IB DP PHYSICS · THEME D FIELDS · D.2 · ~7 MIN READ

D.2 Electric and magnetic fields

Charge and its conservation, charging by friction, contact and induction, Coulomb's law, electric field strength and field lines, the uniform field between plates, Millikan's experiment, magnetic field patterns, and (HL) electric potential and equipotentials.

Charge & charging · Coulomb's law · Electric field strength · Field lines · Parallel plates · Millikan · Magnetic fields · Electric potential (HL)

RS by Riyaz Sir
mentorriyaz.in

No tag = **SL and HL** · HL ONLY HL students only · DATA BOOKLET given in the exam

M1 A1 how marks are awarded · highlight = comes up again and again · Test yourself at the end

IN 30 SECONDS

- Like charges repel, unlike charges attract. **Coulomb's law**: $F = kq_1q_2/r^2$, with $k = 1/4\pi\varepsilon_0$. Charge is **conserved** and **quantised** in units of e.
- **Electric field strength** $E = F/q$, in N C^{-1}. Between parallel plates the field is uniform: **$E = V/d$**.
- **Magnetic fields** come from moving charges: around a wire, inside a solenoid, between magnet poles. Field lines show the direction a north pole would move.
- **HL:** electric potential **$V_e = kQ/r$**, potential energy $E_p = kq_1q_2/r$, $E = -\Delta V/\Delta r$ and $W = q\Delta V$.

BY THE END YOU CAN

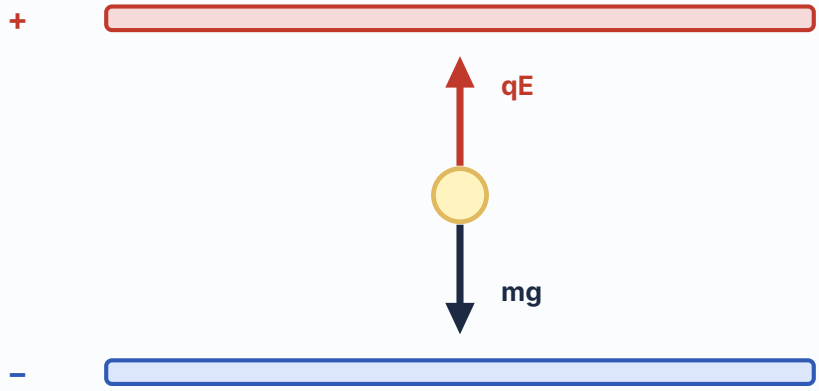
- Describe charging by friction, contact and induction, and use conservation of charge.
- Use Coulomb's law and $E = F/q$, and draw electric field lines.
- Use $E = V/d$ for parallel plates and explain Millikan's experiment.
- Draw magnetic field patterns for magnets, wires and solenoids.
- Use electric potential, potential energy and the potential gradient, and sketch equipotentials. HL

1 Electric charge

- **Charge** is measured in coulombs. The elementary charge $e = 1.60 \times 10^{-19}$ C; every free charge is a whole-number multiple of it (charge is **quantised**).
- **Conservation of charge:** the total charge of an isolated system never changes. Charging moves electrons; it does not make charge.

Method	What happens
friction	rubbing transfers electrons from one material to the other: they gain opposite charges
contact	touching a charged conductor shares its charge; equal conductors share it equally
induction	a charged rod nearby pushes or pulls electrons in a conductor; earthing it and then removing the earth leaves an opposite charge behind

Millikan's oil-drop experiment



stationary:
qE = mg
q = mg/E
always a whole multiple of e

When the electric force balances the weight, the drop hangs still. Its charge is always a multiple of e.

WORKED EXAMPLE

An oil drop of mass 3.0×10^{-15} kg is held stationary between plates where $E = 1.84 \times 10^{5}$ N C^{-1}. Find its charge in units of e.

