Advanced Electricity & Magnetism Learning Lab

Lab Record & Viva-Voce Booklet

30 Experiments — printable, fill-by-hand observation, calculation, result and viva sheets
Companion to the interactive simulator and online User Guide

Student Name: _____

Roll / Enrolment No.: _____

Course & Section: _____

Academic Session: 2026–27

Invertis University, Bareilly, India
Prepared & maintained by Dr. S. K. Jain, Associate Professor in Physics, Department of Applied Sciences and Humanities, Invertis University, Bareilly, India
sanjeev.j@invertis.org

How to Use This Booklet

This booklet mirrors the 30 experiments in the online **User Guide** and the interactive simulator. For each experiment: run the simulator panel as instructed in the guide, record your readings directly in the observation table below, plot your graph on the provided 15×15 grid (choose your own scale per square), complete the calculation and result sections, work out the maximum permissible error using the least counts of the instruments you used, and prepare written answers to the viva-voce questions before your practical examination. Full theoretical background, governing formulas and step-by-step procedure for every experiment are available in the online guide — this booklet intentionally contains only the record-keeping sheets, not the theory, to keep it compact for printing.

Contents

1. Coulomb's Law & Force Between Point Charges
2. Electric Field & Potential Due to an Electric Dipole
3. Gauss's Law — Electric Flux Through Closed Surfaces
4. Capacitance of a Parallel-Plate Capacitor (With & Without Dielectric)
5. Charge Distribution on Conductors & the Van de Graaff Generator
6. Method of Images — Charge Near a Grounded Conducting Plane
7. Multipole Expansion — Linear Electric Quadrupole
8. Biot–Savart Law — Magnetic Field Due to a Current-Carrying Wire
9. Magnetic Field on the Axis of a Circular Coil & Helmholtz Coils
10. Ampere's Circuital Law — Field Inside a Solenoid & a Toroid
11. Force Between Two Parallel Current-Carrying Conductors
12. Magnetic Vector Potential of a Current Loop (Dipole Limit)
13. Crossed E & B Fields — Velocity Selector & Cyclotron Motion
14. Faraday's Law of Electromagnetic Induction
15. Motional EMF & Lenz's Law on a Sliding Rod
16. RC and RL Transient Circuits — Charging & Discharging
17. LCR Series Resonance & Quality Factor (Q)
18. Eddy-Current Damping — Lenz's Law Braking
19. RLC Filters — Low-Pass / High-Pass / Band-Pass Frequency Response
20. Poynting Vector & Power Flow in a Coaxial Cable
21. Maxwell's Equations & Plane Electromagnetic Wave Solutions
22. Propagation of EM Waves in Dielectric & Conducting Media (Skin Depth)
23. Reflection, Refraction & Brewster's Angle for EM Waves
24. Rectangular Waveguide — TE_{10} Mode & Cutoff Frequency
25. Transmission Lines — Characteristic Impedance, Reflection & VSWR
26. Electrostatic & EM Shielding Effectiveness of a Faraday Cage
27. Dielectric Polarization & the Clausius–Mossotti Relation

28. Magnetic Hysteresis & the B–H Curve of Ferromagnetic Materials
29. Hall Effect — Carrier Density & Sign of Charge Carriers
30. Meissner Effect — Flux Expulsion in a Superconductor

Coulomb's Law & Force Between Point Charges

Aim

To verify the inverse-square dependence of the electrostatic force between two point charges on their separation, and its direct proportionality to the product of the charges, using a torsion-balance style virtual setup.

Date performed: _____ Simulator panel used: _____

Formula Used

$F = q_1 q_2 / (4\pi\varepsilon_0 \varepsilon_r r^2)$

F = electrostatic force between the charges (N)
q_1, q_2 = the two point charges (C)
r = separation between the charges (m)
ε_r = relative permittivity of the surrounding medium

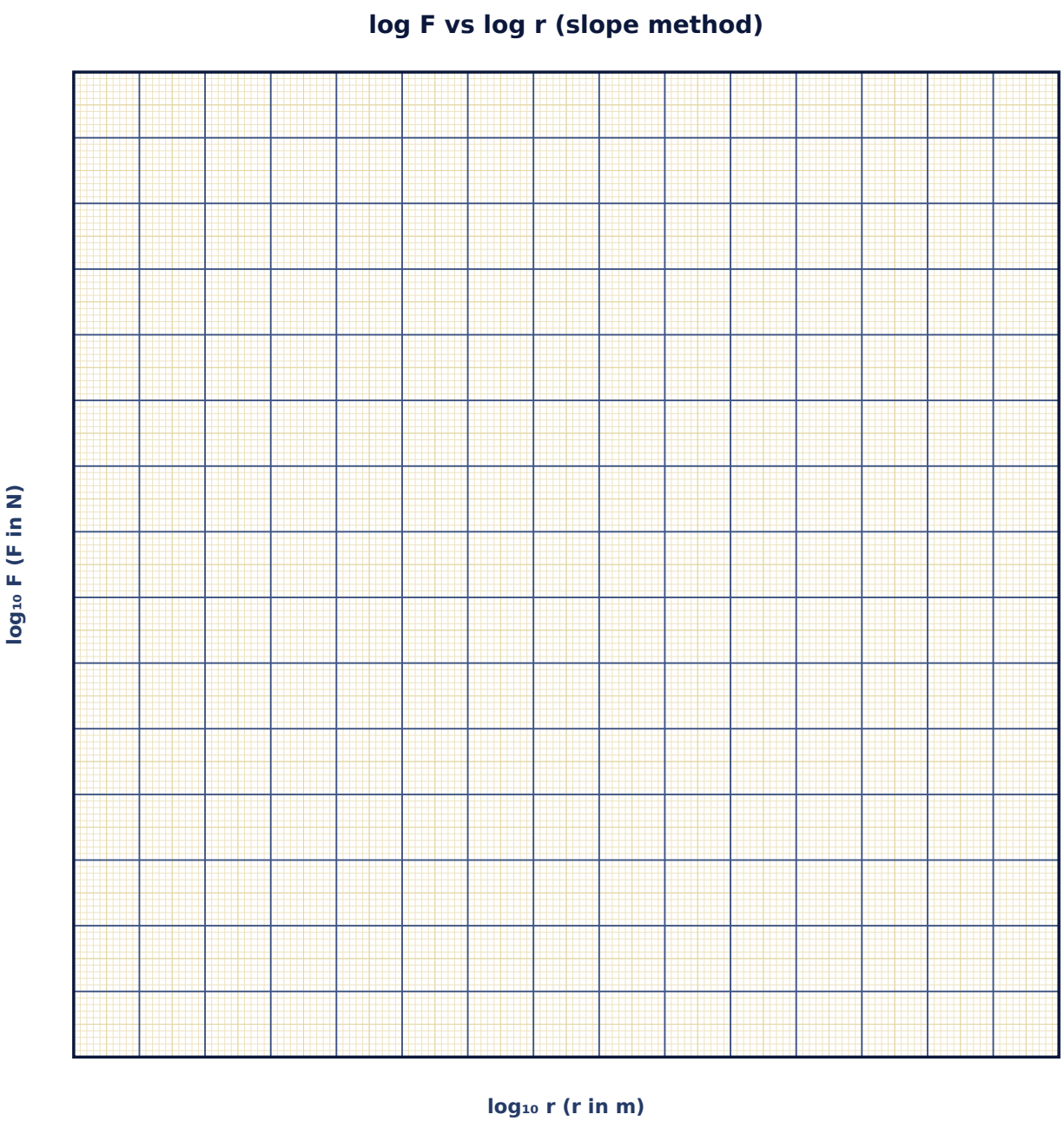
Labelled diagram of the experimental apparatus:

Observation Table

S. No.	Separation r (cm)	q_1 (nC)	q_2 (nC)	Force F ($\times 10^{-6}$ N)	log r	log F

S. No.	Separation r (cm)	q_1 (nC)	q_2 (nC)	Force F ($\times 10^{-6}$ N)	log r	log F

Graph



Calculation

Result

Quantity	Slope of log F vs log r	Expected value	% deviation

Maximum Permissible Error

Formula: $\Delta F/F = \Delta q_1/q_1 + \Delta q_2/q_2 + 2\Delta r/r$

$F \propto q_1 q_2/r^2$ is a product/quotient of measured quantities, with r entering squared, so its fractional error carries a factor of 2.

Quantity	Measured Value	Least Count (LC)
q_1 — Charge 1 (sign sets polarity) (nC)		
q_2 — Charge 2 (sign sets polarity) (nC)		
r — Separation (cm)		
εr — Medium relative permittivity		

Calculation of maximum permissible error:

Viva-Voce Questions

1. State Coulomb's law in vector form and explain each term.

2. Why does the electrostatic force obey an inverse-square law rather than, say, an inverse-cube law?

3. How does the force change if the experiment is repeated in a dielectric medium instead of vacuum?

4. Derive the electric field of a point charge starting from Coulomb's law.

5. Compare the magnitude of the electrostatic and gravitational forces between two electrons.

6. What is the principle of superposition, and how does it apply to a system of more than two charges?

Electric Field & Potential Due to an Electric Dipole

Aim

To compute and plot the electric field and potential of an electric dipole along its axial and equatorial lines, and to study the angular variation of the field at a fixed distance.

Date performed: _____ Simulator panel used: _____

Formula Used

$E_{axial} = 2kp / r^3$, $p = q \cdot (2a)$

E_{axial} = on-axis field of the dipole (N/C)
p = dipole moment
r = distance from the dipole centre

Labelled diagram of the experimental apparatus:

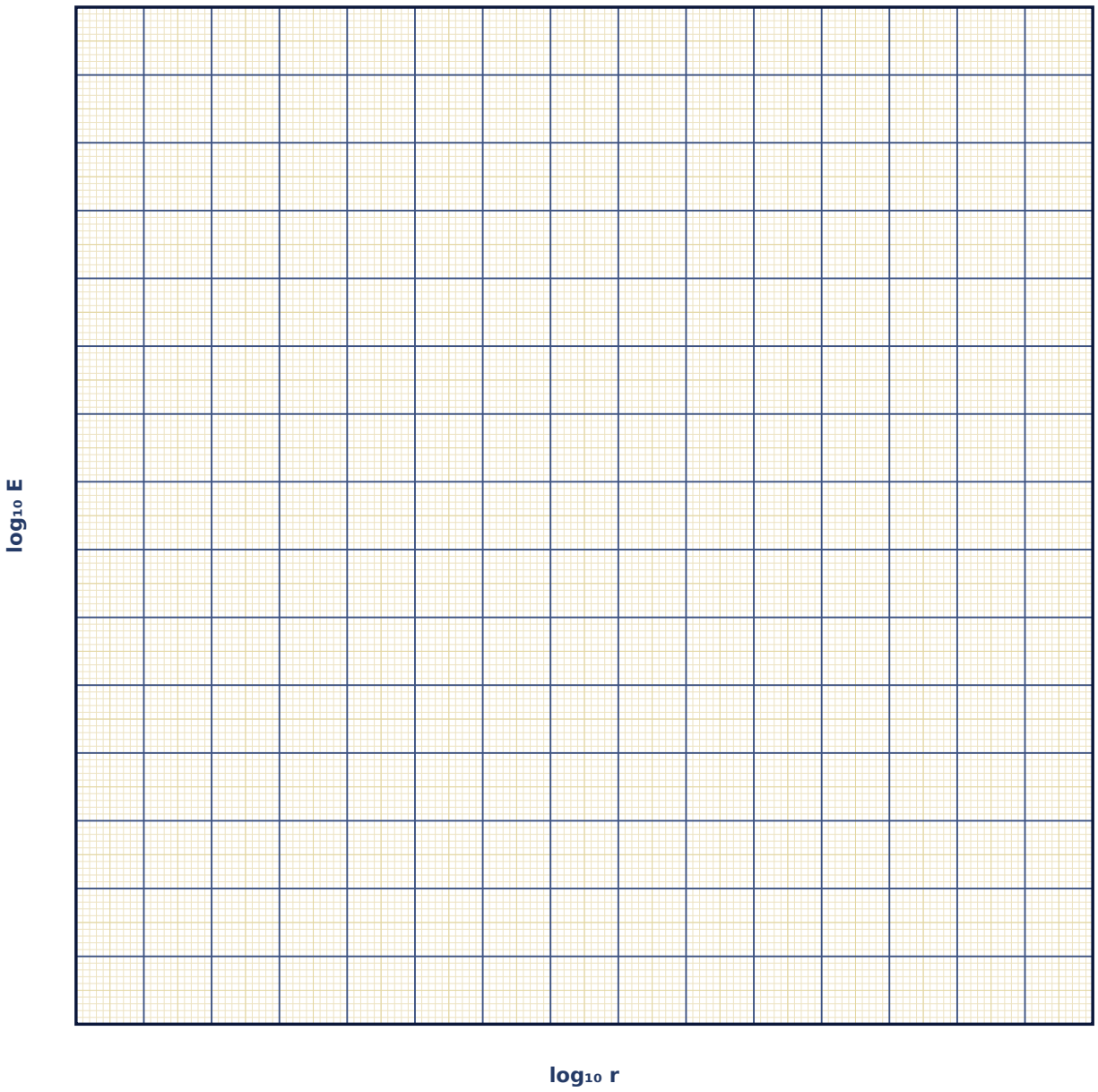
Observation Table

S. No.	θ (°)	r (cm)	Field E (N/C)	Potential V (volt)	log r	log E

S. No.	θ (°)	r (cm)	Field E (N/C)	Potential V (volt)	log r	log E

Graph

Axial Field E vs r (log-log)



Calculation

Result

Line	Field formula verified	Slope obtained	Expected slope

Maximum Permissible Error

Formula: $\Delta E/E = \Delta q/q + \Delta(2a)/(2a) + 3\Delta r/r$

$E_{axial} = 2kp/r^3$ with $p=q\cdot(2a)$ varies as r^{-3}, so its fractional uncertainty carries a factor of 3 from r.

Quantity	Measured Value	Least Count (LC)
q — Charge magnitude on each pole (sign flips the dipole) (nC)		
2a — Charge separation (cm)		
r — Probe distance (cm)		
θ — Probe angle from axis (°)		

Calculation of maximum permissible error:

Viva-Voce Questions

1. Why does the dipole field fall off as $1/r^3$ while a single point charge's field falls off as $1/r^2$?

2. Show that the potential on the equatorial line of a dipole is zero everywhere.

3. What is the torque on a dipole placed in a uniform external field, and at what orientation is it maximum?

4. Define dipole moment as a vector and state its SI unit.

5. How would the field pattern change for a linear quadrupole (two dipoles placed back-to-back)?

6. Explain the physical origin of polar molecules' permanent dipole moment (e.g. in water).

Gauss's Law — Electric Flux Through Closed Surfaces

Aim

To verify Gauss's law by computing the net electric flux through virtual closed Gaussian surfaces (sphere, cube, cylinder) enclosing a known charge, and to relate the flux to the field of standard symmetric charge distributions.

Date performed: _____ Simulator panel used: _____

Formula Used

$\Phi = Q_{enc} / \varepsilon_0$

Φ = total electric flux through the closed surface
Q_enc = net charge enclosed by the surface

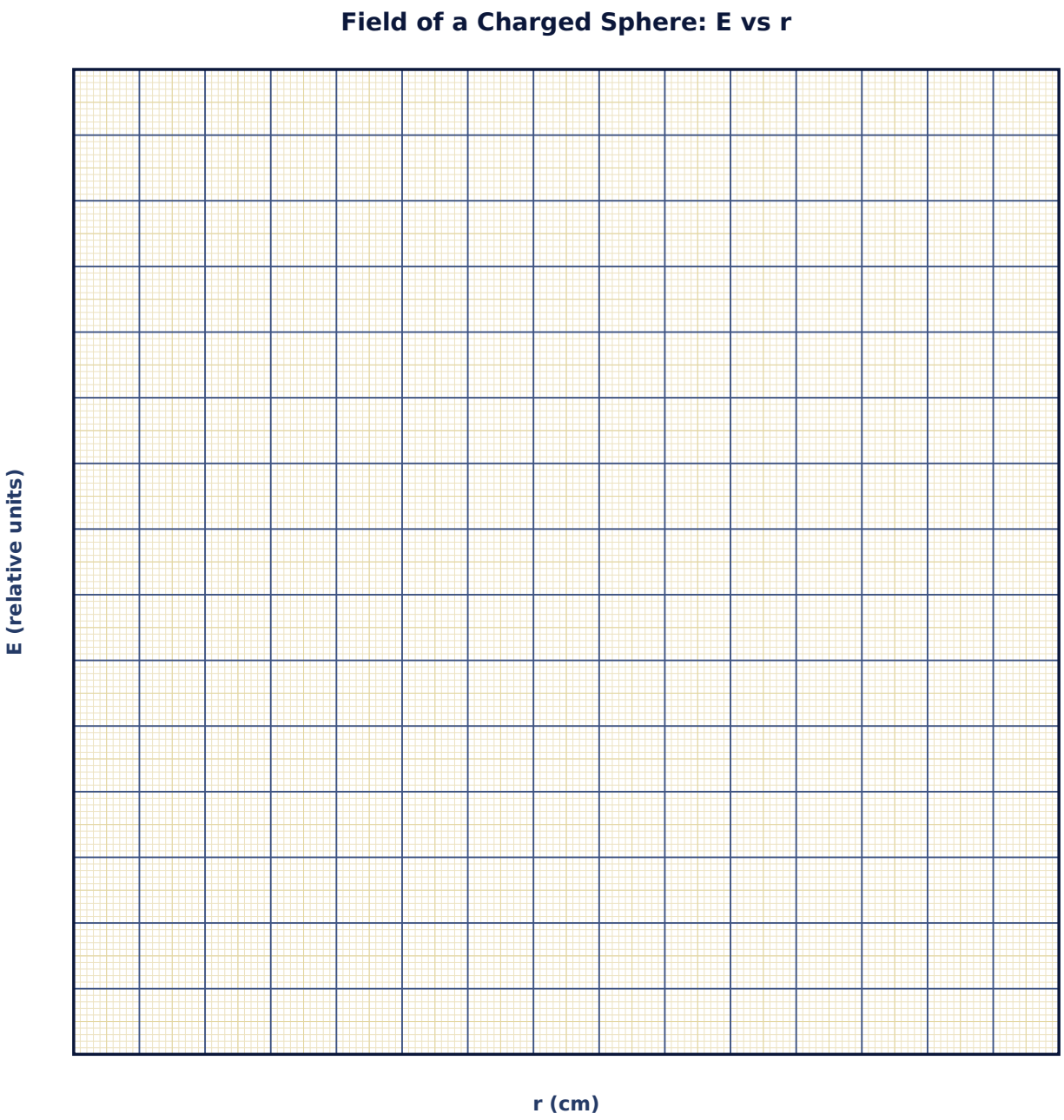
Labelled diagram of the experimental apparatus:

Observation Table

S. No.	Surface shape	Q_enc (nC)	Q_out (nC)	Computed flux Φ (N·m²/C)	Q_{enc}/ε_0 (theory)

S. No.	Surface shape	Q_enc (nC)	Q_out (nC)	Computed flux Φ (N·m²/C)	Q_enc/ε₀ (theory)

Graph



Calculation

Result

Case	Flux measured	Flux predicted (Q_enc/ε₀)	% deviation

Maximum Permissible Error

Formula: ΔΦ/Φ = ΔQ_enc/Q_enc

Since Φ = Q_enc/ε₀ with ε₀ an exact constant, the fractional error in flux equals the fractional error in the enclosed charge measurement.

Quantity	Measured Value	Least Count (LC)
Q_enc — Enclosed charge (nC)		
Q_out — Charge placed outside surface (nC)		
R — Gaussian sphere radius (cm)		

Calculation of maximum permissible error:

Viva-Voce Questions

1. State Gauss's law and explain why it is a direct consequence of Coulomb's law and the inverse-square dependence.

2. Why is Gauss's law most useful only for highly symmetric charge distributions?

3. Show that the field inside a uniformly charged spherical shell is exactly zero.

4. Derive the field of an infinite charged sheet using Gauss's law with a pillbox surface.

5. If a charge lies exactly on the Gaussian surface, how should it be treated?

6. How does Gauss's law extend to Gauss's law for magnetism ($\nabla \cdot B = 0$), and what does that imply physically?

Capacitance of a Parallel-Plate Capacitor (With & Without Dielectric)

Aim

To study the dependence of a parallel-plate capacitor's capacitance on plate area, plate separation, and an inserted dielectric slab, and to determine the dielectric constant of an unknown material.

