Unit 14 · Electricity and Magnetism

STUDY NOTES

Key terms

Electric field: region round a charge in which another charge feels an electrostatic force.

Test charge q_0: small, positive by agreement; small so it doesn't move the charges making the field.

Field intensity E: force on a unit positive charge at a point; vector; N/C.

Point charge: on a body very small compared with the distances.

Electric line of force: path a free, small positive charge would tend to follow; tangent = field's direction.

Neutral point: resultant field zero.

One coulomb: the charge which, 1 m from an equal charge in a vacuum, repels it with 9×10^9 N.

Capacitor: stores charge; two conductors close together, separated by an insulator, the **dielectric**.

Capacitance: ratio of the charge on either plate to the potential difference between the plates.

One farad: 1 V across puts 1 C on its plates.

Magnetic line of force: path a free, isolated N pole would tend to follow; tangent = direction a compass N pole points.

Geographic meridian: vertical plane through the place and the geographic poles. **Magnetic meridian**: vertical plane a freely hanging compass needle settles in.

Declination: angle between the two meridians; compass points that far from true north; east or west.

Dip (inclination): angle of the Earth's field with the horizontal, in the magnetic meridian.

Formulas

$E = \frac{F}{q_0}, F = qE$	E N/C; negative charge: force opposite **Use:** charge in a field
$E = \frac{kQ}{r^2}$	Q C, r m **Use:** field of a point charge
$F = \frac{k\,q_1 q_2}{r^2}$	$k = 9 \times 10^9$ N m^2/C^2 **Use:** Coulomb's law
$C = \frac{Q}{V}, Q = CV$	C F, Q C, V V **Use:** capacitor
$\tan\delta = \frac{V}{H}$	vertical, horizontal parts **Use:** angle of dip

- **change first**
  - 1 μC = 10^{-6} C
  - 1 nC = 10^{-9} C
  - 1 cm = 0.01 m
  - (30 cm)^2 = 0.09 m^2
- 1 μF = 10^{-6} F
- 1 nF = 10^{-9} F
- 1 pF = 10^{-12} F
- one electron 1.6×10^{-19} C; 1 C ≈ 6.25×10^{18} electrons

Electric field and lines of force

- starts on + and ends on − (or goes far away); arrow = force on a + test charge
- **never cross**: field would point two ways
- close together = strong; meet a conductor at right angles
- positive point charge: straight out, like spokes; negative: straight in
- **unlike** charges: lines run from + to −, curve round; attract
- **like** charges
  - no line joins them
  - bend apart
  - repel
  - neutral point halfway (equal charges)
- 2 × distance: $E \div 4$; 3 ×: $\div 9$
- +5 μC at 30 cm: $E = 5 \times 10^5$ N/C, away
- −2 nC in 3,000 N/C up: 6×10^{-6} N, down

Coulomb's law

The force of attraction or repulsion between two point charges is directly proportional to the product of the charges and inversely proportional to the square of the distance between them, and it acts along the line joining them.

- **torsion balance**, Coulomb, 1785
- forces on the two are equal and opposite (third law); depends only on the **product**

Change	New force
one charge × 2	$2F$
both × 2	$4F$
$r \times 2$	$F/4$
$r \times 3$	$F/9$
$r \div 2$	$4F$
both × 2, $r \times 2$	F
one × 3, $r \div 2$	$12F$

- size of the force: use sizes of charges; signs say attract or repel

- $E = F/q_0 = kQ/r^2$: test charge cancels
- +3 μC, +4 μC, 20 cm: 2.7 N; equal charges, 10 cm, 0.9 N: 1 μC each

Gravitational	Electrostatic
masses	charges
always attracts	attracts or repels
$G = 6.67 \times 10^{-11}$ N m^2/kg^2	$k = 9 \times 10^9$ N m^2/C^2
not changed by what lies between	weaker with an insulator between
planets, stars, galaxies	atoms, molecules, solids

- two protons: electric $\approx 10^{36} \times$ gravity; big bodies' charges cancel, masses add

Capacitor

- **charging**
  - battery pulls electrons off one plate, pushes them onto the other
  - none cross
  - stops when capacitor's voltage = battery's
- **discharging:** join plates through a bulb; extra electrons flow round; bulb glows a moment
- plates +Q and −Q
- "stores Q" = on either plate
- total zero
- $Q \propto V$ for one capacitor; C fixed
- **bigger** C
  - bigger plates
  - closer plates
  - better dielectric (mica, ceramic)
- 1 F of plates 1 mm apart in air: about 113 km^2 each
- printed: "470 μF 25 V" = highest safe voltage; above it the dielectric can break down
- 470 μF, 12 V: 5.64 mC
- charge stays after unplugging: **never open** a TV, microwave oven, camera flash

Capacitor	Cell
stores charge on plates	chemical reactions
voltage falls steadily	nearly steady
fraction of a second	minutes or hours
little energy for its size	much more

