Unit 19 · Electric Charges

STUDY NOTES

WHAT NEB'S GRADE 11 EXAM ASKS

- **CDC's grid (2077):** Electricity and Magnetism (Units 19–23 together): 16 of 75 marks
- **The paper:** 11 MCQs × 1 · 8 short × 5 · 3 long × 8; 3 hours; 1 mark per expected point
- **MCQ (1 mark)**
  - new force when charges and distance change (sign too)
  - F at $3\times$ the distance; number of electrons in a charge
  - what moves when a rod is charged (electrons only)
  - charge left by induction with earthing
- **Short (5 marks, in parts)**
  - charging by friction and by induction, with figures; conductors and insulators
  - Coulomb's law: state, ε_0, the medium's ε_r
  - net force or field from charges in a line; where the field is zero
  - dipole: force, field at the midpoint, sketch of its field
  - hanging charged spheres: $F = mg\tan\theta$, then Q

Key terms

Charge: property of protons (+) and electrons (−); unit coulomb (C).

Elementary charge (e): 1.6×10^{-19} C, the charge of a proton (+) or electron (−).

Quantization: every charge is a whole number of e: $Q = ne$.

Conservation of charge: total charge of an isolated system never changes.

Charge carriers: charged particles free to move (electrons in metals; ions in solutions; ions and electrons in gases; electrons and holes in semiconductors).

Conductor: many carriers, charge spreads over it. **Insulator**: very few, charge stays put.

Induction: a charged body moves charges in a conductor without touching it.

Earthing (grounding): connecting a conductor to the Earth. **Discharging**: removing its charge.

Point charge: charge whose size is negligible against the distances.

Permittivity (ε): property of a medium in Coulomb's law; ε_0 for vacuum.

Relative permittivity (dielectric constant) ε_r: $\varepsilon/\varepsilon_0$, how many times weaker the force is in the medium.

Superposition: each charge acts as if the others weren't there; forces add as vectors.

Electric field strength (E): force per coulomb on a positive test charge; N/C.

Formulas

$Q = ne$	n whole number **Use:** quantization
$F = \frac{1}{4\pi\varepsilon_0}\frac{Q_1Q_2}{r^2}$	r center to center **Use:** Coulomb's law
$k = \frac{1}{4\pi\varepsilon_0} \approx 9.0\times10^9$ N m^2/C^2	$\varepsilon_0 = 8.85\times10^{-12}$ C^2/(N m^2) **Use:** constants
$F = \frac{1}{4\pi\varepsilon}\frac{Q_1Q_2}{r^2}, \varepsilon_r = \frac{\varepsilon}{\varepsilon_0}$	medium **Use:** force ε_r times weaker
$\vec{F} = \vec{F}_1 + \vec{F}_2 + \cdots$	vector sum **Use:** superposition
$E = \frac{F}{q}, E = \frac{kQ}{r^2}, F = qE$	q test charge **Use:** field of a point charge

Charge

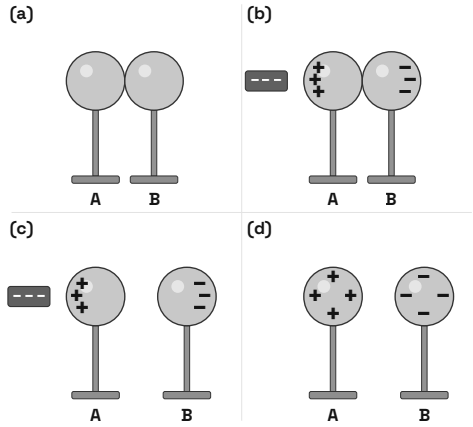
- charging never creates charge: it **moves electrons**; gain → negative, lose → positive
- protons locked in nuclei; only outer electrons move

- 1 C = 6.25×10^{18} electrons; rubbed comb a few nC; lab sphere a few μC
- e.g. -4.8×10^{-9} C → $n = Q/e = 3.0 \times 10^{10}$ electrons gained

By friction: rubbing → electrons cross between surfaces → **equal and opposite** charges

- plastic brush on hair: brush −, hair +; hairs repel each other, attracted to the brush
- polythene with wool → rod **−**; glass with silk → glass **+** (loses electrons to the silk)
- rod's + by losing electrons, never by gaining protons

Induction



In steps: (a) A and B touch, uncharged. (b) − rod near A: electrons pushed to B, A's side +. (c) B moved away, rod still there. (d) Rod removed: A +, B −, equal.

