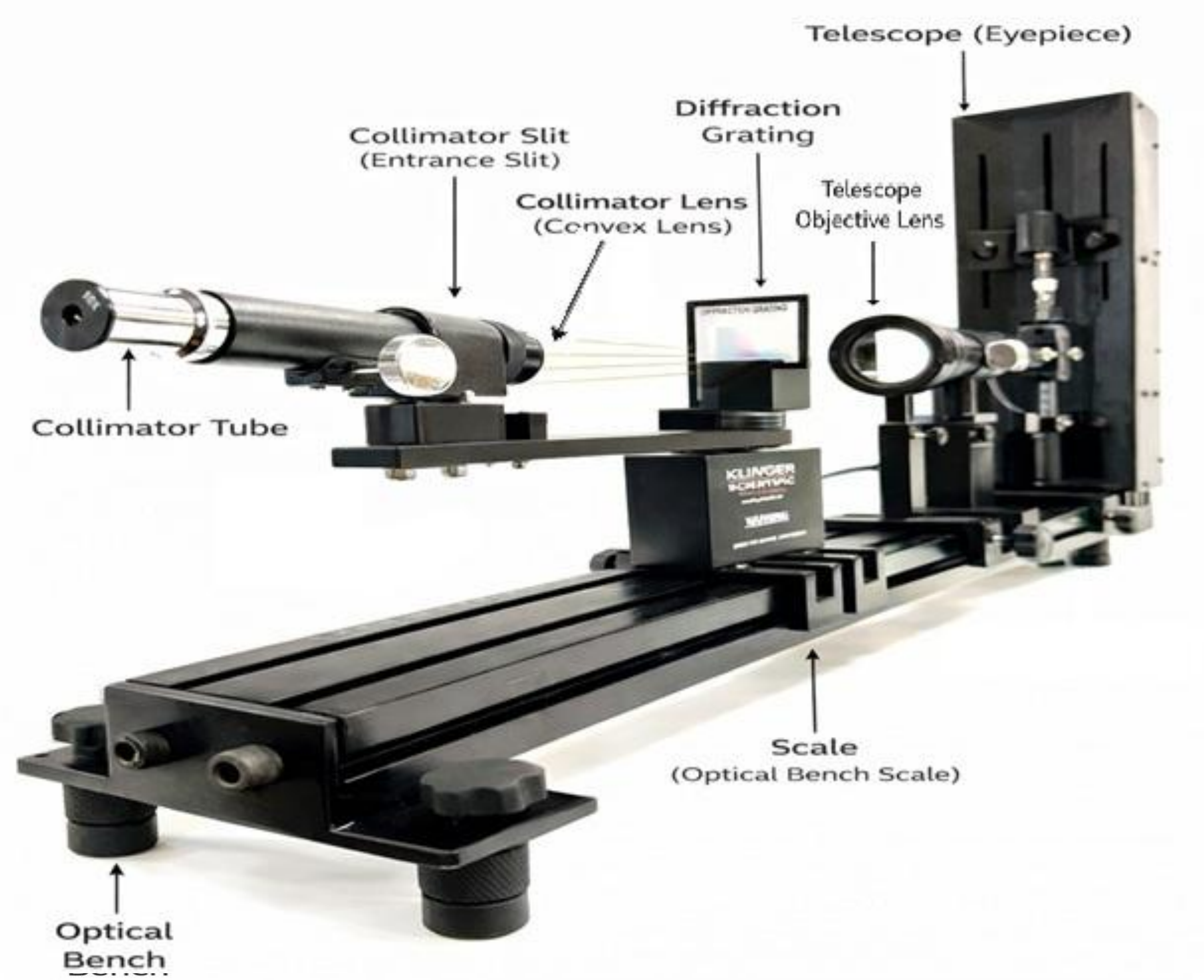


Fig. 14.01 Atomic Sprctra Experimental Set-up **Courtesy: Klingereducational.com**

- **Hydrogen Discharge Tube:** A sealed glass tube containing hydrogen gas at low pressure (~1 torr). When high voltage is applied (~5 kV), electrical energy excites H_2 molecules, which dissociate into excited hydrogen atoms. As electrons fall to lower energy levels, photons of specific wavelengths are emitted.
- **Diffraction Grating Spectroscope:** The emission from the discharge tube is directed through a collimator, then diffracted by a grating, and imaged on a circular scale which is observed by the **Telescope**. The angle for each spectral line gives its wavelength.
- **Wavelength Measurement:** The simulation displays the wavelength of each visible spectral line directly, or the student can calculate it from angular positions using the grating equation.

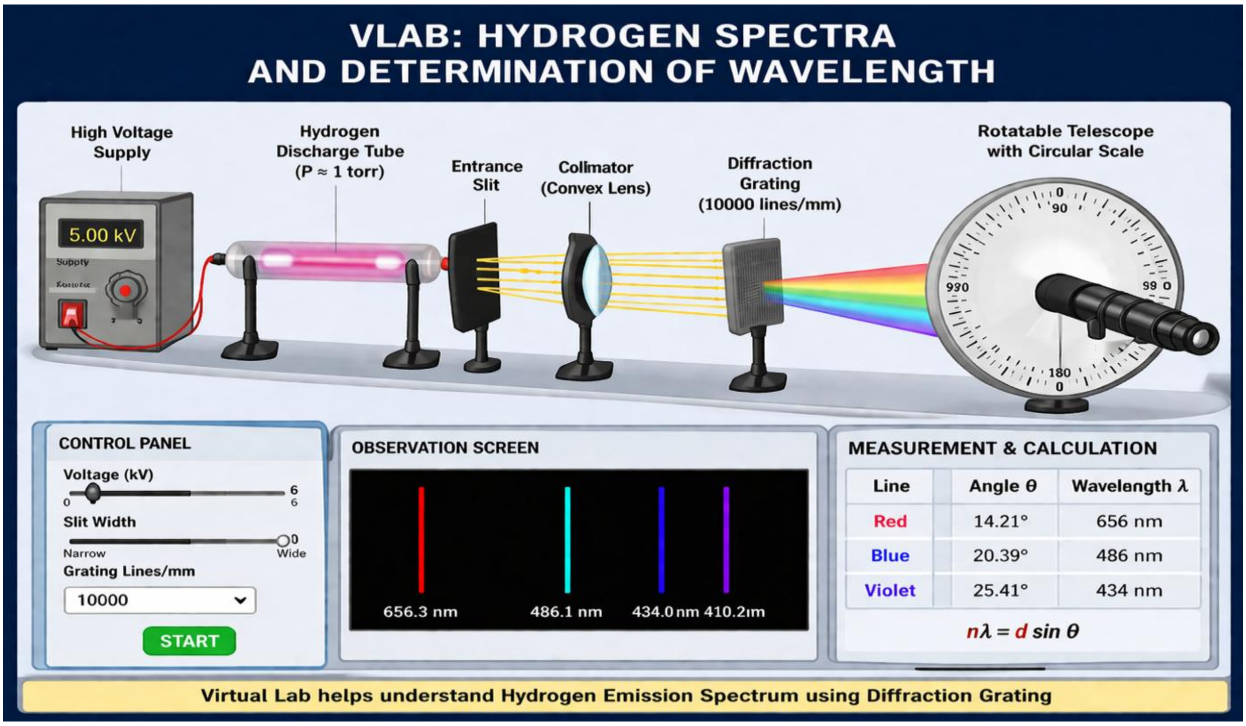


Fig. 14.02: An AI generated Picture

2. Virtual Lab (VLAB):

Primary user interface that appears on the monitor just after logging in the [Hydrogen Emission Spectrum - PhET Interactive Simulations] **used for emission spectrum of Hydrogen atom and also different models of H-atom.** As you press on SIMULTIONS on the right top portion of the screen, you will find many topics such as All Sims, Physics, Math and statistics, Chemistry etc.. Choose Physics by pressing over it. You will get as many as 66 results. Select *Models of the Hydrogen atom*.

As soon as you press the big *triangle* inside the white *circle* of this screen (Fig. 14.03):