Date performed: _____ Simulator panel used: _____

Formula Used

$$C = \varepsilon_0 \varepsilon_r A / d$$

C = capacitance (F)
A = plate area
d = plate separation
εr = relative permittivity of the dielectric, if present

Labelled diagram of the experimental apparatus:

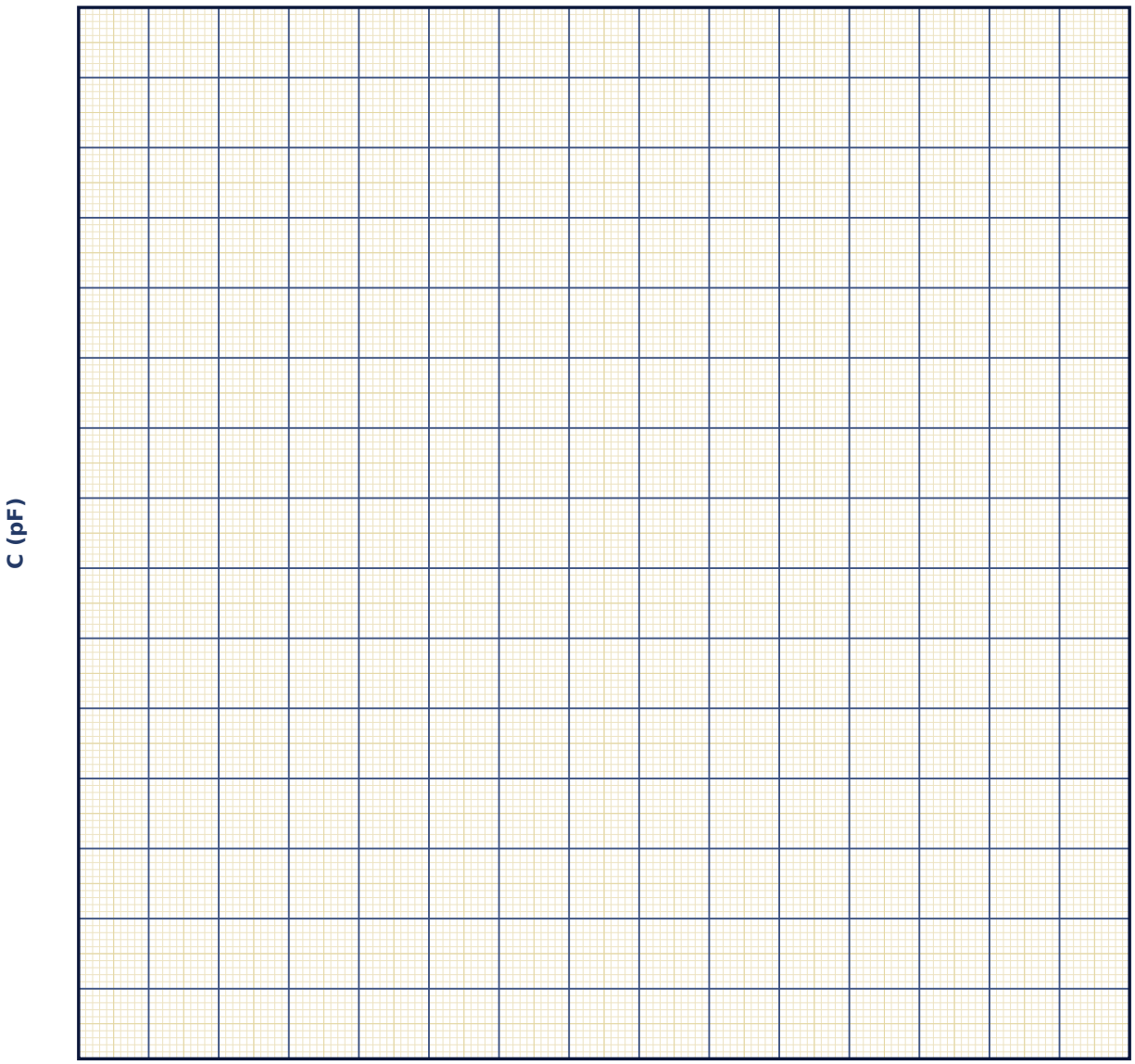
Observation Table

S. No.	d (mm)	A (cm²)	εr	Capacitance C (pF)	1/d (mm⁻¹)

S. No.	d (mm)	A (cm²)	εr	Capacitance C (pF)	1/d (mm⁻¹)

Graph

Capacitance vs 1/d



Calculation

Result

Dielectric material	Measured $\varepsilon_r = C/C_0$	Known/standard ε_r	% deviation

Maximum Permissible Error

Formula: $\Delta C/C = \Delta\varepsilon_r/\varepsilon_r + \Delta A/A + \Delta d/d$

$C = \varepsilon_r\varepsilon_0 A/d$ is a product/quotient of three measured quantities, so fractional errors add.

Quantity	Measured Value	Least Count (LC)
A — Plate area (cm^2)		
d — Plate separation (mm)		
ε_r — Dielectric constant		
V — Applied voltage (V)		

Calculation of maximum permissible error:

Viva-Voce Questions

1. Derive the capacitance of a parallel-plate capacitor from first principles using Gauss's law.

2. Why does inserting a dielectric always increase the capacitance, never decrease it?

3. Distinguish between the behaviour of a dielectric slab at constant charge versus constant voltage.

4. Define dielectric constant (relative permittivity) and polarization P; how are they related?

5. What is dielectric breakdown, and what determines a material's dielectric strength?

6. How would you find the capacitance of a capacitor with the gap only half-filled by a dielectric slab parallel to the plates?

Charge Distribution on Conductors & the Van de Graaff Generator

Aim

To study how charge distributes itself over the surface of conductors of different shapes at electrostatic equilibrium, and to understand the principle of the Van de Graaff generator for building up very high potentials.

Date performed: _____ Simulator panel used: _____

Formula Used

$\sigma = Q / A$ (surface charge density, varies with curvature)

σ = local surface charge density
Q = total charge on the conductor

Labelled diagram of the experimental apparatus:

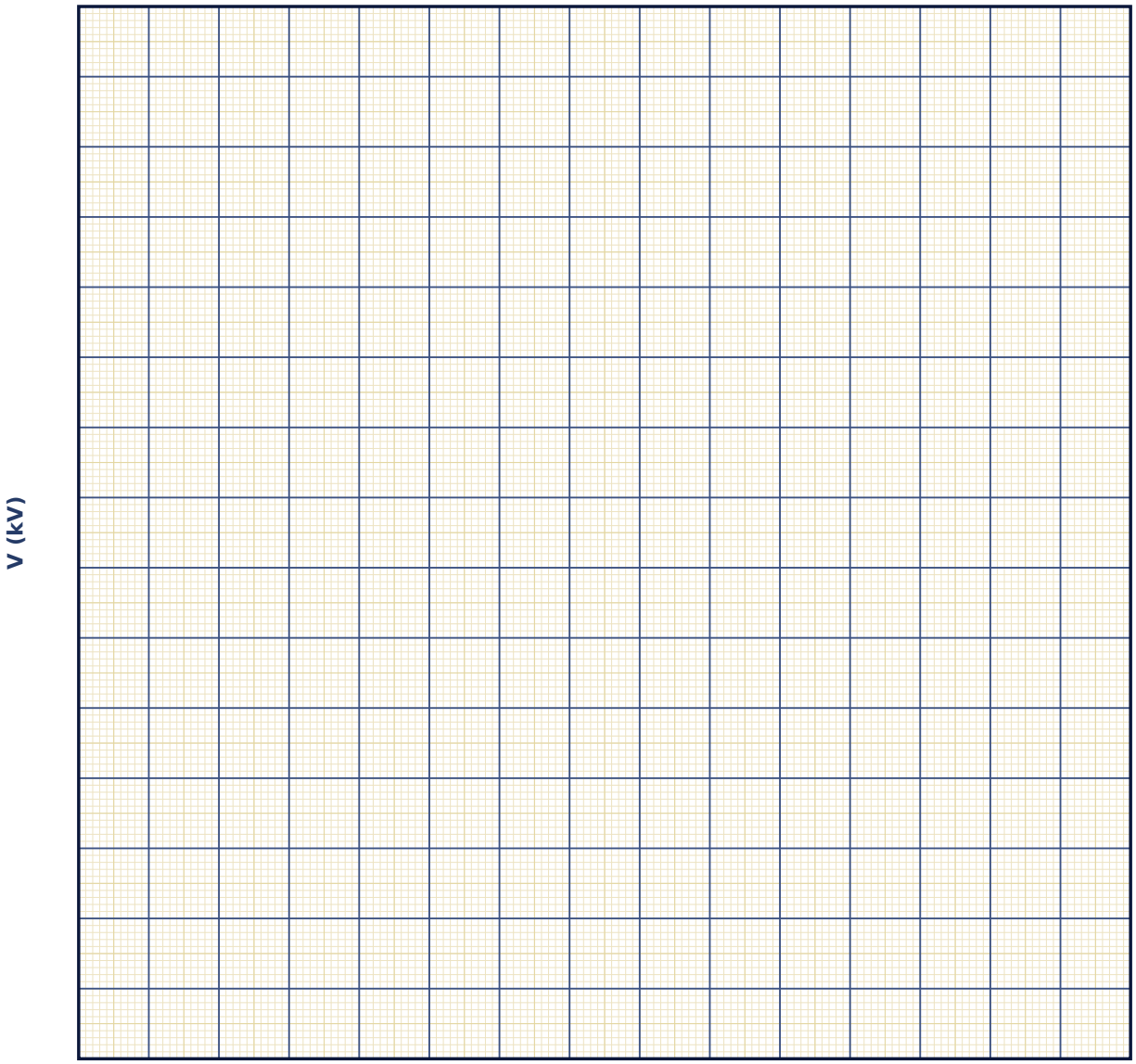
Observation Table

S. No.	Charging time t (s)	Rate (nC/s)	Total charge Q (nC)	Dome radius R (cm)	Dome potential V (kV)

S. No.	Charging time t (s)	Rate (nC/s)	Total charge Q (nC)	Dome radius R (cm)	Dome potential V (kV)

Graph

Dome Potential vs Charging Time



Calculation

Result

Quantity studied	Observed trend	Theoretical prediction	Agreement

Maximum Permissible Error

Formula: $\Delta V/V = \Delta\text{rate}/\text{rate} + \Delta t/t + \Delta R/R$

$V = kQ/R$ with $Q = \text{rate} \times t$ (charging rate times time), so fractional errors in rate, time and R all add.

Quantity	Measured Value	Least Count (LC)
R — Dome radius (cm)		
rate — Belt charging rate (nC/s)		
t — Charging time (s)		
r_tip — Test conductor tip radius (for point-discharge study) (mm)		

Calculation of maximum permissible error:

Viva-Voce Questions

1. Why must the electric field inside a conductor in electrostatic equilibrium be zero?

2. Explain why charge density is greatest at the sharpest points of a charged conductor.

3. How does a Van de Graaff generator manage to raise the dome to a very high potential regardless of the charge already present on it?

4. What is corona discharge and why does it limit the maximum achievable potential?

5. State the boundary condition on E just outside a charged conductor's surface in terms of σ.

6. Why is the interior of a hollow charged conductor field-free even if the shell is not spherical (Faraday cage)?

Method of Images — Charge Near a Grounded Conducting Plane

Aim

To use the method of images to compute the attractive force between a point charge and a nearby infinite grounded conducting plane, and to show that this force equals that between the real charge and an equal-and-opposite image charge at the mirror position.

Date performed: _____ Simulator panel used: _____

Formula Used

$$F = q^2 / (4\pi\varepsilon_0(2d)^2)$$

F = attractive force towards the grounded plane (N)
q = point charge magnitude (C)
d = height of the charge above the plane (m)

Labelled diagram of the experimental apparatus:

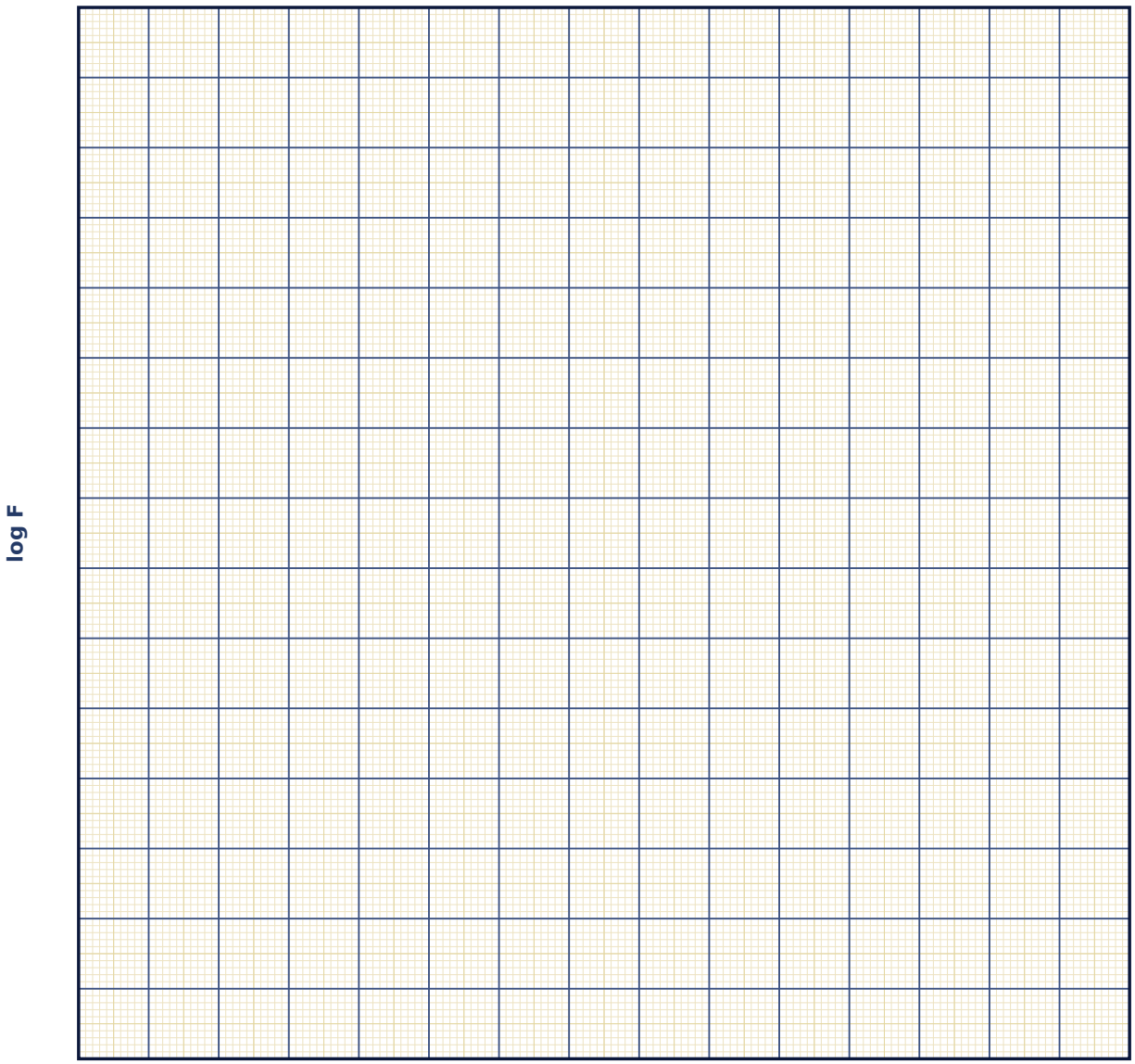
Observation Table

S. No.	Height d (cm)	Charge q (nC)	Force F (×10⁻⁹ N)	log d	log F

S. No.	Height d (cm)	Charge q (nC)	Force F (×10⁻⁹ N)	log d	log F

Graph

log F vs log d (slope method)



Calculation

Result

Quantity	Slope of log F vs log d	Expected value	% deviation

Maximum Permissible Error

Formula: $(\Delta F)/(F) = 2(\Delta q)/(q) + 2(\Delta d)/(d)$

$F \propto q^2/d^2$, so both q and d enter squared and each contributes a factor of 2 to the fractional error.

Quantity	Measured Value	Least Count (LC)
q — Point charge (nC)		
d — Height above the grounded plane (cm)		

Calculation of maximum permissible error:

Viva-Voce Questions

1. State the method of images and explain why it is valid only in the region containing the real charge.

2. Derive the expression for the force of attraction between the charge and the grounded plane.

3. How does the induced surface charge density vary with lateral distance from the point directly below the charge?

4. What would change if the plane were held at a fixed non-zero potential instead of being grounded?

5. Extend the method of images to the case of a charge between two perpendicular grounded planes.

Multipole Expansion — Linear Electric Quadrupole

Aim

To compute the far-field electric potential of a linear quadrupole and verify its characteristic $1/r^3$ fall-off, distinguishing it from the $1/r$ monopole and $1/r^2$ dipole terms of the general multipole expansion.

Date performed: _____ Simulator panel used: _____

Formula Used

$$V_{quad}(r) = 3qa^2 / (4\pi\varepsilon_0 r^3)$$

V = on-axis quadrupole potential (V)
q = end-charge magnitude (C)
a = charge spacing (m)
r = field-point distance, $r \gg a$

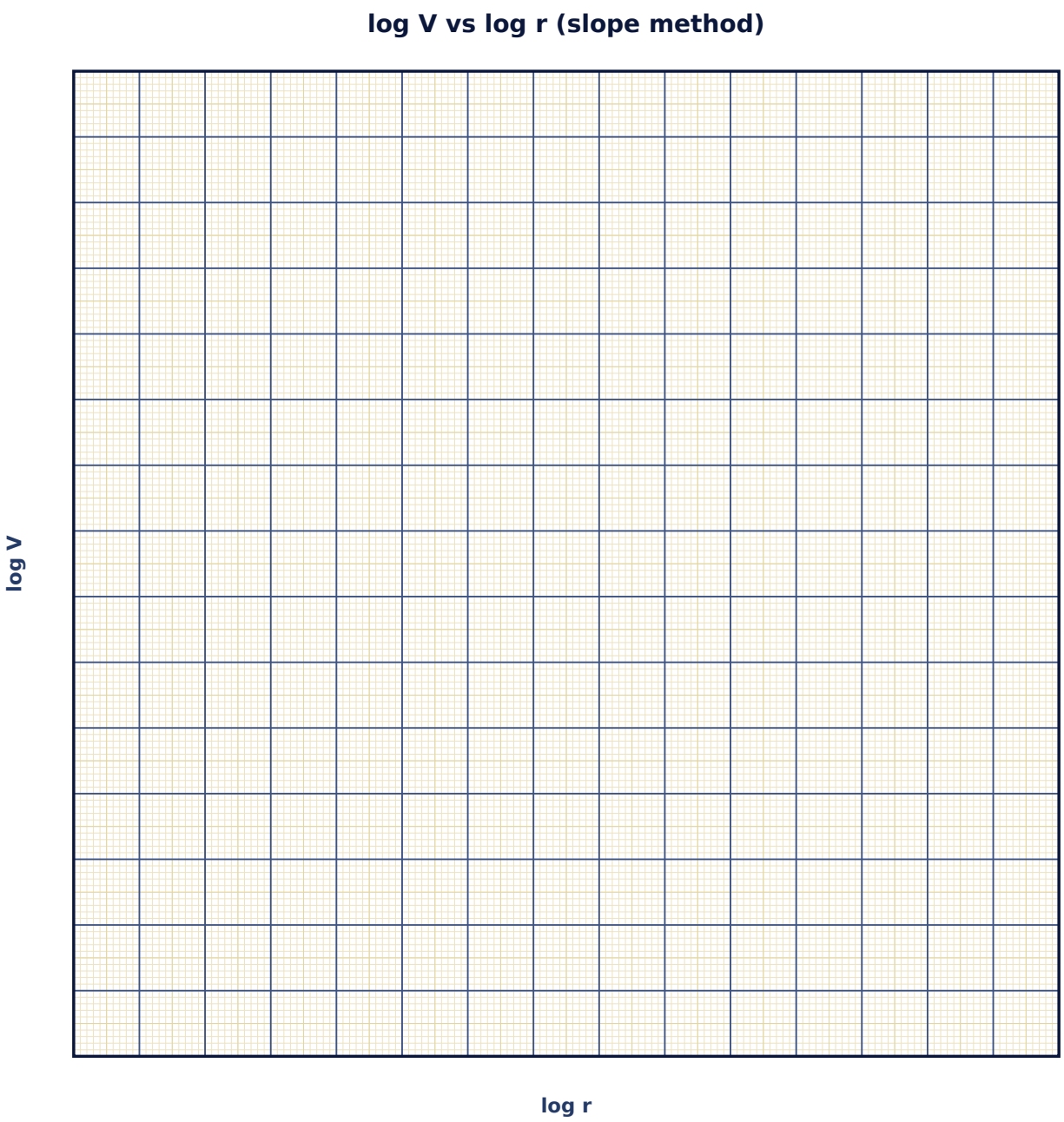
Labelled diagram of the experimental apparatus:

Observation Table

S. No.	r (cm)	q (nC)	a (cm)	V (×10⁻⁹ V)	log r	log V

S. No.	r (cm)	q (nC)	a (cm)	V (×10⁻⁹ V)	log r	log V

Graph



Calculation

Result

Quantity	Slope of log V vs log r	Expected value	% deviation

Maximum Permissible Error

Formula: $(\Delta V)/(V) = (\Delta q)/(q) + 2(\Delta a)/(a) + 3(\Delta r)/(r)$

$V \propto qa^2/r^3$ has a squared and r cubed, contributing factors of 2 and 3 respectively to the fractional error.

Quantity	Measured Value	Least Count (LC)
q — End charge magnitude (nC)		
a — Charge spacing (cm)		
r — Field point distance (on axis) (cm)		

Calculation of maximum permissible error:

Viva-Voce Questions

1. Define the electric quadrupole moment and give an example of a real molecule that possesses one.

2. Why does a linear array of +q, −2q, +q have zero net dipole moment?

3. Explain, in general terms, why successive multipole terms fall off with increasing powers of 1/r.

4. How would the far-field potential change if the two end charges were unequal?

5. What is the physical origin of quadrupole radiation in the time-varying (radiating) case?

Biot–Savart Law — Magnetic Field Due to a Current-Carrying Wire

Aim

To compute the magnetic field due to a finite straight current-carrying wire using the Biot–Savart law, verify the perpendicular-distance dependence, and recover Ampere's infinite-wire result as a limiting case.

