A-LEVEL PHYSICS • EXERCISE SHEET

18.3 Electric force between point charges

Name: ____________ Class: ________ Date: __________ **Total: 23 marks**

KEY WORDS point charge 点电荷 • coulomb's law 库仑定律 • force 力

Objective

Build the skills to answer exam questions on **Coulomb's law** — the force between two point charges.

You must be able to:

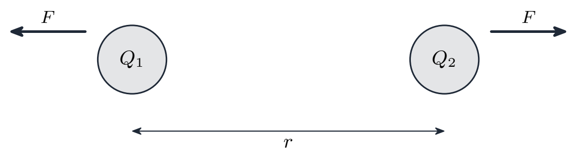
- use Coulomb's law $F = \dfrac{Q_1 Q_2}{4\pi\varepsilon_0 r^2}$
- treat a charged sphere as a **point charge** at its centre

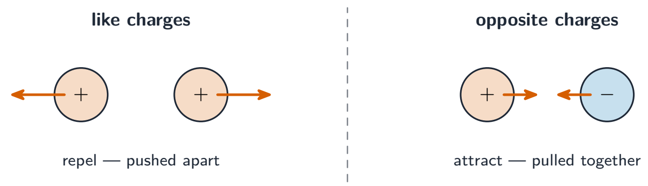
1 Worked examples

Study these first. Each one shows the method for a question type used later — follow the steps and you can do the Practice and Exam-style questions yourself.

■ Coulomb's law

Two point charges a distance r apart exert **equal, opposite** forces along the line joining them:





Coulomb force between point charges

$$F = \frac{Q_1 Q_2}{4\pi\varepsilon_0 r^2}, \qquad \frac{1}{4\pi\varepsilon_0} = 9.0\times10^{9}\ \mathrm{N\,m^2\,C^{-2}}.$$

Like charges repel; **opposite** charges attract. A charged sphere acts as a **point charge at its centre**.

Worked example. $+2.0$ nC and $+3.0$ nC, 4.0 cm apart:

$$F = \frac{(9.0\times10^{9})(2.0\times10^{-9})(3.0\times10^{-9})}{(0.040)^2} = 3.4\times10^{-5}\ \mathrm{N}\ \text{(repulsive)}.$$

2 Practice

Now apply the methods above.

2.1 State **Coulomb's law**. [2]

2.2 State the value of $\dfrac{1}{4\pi\varepsilon_0}$. [1]

2.3 State whether **like** charges attract or repel. [1]

3 Exam-style questions

3.1 If the distance between two charges is **doubled**, the Coulomb force becomes: [1]

- **A** twice as large
- **B** half as large
- **C** one quarter as large
- **D** four times as large

3.2 Calculate the force between point charges of +2.0 nC and +3.0 nC placed 4.0 cm apart. [3]

3.3 Two charges of +5.0 nC are 2.0 cm apart. Calculate the force between them, and state whether it is attractive or repulsive. [3]

3.4 A simplified model of a helium atom has a nucleus of charge $+2e$ with two electrons in a circular orbit of radius 2.6×10^{-11} m around it. Take $e = 1.60 \times 10^{-19}$ C, $\dfrac{1}{4\pi\varepsilon_0} = 8.99 \times 10^{9}$ m F^{-1} and the electron mass as 9.11×10^{-31} kg. Ignore the force between the two electrons.

(a) **State** Coulomb's law. [2]

(b) **Show that** the electric force between the nucleus and one electron is about 1.4×10^{-7} N. [2]

(c) This force provides the centripetal force on the electron. **Calculate** the speed of the orbiting electron. [3]

(d) **Determine** the period of the orbit. [2]

(e) **Determine** the ratio $\dfrac{\text{electric force on the electron}}{\text{gravitational force on the electron}}$, given that the nucleus has mass 6.6×10^{-27} kg and $G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}, and **suggest** what your answer means for a model of the atom. [3]

Solutions

Each answer shows the steps, then the **result**.

2.1

- the force between two **point charges** is **proportional to the product of the charges**
- and **inversely proportional to the square of their separation**

2.2

- $1/(4\pi\varepsilon_0) = 9.0 \times 10^9\ \mathrm{N\ m^2\ C^{-2}}$

2.3

- they **repel**

3.1 C

- $F \propto 1/r^2$, so doubling r makes F **one quarter**

3.2

- $F = Q_1Q_2/(4\pi\varepsilon_0 r^2)$

$$F = \frac{(9.0 \times 10^9\ \mathrm{N\ m^2\ C^{-2}})(2.0 \times 10^{-9}\ \mathrm{C})(3.0 \times 10^{-9}\ \mathrm{C})}{(0.040\ \mathrm{m})^2} = \mathbf{3.4 \times 10^{-5}}\ \mathrm{N}$$

3.3

- $F = Q^2/(4\pi\varepsilon_0 r^2)$

$$F = \frac{(9.0 \times 10^9\ \mathrm{N\ m^2\ C^{-2}})(5.0 \times 10^{-9}\ \mathrm{C})^2}{(0.020\ \mathrm{m})^2} = \mathbf{5.6 \times 10^{-4}}\ \mathrm{N}$$

- **repulsive** (like charges)

3.4

(a) the electric force between two **point charges** is proportional to the **product of the charges**

- and inversely proportional to the **square of their separation**

(b) $F = Q_1Q_2/(4\pi\varepsilon_0 r^2)$

$$F = (8.99 \times 10^9\ \mathrm{N\ m^2\ C^{-2}})\frac{(2 \times 1.60 \times 10^{-19}\ \mathrm{C})(1.60 \times 10^{-19}\ \mathrm{C})}{(2.6 \times 10^{-11}\ \mathrm{m})^2} \approx \mathbf{1.4 \times 10^{-7}}\ \mathrm{N}$$

(c) the electric force is the centripetal force: $mv^2/r = F$

$$v = \sqrt{\frac{Fr}{m}} = \sqrt{\frac{(1.36 \times 10^{-7}\ \mathrm{N})(2.6 \times 10^{-11}\ \mathrm{m})}{9.11 \times 10^{-31}\ \mathrm{kg}}} = \mathbf{2.0 \times 10^6}\ \mathrm{m\ s^{-1}}$$

(d) $T = 2\pi r/v$

$$T = \frac{2\pi(2.6 \times 10^{-11}\ \mathrm{m})}{2.0 \times 10^6\ \mathrm{m\ s^{-1}}} = \mathbf{8.2 \times 10^{-17}}\ \mathrm{s}$$

(e) $F_{\mathrm{grav}} = GMm/r^2$

$$F_{\mathrm{grav}} = \frac{(6.67 \times 10^{-11}\ \mathrm{N\ m^2\ kg^{-2}})(6.6 \times 10^{-27}\ \mathrm{kg})(9.11 \times 10^{-31}\ \mathrm{kg})}{(2.6 \times 10^{-11}\ \mathrm{m})^2} = 5.9 \times 10^{-46}\ \mathrm{N}$$

$$\frac{1.4 \times 10^{-7}\ \mathrm{N}}{5.9 \times 10^{-46}\ \mathrm{N}} = \mathbf{2 \times 10^{38}}$$

- gravity is utterly negligible on this scale, so a model of the atom can ignore it and keep only the electric force