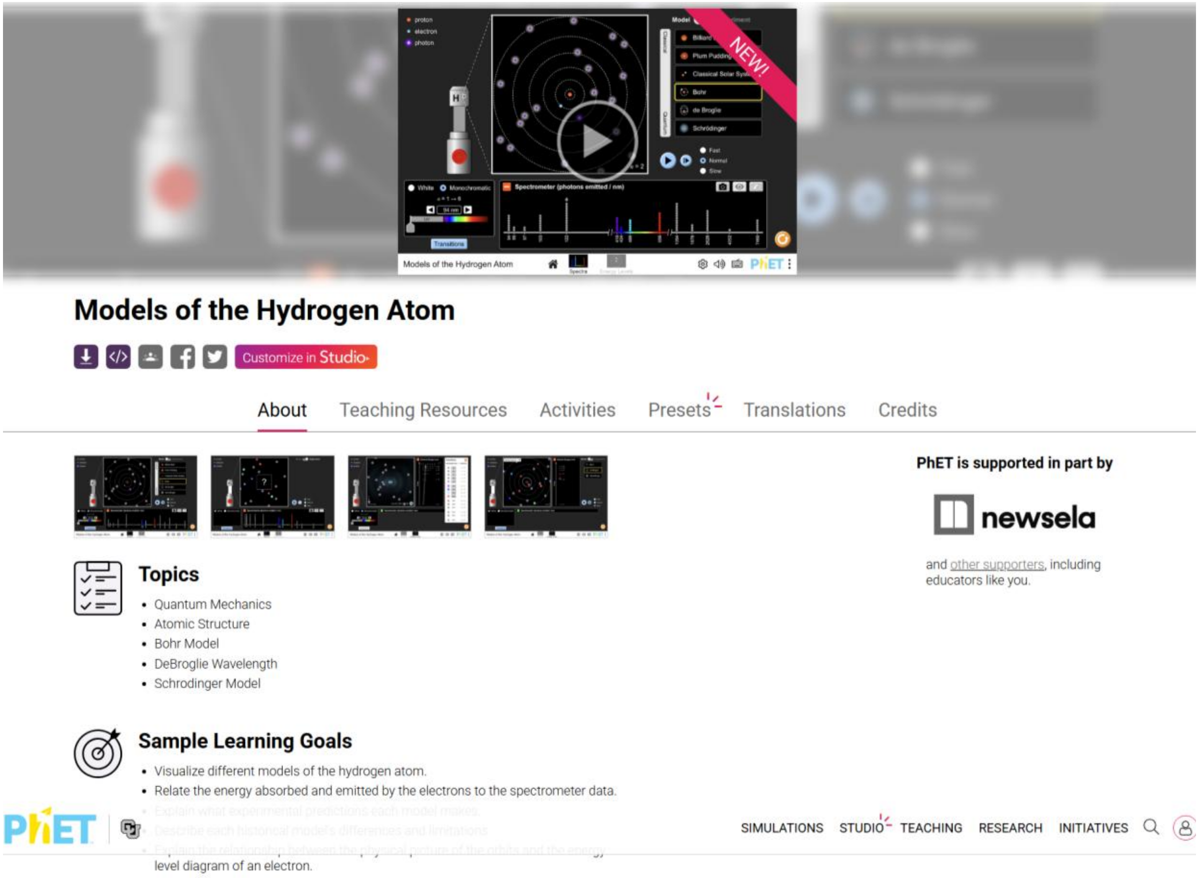


Fig. 14.04 First Screen on selection of *Models of the Hydrogen atom* **Courtesy: PhET**

You will have this screen given below:

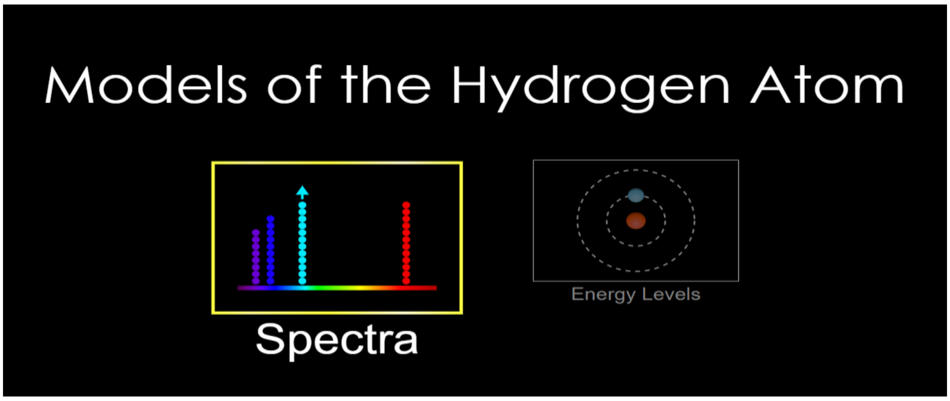


Fig. 14.05 Spectra and energy Levels kiosk **Courtesy: phet.colorado.edu**

Now select *Energy Levels* for better visualisation. Then you will get the screen (Fig. 14.06) demonstrating proton, electron, photon on top left corner, different models of H-atom on right side; Spectrometer; White and Monochromatic. On choosig White button, photons of sevevn different colours are emitted wheras on Choosing Monochromatic, photons of single colour are released to strike over the Atom of Hydrogen.

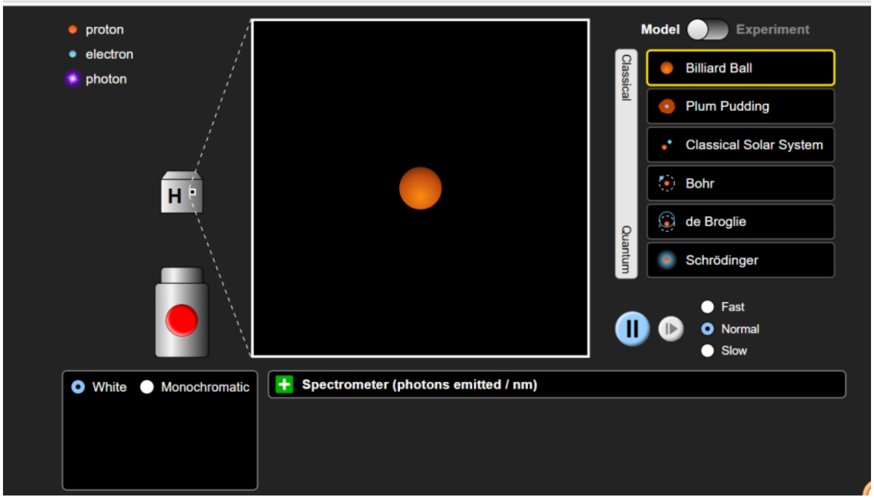


Fig. 14.06 different Models of H-atom **Courtesy: PhET Simulation**

V. Virtual Lab Platforms

Recommended Simulations:

- Hydrogen Emission Spectrum - PhET Interactive Simulations for Emission Spectra of Hydrogen atom and different models of H-atom
- Hydrogen Atom Models | Simulations4All for Emission and Absorption Spectra of Hydrogen atom

VIII. Resources Required: Table 14.01

Sr. No.	Item	Specification	Quantity	Remarks
1	Computer / Tablet	Internet browser, min 4 GB RAM	1	Updated browser needed
2	Virtual Spectroscope	1) Hydrogen Emission Spectrum - PhET Interactive Simulations 2) Hydrogen Atom Models | Simulations4All	1	
3	Graph Paper	Millimetre ruled, A4	1 sheet	For energy level diagram
4	Scientific Calculator	For Rydberg constant calculation	1	
5	Observation Notebook	For recording virtual readings	1	

IX. Precautions (Virtual Lab)

Related to Safety:

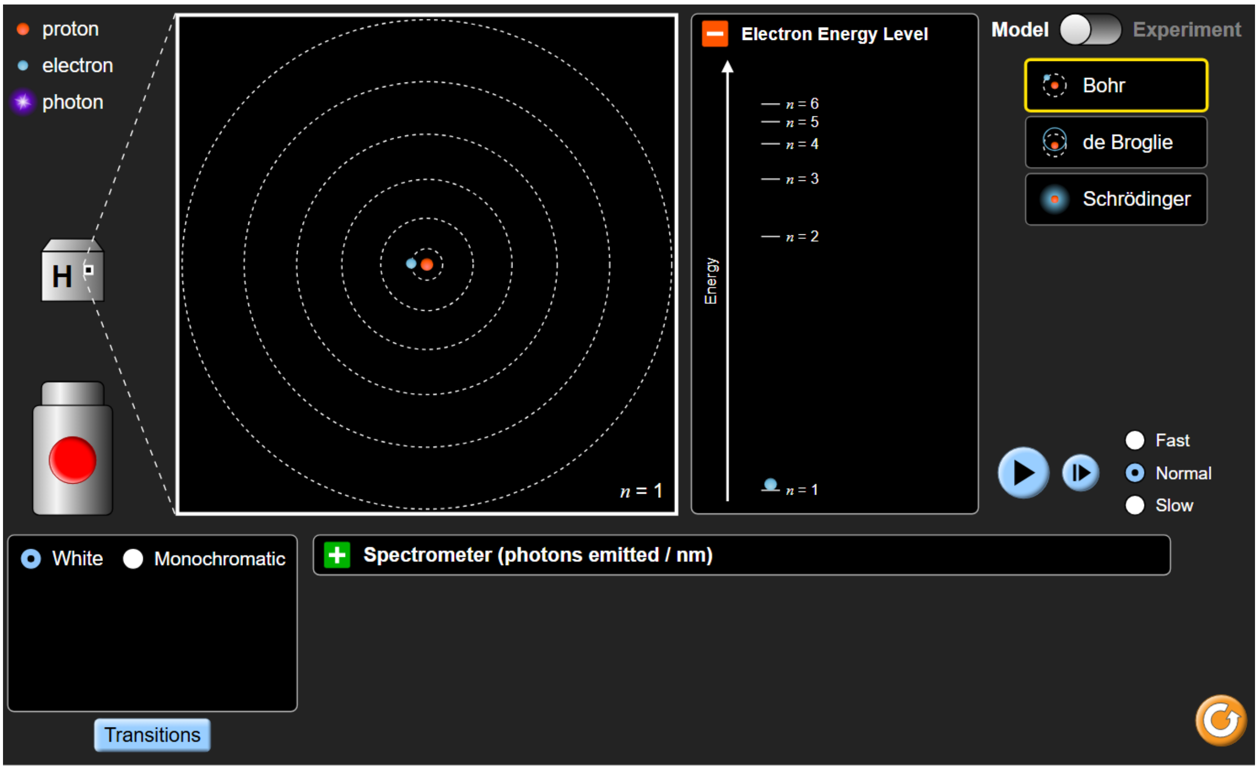
- **Before switching on the system ensure that it is connected with uninterrupted power supply (UPS) to avoid immediate shutdown of the system.**
- Ensure key board and mouse are working properly.
- Check availability of network connection.
- Ensure the browser is updated to prevent lag or simulation freezing during readings.
- Ensure that **valid Id** and **password** are available for log in the **VLAB,** if required**.**
- After log in, go through the instructions before operating the simulator.
- Observe and follow any warning if given.
- Do read the theoretical information/ concept for better understanding.
- place the required model instruments as per specified features.
- Care should be taken while plotting the best-fit line in the graph.
- **After completion of experiment shut down the system properly**.

