Exercise walk-through

Electric force between point charges ▪ 18.3

eXercise

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

Method — Coulomb's law

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

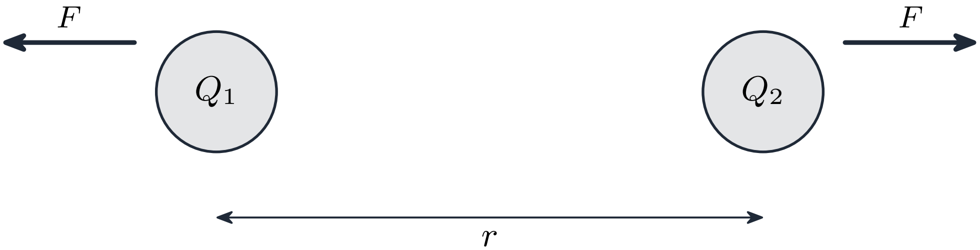
$$F = \frac{Q_1 Q_2}{4\pi\varepsilon_0 r^2}, \qquad \frac{1}{4\pi\varepsilon_0} = 9.0 \times 10^9 \text{ N m}^2\,\text{C}^{-2}.$$

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:

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

Method — Coulomb's law



Coulomb force between point charges

Practice 2.1 ▪ 2 marks

State **Coulomb's law**.

Solution 2.1

Worked steps

The force between two **point charges** is **proportional to the product of the charges** and **inversely proportional to the square of their separation** B1 B1.

Practice 2.2 ▪ 1 mark

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

Solution 2.2

Worked steps

$$\frac{1}{4\pi\varepsilon_0} = 9.0 \times 10^9 \text{ N m}^2\,\text{C}^{-2} \quad \textbf{B1}.$$

Practice 2.3 ▪ 1 mark

State whether **like** charges attract or repel.

Solution 2.3

Method: Coulomb's law

Worked steps

They **repel** B1.

Exam-style 3.1 ▪ 1 mark

If the distance between two charges is **doubled**, the Coulomb force becomes:

A twice as large

B half as large

C one quarter as large

D four times as large

Solution 3.1

Method: Coulomb's law

A twice as large

B half as large

C one quarter as large ✓

D four times as large

Worked steps

C — one quarter.

Exam-style 3.2 ▪ 3 marks

Calculate the force between point charges of $+2.0$ nC and $+3.0$ nC placed 4.0 cm apart.

Solution 3.2

Method: Coulomb's law

Worked steps

$$F = \frac{(9.0 \times 10^9)(2.0 \times 10^{-9})(3.0 \times 10^{-9})}{(0.040)^2} \quad \textbf{M1} \textbf{M1} = 3.4 \times 10^{-5}\ \mathrm{N} \quad \textbf{A1}.$$

Exam-style 3.3 ▪ 3 marks

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

Solution 3.3

Method: Coulomb's law

Worked steps

$F = \dfrac{(9.0 \times 10^{9})(5.0 \times 10^{-9})^{2}}{(0.020)^{2}}$ M1 $= 5.6 \times 10^{-4}$ N A1; **repulsive** (like charges) A1.

Exam-style 3.5 ▪ 2 marks

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.

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

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

(d) **Determine** the period of the orbit.

Exam-style 3.5 ▪ 2 marks

(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.

Solution 3.5

Method: Coulomb's law

Worked steps

(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** B1 B1.

(b) $F = \dfrac{Q_1 Q_2}{4\pi\varepsilon_0 r^2} = 8.99 \times 10^9 \times \dfrac{(2 \times 1.60 \times 10^{-19})(1.60 \times 10^{-19})}{(2.6 \times 10^{-11})^2}$ M1

$= 1.4 \times 10^{-7}$ N A1.

(c) The electric force is the centripetal force: $\dfrac{mv^2}{r} = F$ M1, so

$v = \sqrt{\dfrac{Fr}{m}} = \sqrt{\dfrac{1.36 \times 10^{-7} \times 2.6 \times 10^{-11}}{9.11 \times 10^{-31}}}$ M1 $= 2.0 \times 10^6$ m s^{-1} A1.

Solution 3.5

(d) $T = \dfrac{2\pi r}{v} = \dfrac{2\pi(2.6 \times 10^{-11})}{2.0 \times 10^{6}}$ **M1** $= 8.2 \times 10^{-17}$ s **A1**.

(e) $F_{\text{grav}} = \dfrac{GMm}{r^2} = \dfrac{6.67 \times 10^{-11}(6.6 \times 10^{-27})(9.11 \times 10^{-31})}{(2.6 \times 10^{-11})^2} = 5.9 \times 10^{-46}$ N **M1**;

the ratio is $\dfrac{1.4 \times 10^{-7}}{5.9 \times 10^{-46}} = 2 \times 10^{38}$ **A1**. Gravity is utterly negligible on this scale, so a model of the atom can ignore it and keep only the electric force **B1**.