Date performed: _____ Simulator panel used: _____

Formula Used

$B = \mu_0 I / (2\pi r)$

B = magnetic flux density at distance r (T)
I = current in the wire (A)
r = perpendicular distance from the wire

Labelled diagram of the experimental apparatus:

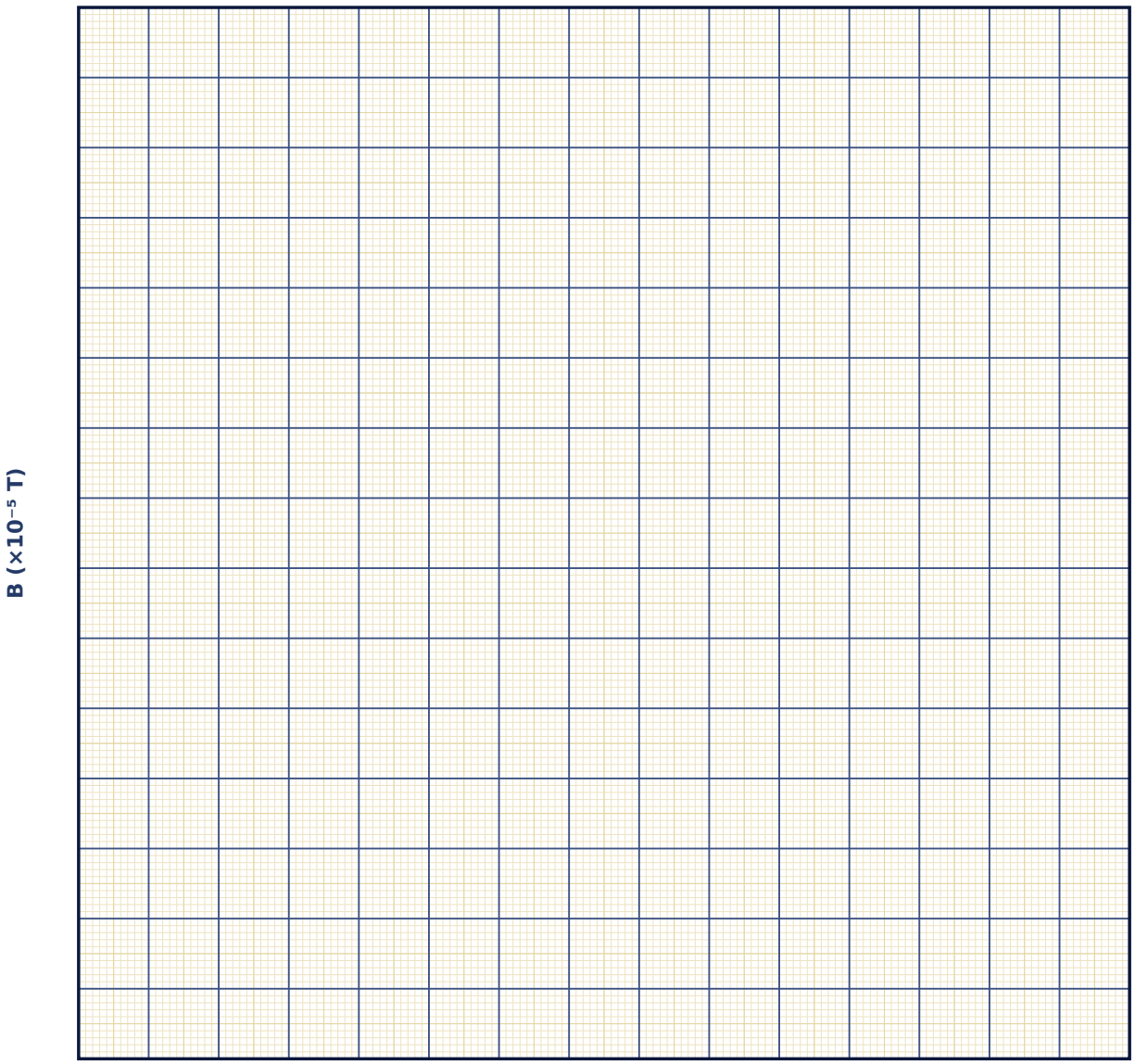
Observation Table

S. No.	Current I (A)	Distance a (cm)	Wire length L (cm)	α_1 (°)	α_2 (°)	Field B ($\times 10^{-5}$ T)

S. No.	Current I (A)	Distance a (cm)	Wire length L (cm)	α_1 (°)	α_2 (°)	Field B ($\times 10^{-5}$ T)

Graph

B vs 1/a at fixed I, L



Calculation

Result

Wire length L	B (finite wire)	B (infinite-wire formula)	% difference

Maximum Permissible Error

Formula: $\Delta B/B = \Delta I/I + \Delta a/a$

For the infinite-wire limit $B = \mu_0 I/2\pi a$, a simple quotient, so fractional errors in I and a add.

Quantity	Measured Value	Least Count (LC)
I — Current (sign reverses direction) (A)		
a — Perpendicular distance (cm)		
L — Wire length (cm)		

Calculation of maximum permissible error:

Viva-Voce Questions

1. State the Biot–Savart law in vector form and compare its structure with Coulomb's law.

2. Derive the infinite-wire field formula $B = \mu_0 I/2\pi a$ as a limiting case of the finite-wire result.

3. In which direction does B point around a current-carrying wire, and which rule fixes this?

4. Why is the field due to a straight wire independent of its cross-sectional shape (for a thin wire)?

5. How would the Biot–Savart integral change for a wire bent into an L-shape?

6. Compare and contrast the Biot–Savart law with Ampere's circuital law — when is each more convenient to use?

Magnetic Field on the Axis of a Circular Coil & Helmholtz Coils

Aim

To study the magnetic field along the axis of a single circular current loop, locate the point of maximum field, and demonstrate how a Helmholtz pair produces a highly uniform field at its centre.

Date performed: _____ Simulator panel used: _____

Formula Used

$B_{axis} = \mu_0 I a^2 / (2(a^2+x^2)^{(3/2)})$

B_axis = on-axis field of a circular coil (T)
I = coil current (A)
a = coil radius
x = axial distance from the coil centre

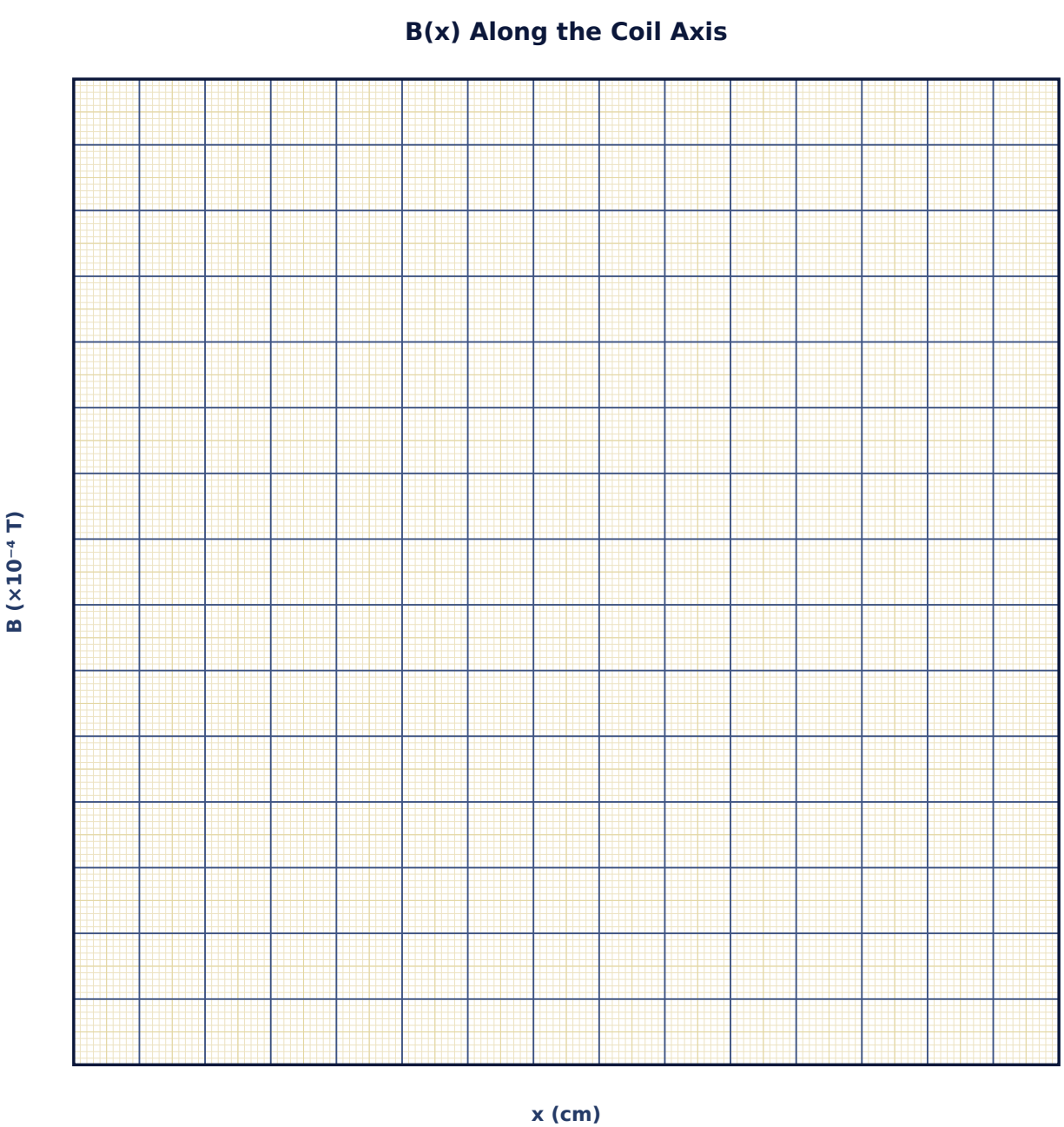
Labelled diagram of the experimental apparatus:

Observation Table

S. No.	x (cm)	R (cm)	N	I (A)	Field B (×10⁻⁴ T)

S. No.	x (cm)	R (cm)	N	I (A)	Field B (×10⁻⁴ T)

Graph



Calculation

Result

Configuration	Field uniformity (ΔB/B over ±2 cm)	Optimum separation d	Remarks

Maximum Permissible Error

Formula: $\Delta B_0/B_0 = \Delta N/N + \Delta I/I + \Delta R/R$

$B_0 = \mu_0 NI/2R$ at the coil centre is a simple product/quotient, so fractional errors add.

Quantity	Measured Value	Least Count (LC)
R — Coil radius (cm)		
N — Number of turns		
I — Current (sign reverses direction) (A)		
x — Axial distance from centre (cm)		
d — Helmholtz coil separation (mode 2) (cm)		

Calculation of maximum permissible error:

Viva-Voce Questions

1. Derive the on-axis field of a circular current loop starting from the Biot–Savart law.

2. At what axial distance does B(x) fall to half its central value, for a single coil?

3. Why is the Helmholtz coil separation chosen equal to the coil radius?

4. What physical quantity being zero at the midpoint makes the Helmholtz field so uniform there?

5. How would you use a Helmholtz pair to cancel the Earth's magnetic field in a sensitive experiment?

6. Compare the on-axis field of a coil with that of a long solenoid — under what condition does one reduce to the other?

Ampere's Circuital Law — Field Inside a Solenoid & a Toroid

Aim

To verify Ampere's circuital law by computing the magnetic field inside a long solenoid and a toroid, and to study the field's uniformity and its dependence on turns density and current.

Date performed: _____ Simulator panel used: _____

Formula Used

$B_{solenoid} = \mu_0 n I$, $B_{toroid} = \mu_0 N I / (2\pi r)$

n = turns per unit length (solenoid)
N = total turns (toroid)
I = current (A)

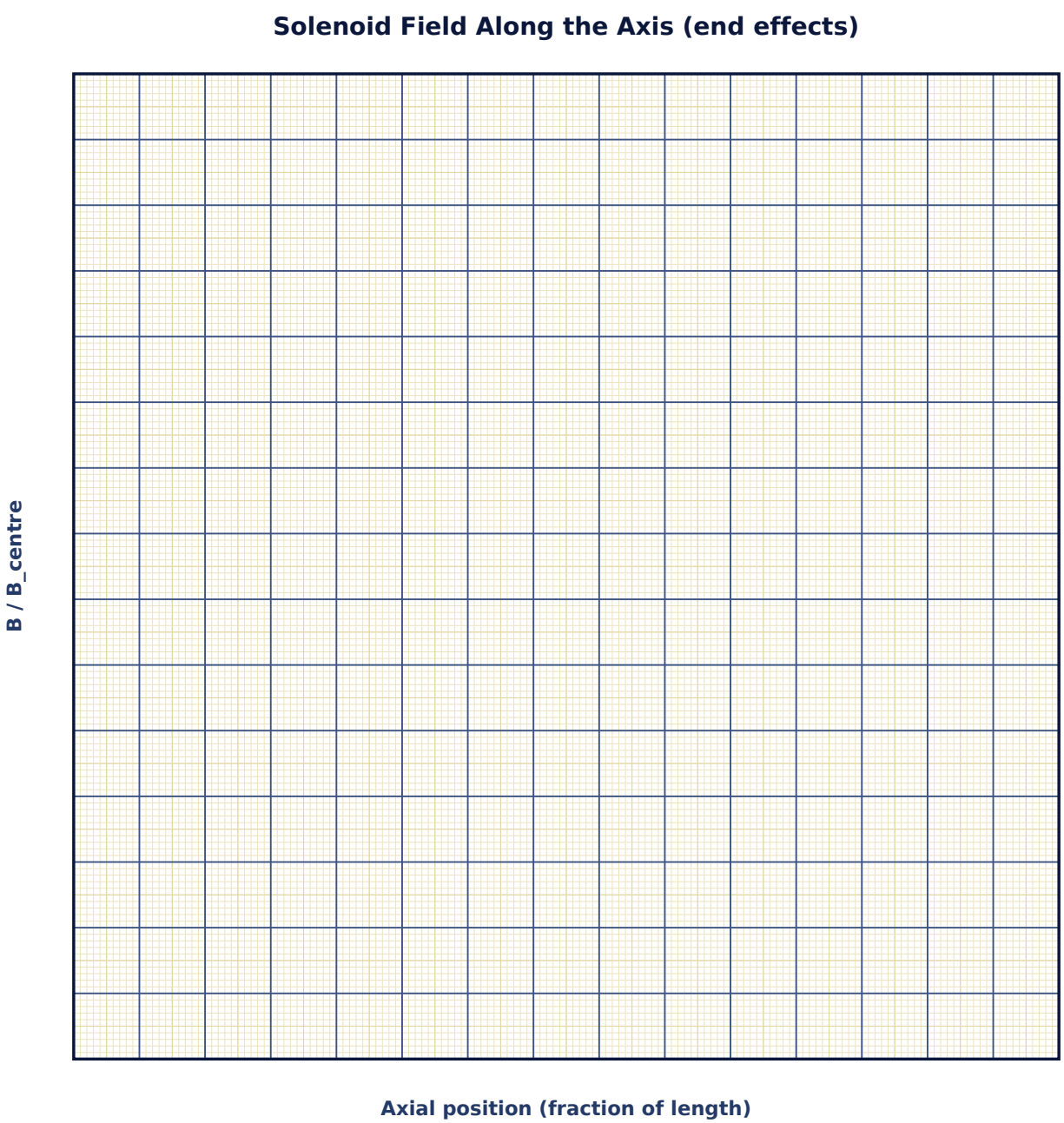
Labelled diagram of the experimental apparatus:

Observation Table

S. No.	Configuration	n or N	Current I (A)	Probe position	Field B (×10⁻³ T)

S. No.	Configuration	n or N	Current I (A)	Probe position	Field B (×10⁻³ T)

Graph



Calculation

Result

Configuration	Field uniformity	Verified law	Remarks

Maximum Permissible Error

Formula: $\Delta B/B = \Delta n/n + \Delta I/I$

$B = \mu_0 nI$ is a simple product, so fractional errors in n and I add directly.

Quantity	Measured Value	Least Count (LC)
n — Solenoid turns density (turns/cm)		
I — Current (sign reverses direction) (A)		
x — Probe position (0=centre, 1=at the end, 2=outside)		
R — Toroid major radius (cm)		
N_t — Toroid total turns		

Calculation of maximum permissible error:

Viva-Voce Questions

1. State Ampere's circuital law and explain the choice of Amperian loop used to derive the solenoid's field.

2. Why is the field of an ideal solenoid exactly zero outside the winding, but not exactly zero for a real, finite solenoid?

3. Derive the toroid's field formula using a circular Amperian loop.

4. Why is a toroid's field not perfectly uniform across its cross-section, unlike an idealized long solenoid?

5. Under what conditions does Ampere's law alone suffice to determine B, without needing the full Biot–Savart integral?

6. How is Ampere's law modified for time-varying fields (Maxwell's displacement-current correction)?

Force Between Two Parallel Current-Carrying Conductors

Aim

To compute the force per unit length between two long parallel current-carrying wires, verify its dependence on the currents and their separation, and relate it to the SI definition of the ampere.

Date performed: _____ Simulator panel used: _____

Formula Used

$F/L = \mu_0 I_1 I_2 / (2\pi d)$

F/L = force per unit length between the wires (N/m)
I_1, I_2 = currents in the two wires (A)
d = separation between the wires

Labelled diagram of the experimental apparatus:

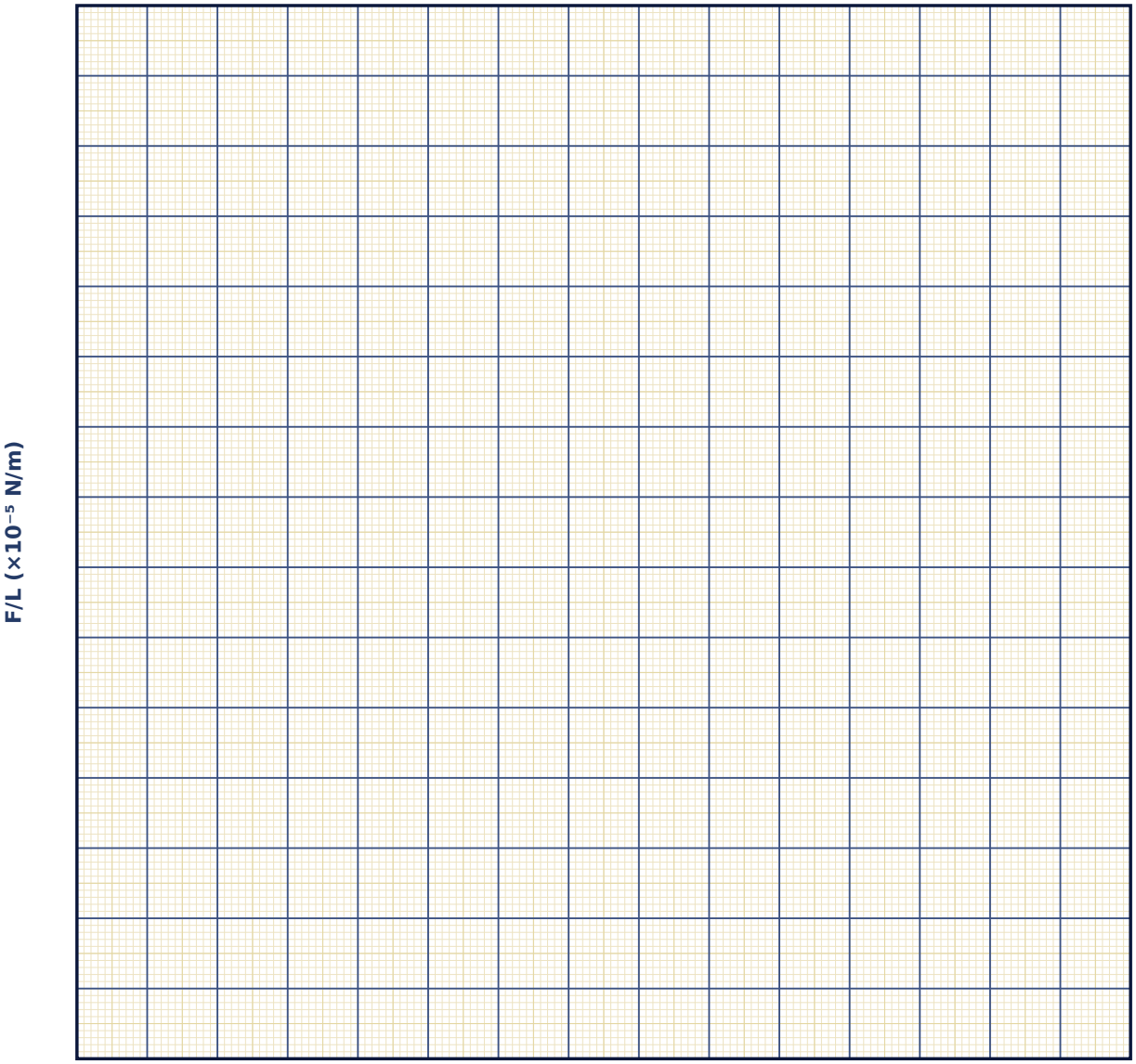
Observation Table

S. No.	I_1 (A)	I_2 (A)	Separation d (cm)	Direction (same/opp.)	Force/length ($\times 10^{-5}$ N/m)

S. No.	I_1 (A)	I_2 (A)	Separation d (cm)	Direction (same/opp.)	Force/length ($\times 10^{-5}$ N/m)

Graph

Force per Unit Length vs 1/d



Calculation

Result

Configuration	F/L measured	F/L predicted	% deviation

Maximum Permissible Error

Formula: $\Delta(F/L)/(F/L) = \Delta I_1/I_1 + \Delta I_2/I_2 + \Delta d/d$

$F/L = \mu_0 I_1 I_2/2\pi d$ is a product/quotient of three measured quantities.

Quantity	Measured Value	Least Count (LC)
I_1 — Current in wire 1 (A)		
I_2 — Current in wire 2 (A)		
d — Separation (cm)		
dir — Relative direction (0=same, 1=opposite)		

Calculation of maximum permissible error:

Viva-Voce Questions

1. Derive the force per unit length between two parallel current-carrying wires using the Biot–Savart/Ampere field of one wire acting on the other.