Related to Data:

- Record every spectral line wavelength precisely from the simulation.
- While using Rydberg formula, ensure $n_2 > n_1$ otherwise we get a negative λ.
- Convert all wavelengths to metres (1 nm = 10^{-9} m) before substituting into the Rydberg formula. R_H is in m^{-1}.
- The energy level diagram must be drawn to scale. Use the formula $E_n = -13.6/n^2$ eV to different energy levels and draw vertical lines for transitions.

X. Experimental Procedure (Virtual Lab)

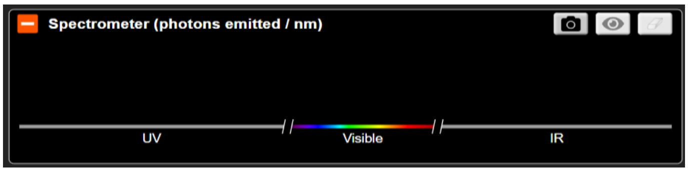
1. Open Simulation: Go to Hydrogen Emission Spectrum - PhET Interactive Simulations for Hydrogen Atom Spectra using Bohr model and follow the steps described in 2. VLAB section of VII. Experimntal Set-up and get the screen shown in Fig. 14.06.Then select Bohr under Model section. You can easily look the screen (Fig 14.07) in which an electron is revolving around the proton. The revolution of electron is taking place in Orbit 1 which is also manifested in Electron Energy Level where an electron is seen in energy level n = 1.



Courtesy: PhET Interactive Simulations

Fig. 14.07 Electron revolving around the nucleus(proton) in H_1^1

2. Now press on + sign of Spectrometer. The spectrometer window opens in which three ranges – Ultraviolet UV, Visible and Infrared IR becomes visible.



3. The *speed* of photons emitted by the Photon Gun (on the left side: bottle like appearance with a red-coloured circular button) can be controlled using three modes of Speed Controller- Fast, Normal, Slow. Better to use Normal mode of speed.

4. As you press the Normal button of Speed Controller and Photon Gun in White mode, seven different types of photons in different colrs start moving towards the atom of Hydrogen.

5. When any photon strikes the electron of H-atom, it may transfer full or part of its energy to the electron. The electron may gain energy sufficiently high to go to the next higher energy level or may remain there with no change in its position.

6. If it gains enough energy to go to higher level, the electron may be seen to be at any higher energy level namely n = 2 or n= 3 or n= 4 or n =5 or n = 6. In this screenshot (Fig. 14.08) we observe that electron has gone to the higher energy level n = 5.

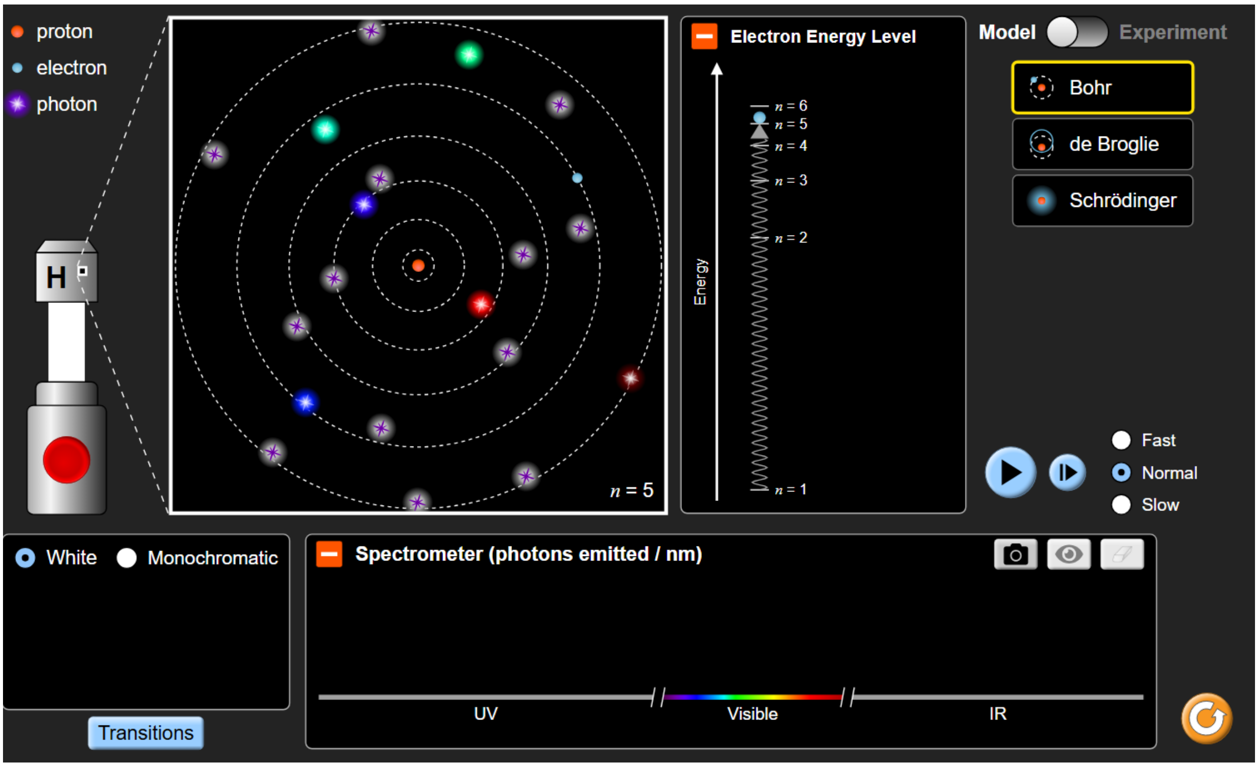


Fig. 14.08: Electron in Orbit 5 **Photo Credit: PhET Interactive Simulations**

7. As the electron is in n=5, it may come down the lower energy level n=4 or 3 or 2 or 1 by releasing photon of energy equal to the Energy Gap/ Energy Difference between the two levels.

8. If the electron comes back from any of the energy level $n \geq 2$ to the Energy Level $n = 1$, then the photon released has energy in UV range (Lyman Series). If the electron comes back from any of the energy level $n \geq 3$ to the Energy Level $n = 2$, then the photon released has energy in VISIBLE range (Balmer Series). If the electron comes back from any of the energy level $n \geq 4$ to the lower energy level, then the photon released has energy in IR range. One such photon is released in IR Range when the electron falls through n=5 to n=3 (Fig. 14.09).