Uses:

- camera flash (about 300 V; empties in about 1/1000 s)
- ceiling fan and pump motors (start, run smoothly)
- chargers (smooth the bumps)
- radio and TV tuning (with a coil)
- touchscreens (a finger changes C)
- DRAM (charged 1, empty 0)
- defibrillators
- soak up voltage spikes

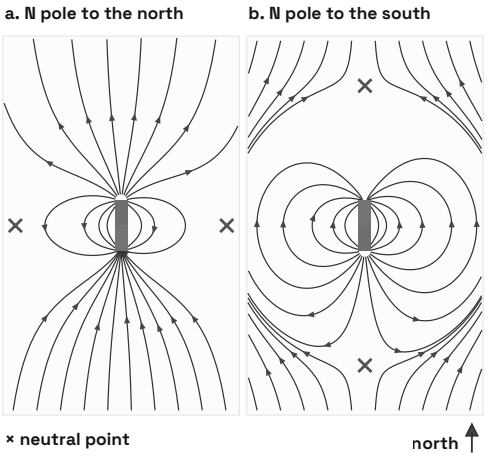
Magnetic lines of force

- N to S outside; S to N inside: **closed loops** (electric lines aren't)
- **never cross**; tangent = field direction
- crowded near the poles, spread out farther away
- uniform field (Earth's over a small table): straight, parallel, evenly spaced
- tend to shorten (unlike poles pull) and push sideways (like poles push)

Practical 26:

1. compass alone: draw the magnetic meridian
2. magnet along it; draw its outline; mark N, S
3. compass near N pole; dots at both needle ends
4. move compass: S end over the dot of its N end; next dot
5. to the S pole or the edge; smooth curve; arrow N → S
6. eight or ten lines; mark crosses where the needle won't settle; repeat with N pointing south

Neutral point: magnet's field equal and opposite to the Earth's horizontal field; compass doesn't point any way



Neutral points (×): with the N pole north, east and west of the middle; with it south, on the axis, beyond both ends.

- only where the magnet's field points **south**, against the Earth's
- N pole north, beyond N end: fields add, can't cancel
- compass needle doesn't spin there: nothing pushes it

The Earth's field

- like a bar magnet at the center, **S pole toward geographic north**
- from slow currents of molten iron in the outer core (about 2,900 km down); Gilbert's terrella, 1600
- lines out of the southern half, into the northern half
- pole in the far north: magnetically **south** (attracts the N pole)
- magnetic axis about 10° from the spin axis (9.2° in 2026)
- about 25 μT at the magnetic equator
- 65 μT near the poles
- Kathmandu about 49 μT
- steers particles from the Sun near the poles: **aurora**; birds, turtles, salmon find their way

Declination and dip

Place (2026, IGRF-14)	Declination	Dip
Biratnagar	0.1° E	42°
Kathmandu	0.4° E	44° (older books 42°)
Pokhara	0.6° E	45°
Mahendranagar	1.1° E	46°

Where	Dip
magnetic equator	0°
north of it (Nepal, India, Europe)	N end down, more farther north
magnetic north pole	90°, N end down
south of it (Australia, South Africa)	S end down

Uses:

- compass with a map
- ships, aircraft
- runways by magnetic direction (Kathmandu 02, 20)
- phones
- latitude (dip)
- minerals (changes above iron ore)
- observatories

Declination by shadow:

- stick
- shadow tip A in the morning
- circle through A
- afternoon tip B on the circle
- foot to middle of AB = true north
- compass on it
- measure the angle (Nepal: under 1.5°)

Dip circle (Practicals 27, 29):

1. level the base (screws, spirit level)
2. turn until the needle stands straight up and down; note the reading; turn through exactly 90° → in the magnetic meridian
3. read both ends; turn 180°; read both again; mean

- off the meridian: same V, less H → **dips too steeply**; $\tan\delta' = V/(H\cos\phi)$; 44° true, 60° off → 63°; at right angles: 90°
- smallest reading while turning = the dip
- own needle
  - balance **before** magnetizing
  - stroke 30 times one way
  - set in the meridian

COMMON MISTAKES

✗ Distance left in cm.
✓ Meters, then square.

✗ Force doubles when r halves.
✓ Four times.

✗ Electric lines form closed loops.
✓ Start on +, end on −.

✗ Magnetic lines stop at the poles.
✓ Closed loops, S to N inside.

✗ A wrong sign changes the size of F.
✓ Sizes for size; signs for direction.

✗ A capacitor makes charge.
✓ Stores it; a cell uses chemical reactions.

✗ The pole in the far north is a north pole.
✓ Magnetically south.

✗ Neutral points always beside the magnet.
✓ N pole north: beside; N pole south: on the axis.

✗ Declination and dip mixed up.
✓ Declination: horizontal plane; dip: vertical plane.