2. Why do parallel currents in the same direction attract while antiparallel currents repel?

3. Explain the historical (pre-2019) SI definition of the ampere in terms of this force.

4. How does the modern (2019 revision) SI definition of the ampere differ, and why was it changed?

5. If both currents are doubled, by what factor does the force per unit length change?

6. How would you measure this force experimentally using a current balance?

Magnetic Vector Potential of a Current Loop (Dipole Limit)

Aim

To evaluate the magnetic vector potential A of a small current loop in the far-field (magnetic dipole) approximation, and relate its spatial dependence to the resulting dipole field B = ∇ × A.

Date performed: _____ Simulator panel used: _____

Formula Used

$A_\varphi(r,\theta) = \mu_0 I a^2 \sin\theta / (4r^2)$

A_φ = azimuthal vector potential (T·m)
I = loop current (A)
a = loop radius
r, θ = spherical field-point coordinates, r ≫ a

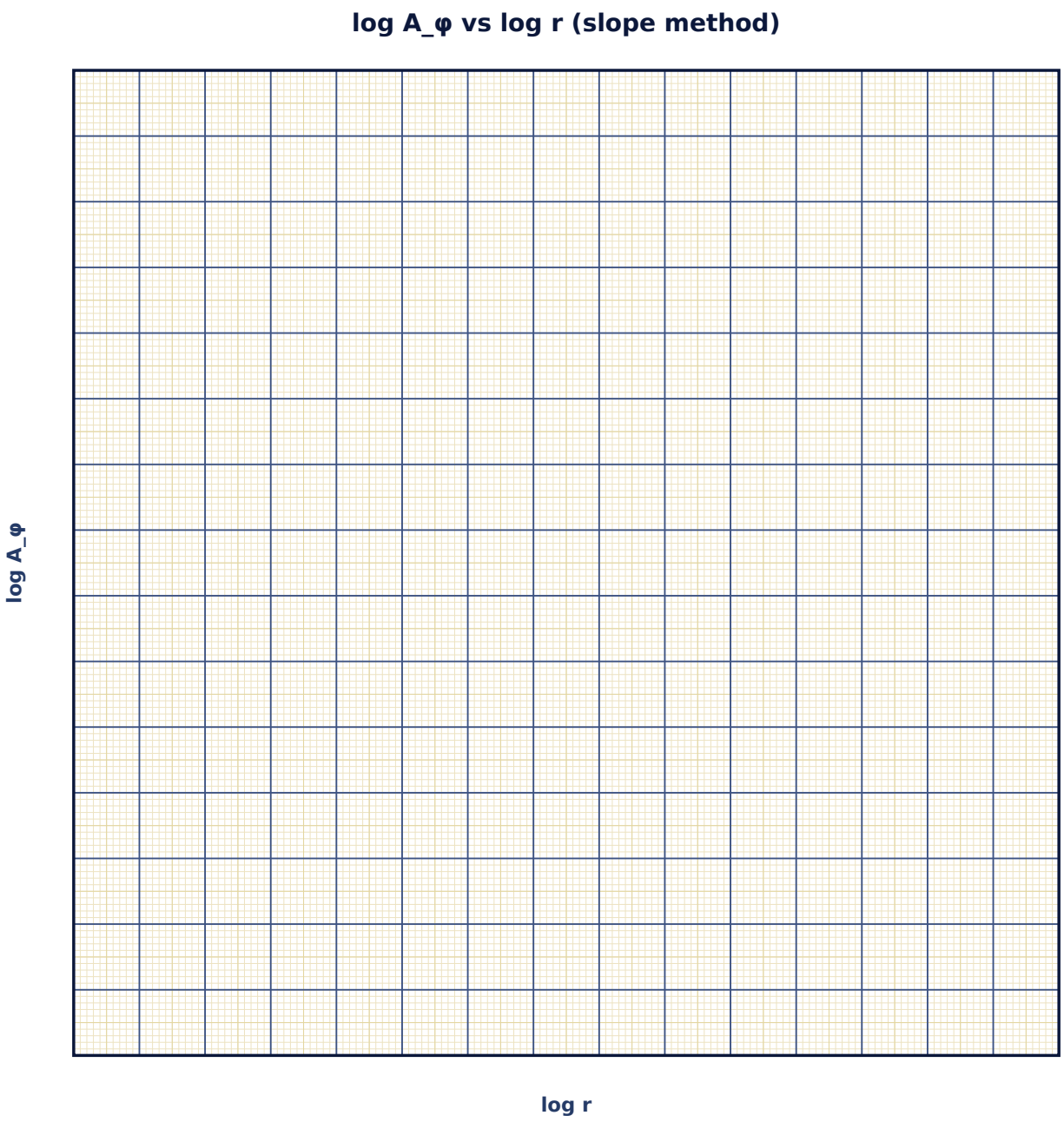
Labelled diagram of the experimental apparatus:

Observation Table

S. No.	r (cm)	θ (deg)	I (A)	A_φ ($\times 10^{-6}$ T·cm)	log r	log A_φ

S. No.	r (cm)	θ (deg)	I (A)	A_φ ($\times 10^{-6}$ T·cm)	log r	log A_φ

Graph



Calculation

Result

Quantity	Slope of log A_φ vs log r	Expected value	% deviation

Maximum Permissible Error

Formula: $(\Delta A)/(A) = (\Delta I)/(I) + 2(\Delta a)/(a) + 2(\Delta r)/(r)$

$A_\varphi \propto Ia^2/r^2$ has a and r both squared, each contributing a factor of 2 to the fractional error.

Quantity	Measured Value	Least Count (LC)
I — Loop current (A)		
a — Loop radius (cm)		
r — Field point distance (cm)		
θ — Polar angle from loop axis (deg)		

Calculation of maximum permissible error:

Viva-Voce Questions

1. Why is the magnetic field described using a vector potential rather than a scalar potential?

2. Define the magnetic dipole moment of a current loop and state its units.

3. Show qualitatively how $B = \nabla \times A$ reproduces the dipole field pattern from A_φ.

4. Compare the r-dependence and angular dependence of A_φ with the electric dipole potential V.

5. Why does A_φ vanish on the axis of the loop even though B does not?

Crossed E & B Fields — Velocity Selector & Cyclotron Motion

Aim

To determine the velocity selected (undeflected) by a region of crossed uniform electric and magnetic fields, and to compute the cyclotron radius of the selected charged particle once it enters a pure magnetic field region.

Date performed: _____ Simulator panel used: _____

Formula Used

$v = E/B$, $r_c = mv/(qB)$

v = selected (undeflected) speed (m/s)
E, B = crossed electric and magnetic fields
r_c = cyclotron radius in the pure B-field region

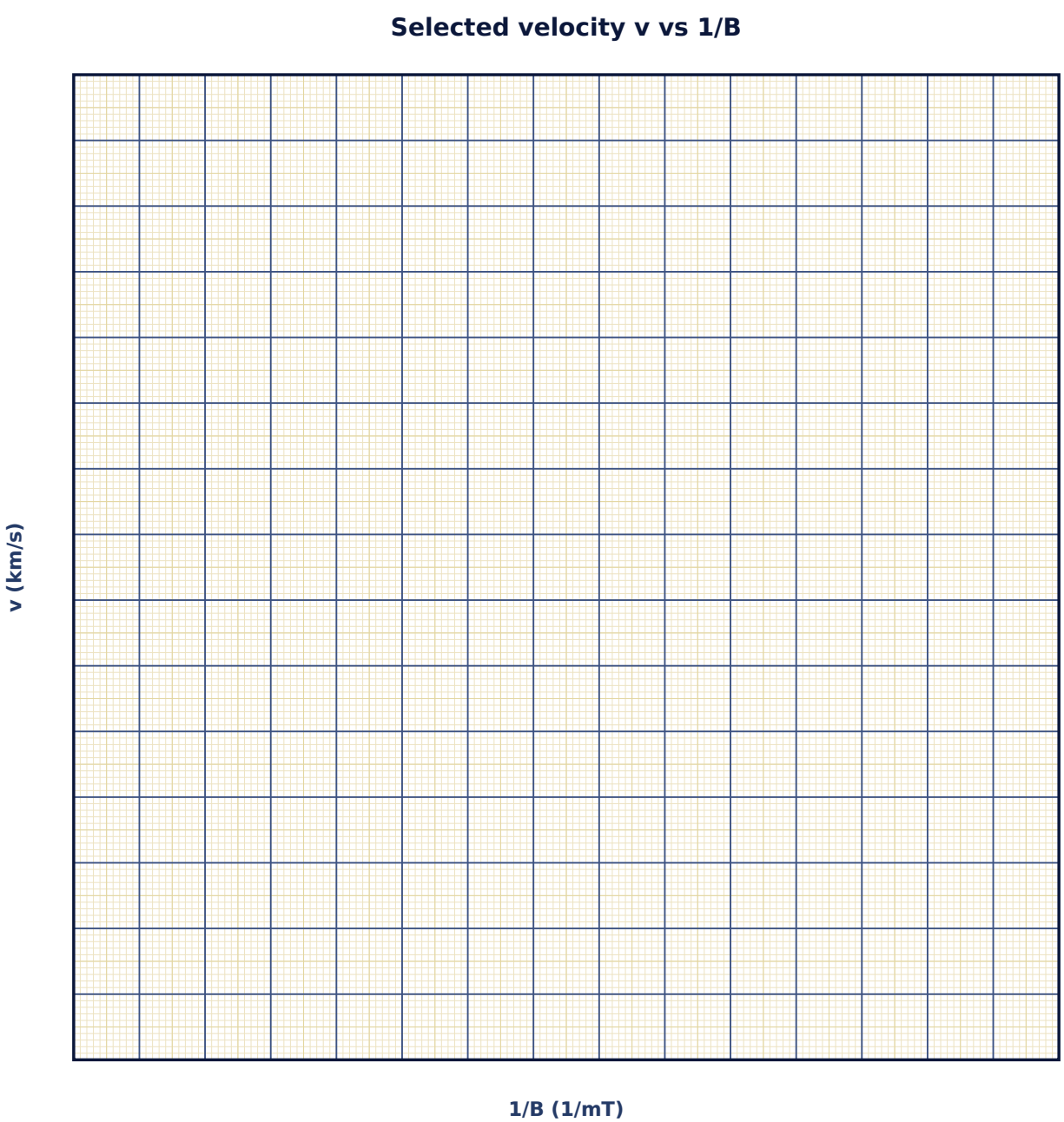
Labelled diagram of the experimental apparatus:

Observation Table

S. No.	E (kV/m)	B (mT)	v = E/B (km/s)	m/q (×10⁻⁸ kg/C)	r_c (m)

S. No.	E (kV/m)	B (mT)	v = E/B (km/s)	m/q (×10⁻⁸ kg/C)	r_c (m)

Graph



Calculation

Result

Quantity	Slope of v vs 1/B	Expected value	% deviation

Maximum Permissible Error

Formula: $(\Delta v)/(v) = (\Delta E)/(E) + (\Delta B)/(B)$

v = E/B is a simple quotient of two measured quantities, so their fractional errors add directly.

Quantity	Measured Value	Least Count (LC)
E — Electric field (kV/m)		
B — Magnetic flux density (mT)		
m/q — Mass-to-charge ratio ($\times 10^{-8}$ kg/C)		

Calculation of maximum permissible error:

Viva-Voce Questions

1. Derive the velocity-selection condition v = E/B from the balance of electric and magnetic forces.

2. Why is the selected velocity independent of the particle's mass and charge?

3. Derive the cyclotron radius formula r_c = mv/(qB) from Newton's second law for circular motion.

4. How is a velocity selector used as the first stage of a mass spectrometer?

5. What happens to the trajectory if the particle's speed does not exactly equal E/B?

Faraday's Law of Electromagnetic Induction

Aim

To verify Faraday's law of electromagnetic induction by studying the EMF induced in a coil due to a changing magnetic flux, and to confirm Lenz's law for the direction of the induced current.

Date performed: _____ Simulator panel used: _____

Formula Used

$EMF = -N \, d\Phi/dt$

EMF = induced electromotive force (V)
N = number of turns in the coil
dΦ/dt = rate of change of magnetic flux linkage

Labelled diagram of the experimental apparatus:

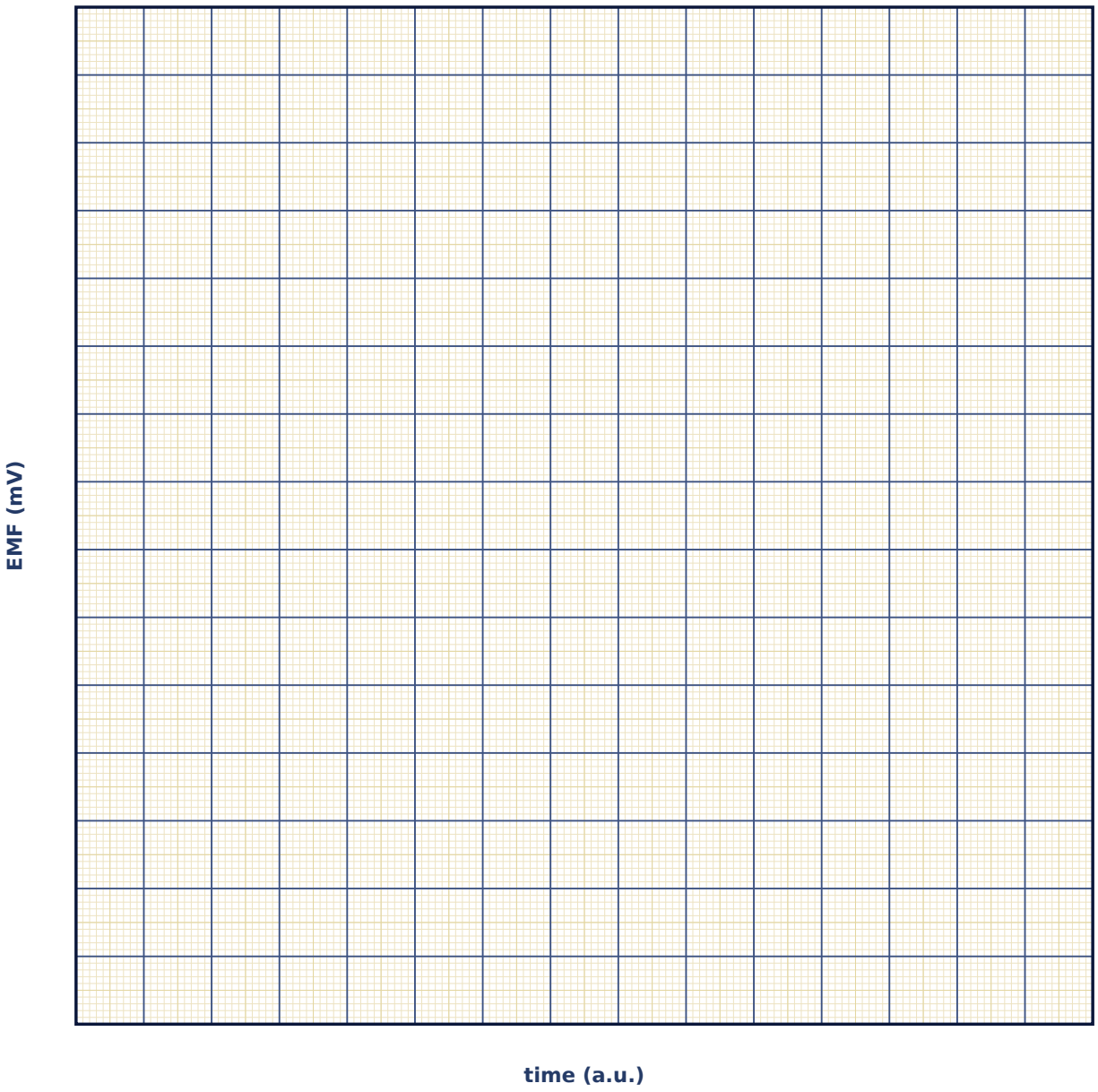
Observation Table

S. No.	Turns N	Magnet speed v (cm/s)	Peak field B_max (mT)	Peak EMF ε (mV)	Direction (approach/withdraw)

S. No.	Turns N	Magnet speed v (cm/s)	Peak field B_max (mT)	Peak EMF ε (mV)	Direction (approach/withdraw)

Graph

Induced EMF vs Time (magnet passing through coil)



Calculation

Result

Case	EMF observed	EMF predicted (−N dΦ/dt)	Lenz's law direction verified?

Maximum Permissible Error

Formula: $\Delta\varepsilon/\varepsilon = \Delta N/N + \Delta B_{max}/B_{max} + \Delta v/v$

For a magnet swept through at speed v, peak EMF scales with N, the field's peak value and its rate of change ($\propto$ v), so fractional errors add.

Quantity	Measured Value	Least Count (LC)
N — Number of turns		
v — Magnet approach speed (cm/s)		
B_{max} — Peak field of the magnet (mT)		
A — Coil cross-sectional area (cm^2)		
μ_r — Core relative permeability ($\chi = \mu_r - 1$, so $0 \leftrightarrow \chi = -1$ and $1.7 \leftrightarrow \chi = 0.7$)		

Calculation of maximum permissible error:

Viva-Voce Questions

1. State Faraday's law and explain the physical meaning of the negative sign (Lenz's law).

2. Why is no EMF induced by a strong but unchanging magnetic field through a stationary coil?

3. Derive the motional EMF formula $\varepsilon = BLv$ from Faraday's law for a rod sliding on rails in a magnetic field.

4. Explain how Lenz's law is a direct consequence of energy conservation.

5. How does eddy-current braking make use of Faraday's and Lenz's laws?

6. What is self-inductance, and how does it relate to Faraday's law applied to a coil's own changing current?

Motional EMF & Lenz's Law on a Sliding Rod

Aim

To study the motional EMF generated by a conducting rod sliding on rails in a uniform magnetic field, verify ε = BLv, and observe the retarding (Lenz's-law) force that opposes the rod's motion when the circuit is closed.

Date performed: _____ Simulator panel used: _____

Formula Used

EMF = BLv

EMF = motional electromotive force (V)
B = magnetic flux density (T)
L = rail separation (rod length in the field)
v = velocity of the sliding rod

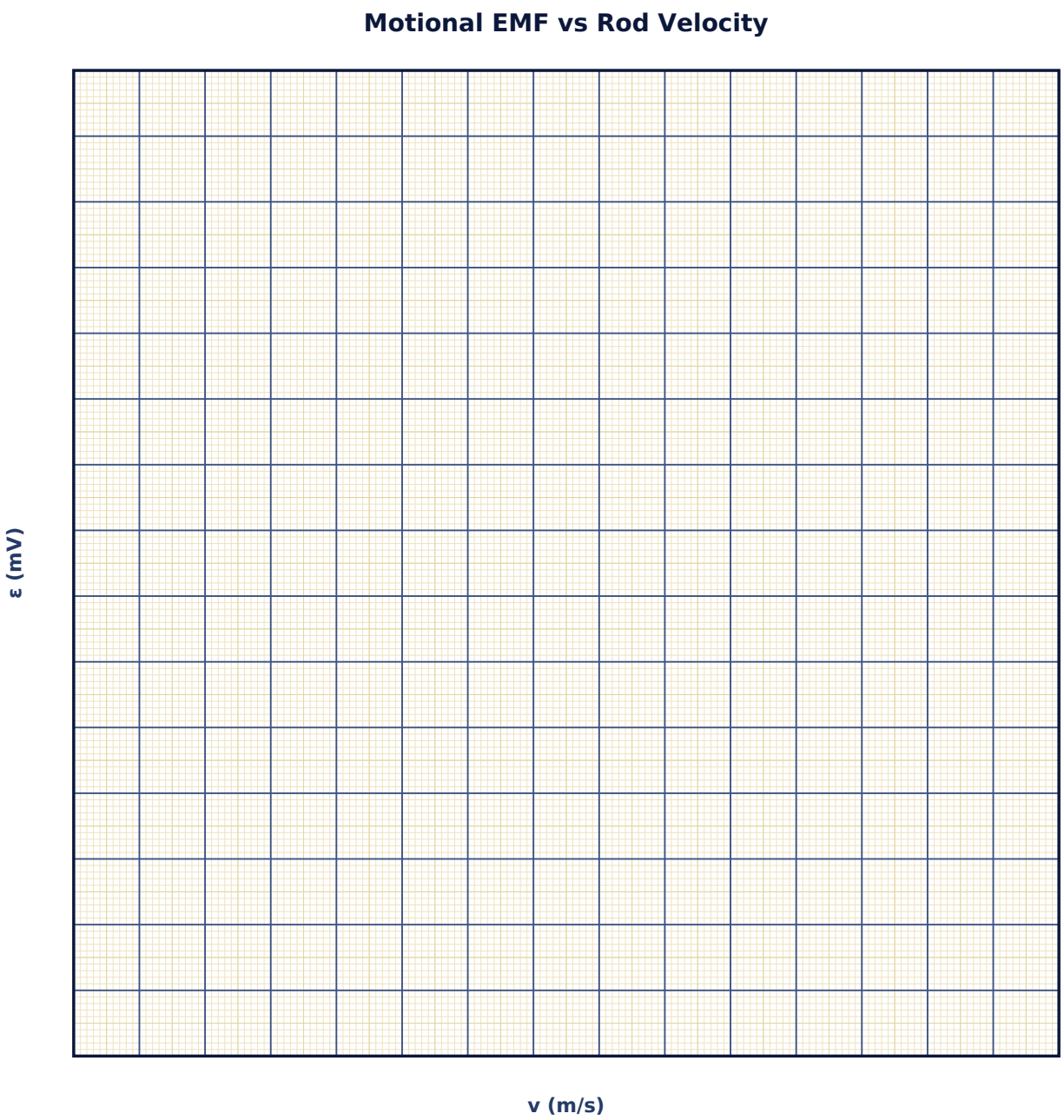
Labelled diagram of the experimental apparatus:

Observation Table

S. No.	B (mT)	L (cm)	v (m/s)	R (Ω)	EMF ε (mV)	Current I (mA)	Retarding force F (×10⁻⁴ N)

S. No.	B (mT)	L (cm)	v (m/s)	R (Ω)	EMF ε (mV)	Current I (mA)	Retarding force F ($\times 10^{-4}$ N)

Graph



Calculation

Result

Quantity	Measured value	Predicted value	% deviation

Maximum Permissible Error

Formula: $\Delta\varepsilon/\varepsilon = \Delta B/B + \Delta L/L + \Delta v/v$

$\varepsilon = BLv$ is a simple product of three measured quantities.

