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:**

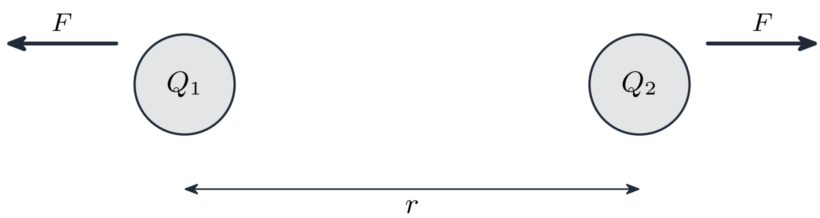
- use Coulomb's law $F = \dfrac{Q_1Q_2}{4\pi\varepsilon_0 r^2}$
- treat a charged sphere as a **point charge** at its centre

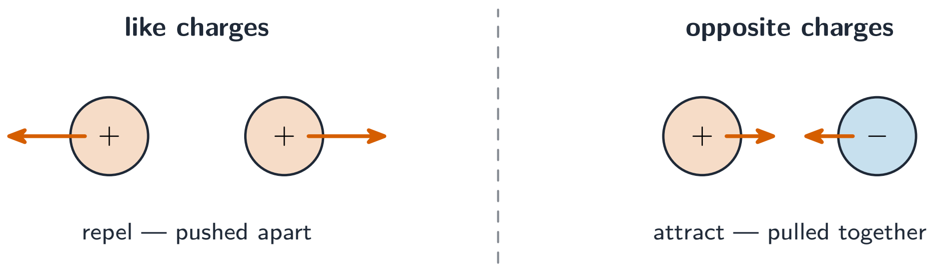
## 1 Worked examples

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*

$$F = \frac{Q_1 Q_2}{4\pi\varepsilon_0 r^2}, \qquad \frac{1}{4\pi\varepsilon_0} = 9.0 \times 10^9\ \mathrm{N\ m^2\ C^{-2}}.$$

**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:

$$F = \frac{(9.0 \times 10^9)(2.0 \times 10^{-9})(3.0 \times 10^{-9})}{(0.040)^2} = 3.4 \times 10^{-5}\ \mathrm{N}\ \text{(repulsive)}.$$

## 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

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**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]

**3.5** A simplified model of a helium atom has a nucleus of charge $+2e$ with two electrons in a circular orbit of radius $2.6 \times 10^{-11}$ 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 $9.11 \times 10^{-31}$ 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 $1.4 \times 10^{-7}$ 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 $6.6 \times 10^{-27}$ 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

**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** $\dfrac{1}{4\pi\varepsilon_0} = 9.0 \times 10^9\ \mathrm{N\ m^2\ C^{-2}}$.

**2.3** They **repel**.

**3.1** **C** — one quarter.

**3.2** $F = \dfrac{(9.0 \times 10^9)(2.0 \times 10^{-9})(3.0 \times 10^{-9})}{(0.040)^2} = 3.4 \times 10^{-5}$ N.

**3.3** $F = \dfrac{(9.0 \times 10^9)(5.0 \times 10^{-9})^2}{(0.020)^2} = 5.6 \times 10^{-4}$ N; **repulsive** (like charges).

**3.5** (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) $F = \dfrac{Q_1 Q_2}{4\pi\varepsilon_0 r^2} = 8.99 \times 10^9 \times \dfrac{(2 \times 1.60 \times 10^{-19})(1.60 \times 10^{-19})}{(2.6 \times 10^{-11})^2} = 1.4 \times 10^{-7}$ N.
(c) The electric force is the centripetal force: $\dfrac{mv^2}{r} = F$, so $v = \sqrt{\dfrac{Fr}{m}} = \sqrt{\dfrac{1.36 \times 10^{-7} \times 2.6 \times 10^{-11}}{9.11 \times 10^{-31}}}$ $= 2.0 \times 10^6\ \mathrm{m\ s^{-1}}$.
(d) $T = \dfrac{2\pi r}{v} = \dfrac{2\pi(2.6 \times 10^{-11})}{2.0 \times 10^6} = 8.2 \times 10^{-17}$ s.
(e) $F_{\mathrm{grav}} = \dfrac{GMm}{r^2} = \dfrac{6.67 \times 10^{-11}(6.6 \times 10^{-27})(9.11 \times 10^{-31})}{(2.6 \times 10^{-11})^2} = 5.9 \times 10^{-46}$ N; the ratio is $\dfrac{1.4 \times 10^{-7}}{5.9 \times 10^{-46}} = 2 \times 10^{38}$. Gravity is utterly negligible on this scale, so a model of the atom can ignore it and keep only the electric force.