1. $qE = mg \Rightarrow q = 3.0 \times 10^{-15} \times 9.8/1.84 \times 10^{5}$ M1
2. **$= 1.6 \times 10^{-19}$ C = 1e (one extra electron)** A1

2 Coulomb's law

$$F = k\frac{q_1 q_2}{r^2}$$ DATA BOOKLET

$k = 1/4\pi\varepsilon_0 = 8.99 \times 10^{9}$ N m^2 C^{-2}

WORKED EXAMPLE

Find the force between +2.0 μC and −3.0 μC charges 10 cm apart.

1. $F = 8.99 \times 10^{9} \times 2.0 \times 10^{-6} \times 3.0 \times 10^{-6}/0.10^{2}$ M1
2. **$= 5.4$ N, attractive** A1

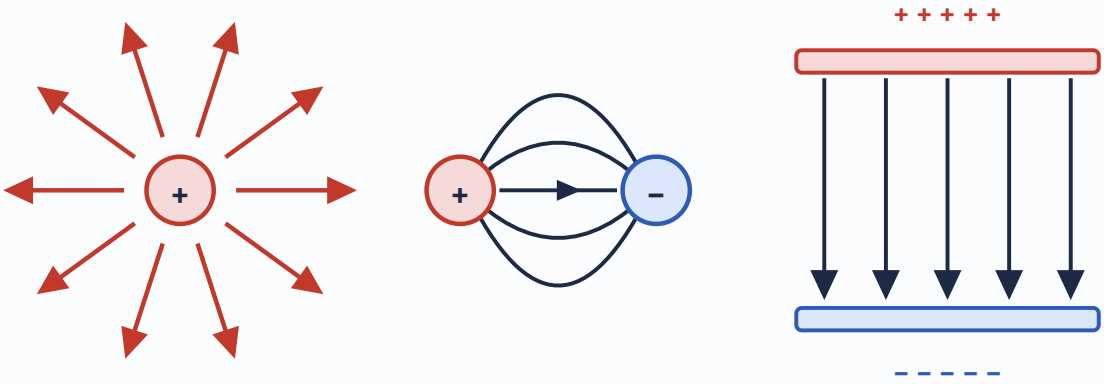
- **Permittivity ε_0** (8.85×10^{-12} C^2 N^{-1} m^{-2}) describes the vacuum. In a material the force is weaker.

3 Electric field

$$E = \frac{F}{q}$$ DATA BOOKLET

the force per unit positive test charge, N C^{-1}

- For a point charge, $E = kQ/r^2$. **Field lines** start on positive charges and end on negative ones; their density shows the field strength; they never cross.



positive: lines outwards | **dipole** | **parallel plates: uniform**

Field line patterns. Between parallel plates the lines are parallel and evenly spaced, so the field is uniform.

WORKED EXAMPLE

Find the field strength 20 cm from a +1.0 nC point charge.

1. $E = kQ/r^2 = 8.99 \times 10^9 \times 1.0 \times 10^{-9}/0.20^2$ M1
2. **$= 225\ N\ C^{-1}$, pointing away from the charge** A1

$$E = \frac{V}{d}$$ DATA BOOKLET

uniform field between parallel plates, V m^{-1} (= N C^{-1})

WORKED EXAMPLE

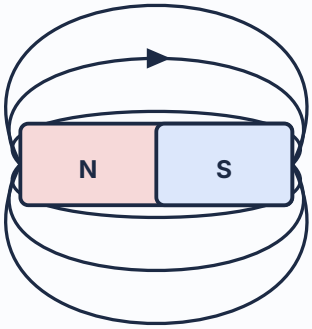
Plates 2.0 cm apart are connected to 500 V. Find E and the force on an electron between them.

1. $E = 500/0.020 =$ **$2.5 \times 10^4\ V\ m^{-1}$** A1
2. **$F = eE = 1.6 \times 10^{-19} \times 2.5 \times 10^4 = 4.0 \times 10^{-15}$ N towards the + plate** A1

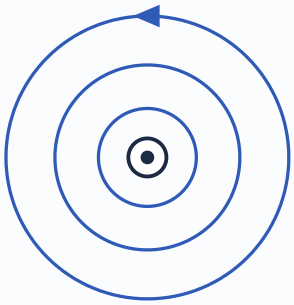
COMMON MISTAKE

Thinking the field between plates is strongest near one plate. It is uniform: the same everywhere except near the edges.