Quantity	Measured Value	Least Count (LC)
B — Magnetic field (mT)		
L — Rail separation (cm)		
v — Rod velocity (m/s)		
R — Circuit resistance (Ω)		

Calculation of maximum permissible error:

Viva-Voce Questions

1. Derive the motional EMF $\varepsilon = BLv$ from the magnetic force on free charges in the moving rod.

2. Show that the same result follows from Faraday's law applied to the changing enclosed area.

3. Why does the rod experience a retarding force only when the circuit is closed?

4. Show that the electrical power dissipated equals the mechanical power delivered to keep the rod moving at constant velocity.

5. How would the terminal (constant) velocity of a freely falling conducting rod on vertical rails in a field be determined?

6. Explain the connection between this experiment and the working principle of an AC generator.

RC and RL Transient Circuits — Charging & Discharging

Aim

To study the exponential charging and discharging behaviour of RC and RL circuits, measure the time constant in each case, and verify its dependence on the circuit parameters.

Date performed: _____ Simulator panel used: _____

Formula Used

$V_C(t) = V(1-e^{(-t/RC)})$, $I_L(t) = (V/R)(1-e^{(-Rt/L)})$

$V_C(t)$, $I_L(t)$ = capacitor voltage / inductor current during charging
R, C, L = resistance, capacitance, inductance

Labelled diagram of the experimental apparatus:

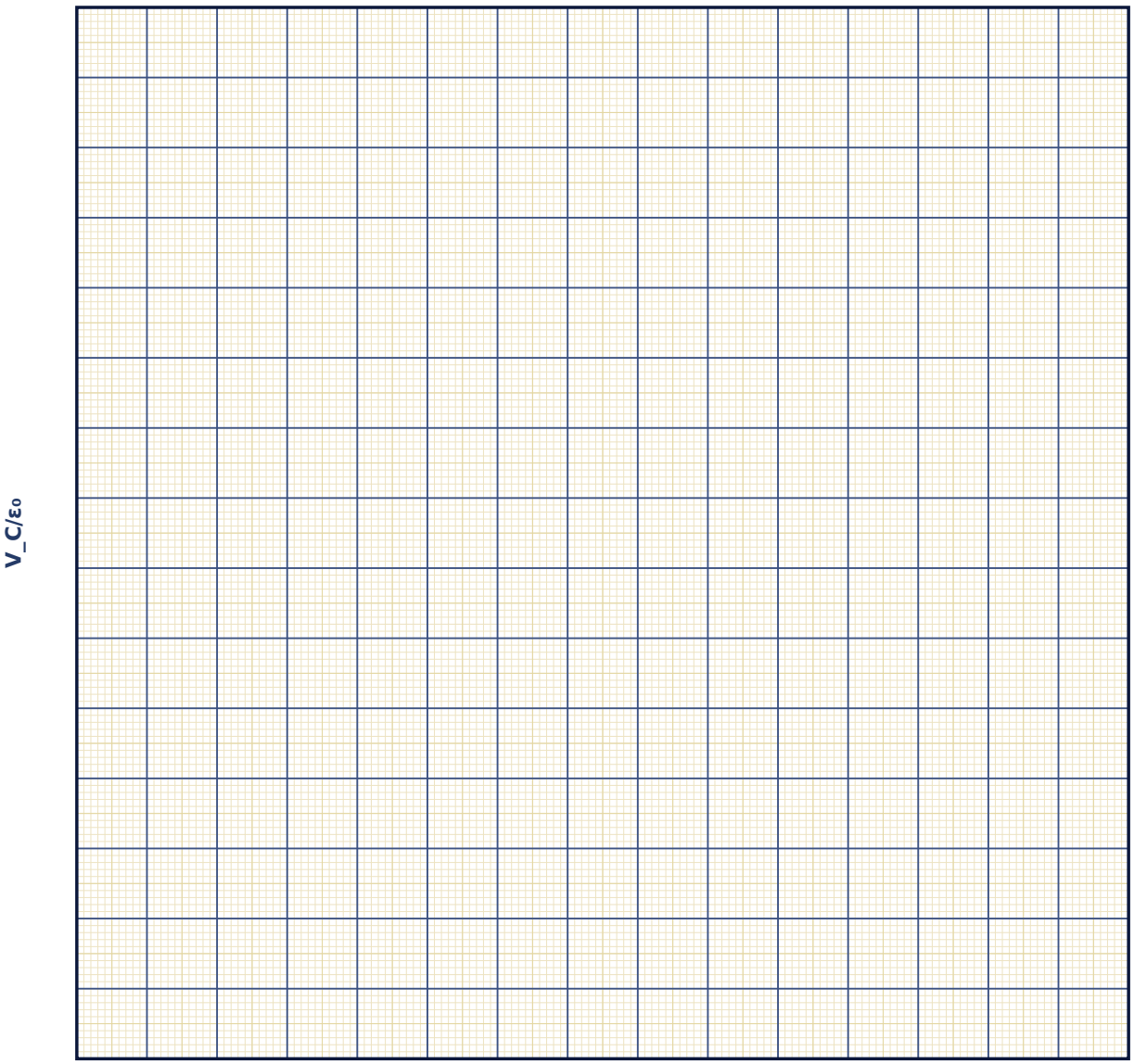
Observation Table

S. No.	Circuit type	R (kΩ)	C (μF) or L (H)	Measured τ (ms)	Calculated τ = RC or L/R (ms)

S. No.	Circuit type	R (kΩ)	C (μF) or L (H)	Measured τ (ms)	Calculated τ = RC or L/R (ms)

Graph

Capacitor Charging Curve



Calculation

Result

Circuit	τ measured	τ calculated	% deviation

Maximum Permissible Error

Formula: $\Delta\tau/\tau = \Delta R/R + \Delta C/C$ (RC circuit)

τ = RC is a simple product, so fractional errors in R and C add directly.

Quantity	Measured Value	Least Count (LC)
R — Resistance (kΩ)		
C — Capacitance (μF)		
L — Inductance (RL mode) (H)		
ε_0 — Source EMF (V)		
mode — Circuit (0=RC, 1=RL)		

Calculation of maximum permissible error:

Viva-Voce Questions

1. Derive the charging equation of an RC circuit from Kirchhoff's voltage law.

2. What is the physical significance of the time constant τ, and how is it read off an exponential curve graphically?

3. Why do the RC-charging and RL-growth curves have the same mathematical form?

4. How much energy is ultimately stored in the capacitor after full charging, and how does this compare with the energy dissipated in R during charging?

5. What happens to the time constant if R is doubled while C is halved?

6. Explain the duality between RC and RL transient circuits in terms of the roles of voltage and current.

LCR Series Resonance & Quality Factor (Q)

Aim

To study the resonance behaviour of a series LCR circuit driven by an AC source, locate the resonant frequency, and determine the quality factor from the sharpness of the resonance curve.

Date performed: _____ Simulator panel used: _____

Formula Used

$$f_0 = 1/(2\pi\sqrt{(LC)}) \text{ , } Q = \omega_0 L/R$$

f_0 = series-resonance frequency (Hz)
Q = quality factor of the circuit
L, C, R = inductance, capacitance, resistance

Labelled diagram of the experimental apparatus:

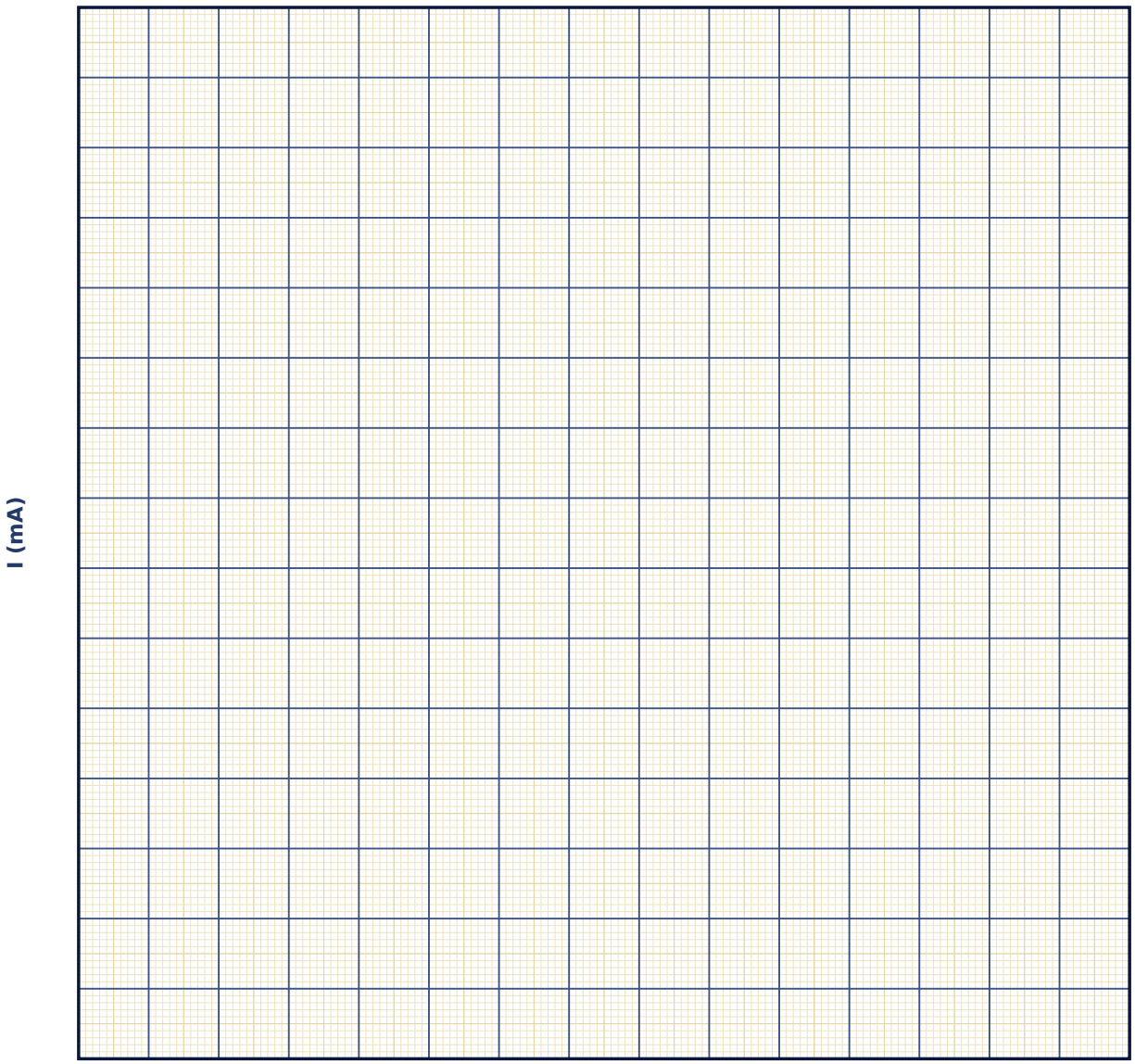
Observation Table

S. No.	R (Ω)	L (mH)	C (μF)	Frequency f (Hz)	Current amplitude I (mA)

S. No.	R (Ω)	L (mH)	C (μF)	Frequency f (Hz)	Current amplitude I (mA)

Graph

Resonance Curve: Current vs Frequency



Calculation

Result

Quantity	Measured value	Calculated value	% deviation

Maximum Permissible Error

Formula: $\Delta f_0/f_0 = \frac{1}{2}(\Delta L/L + \Delta C/C)$

$f_0 = 1/(2\pi\sqrt{LC})$ involves a square root of the product LC, halving the summed fractional errors.

Quantity	Measured Value	Least Count (LC)
R — Resistance (Ω)		
L — Inductance (mH)		
C — Capacitance (μF)		
V_0 — Source amplitude (V)		
f — Drive frequency (Hz)		

Calculation of maximum permissible error:

Viva-Voce Questions

1. Derive the resonant frequency of a series LCR circuit from its impedance expression.

2. Define quality factor Q in at least two equivalent ways and show they are consistent.

3. Why can the voltage across the inductor or capacitor individually exceed the applied source voltage at resonance?

4. How does increasing R affect the sharpness and height of the resonance curve?

5. Compare series and parallel LCR resonance — which one gives minimum impedance and which gives maximum impedance at resonance?

6. Explain how this resonance principle is used in radio-frequency tuning circuits.

Eddy-Current Damping — Lenz's Law Braking

Aim

To model the retarding force experienced by a conducting plate moving through a non-uniform magnetic field due to induced eddy currents, and study its dependence on conductivity, plate thickness, speed and field strength.

Date performed: _____ Simulator panel used: _____

Formula Used

$$F_{eddy} \propto \sigma\, t\, B^2\, v\, w^2$$

F_{eddy} = eddy-current retarding force (N)
σ, t = plate conductivity and thickness
B, v = field strength and plate velocity

Labelled diagram of the experimental apparatus:

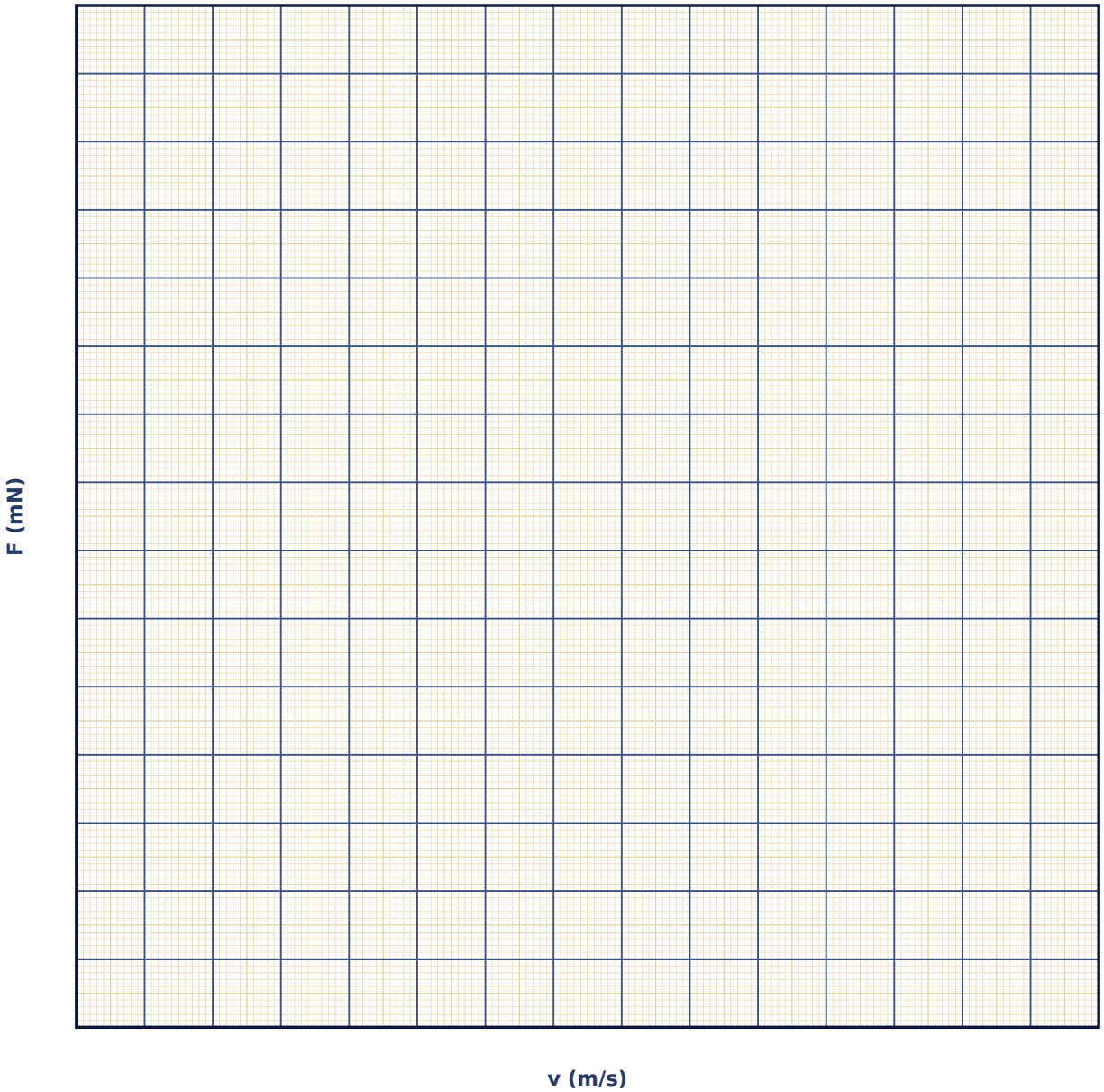
Observation Table

S. No.	v (m/s)	B (mT)	σ (×10⁶ S/m)	t (mm)	F (mN)

S. No.	v (m/s)	B (mT)	σ (×10⁶ S/m)	t (mm)	F (mN)

Graph

Retarding force F vs velocity v



Calculation

Result

Quantity	Slope of F vs v	Expected value	% deviation

Maximum Permissible Error

Formula: $(\Delta F)/(F) = (\Delta\sigma)/(\sigma) + (\Delta t)/(t) + 2(\Delta B)/(B) + (\Delta v)/(v)$

$F \propto \sigma t B^2 v$ has B squared, so its fractional error contributes twice to the total.

Quantity	Measured Value	Least Count (LC)
B — Magnetic flux density (mT)		
v — Plate velocity (m/s)		
σ — Plate conductivity ($\times 10^6$ S/m)		
t — Plate thickness (mm)		

Calculation of maximum permissible error:

Viva-Voce Questions

1. Explain, using Lenz's law, why eddy currents always oppose the motion that creates them.

2. Why does eddy-current braking require a non-uniform (spatially varying) field rather than a uniform one?

3. Where does the kinetic energy lost by the moving conductor ultimately go?

4. Name two practical applications of eddy-current damping.

5. Why are laminated cores (thin insulated sheets) used in transformers to reduce eddy-current losses?

RLC Filters — Low-Pass / High-Pass / Band-Pass Frequency Response

Aim

To compute the frequency-dependent voltage-gain response of a series RLC circuit configured as a band-pass filter, and to locate its resonant (centre) frequency and −3 dB bandwidth.

Date performed: _____ Simulator panel used: _____

Formula Used

$$|H(f)|_{bandpass} = R / \sqrt{(R^2+(\omega L - 1/\omega C)^2)}$$

|H(f)| = band-pass voltage-gain magnitude (0–1)
R, L, C = series resistance, inductance, capacitance
ω = angular frequency, ω = 2πf

Labelled diagram of the experimental apparatus:

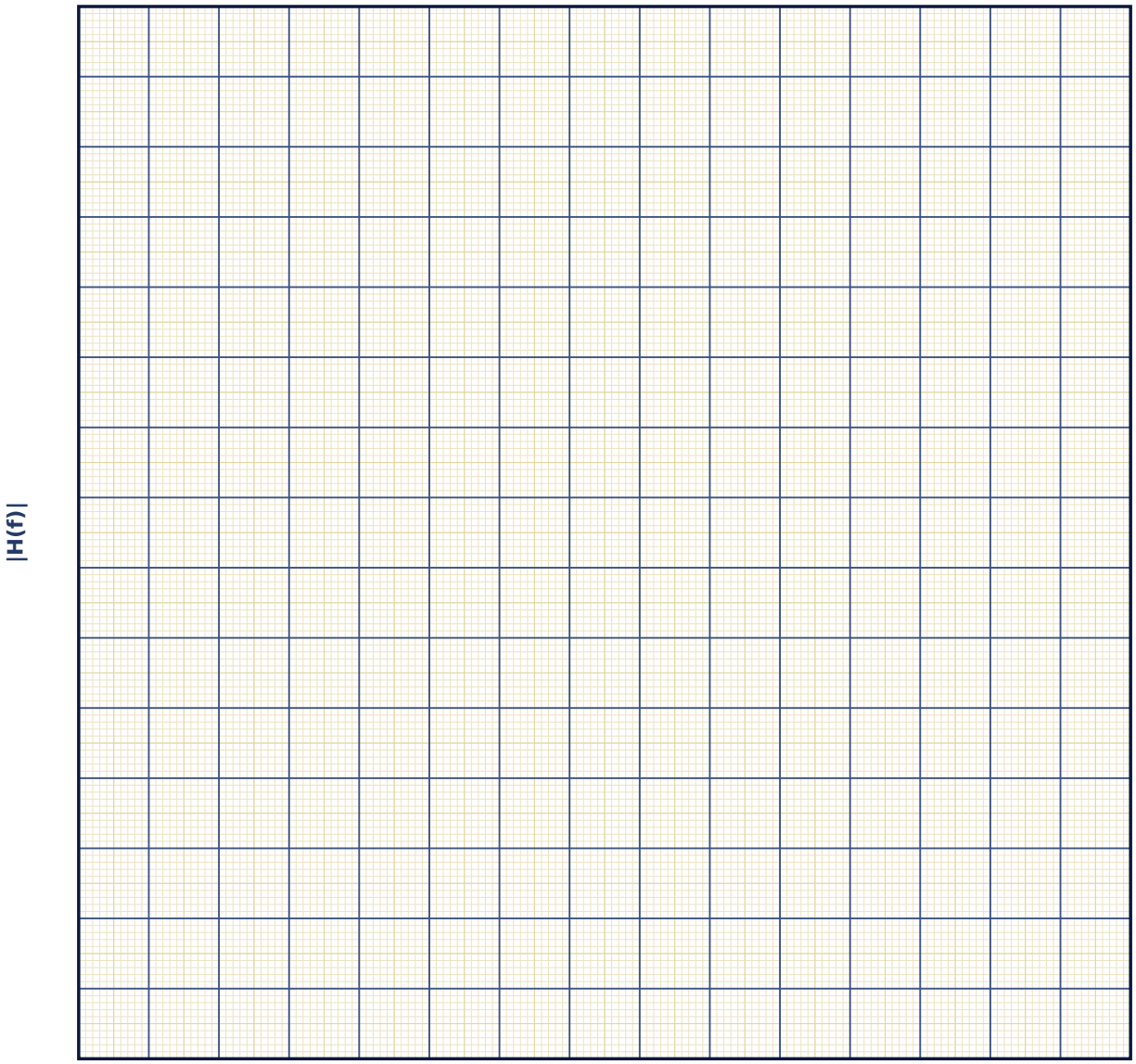
Observation Table

S. No.	f (Hz)	R (Ω)	L (mH)	C (μF)		H(f)	

S. No.	f (Hz)	R (Ω)	L (mH)	C (μF)		H(f)	

Graph

Gain |H(f)| vs frequency f



Calculation

Result

Quantity	Resonant frequency f_0 and Q-factor	Expected value	% deviation

Maximum Permissible Error

Formula: Evaluated numerically at each swept frequency; no simple closed-form propagation

The band-pass gain is a non-monomial function of R, L, C and f, so its uncertainty is best explored numerically by perturbing each input in turn rather than via a single algebraic formula.