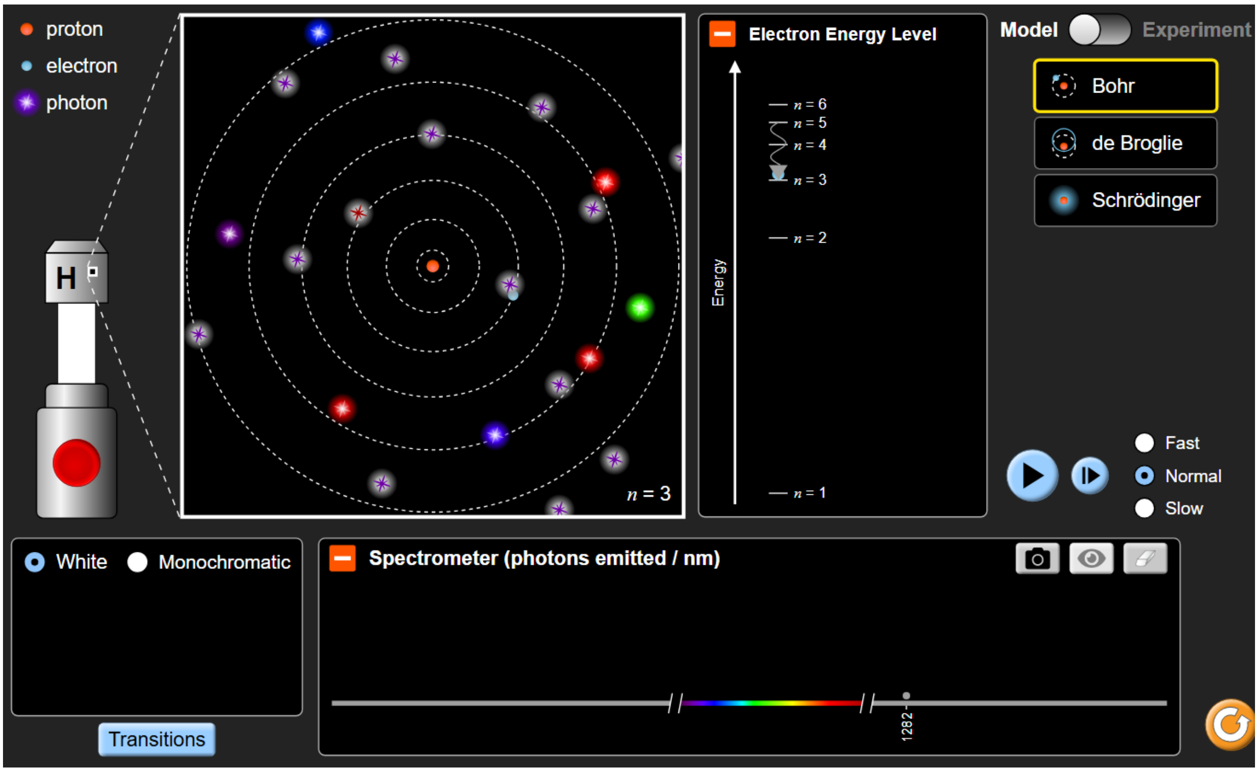


Photo Credit: PhET Interactive Simulations

Fig. 14.09: Falling of electron through n=5 to n=3

9. As our interest lies in the visualization of the Emission Spectra in VISIBLE range, so we have to consider those events in which electron falls to Energy Level **n=2 (or Orbit 2)** from any of the higher orbits. Considering this, some of the snapshots captured are provided for better visualization of the events. In Fig. 14.10, we see that the jumping of electron from Orbit 4 to Orbit 2 gives rise to the emission of photon H_β (electromagnetic radiation) of wavelength $\lambda = 486$ nm resulting in 2nd spectral line. Here it appears as ball in cyan colour (bright, greenish-blue colour) in Spectrometer reading and emission of radiation (waveform in cyan colour) under Electron Energy Level icon. Reord the reading.

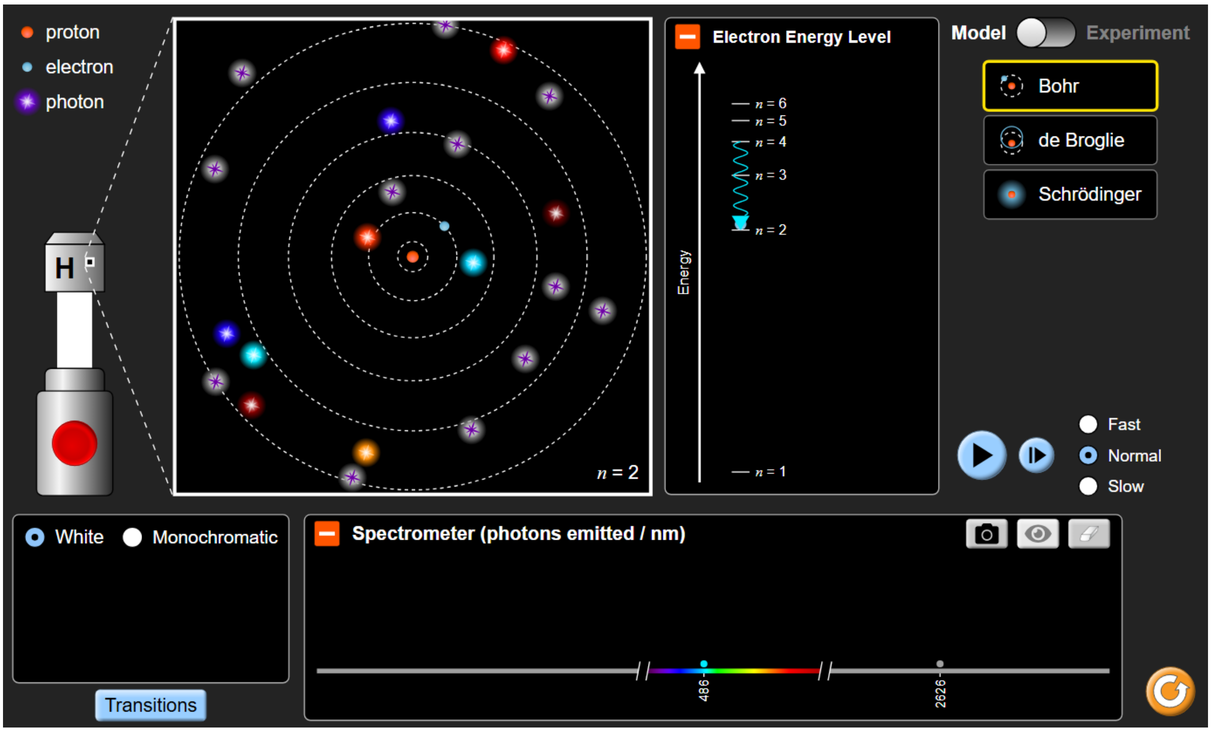


Photo Credit: PhET Interactive Simulations

Fig. 14.10: Falling of electron through n=4 to n=2 and Creation of Photon in cyan colour

10. When the electron jumps from Orbit 3 to Orbit 2 (Fig. 14.11), it loses energy and emits a photon (H_α) of wavelength 656 nm, in red colour, which can be seen easily as red wave-form under Electron Energy Level icon and in the form of a red ball in the Spectrometer reading in visible range.This creats 1st line in visble spectrum.

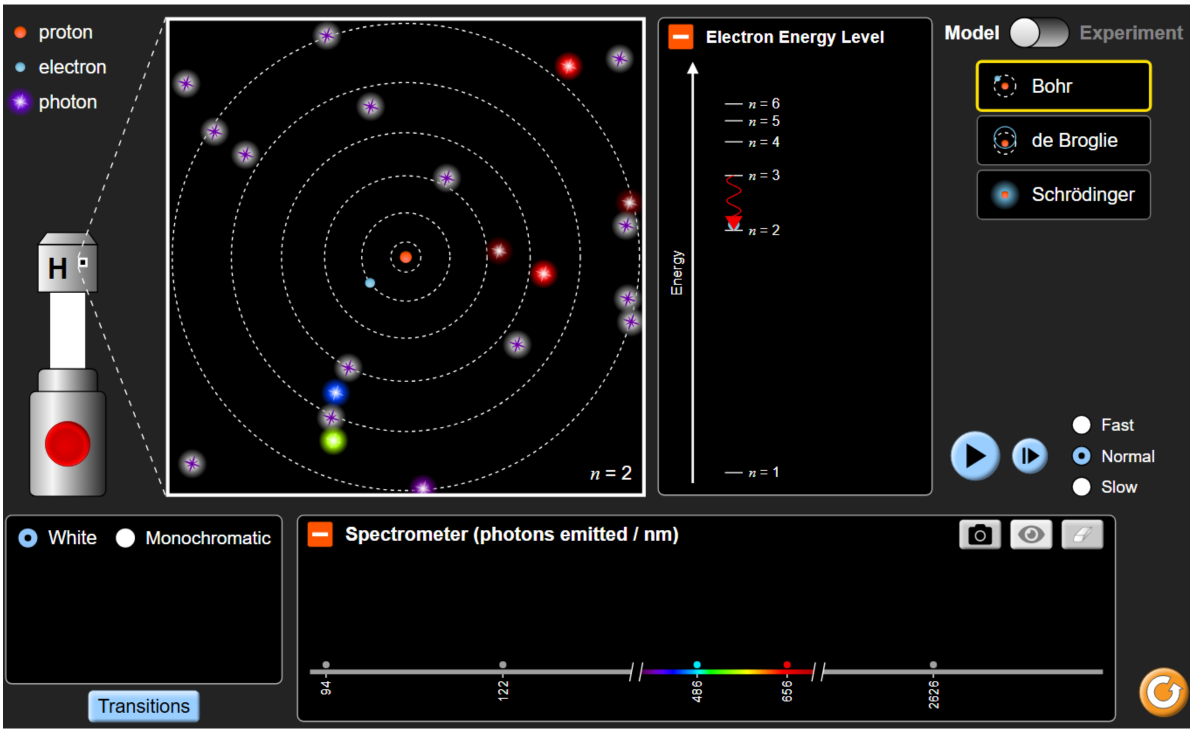


Photo Credit: PhET Interactive Simulations

Fig. 14.11: Falling of electron through n=3 to n=2

11. In Fig. 14.12, we see the jumping of electron from Orbit 5 to Orbit 2 and creation of a photon (H_γ) in violet colour having wavelength λ = 434 nm. This is the 3rd line of Visible spectrum. Record all the values.