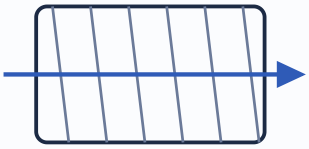
4 Magnetic fields



bar magnet: N to S outside



current out of page: anticlockwise circles



solenoid: uniform field inside

Field lines go from N to S outside a magnet; around a wire they are circles; inside a long solenoid they are straight and uniform.

- **Right-hand grip rule:** thumb along the conventional current, fingers curl in the direction of the field. For a solenoid, fingers along the current in the turns and the thumb points to the N end.
- **Symbols:** × means field into the page, • means out of the page.

5 Electric potential HL

Electric potential V_e — the work done per unit positive charge in bringing a small test charge from infinity to that point. A scalar, zero at infinity.

$$V_e = k\frac{Q}{r}$$ DATA BOOKLET

positive near a positive charge, negative near a negative one

$$E_p = k\frac{q_1 q_2}{r}$$ DATA BOOKLET

work done in assembling the pair from infinity

$$E = -\frac{\Delta V_e}{\Delta r}$$ DATA BOOKLET

field strength is minus the potential gradient

$$W = q\Delta V_e$$ DATA BOOKLET

work done moving charge q through a potential difference

WORKED EXAMPLE

Find the potential 30 cm from a +5.0 nC charge, and the work needed to bring a +2.0 μC charge there from infinity.

1. $V = kQ/r = 8.99 \times 10^9 \times 5.0 \times 10^{-9}/0.30 =$ **150 V** A1
2. **$W = qV = 2.0 \times 10^{-6} \times 150 = 3.0 \times 10^{-4}$ J** A1

WORKED EXAMPLE

The potential changes by 200 V over 5.0 cm in a region. Find the field strength.

1. $E = \Delta V/\Delta r = 200/0.050$ M1
2. **$= 4.0 \times 10^3$ V m^{-1}, pointing towards lower potential** A1

- **Equipotentials** around a point charge are concentric spheres; between parallel plates they are planes parallel to the plates. They are always perpendicular to the field lines.

EXAM TIP

Gravity and electricity look alike, with two differences to mention in comparison questions: charges can repel (masses cannot), and electric potential near a positive charge is positive.

LINKING QUESTION

Fields exert forces: D.3 follows charges as they move through electric and magnetic fields, and E.1 uses Coulomb's law to explain Rutherford scattering.

IDEA FOR YOUR IA / EXPLORATION

Map the equipotentials in conducting paper (or a tray of water) between two electrodes with a voltmeter, and compare with the field-line pattern you expect.

Test yourself — cover the answers first

QUICK CHECK

1. What is the elementary charge?
2. Define electric field strength.
3. If the separation of two charges triples, what happens to the force?
4. What is the field like between parallel plates?
5. Which way does the field point around a wire carrying current out of the page?
6. HL Is electric potential a vector?

EXAM-STYLE

7. Two charges of +4.0 nC sit 0.20 m apart. Find the field strength at the midpoint and at a point 0.10 m beyond one charge on the line.
8. HL An electron is accelerated from rest through 2000 V. Find the kinetic energy gained in J and eV, and its final speed.

Show answers

1. e = 1.60 × 10^{-19} C
2. force per unit positive test charge
3. it falls to 1/9
4. uniform (except near the edges)
5. anticlockwise
6. no, a scalar
7. midpoint: equal and opposite fields, so **E = 0**
   beyond: E = k(4.0 × 10^{-9})/0.10^2 + k(4.0 × 10^{-9})/0.30^2 = 3596 + 400
   = **4.0 × 10^3 N C^{-1}**
8. E_k = eV = 1.6 × 10^{-19} × 2000 = **3.2 × 10^{-16} J = 2000 eV**
   v = √(2E_k/m) = √(2 × 3.2 × 10^{-16}/9.11 × 10^{-31})
   = **2.7 × 10^7 m s^{-1}**

Stuck on a question?

Send it to me on WhatsApp. I read every message.

Share with a friend

Ask Riyaz Sir

Want regular help? Send this to your parent →