Quantity	Measured Value	Least Count (LC)
R — Resistance (Ω)		
L — Inductance (mH)		
C — Capacitance (μF)		
f — Signal frequency (Hz)		

Calculation of maximum permissible error:

Viva-Voce Questions

1. Derive the resonant frequency $f_0 = 1/(2\pi\sqrt{(LC)})$ for a series RLC circuit.

2. Define the quality factor Q and explain how it relates to the sharpness of the resonance peak.

3. Explain how the same RLC network can realise low-pass, high-pass and band-pass responses depending on which element's voltage is tapped.

4. What is the phase relationship between current and applied voltage exactly at resonance?

5. Give one practical application of a band-pass RLC filter (e.g. radio tuning circuits).

Poynting Vector & Power Flow in a Coaxial Cable

Aim

To compute the Poynting vector S = E × H in the dielectric region between the inner and outer conductors of a coaxial cable carrying DC power, and to verify that its integral over the annular cross-section reproduces the transmitted electrical power P = VI.

Date performed: _____ Simulator panel used: _____

Formula Used

$S(r) = VI / (2\pi r^2 \ln(b/a))$

S(r) = axial Poynting flux at radius r (W/m²)
V, I = conductor voltage and current
a, b = inner- and outer-conductor radii

Labelled diagram of the experimental apparatus:

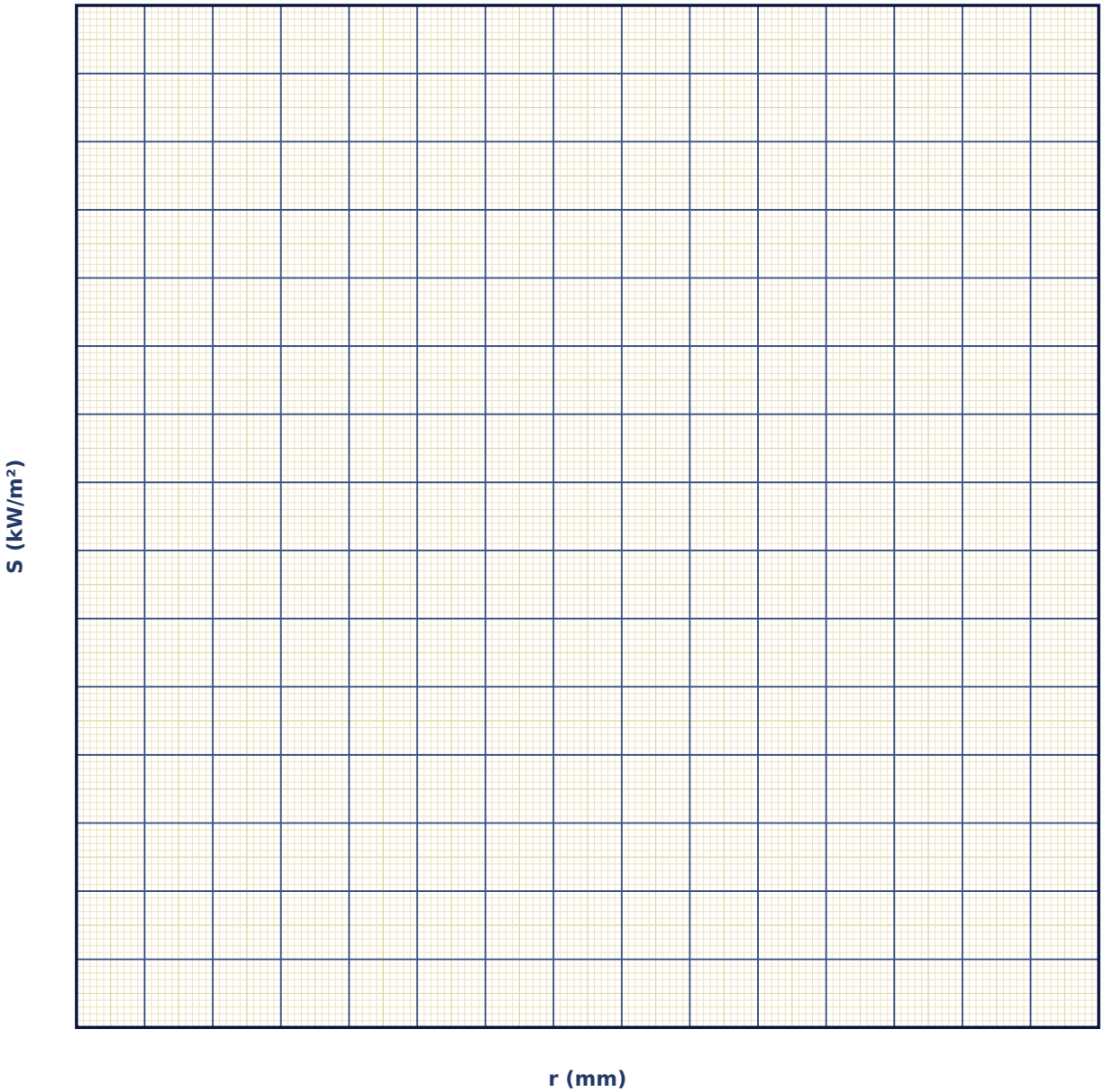
Observation Table

S. No.	r (mm)	V (V)	I (A)	S(r) (kW/m²)

S. No.	r (mm)	V (V)	I (A)	S(r) (kW/m²)

Graph

Poynting flux S vs radius r



Calculation

Result

Quantity	∫ S · dA over annulus (→ compare with VI)	Expected value	% deviation

Maximum Permissible Error

Formula: (Δ S)/(S) = (Δ V)/(V) + (Δ I)/(I) + 2(Δ r)/(r)

S(r) ∝ VI/r² has r squared in the denominator, contributing a factor of 2 to the fractional error.

Quantity	Measured Value	Least Count (LC)
V — Conductor voltage (V)		
I — Conductor current (A)		
a — Inner-conductor radius (mm)		
b — Outer-conductor (shield) radius (mm)		
r — Field point radius (a<r<b) (mm)		

Calculation of maximum permissible error:

Viva-Voce Questions

1. State Poynting's theorem and define the Poynting vector.

2. Explain the common misconception that power flows 'through the wire', and how the Poynting-vector picture corrects it.

3. Why does S point purely axially in a coaxial cable carrying steady current?

4. Show that integrating S over the annular cross-section reproduces P = VI.

5. How would the picture change for an AC (time-varying) signal instead of DC?

Maxwell's Equations & Plane Electromagnetic Wave Solutions

Aim

To explore how Maxwell's four equations, together, predict self-sustaining transverse electromagnetic waves in free space, and to verify the relations between E, B, their phase, and the speed of light.

Date performed: _____ Simulator panel used: _____

Formula Used

$c = 1/\sqrt{(\mu_0 \varepsilon_0)}$, $E/B = c$

c = speed of light in vacuum
E, B = transverse, mutually perpendicular, in-phase field amplitudes

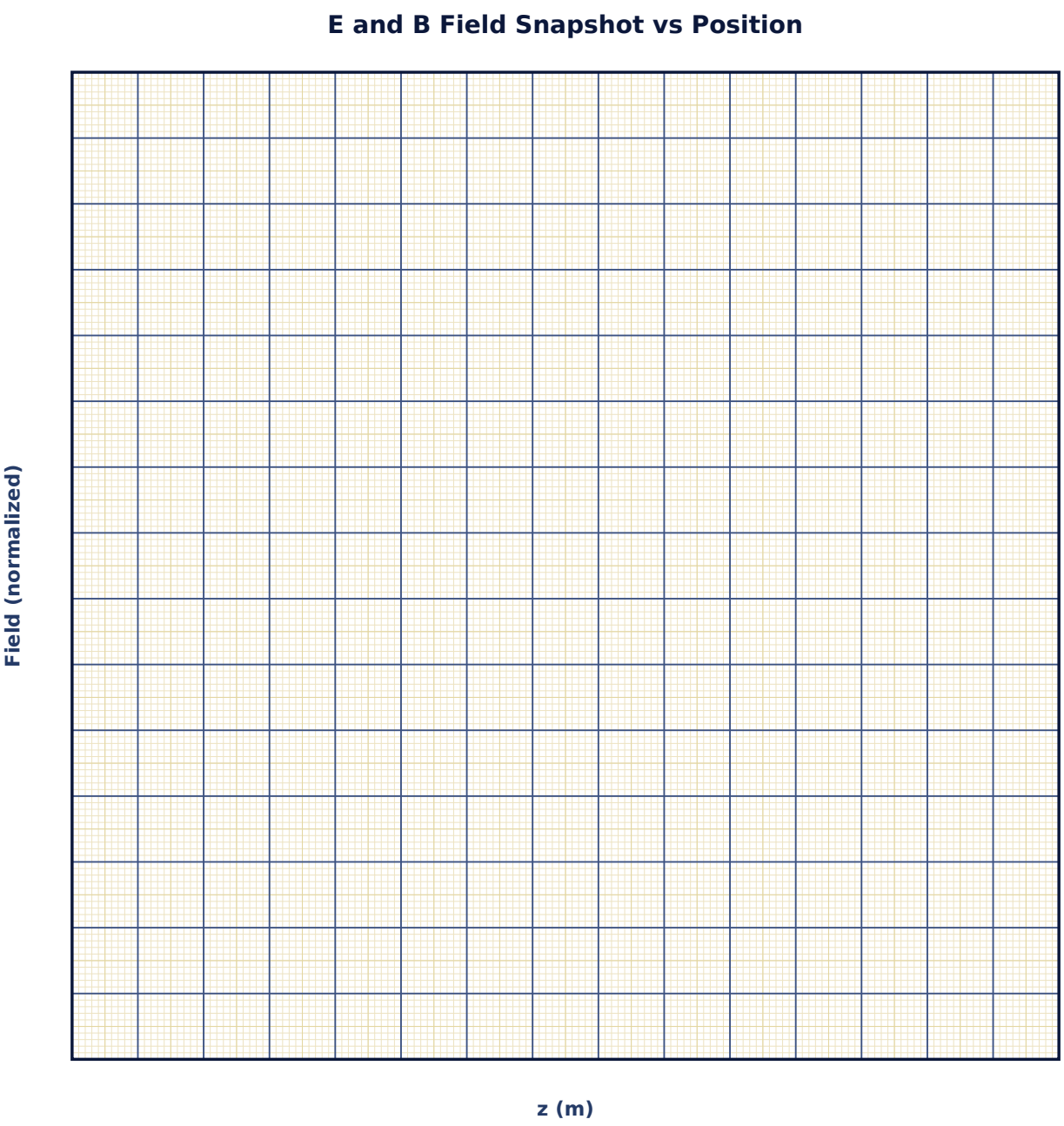
Labelled diagram of the experimental apparatus:

Observation Table

S. No.	Frequency f (MHz)	E_0 (V/m)	Computed B_0 (nT)	Wavelength λ (m)	E_0/B_0 ratio ($\times 10^8$ m/s)

S. No.	Frequency f (MHz)	E_0 (V/m)	Computed B_0 (nT)	Wavelength λ (m)	E_0/B_0 ratio ($\times 10^8$ m/s)

Graph



Calculation

Result

Quantity	Measured value	Theoretical value (c)	% deviation

Maximum Permissible Error

Formula: $\Delta B_0/B_0 = \Delta E_0/E_0$

Since $B_0 = E_0/c$ with c an exact constant, the fractional error in B_0 equals the fractional error in the measured E_0.

Quantity	Measured Value	Least Count (LC)
f — Wave frequency (MHz)		
E_0 — Electric field amplitude (V/m)		
$\Delta\varphi$ — Artificial E-B phase offset (should be 0 physically) (°)		

Calculation of maximum permissible error:

Viva-Voce Questions

1. Starting from Maxwell's curl equations, outline the steps to derive the electromagnetic wave equation.

2. Why must E and B be mutually perpendicular and both transverse to the direction of propagation?

3. Show dimensionally that $1/\sqrt{(\mu_0\varepsilon_0)}$ has the units of speed.

4. What physical role does Maxwell's displacement current term play in predicting wave propagation?

5. How is the Poynting vector defined, and what does it represent physically?

6. Why was the prediction of electromagnetic waves by Maxwell considered one of the great unifications in physics?

Propagation of EM Waves in Dielectric & Conducting Media (Skin Depth)

Aim

To study how the speed, wavelength, and attenuation of an electromagnetic wave change on entering a dielectric or a conducting medium, and to determine the skin depth for a conductor as a function of frequency and conductivity.

Date performed: _____ Simulator panel used: _____

Formula Used

$\delta = \sqrt{(2/(\omega\mu\sigma))}$, $E(x) = E_0\, e^{(-x/\delta)}$

δ = skin depth in the conducting medium
ω, μ, σ = angular frequency, permeability, conductivity

Labelled diagram of the experimental apparatus:

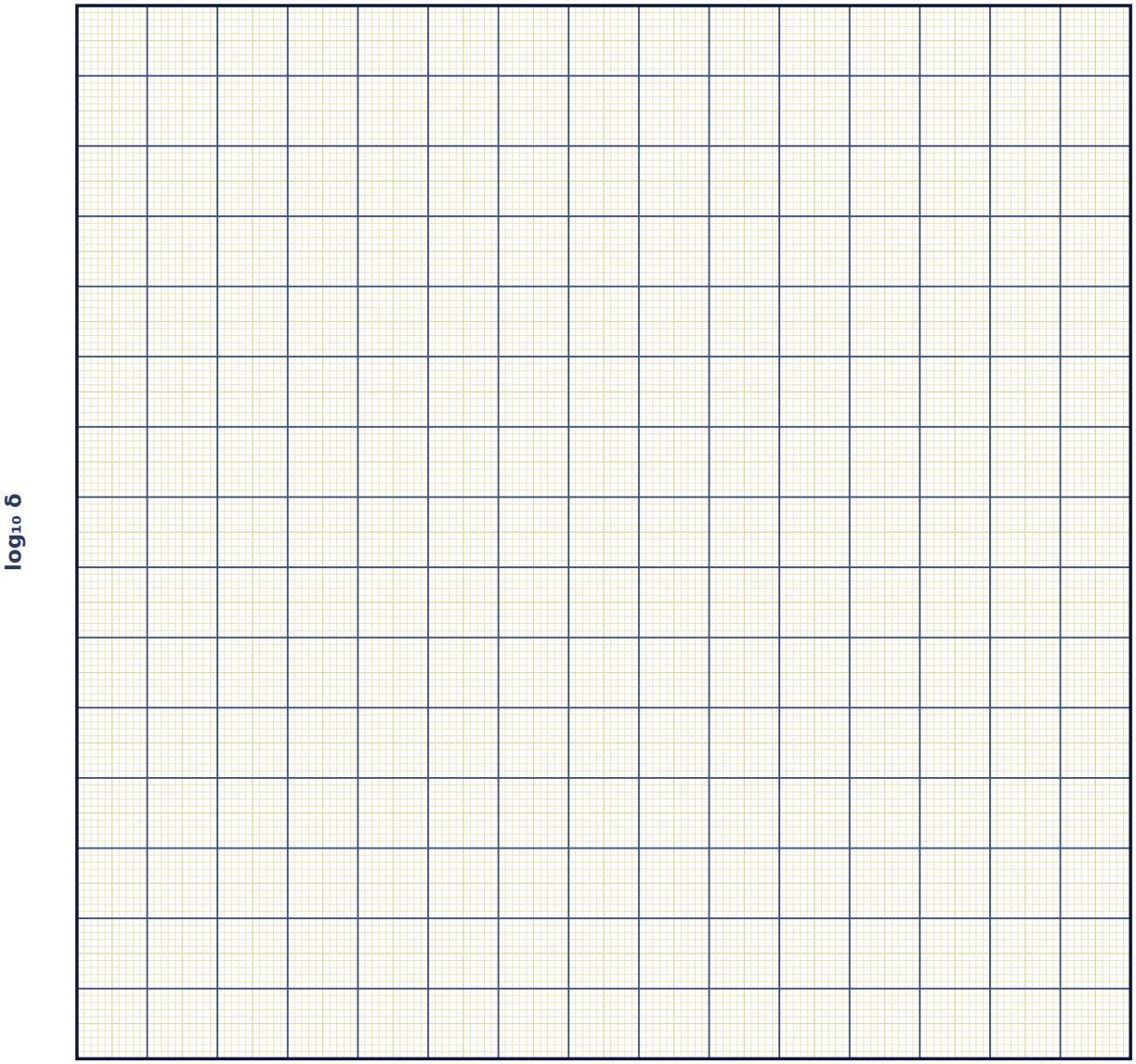
Observation Table

S. No.	Mode	Frequency f (MHz)	εr or σ	Wave speed / Skin depth	Wavelength (dielectric mode)

S. No.	Mode	Frequency f (MHz)	εr or σ	Wave speed / Skin depth	Wavelength (dielectric mode)

Graph

Skin Depth vs Frequency (log-log)



Calculation

Result

Case	Measured quantity	Theoretical value	% deviation

Maximum Permissible Error

Formula: $\Delta\delta/\delta = \frac{1}{2}(\Delta f/f + \Delta\sigma/\sigma)$

$\delta \propto 1/\sqrt{(f\sigma)}$, so the fractional errors in f and σ are each halved before summing.

Quantity	Measured Value	Least Count (LC)
εr — Relative permittivity (dielectric mode)		
f — Wave frequency (MHz)		
σ — Conductivity (conductor mode) (MS/m)		
mode — Medium (0=dielectric, 1=conductor)		

Calculation of maximum permissible error:

Viva-Voce Questions

1. Derive the refractive index $n = \sqrt{(\mu_r \varepsilon_r)}$ from the wave equation in a dielectric medium.

2. Why does an EM wave attenuate exponentially inside a conductor but not inside an ideal (lossless) dielectric?

3. Derive the expression for skin depth starting from the wave equation with a conduction-current term.

4. Why are radio antennas and high-frequency circuit traces often silver-plated even though bulk silver is only marginally more conductive than copper?

5. How does skin depth explain why AC power transmission cables sometimes use stranded or hollow conductors?

6. Relate the concept of skin depth to electromagnetic shielding effectiveness of an enclosure.

Reflection, Refraction & Brewster's Angle for EM Waves

Aim

To study the reflection and transmission of an electromagnetic wave at a dielectric interface using the Fresnel equations, and to locate Brewster's angle at which p-polarized reflection vanishes.