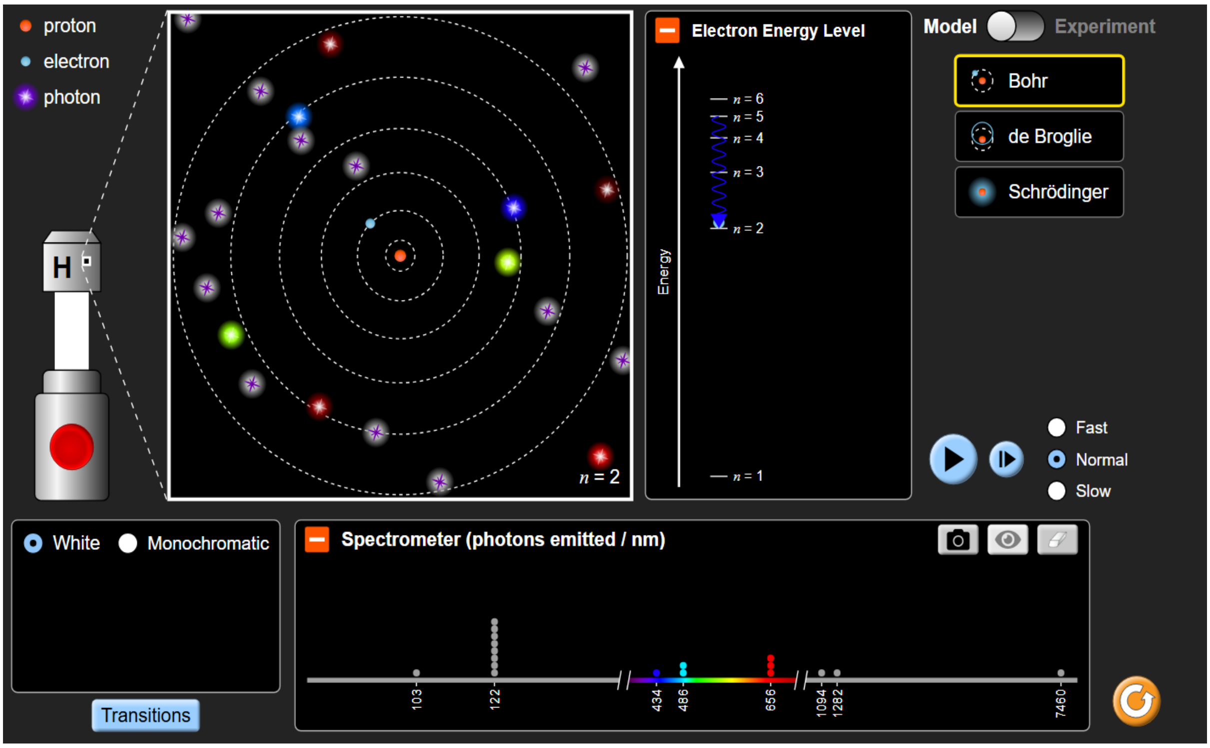


Photo Credit: PhET Interactive Simulations

Fig. 14.12: Falling of electron through n=5 to n=2

12. We can easily see in this snapshot (Fig. 14.13) the release of photon H_δ (violet, λ = 410 nm) when the electron transits from n=6 to n=2. This is the fouth line in Visible spetctrum.

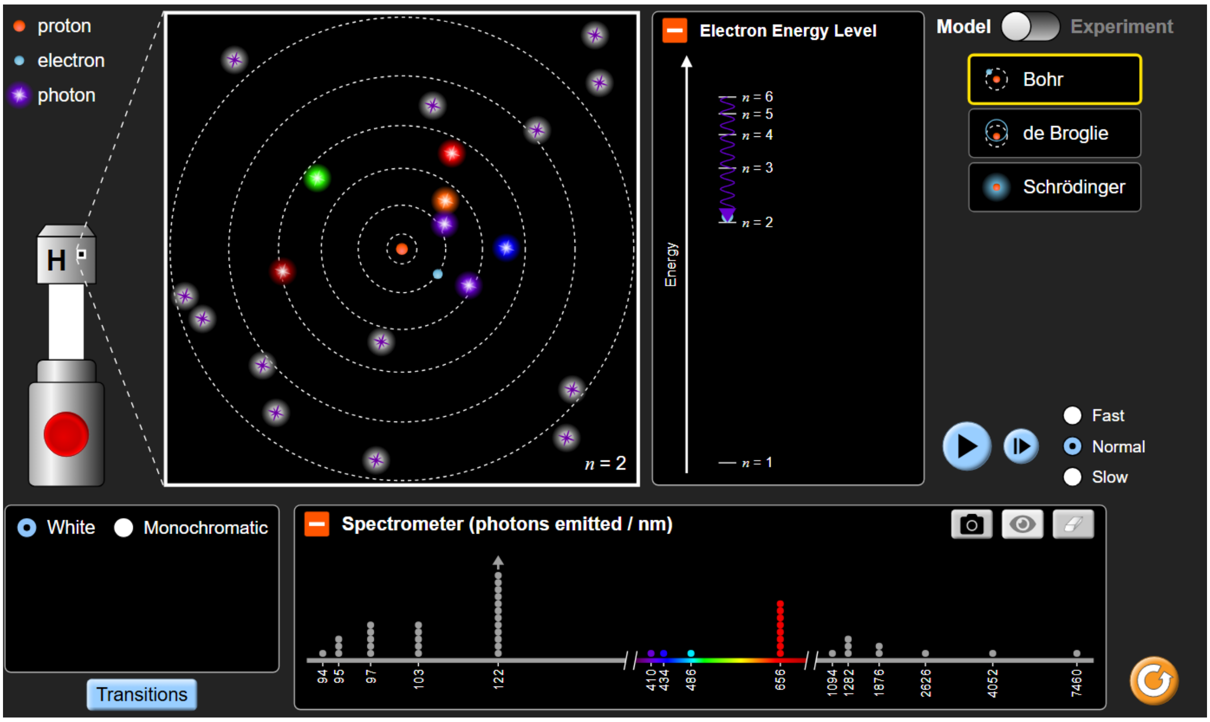


Photo Credit: PhET Interactive Simulations

Fig. 14.13: Falling of electron through n=6 to n=2

13. These obsevations can be written categorically in tabular form to **calculate Rydberg constant** R_H individually using the formula: $\mathbf{R_H = (1/\lambda)/(1/n_1^2 - 1/n_2^2)\ (m^{-1})}$ **.**

14. Draw Energy Level Diagram: On graph paper, draw horizontal lines at energies $E_n = -13.6/n^2$ eV for n = 1 to 6. Draw arrows for each Balmer transition and label with wavelength and colour.

XI. Observations and Calculations

Balmer Series: n_1 = 2 (lower level) for all lines.

Table 14.02: Wavelengths of Hydrogen Balmer Series Lines

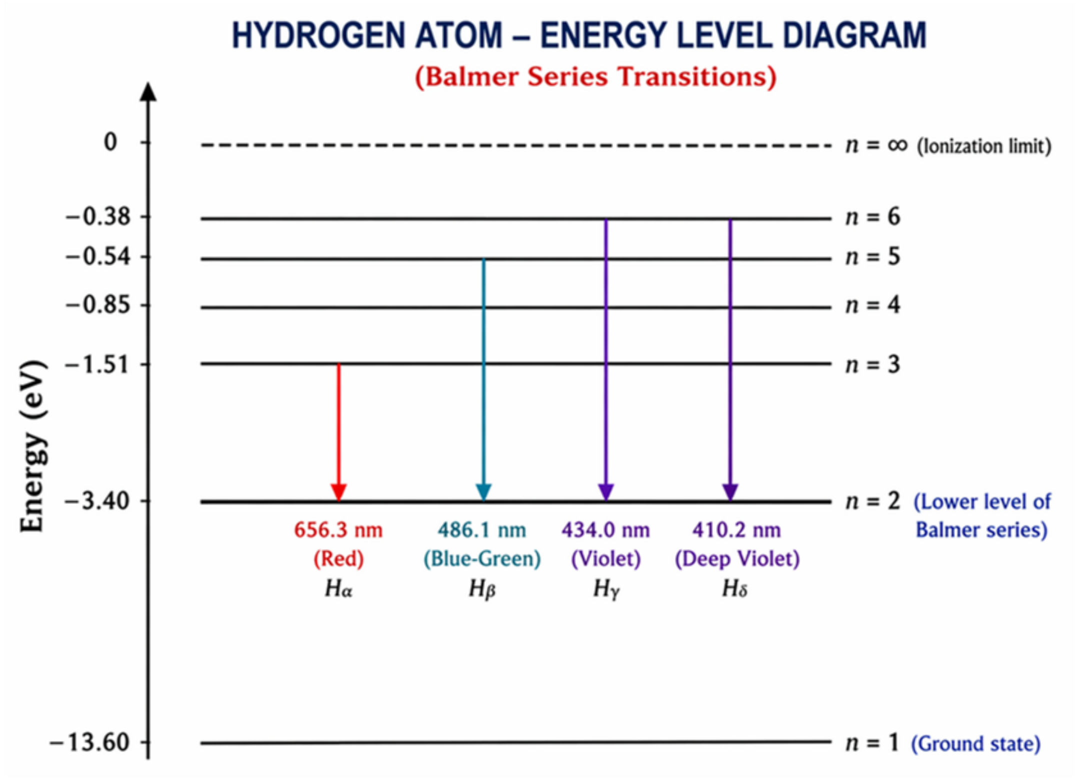
S. No.	Transition	Colour	λ (nm)	1/λ (m^{-1})	$1/n_1^2 - 1/n_2^2$	$R_H = (1/\lambda)/(1/n_1^2 - 1/n_2^2)$ (m^{-1})
1	n=3 → 2	Red (H_α)	656.3	1.524×10^7	0.13889	1.097×10^7
2	n=4 → 2	Blue-Green (H_β)	486.1	2.057×10^7	0.18750	1.097×10^7
3	n=5 → 2	Violet (H_γ)	434.0	2.304×10^7	0.21000	1.097×10^7
4	n=6 → 2	Deep Vio (H_δ)	410.2	2.438×10^7	0.22222	1.097×10^7

Mean Rydberg's Constant $R_H = 1.097 \times 10^7\ m^{-1}$

Standard Value of $R_H = 1.0974 \times 10^7\ m^{-1}$

Percentage Error $= \frac{Calculated\ Value - Standard\ Value}{Standard\ value} \times\ 100\%$