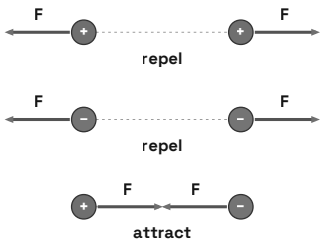
1. two spheres touching, uncharged
2. charged rod near one: free electrons pushed or pulled
3. separate them **with the rod in place**
4. remove the rod → equal, opposite charges

- rod never touches, keeps its charge → charges any number of pairs
- **one sphere**: rod near, touch the far side (earth), finger off **first**, then rod → charge **opposite** to the rod
- a + rod, earthed sphere → electrons flow up from the Earth → sphere **−**

Activities 19.1–19.3

- rubbed rod touches a sphere → sphere picks up paper, repels the hanging rubbed rod: charge passed by **contact**
- finger along the rod / one touch on the sphere → discharged; insulator only where touched, conductor at once
- spheres joined by plastic: only the touched one charged; by a wire: both
- charge **transferred** only by contact (or a spark); induction only pushes charges already there
- conductors: metals, salt water, body, Earth; insulators: plastic, glass, rubber, dry wood, dry air

Coulomb's law

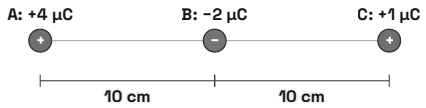


Like charges repel, unlike attract; the two forces equal and opposite (Newton's third law).

1. $F \propto Q_1 Q_2$
2. $F \propto 1/r^2$
3. along the line joining them; like repel, unlike attract

- Coulomb, 1785, torsion balance
- signs put in: F + → repulsion, − → attraction
- 3 × distance → $F/9$
- **4**π: influence spreads over a sphere's area $4\pi r^2$
- **medium**: ε replaces ε_0; air 1.0006 (use ε_0), paper ≈ 3, glass 5–10, water ≈ 80 (salt dissolves)
- **uniformly charged spheres** = point charges at their centers; radius 1 cm, surfaces 3 cm apart → r = 5 cm
- metal spheres very close: induction shifts charges → law approximate
- e.g. hydrogen, $r = 0.53 \times 10^{-10}$ m → $F = 8.2 \times 10^{-8}$ N, attractive
- $F_e/F_g \approx 2 \times 10^{39}$ in hydrogen, at every distance (both $\propto 1/r^2$)
- e.g. −2Q, +Q at d; add +Q to each → −Q, +2Q at 2 d → product same → **attractive, F/4**

Several charges, a first look at the field



A = +4.0 μC, B = −2.0 μC, C = +1.0 μC, 10 cm apart.

- each force by Coulomb's law alone, then **vector** sum; in a line, + for one direction
- e.g. on C: 0.90 N right (A, 20 cm) + 1.8 N left (B, 10 cm) → **0.90 N left**
- field direction: **away** from +, **towards** −; fix directions first, then add sizes
- e.g. $Q = -3.0$ μC, 30 cm → $E = 3.0 \times 10^5$ N/C, towards Q
- e.g. −25 μC and +50 μC, 10 cm apart, P 2 cm from −: both fields towards the − → 6.3×10^8 N/C; electron there $a = eE/m = 1.1 \times 10^{20}$ m/s^2, opposite to E

Where $E = 0$ on the line

- unlike charges: **outside**, beyond the **smaller** one
- like charges: **between**, nearer the smaller
- e.g. −32 μC, +45 μC, 12 cm: $(x + 0.12)/x = \sqrt{45/32}$ → $x = 65$ cm beyond Q_1
- e.g. zero ⅓ of the way from Q_1: $Q_1/Q_2 = (1/3)^2/(2/3)^2 = 1/4$, same sign

Dipole ±30 nC, 0.25 m

- $F = 1.3 \times 10^{-4}$ N, attractive
- midpoint: both fields towards −, add → $2kQ/r^2 = 3.5 \times 10^4$ N/C
- sketch: lines leave + and end on −, crowded near and between the charges (figure in Unit 20)

Hanging charged spheres

- forces on one sphere: weight mg down, electric force F sideways, tension T along the thread

1. $T\cos\theta = mg$, $T\sin\theta = F \rightarrow F = mg\tan\theta$
2. $F = kQ^2/r^2 \rightarrow Q = r\sqrt{F/k}$

- e.g. threads 15 cm, each 3.0 cm out, 0.08 g: $\tan\theta = 0.204$, $F = 1.60 \times 10^{-4}$ N, $r = 6.0$ cm → $Q = 8.0$ nC

COMMON MISTAKES

✗ a rod becomes + by gaining protons
✓ by **losing electrons**.

✗ friction creates charge
✓ it moves electrons; total stays zero.

✗ induction leaves the same sign as the rod
✓ **opposite** sign.

✗ removing the rod before the finger
✓ finger off **first**, or the charge flows back.

✗ r = gap between surfaces
✓ **center to center**.

✗ $F \propto 1/r$
✓ $1/r^2$: 3 × distance → $F/9$.

✗ adding field sizes without directions
✓ fix each direction, then add as vectors.

✗ $E = 0$ between unlike charges
✓ between them both fields point the **same** way.

✗ force on an electron along E
✓ **opposite** to E.

✗ grams in Coulomb problems
✓ kg, m, C.