Date performed: _____ Simulator panel used: _____

Formula Used

$n_1 \sin\theta_i = n_2 \sin\theta_t$, $\tan\theta_B = n_2/n_1$

θ_i, θ_t = angles of incidence and refraction
θ_B = Brewster angle (fully polarised reflection)
n_1, n_2 = refractive indices of the two media

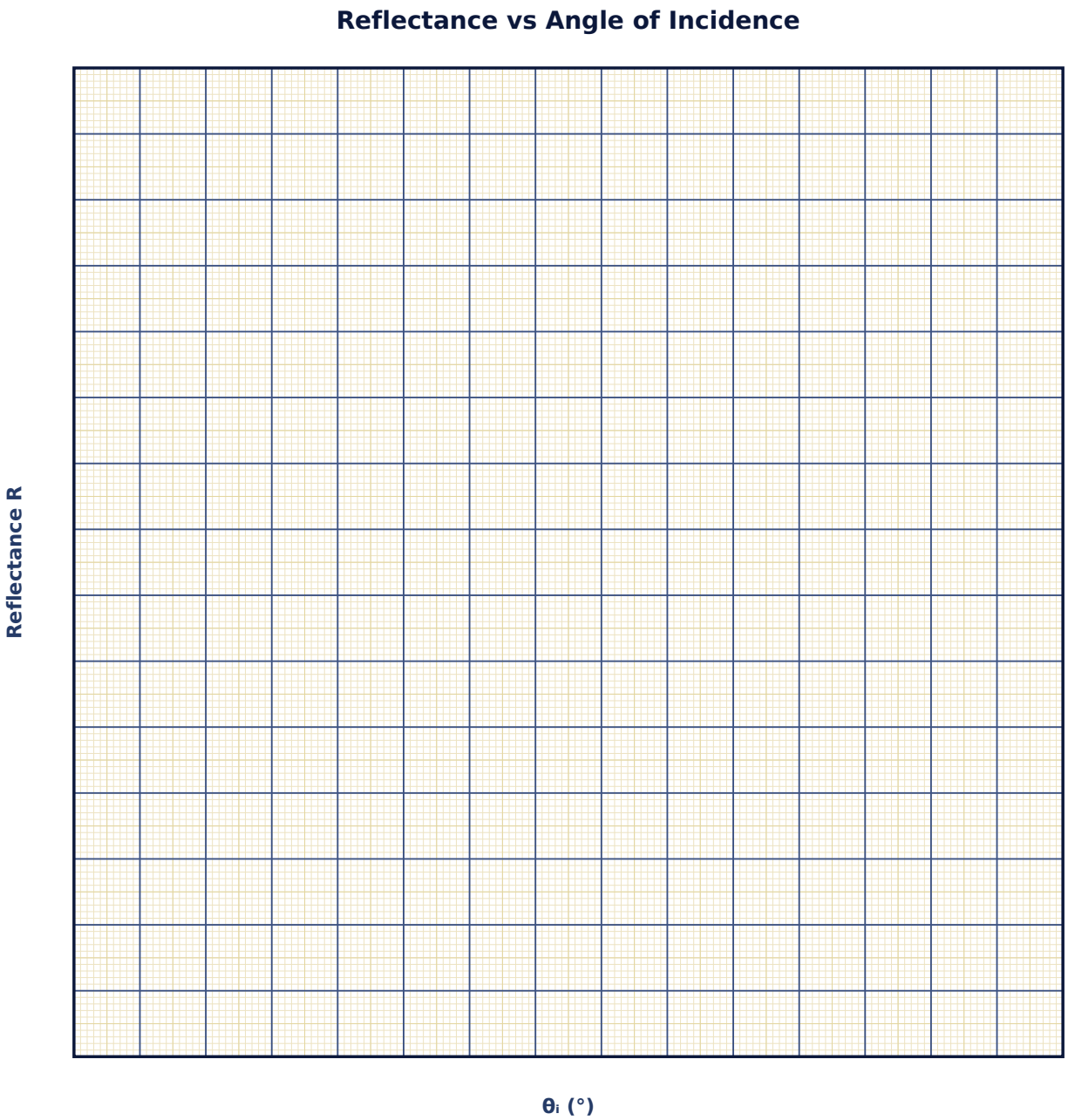
Labelled diagram of the experimental apparatus:

Observation Table

S. No.	n_1	n_2	θ_i (°)	R_p (%)	R_s (%)

S. No.	n_1	n_2	θ_i (°)	R_p (%)	R_s (%)

Graph



Calculation

Result

n_2/n_1	Brewster angle (measured)	Brewster angle (arctan n_2/n_1)	% deviation

Maximum Permissible Error

Formula: $\Delta\theta_B \approx [1/(1+(n_2/n_1)^2)]\cdot(n_2/n_1)\cdot(\Delta n_2/n_2 + \Delta n_1/n_1)$

Obtained by differentiating $\theta_B = \arctan(n_2/n_1)$ with respect to the ratio n_2/n_1.

Quantity	Measured Value	Least Count (LC)
n_1 — Incident medium index		
n_2 — Transmitting medium index		
θ_i — Angle of incidence (°)		
pol — Polarization (0=s, 1=p)		

Calculation of maximum permissible error:

Viva-Voce Questions

1. Derive Brewster's angle condition from the Fresnel equation for p-polarized reflectance.

2. Why does no Brewster angle exist for s-polarized light?

3. Show that at Brewster's angle the reflected and refracted rays are perpendicular.

4. How are Brewster windows used inside a laser cavity, and why?

5. Distinguish Brewster's angle from the critical angle for total internal reflection.

6. How do polarizing sunglasses exploit Brewster-angle reflection from horizontal surfaces like water or roads?

Rectangular Waveguide — TE_{10} Mode & Cutoff Frequency

Aim

To compute the cutoff frequency of the dominant TE_{10} mode of a rectangular waveguide from its broad-wall dimension, and determine whether a given signal frequency will propagate or be evanescently attenuated.

Date performed: _____ Simulator panel used: _____

Formula Used

$f_c(TE10) = c / (2a)$

f_c = cutoff frequency of the dominant TE_{10} mode (Hz)
a = waveguide broad-wall dimension (m)

Labelled diagram of the experimental apparatus:

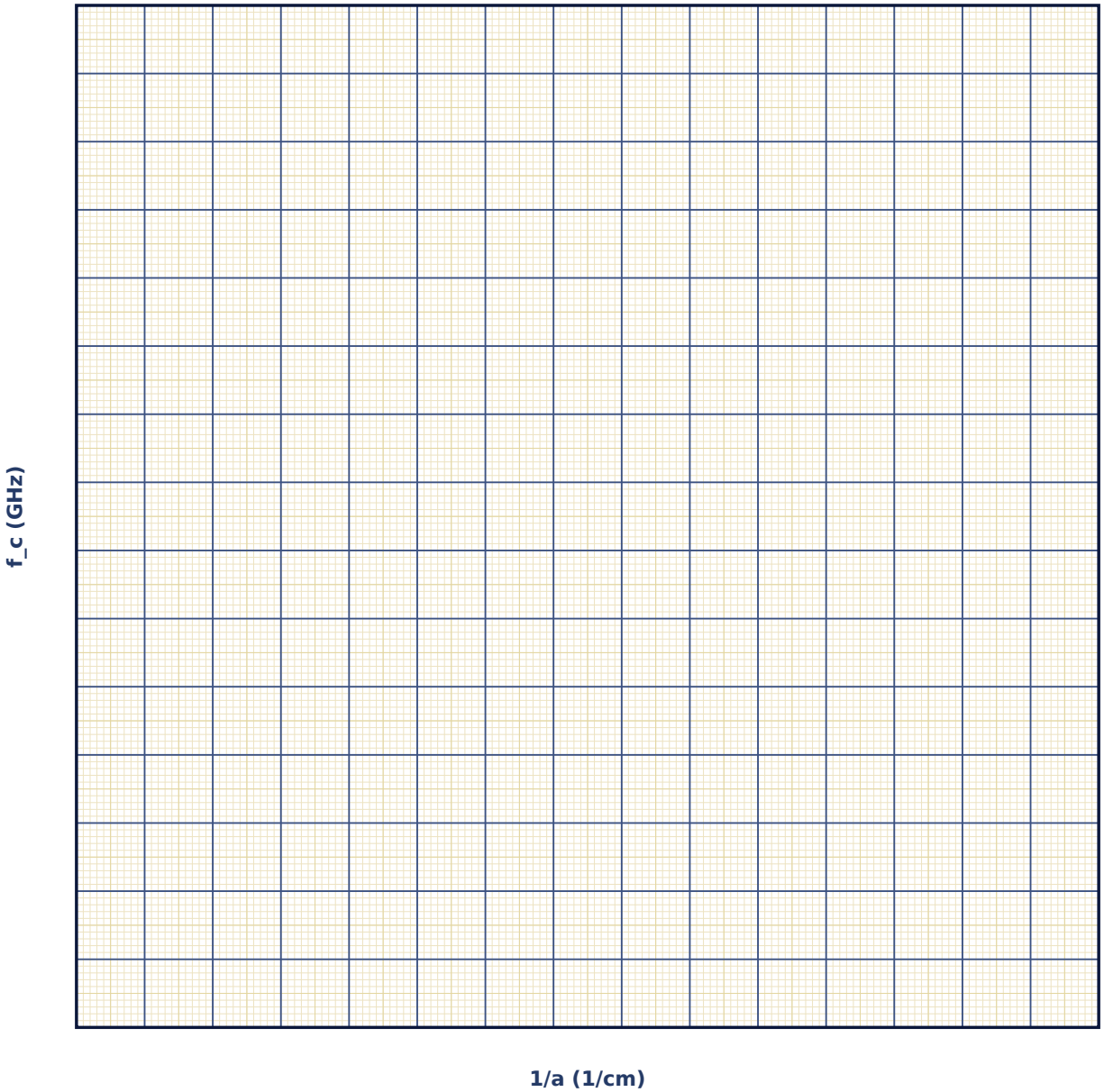
Observation Table

S. No.	a (cm)	f_c (GHz)	f tested (GHz)	Propagates? (Y/N)

S. No.	a (cm)	f_c (GHz)	f tested (GHz)	Propagates? (Y/N)

Graph

Cutoff frequency f_c vs 1/a



Calculation

Result

Quantity	Slope of f_c vs 1/a (→ c/2)	Expected value	% deviation

Maximum Permissible Error

Formula: (Δ f_c)/(f_c) = (Δ a)/(a)

f_c = c/(2a) is inversely proportional to a alone, so its fractional error equals that of the measured dimension a.

Quantity	Measured Value	Least Count (LC)
a — Waveguide broad-wall dimension (cm)		
f — Signal frequency (GHz)		

Calculation of maximum permissible error:

Viva-Voce Questions

1. Explain physically why a hollow waveguide has a cutoff frequency while a coaxial cable does not.

2. Derive the TE_{10} cutoff frequency from the boundary conditions on the waveguide walls.

3. What happens to a signal launched below the cutoff frequency?

4. Why is TE_{10} called the 'dominant mode'?

5. How would you choose waveguide dimensions for an X-band radar system operating near 9–10 GHz?

Transmission Lines — Characteristic Impedance, Reflection & VSWR

Aim

To compute the reflection coefficient and voltage standing-wave ratio (VSWR) on a transmission line of characteristic impedance Z_0 terminated in a mismatched load impedance Z_L, and to see how impedance matching minimises reflected power.

Date performed: _____ Simulator panel used: _____

Formula Used

$$\Gamma = (Z_L - Z_0)/(Z_L + Z_0) \text{ , } VSWR = (1+|\Gamma|)/(1-|\Gamma|)$$

Γ = voltage reflection coefficient
Z_0, Z_L = line characteristic impedance and load impedance
VSWR = voltage standing-wave ratio (≥ 1)

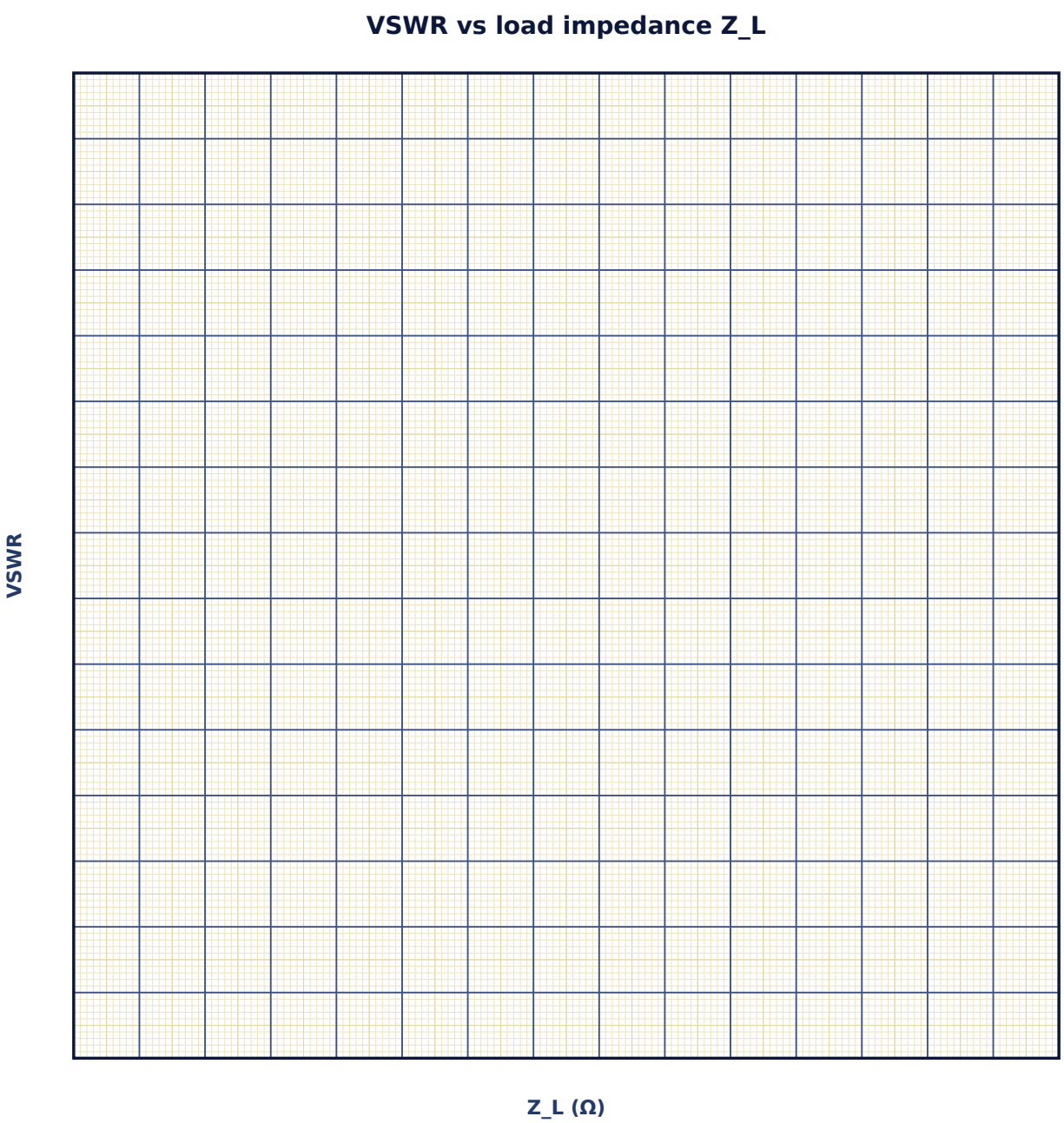
Labelled diagram of the experimental apparatus:

Observation Table

S. No.	Z_0 (Ω)	Z_L (Ω)	Γ	VSWR	Reflected power fraction	Γ	²

S. No.	Z_0 (Ω)	Z_L (Ω)	Γ	VSWR	Reflected power fraction	Γ	²

Graph



Calculation

Result

Quantity	Z_L giving minimum VSWR	Expected value	% deviation

Maximum Permissible Error

Formula: Evaluated numerically from Z_0 and Z_L via

VSWR is a nonlinear function of the reflection coefficient Γ, so its propagated uncertainty is best evaluated numerically by perturbing Z_0 and Z_L in turn rather than via one closed-form expression.

Quantity	Measured Value	Least Count (LC)
Z_0 — Line characteristic impedance (Ω)		
Z_L — Load impedance (resistive) (Ω)		

Calculation of maximum permissible error:

Viva-Voce Questions

1. Define the reflection coefficient Γ and the voltage standing-wave ratio (VSWR).

2. Why does a matched load ($Z_L = Z_0$) give zero reflection?

3. What are the VSWR values for a short-circuit and an open-circuit termination, and why?

4. Explain the practical importance of minimising VSWR in an RF transmitter feed line.

5. What technique(s) can be used to match a mismatched load to a transmission line?

Electrostatic & EM Shielding Effectiveness of a Faraday Cage

Aim

To compute the shielding effectiveness of a conducting enclosure (Faraday cage) as a function of wall thickness, conductivity and frequency, via the skin-depth attenuation of the incident field as it penetrates the conducting wall.

Date performed: _____ Simulator panel used: _____

Formula Used

SE (dB) = 8.69 t/δ , δ = √(2/(ωμσ))

SE = shielding effectiveness (dB, absorption loss)
t = enclosure wall thickness
δ = skin depth of the wall material

Labelled diagram of the experimental apparatus:

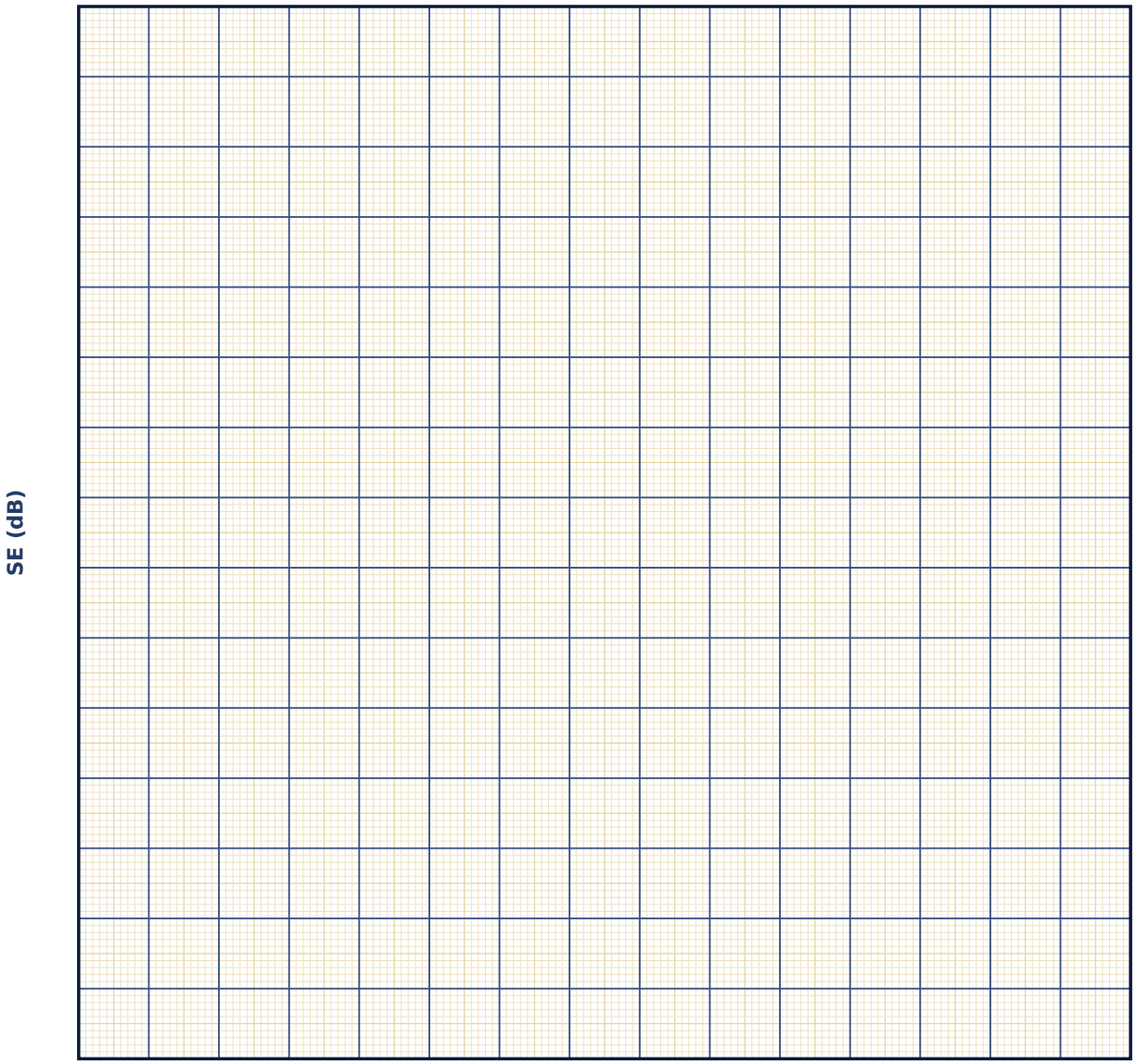
Observation Table

S. No.	f (MHz)	t (mm)	σ (×10⁶ S/m)	δ (μm)	SE (dB)

S. No.	f (MHz)	t (mm)	σ (×10⁶ S/m)	δ (μm)	SE (dB)

Graph

Shielding effectiveness SE vs frequency f



Calculation

Result

Quantity	SE at reference frequency f_0	Expected value	% deviation

Maximum Permissible Error

Formula: $(\Delta SE)/(SE) = (\Delta t)/(t) + (1)/(2)((\Delta f)/(f) + (\Delta\sigma)/(\sigma))$

SE = 8.69t/δ with $\delta \propto 1/\sqrt{(f\sigma)}$, so f and σ each enter with a half-power (square-root) dependence, contributing half their fractional error.

Quantity	Measured Value	Least Count (LC)
t — Wall / mesh thickness (mm)		
σ — Wall conductivity ($\times 10^6$ S/m)		
f — Field frequency (MHz)		

Calculation of maximum permissible error:

Viva-Voce Questions

1. Explain why a Faraday cage shields static electric fields completely, regardless of wall thickness.

2. Define skin depth and explain why it decreases with increasing frequency.

3. Derive the approximate absorption-loss formula SE ≈ 8.69t/δ.

4. Why can a fine wire mesh be nearly as effective as a solid metal sheet at RF shielding?

5. What other loss mechanisms, besides absorption, contribute to a real enclosure's total shielding effectiveness?

Dielectric Polarization & the Clausius–Mossotti Relation

Aim

To study how an external electric field polarizes a dielectric material, relate the macroscopic polarization to the microscopic atomic polarizability using the Clausius–Mossotti relation, and observe the resulting bound charges.