$= \frac{(1.0974\ -\ 1.097)}{1.0974} \times\ 100$ = 0.04% (Excellent agreement)



XII. Results

- **Hα (Red):** Measured: 656.3 nm | Theoretical: 656.3 nm | Error: 0.00%
- **Hβ (Blue-Green):** Measured: 486.1 nm | Theoretical: 486.1 nm | Error: 0.00%
- **Hγ (Violet):** Measured: 434.0 nm | Theoretical: 434.0 nm | Error: 0.00%
- **Hδ (Deep Violet):** Measured: 410.2 nm | Theoretical: 410.2 nm | Error: 0.00%
- **Rydberg's Constant:** R_H = $1.097 \times 10^7\ m^{-1}$ (Experimental) vs $1.0974 \times 10^7\ m^{-1}$ (Standard)

XIII. Interpretation of Results and Conclusions

The virtual lab experiment on hydrogen emission spectra demonstrates with perfect clarity that atomic emission is not continuous but consists of discrete lines at specific wavelengths. All four visible Balmer series lines are unambiguously identified and their wavelengths agree exactly with Rydberg's formula (error < 0.1%). The experimental value of Rydberg's constant $R_H = 1.097 \times 10^7\ m^{-1}$ matches the standard value to within 0.04%, validating both Bohr's model and the quantum mechanical treatment of the hydrogen atom. The energy level diagram visually reinforces the concept of quantised atomic energy states.

XIV. Practical Related Questions

1. Using Bohr's model, derive the expression for the wavelength of lines in the Balmer series.
2. Calculate the wavelength of the first line (Hα) of the Lyman series. In which region of the electromagnetic spectrum does it lie?

3. What is Rydberg's constant? What are its units and numerical value? How is it related to fundamental constants?
4. An electron jumps from n = 4 to n = 2 in hydrogen. Calculate the energy of the emitted photon in eV and the wavelength in nm.
5. Why are there no visible spectral lines from the Lyman series ($n_1 = 1$)? What would you need to observe them?
6. Draw an energy level diagram for hydrogen showing transitions for Lyman, Balmer, and Paschen series.

XV. Suggested Activities

- Use the NIST database (https://physics.nist.gov/asd) to look up spectral lines for Helium, Neon, and Mercury and compare their spectral complexity with hydrogen.
- Using the energy level diagram, predict and calculate the wavelength of the first line of the Brackett series ($n_1 = 4$, $n_2 = 5$).
- Learn different models of H-atom and its spectra using different simulations of different VLABs.
- By changing size of the radius of different orbits using model in Bohr Model Simulation , draw spectral lines for different radii. Notice the change in wavelength, if any.
- Using Hydrogen Atom Models | Simulations4All learn motion of electron in different orbitals in different different models.

XVI. References for Further Reading

- Halliday, Resnick & Walker. Fundamentals of Physics (10th Ed.). Wiley. Chapter 40: Hydrogen Atom.
- Verma, H.C. Concepts of Physics – Part II. Bharati Bhawan. Chapter on Bohr's Model.
- Atkins, P. Physical Chemistry (10th Ed.). OUP. Chapter on Atomic Structure.
- Hydrogen Atom Models | Simulations4All for Emission and Absorption Spectra of Hydrogen atom
- Bohr Model Simulation for Emission and Absorption Spectra of Hydrogen atom
- 12.3 Hydrogen Spectrum Simulation | 1Mole
- Models of the Hydrogen Atom Bohr Model Simulator: Interactive Hydrogen Spectrum & Energy Levels Lab - Luminous Learner
- Hydrogen Atom Simulator (NAAP)
- Atomic Spectra of Hydrogen and red shift for the change in position of red shift with the change in frequency/ wavelength or due to transition in energy levels
- https://physics.nist.gov/asd — NIST Atomic Spectra Database (reference wavelengths).

XVII. Rubric for Assessment

Table 14.03: Assessment Rubric for Experiment 14

Sr. No.	Indicator	Excellent (4)	Good (3)	Basic (2)	Poor (1)
1	Conceptual Clarity	Clear explanation	Good, minor gap	Basic understanding	Unable to explain
2	System Handling	Perfect, safe, accurate	Minor error, self-corrected	Needs assistance	Incorrect handling
3	Procedure Followed	All steps in systematic order	Minor lapse	Incomplete	Not done / unsafe
4	Data & Calculations	Accurate, error < 2%	Minor computation error	Major error	Not calculated
5	Graph / Conclusion	Correct graph, valid inference	Partial graph/inference	Weak conclusion	No graph/conclusion

Appendix

Motivation for the quest of atomic parameters

For excellent visualization of electron probability density clouds and radial distribution functions of orbiting electrons in different orbits/orbitals (n,l,m) in different Hydrogen Atom Models, it is suggested to open Hydrogen Atom Models | Simulations4All . You will surely enjoy when you explore this simulation. Some of the beautiful events captured are presented before you to delve into the fascinating world of Quantum Physics with special reference to H-Atom.

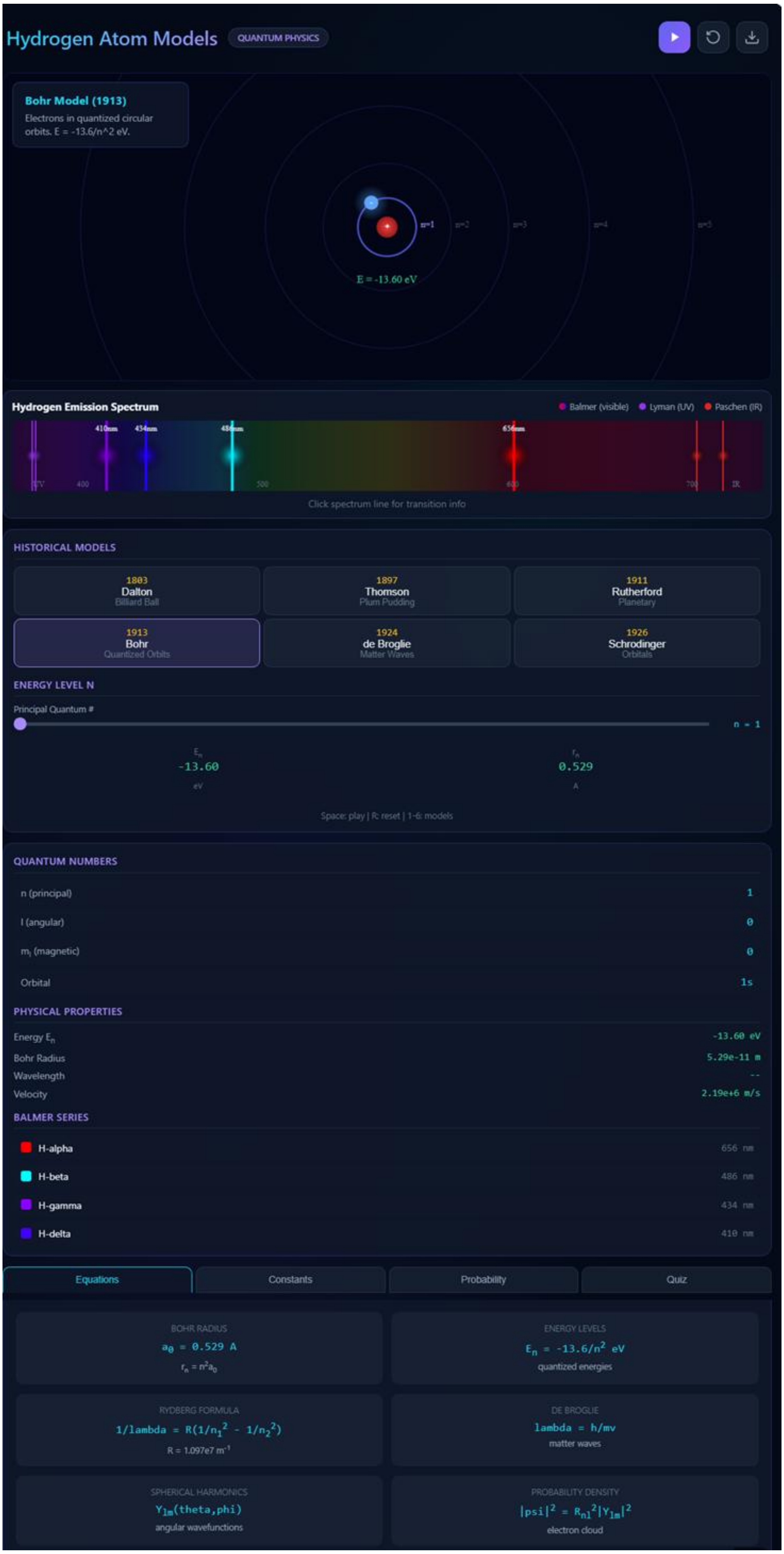

Hydrogen Atom Models
QUANTUM PHYSICS
Bohr Model (1913)
Electrons in quantized circular orbits. E = -13.6/n^2 eV.
n=1
n=2
n=3
n=4
n=5
E = -13.60 eV
Hydrogen Emission Spectrum
Balmer (visible)
Lyman (UV)
Paschen (IR)
410nm
434nm
486nm
656nm
UV
400
500
600
700
IR
Click spectrum line for transition info
HISTORICAL MODELS
1803 Dalton Billiard Ball
1897 Thomson Plum Pudding
1911 Rutherford Planetary
1913 Bohr Quantized Orbits
1924 de Broglie Matter Waves
1926 Schrodinger Orbitals
ENERGY LEVEL N
Principal Quantum #
n = 1
E_n -13.60 eV
r_n 0.529 A
Space: play | R: reset | 1-6: models
QUANTUM NUMBERS
n (principal) 1
l (angular) 0
m_l (magnetic) 0
Orbital 1s
PHYSICAL PROPERTIES
Energy E_n -13.60 eV
Bohr Radius 5.29e-11 m
Wavelength --
Velocity 2.19e+6 m/s
BALMER SERIES
H-alpha 656 nm
H-beta 486 nm
H-gamma 434 nm
H-delta 410 nm
Equations
Constants
Probability
Quiz
BOHR RADIUS
a0 = 0.529 A
r_n = n^2 a0
ENERGY LEVELS
E_n = -13.6/n^2 eV
quantized energies
RYDBERG FORMULA
1/lambda = R(1/n1^2 - 1/n2^2)
R = 1.097e7 m^-1
DE BROGLIE
lambda = h/mv
matter waves
SPHERICAL HARMONICS
Ylm(theta,phi)
angular wavefunctions
PROBABILITY DENSITY
|psi|^2 = Rnl^2|Ylm|^2
electron cloud