Date performed: _____ Simulator panel used: _____

Formula Used

$$(\varepsilon_r - 1)/(\varepsilon_r + 2) = N\alpha/(3\varepsilon_0)$$

ε_r = relative permittivity of the dielectric
N = number density of molecules
α = molecular polarizability

Labelled diagram of the experimental apparatus:

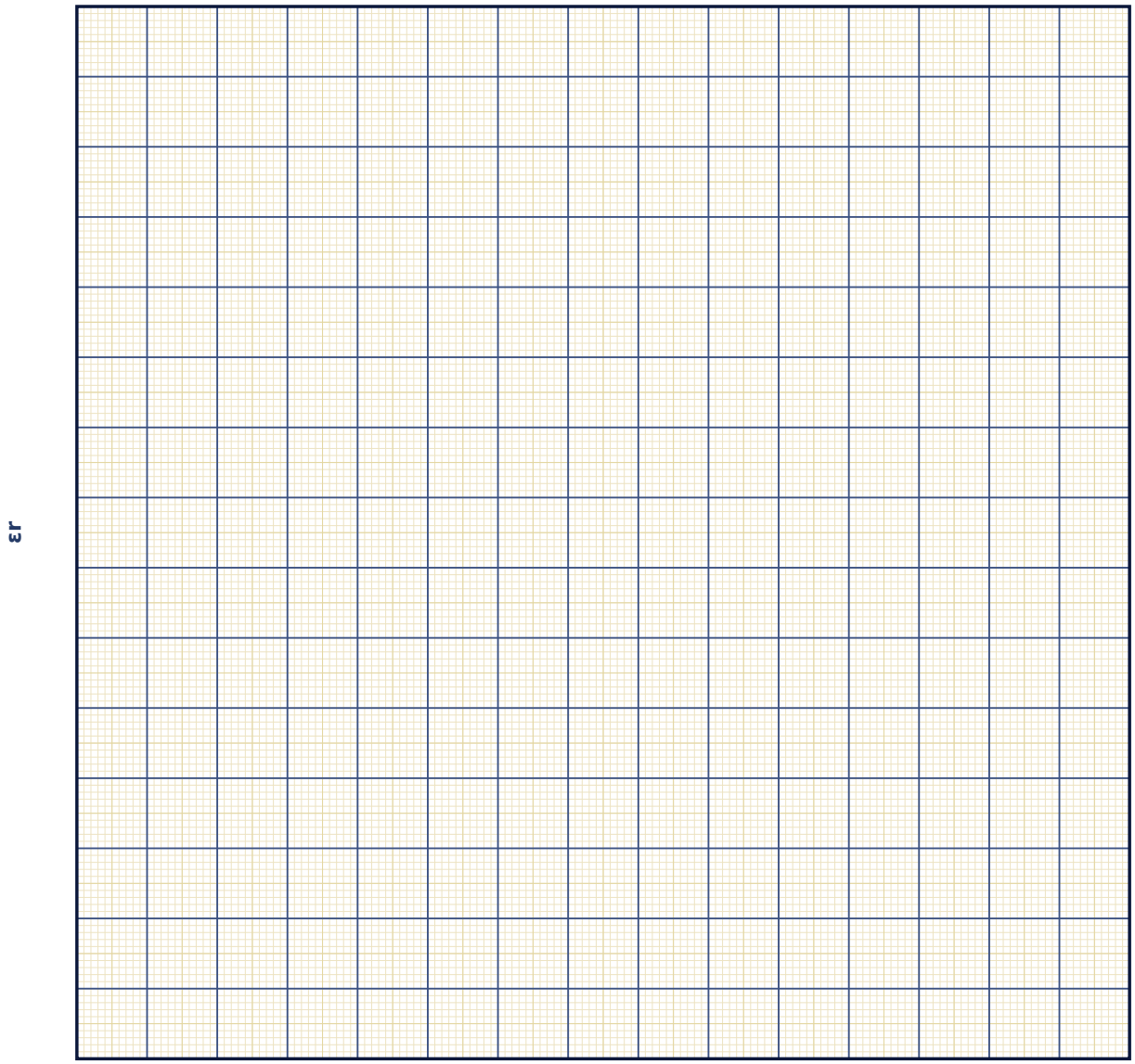
Observation Table

S. No.	N ($\times 10^{28}$ m^{-3})	α ($\times 10^{-40}$ $C \cdot m^2/V$)	ε_r (Clausius-Mossotti)	Applied field E (kV/m)	Polarization P ($\mu C/m^2$)

S. No.	N (×10²⁸ m⁻³)	α (×10⁻⁴⁰ C·m²/V)	εr (Clausius-Mossotti)	Applied field E (kV/m)	Polarization P (μC/m²)

Graph

Dielectric Constant vs Number Density N



Calculation

Result

Case	εr computed	Bound charge σ_b	Remarks

Maximum Permissible Error

Formula: via Clausius–Mossotti; Δεr estimated numerically from ΔN/N + Δα/α

εr is a nonlinear function of Nα, so its propagated error is evaluated numerically from the fractional errors of N and α rather than a simple closed form.

Quantity	Measured Value	Least Count (LC)
N — Number density (×10²⁸ m⁻³)		
α — Molecular polarizability (×10⁻⁴⁰ C·m²/V)		
E — Applied field (kV/m)		

Calculation of maximum permissible error:

Viva-Voce Questions

1. Define polarization P and relate it to the electric susceptibility χe.

2. Derive the Clausius–Mossotti relation, explaining the role of the local (Lorentz) field correction.

3. What is meant by 'bound charge', and where does it appear on/in a polarized dielectric?

4. Why does the simple relation εr−1 ≈ Nα/ε₀ (without the local-field correction) become inaccurate at high densities?

5. How does the Clausius–Mossotti relation connect to the Lorentz–Lorenz relation for the refractive index?

6. Explain qualitatively what a 'polarization catastrophe' represents physically (link to ferroelectricity).

Magnetic Hysteresis & the B–H Curve of Ferromagnetic Materials

Aim

To trace the B–H hysteresis loop of a ferromagnetic material as the applied field H is cycled, and to determine the saturation magnetization, retentivity (remanence), coercivity, and hysteresis energy loss per cycle.

Date performed: _____ Simulator panel used: _____

Formula Used

$H_c \approx 0.15 \times H_{max}$ (model estimate of coercivity)

H_c = coercivity of the ferromagnetic core
H_{max} = peak applied magnetising field

Labelled diagram of the experimental apparatus:

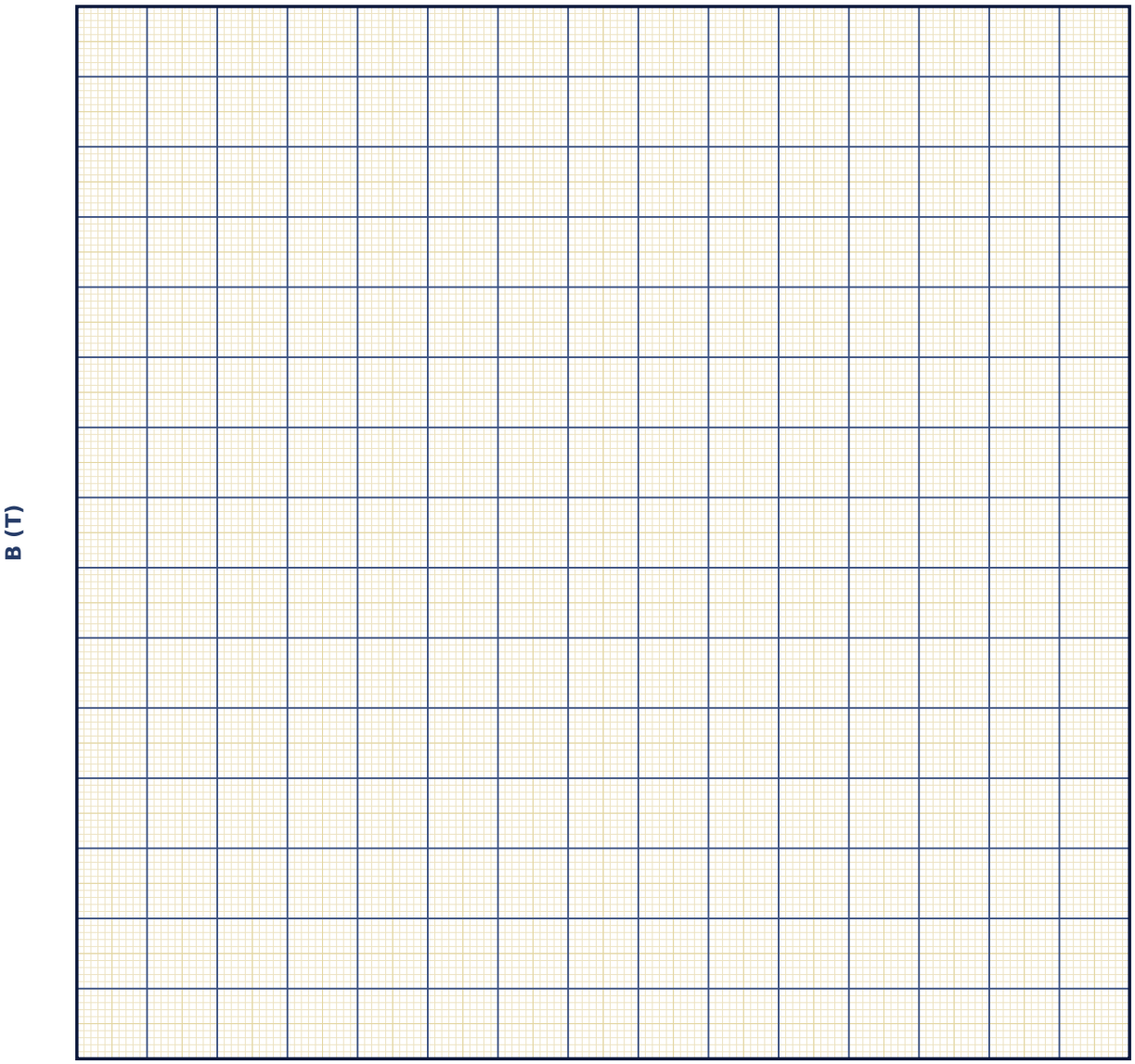
Observation Table

S. No.	Material	H (A/m)	B (T)	Cycle number

S. No.	Material	H (A/m)	B (T)	Cycle number

Graph

B–H Hysteresis Loop



Calculation

Result

Material	B_sat (T)	Retentivity B_r (T)	Coercivity H_c (A/m)	Loop area / cycle loss

Maximum Permissible Error

Formula: $H_c \approx 0.15 \times H_{max}$ (model estimate); $\Delta H_c/H_c = \Delta H_{max}/H_{max}$

In this model, coercivity is estimated as a fixed fraction of the peak applied field; its uncertainty tracks the peak-field setting's fractional uncertainty.

Quantity	Measured Value	Least Count (LC)
mat — Material (0=soft iron, 1=ferrite, 2=hard steel)		
H_max — Peak applied field (A/m)		
n — Number of cycles to trace		

Calculation of maximum permissible error:

Viva-Voce Questions

1. Define retentivity and coercivity, and explain how each is read off a B–H loop.

2. Why does the area enclosed by the hysteresis loop represent energy dissipated as heat?

3. Distinguish between magnetically 'soft' and 'hard' materials in terms of their hysteresis loops, and give one application of each.

4. Why do transformer cores use soft magnetic materials with narrow loops rather than hard materials?

5. What is a domain, and how does domain-wall motion explain the irreversibility seen in hysteresis?

6. How does the hysteresis loss per cycle relate to the total power loss in an AC-excited transformer core operating at 50 Hz?

Hall Effect — Carrier Density & Sign of Charge Carriers

Aim

To measure the Hall voltage developed across a current-carrying conducting slab placed in a transverse magnetic field, and use it to determine the density and sign (electron or hole) of the majority charge carriers in the sample.

Date performed: _____ Simulator panel used: _____

Formula Used

$V_H = IB / (n \cdot e \cdot t)$

V_H = Hall voltage across the sample (V)
I, B = sample current and transverse field
n, t = carrier density and sample thickness

Labelled diagram of the experimental apparatus:

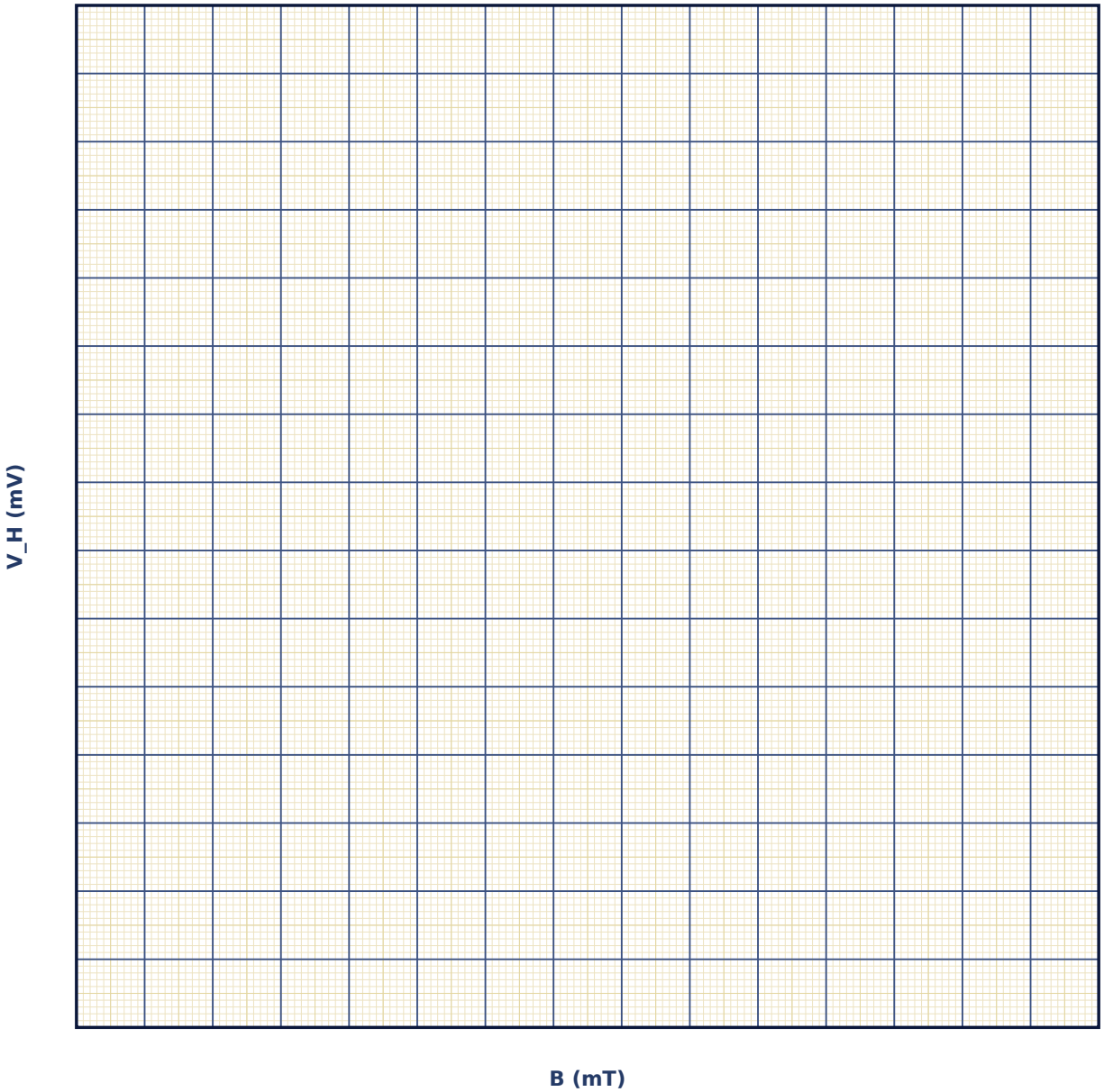
Observation Table

S. No.	I (mA)	B (mT)	n (×10²⁰ m⁻³)	t (mm)	V_H (mV)

S. No.	I (mA)	B (mT)	n (×10²⁰ m⁻³)	t (mm)	V_H (mV)

Graph

Hall voltage V_H vs magnetic field B



Calculation

Result

Quantity	Slope of V_H vs B (→ carrier density n)	Expected value	% deviation

Maximum Permissible Error

Formula: (Δ V_H)/(V_H) = (Δ I)/(I) + (Δ B)/(B) + (Δ n)/(n) + (Δ t)/(t)

V_H = IB/(net) is a product/quotient of four measured quantities, so all four fractional errors add directly.

Quantity	Measured Value	Least Count (LC)
I — Current through sample (mA)		
B — Transverse magnetic field (mT)		
n — Carrier density (doped semiconductor sample) ($\times 10^{20}$ m^{-3})		
t — Sample thickness (mm)		

Calculation of maximum permissible error:

Viva-Voce Questions

1. Explain the physical origin of the Hall voltage in terms of the Lorentz force on moving charge carriers.

2. How does the sign of the Hall voltage reveal whether the majority carriers are electrons or holes?

3. Why are semiconductors, rather than metals, generally used in practical Hall-effect sensors?

4. Derive the expression for the Hall coefficient R_H and relate it to the carrier density.

5. Describe one real-world application of the Hall effect (e.g. current sensing, position sensing).

Meissner Effect — Flux Expulsion in a Superconductor

Aim

To model the exponential decay of an applied magnetic field with depth inside a superconductor below its critical temperature, characterised by the London penetration depth λ, demonstrating the Meissner effect.

Date performed: _____ Simulator panel used: _____

Formula Used

$B(x) = B_0 e^{(-x/\lambda)}$

B(x) = field remaining at depth x inside the superconductor
B_0 = applied surface field
λ = London penetration depth

Labelled diagram of the experimental apparatus:

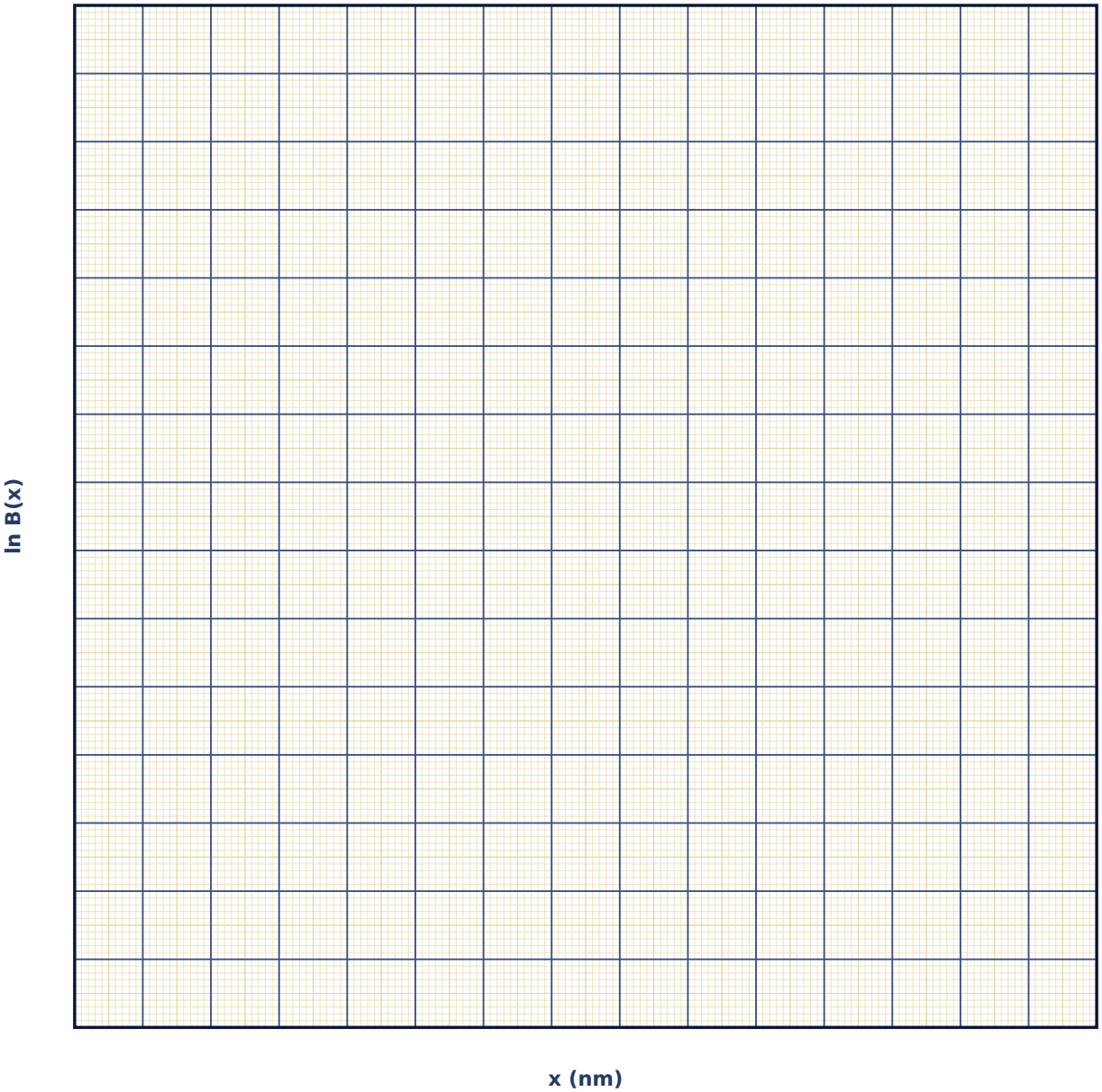
Observation Table

S. No.	x (nm)	B_0 (mT)	λ (nm)	B(x) (mT)	ln B(x)

S. No.	x (nm)	B_0 (mT)	λ (nm)	B(x) (mT)	ln B(x)

Graph

ln B(x) vs depth x



Calculation

Result

Quantity	−(Slope) of ln B vs x (→ 1/λ)	Expected value	% deviation

Maximum Permissible Error

Formula: (Δ B)/(B) = (Δ B_0)/(B_0) + (x)/(λ)·(Δλ)/(λ) + (Δ x)/(λ)

B(x) = B_0 e^(−x/λ) is exponential in x/λ, so its logarithmic derivative brings down a factor of x/λ for the λ term.

Quantity	Measured Value	Least Count (LC)
B_0 — Applied surface field (mT)		
λ — London penetration depth (nm)		
x — Depth into superconductor (nm)		

Calculation of maximum permissible error:

Viva-Voce Questions

1. Distinguish between the Meissner effect and simple perfect conductivity (zero resistance).

2. Define the London penetration depth and give its typical order of magnitude.

3. Why do screening currents flow in a thin surface layer rather than as an infinitesimally thin sheet?

4. What happens to superconductivity if the applied field exceeds the critical field B_c?

5. Name one practical application that relies on the Meissner effect (e.g. magnetic levitation).