Photo credit: Hydrogen Atom Models | Simulations4All

Fig.14.06 Bohr model depicting energy, radius, and other parameters- Electron revolving in 1s orbital Energy Level n=1, l=0, m_l=0

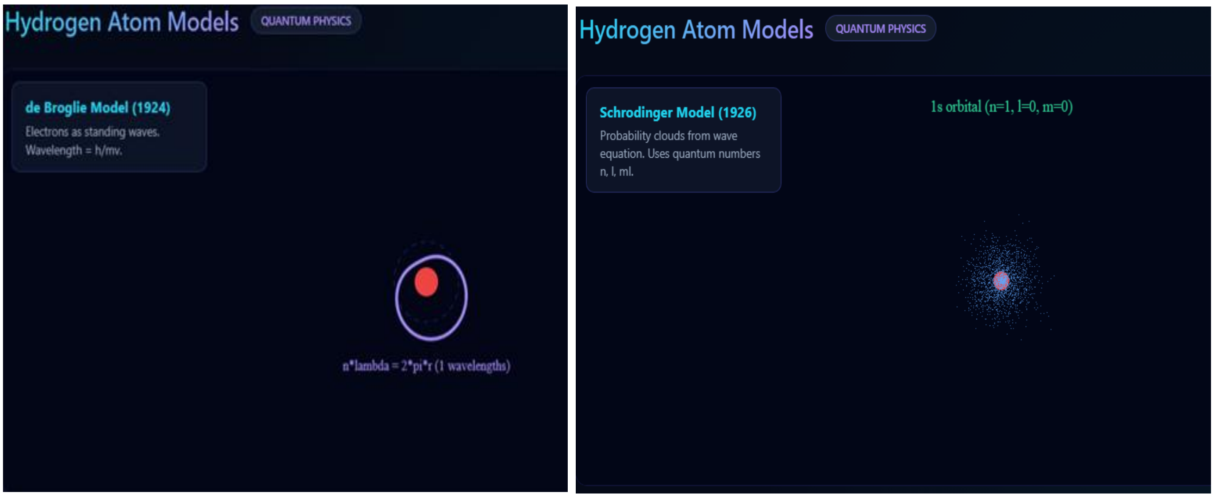


Photo credit: Hydrogen Atom Models | Simulations4All

Fig.14.07: de Broglie and Schrodinger Models of 1s Orbital State of H-atom

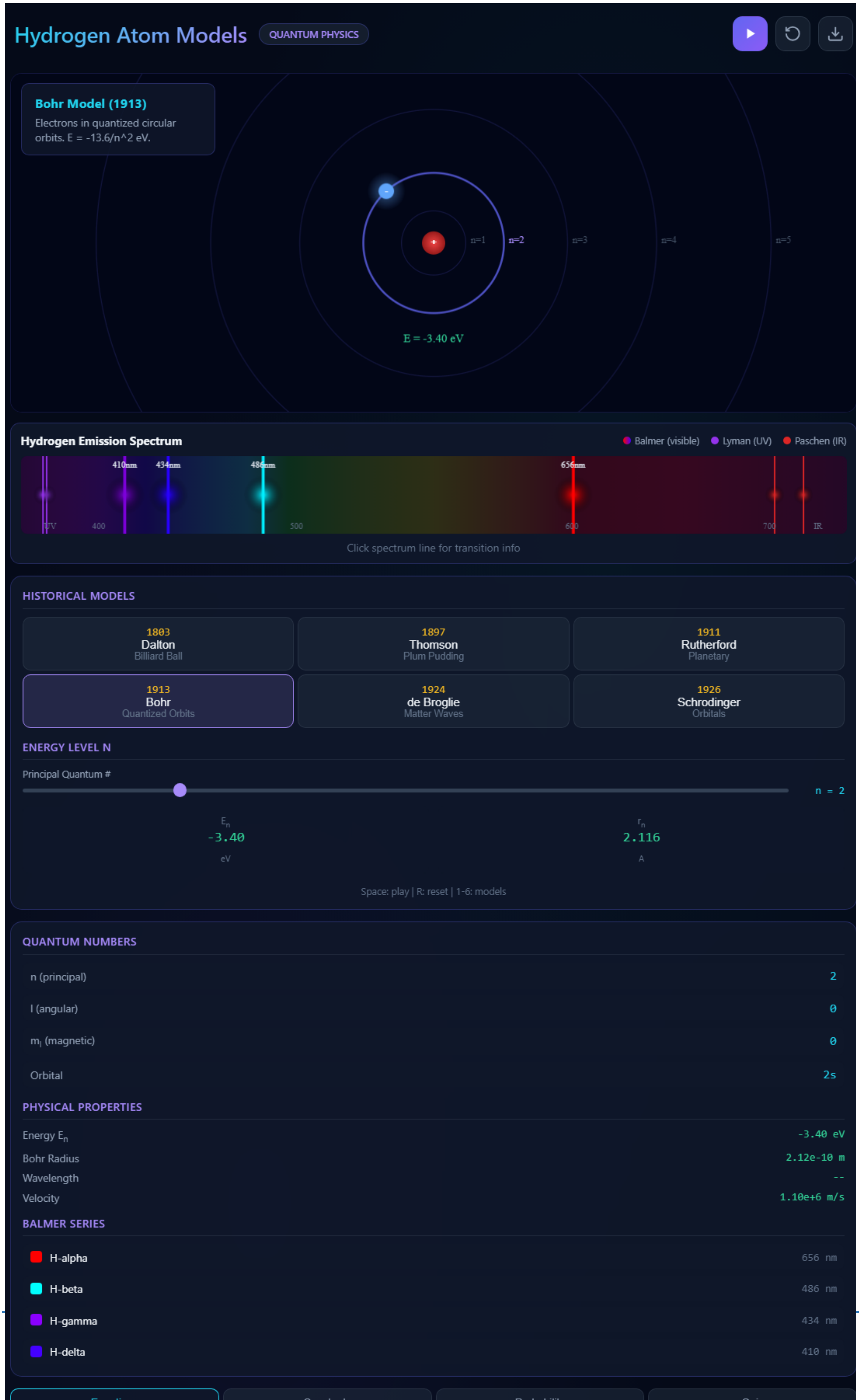

Hydrogen Atom Models
QUANTUM PHYSICS
Bohr Model (1913)
Electrons in quantized circular orbits. E = -13.6/n^2 eV.
n=1
n=2
n=3
n=4
n=5
E = -3.40 eV
Hydrogen Emission Spectrum
Balmer (visible)
Lyman (UV)
Paschen (IR)
410nm
434nm
486nm
656nm
UV
400
500
600
700
IR
Click spectrum line for transition info
HISTORICAL MODELS
1803
Dalton
Billiard Ball
1897
Thomson
Plum Pudding
1911
Rutherford
Planetary
1913
Bohr
Quantized Orbits
1924
de Broglie
Matter Waves
1926
Schrodinger
Orbitals
ENERGY LEVEL N
Principal Quantum #
n = 2
En
-3.40
eV
rn
2.116
A
Space: play | R: reset | 1-6: models
QUANTUM NUMBERS
n (principal) 2
l (angular) 0
ml (magnetic) 0
Orbital 2s
PHYSICAL PROPERTIES
Energy En -3.40 eV
Bohr Radius 2.12e-10 m
Wavelength --
Velocity 1.10e+6 m/s
BALMER SERIES
H-alpha 656 nm
H-beta 486 nm
H-gamma 434 nm
H-delta 410 nm

Photo credit: Hydrogen Atom Models | Simulations4All

Fig. 14.08 : Bohr Model:- Electron revolving in 2s Energy Level n=2, l=0, m_l=0

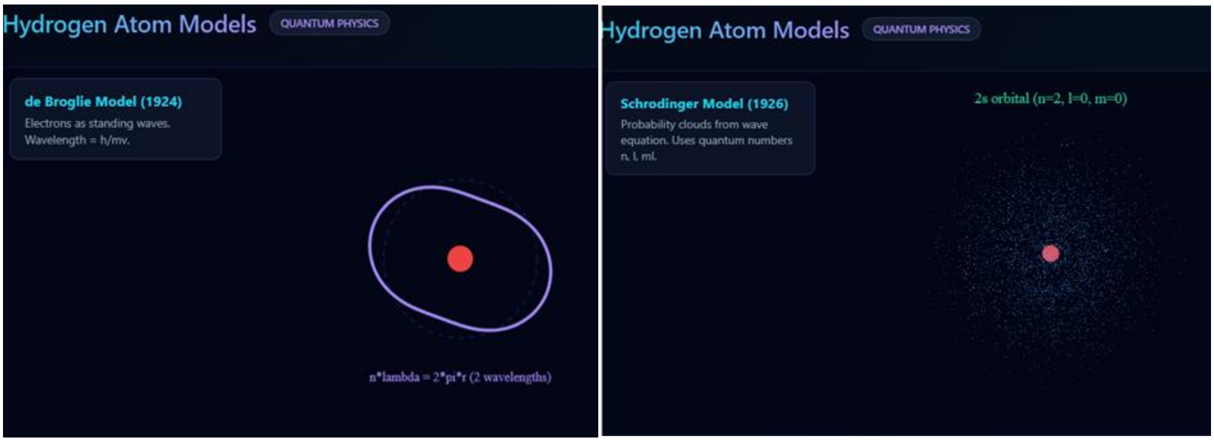


Photo credit: Hydrogen Atom Models | Simulations4All

Fig.14.09: de Broglie and Schrodinger Models of 2s Orbital State of H-atom

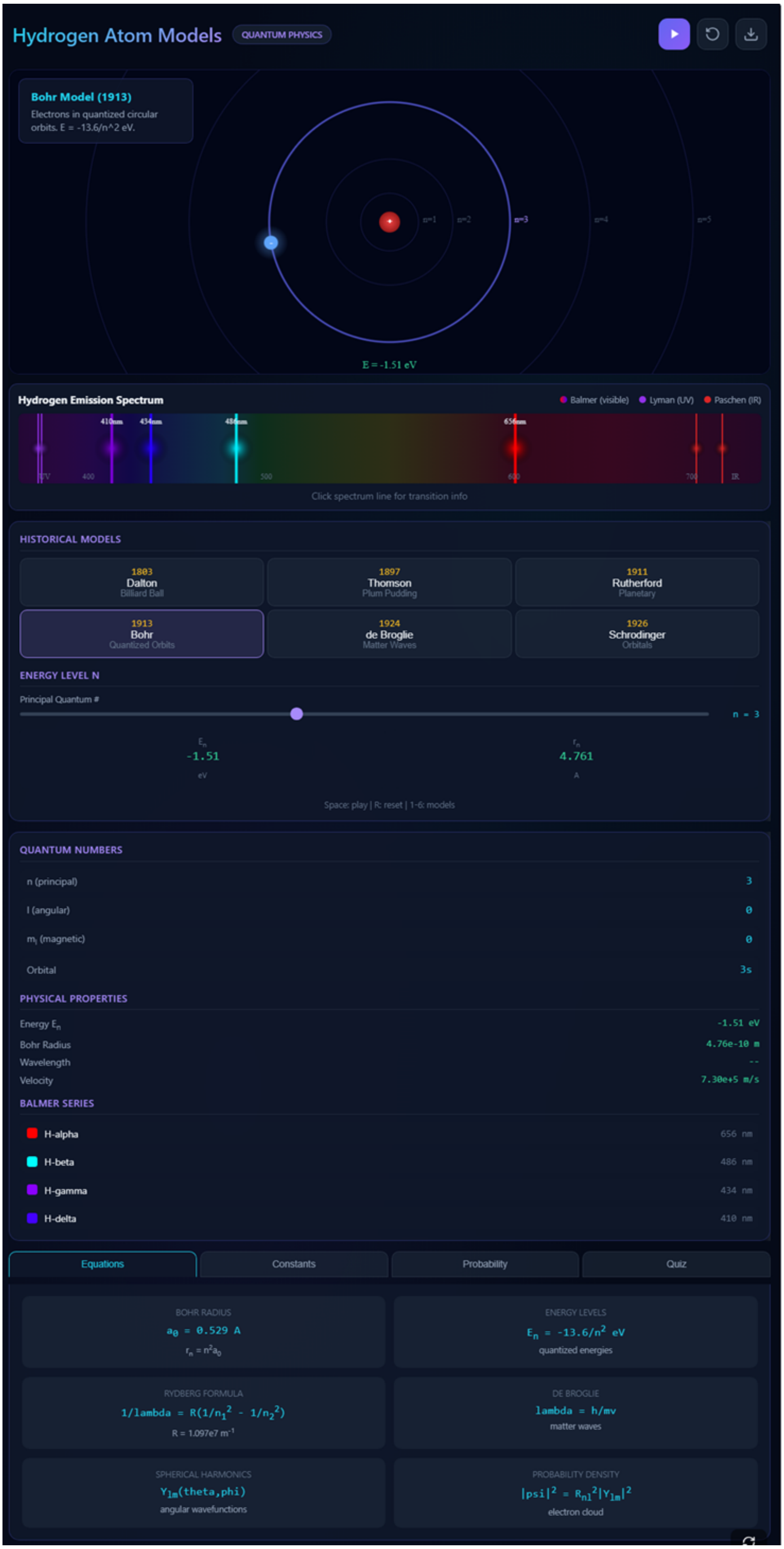

Hydrogen Atom Models
QUANTUM PHYSICS
Bohr Model (1913)
Electrons in quantized circular orbits. E = -13.6/n^2 eV.
n=3
E = -1.51 eV
Hydrogen Emission Spectrum
Balmer (visible)
Lyman (UV)
Paschen (IR)
410nm
434nm
486nm
656nm
400
500
600
700
IR
Click spectrum line for transition info
HISTORICAL MODELS
1803 Dalton Billiard Ball
1897 Thomson Plum Pudding
1911 Rutherford Planetary
1913 Bohr Quantized Orbits
1924 de Broglie Matter Waves
1926 Schrodinger Orbitals
ENERGY LEVEL N
Principal Quantum #
n = 3
-1.51
eV
4.761
A
Space: play | R: reset | 1-6: models
QUANTUM NUMBERS
n (principal) 3
l (angular) 0
m (magnetic) 0
Orbital 3s
PHYSICAL PROPERTIES
Energy E -1.51 eV
Bohr Radius 4.76e-10 m
Wavelength --
Velocity 7.30e+5 m/s
BALMER SERIES
H-alpha 656 nm
H-beta 486 nm
H-gamma 434 nm
H-delta 410 nm
Equations
Constants
Probability
Quiz
BOHR RADIUS
a0 = 0.529 A
rn = n²a0
ENERGY LEVELS
En = -13.6/n² eV
quantized energies
RYDBERG FORMULA
1/lambda = R(1/n1² - 1/n2²)
R = 1.097e7 m⁻¹
DE BROGLIE
lambda = h/mv
matter waves
SPHERICAL HARMONICS
Ylm(theta,phi)
angular wavefunctions
PROBABILITY DENSITY
|psi|² = Rnl²|Ylm|²
electron cloud

Photo credit: Hydrogen Atom Models | Simulations4All

Fig. 14.10: Bohr Model:- Electron revolving in 3s Energy Level n=3, l=0, m_l=0

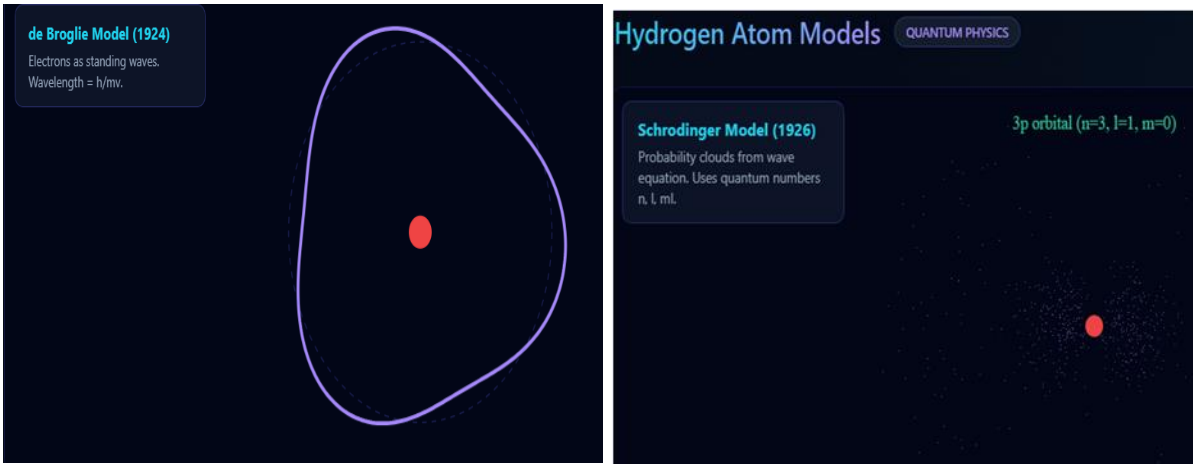


Photo credit: Hydrogen Atom Models | Simulations4All

Fig.14.11: de Broglie and Schrodinger Models of 3p (n=3, l=1, m_l=0)Orbital State of H-atom

THE END