Past-paper walk-through

Electric force between point charges ▪ 18.3

eXercise

Questions in this set

- 9702/41 J25 Q2 ▪ 11 marks
- 9702/43 J25 Q2 ▪ 11 marks
- 9702/42 M23 Q4 ▪ 12 marks

Reading the mark scheme

- **B1** a mark that stands on its own – the point is either made or not.
- **M1** a *method* mark: the right approach, even if the number is wrong.
- **A1** an *answer* mark, and it usually needs its M mark first.
- **C1** a working mark on the way to the answer.
- // separates answers the examiner accepts equally.
- **ecf** = error carried forward: a later part is marked on your own earlier answer.
- **owtte** = "or words to that effect" – the wording need not match.

Question 2

9702/41 J25 ▪ Q2 ▪ 11 marks

A helium atom may be modelled as a nucleus surrounded by two electrons in diametrically opposite circular orbits, each of radius 170 pm, as shown in Fig. 2.1.

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

(b)(i) State the charge on the nucleus, in terms of the elementary charge *e*. **[1]**

(b)(ii) Show that the electric force between the nucleus and one of the electrons is 1.6×10^{-8} N. **[1]**

(c)(i) Calculate the speed of the orbiting electrons. **[2]**

(c)(ii) Calculate the period of the orbit of the electrons. **[2]**

(d)(i) For the position of one of the electrons, determine the ratio

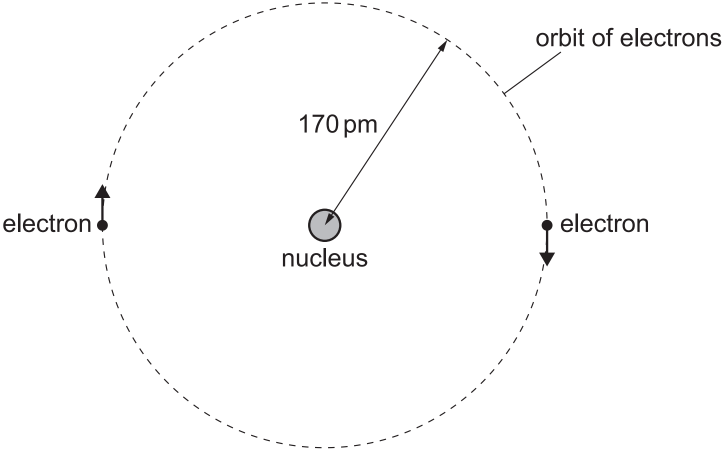
$$\frac{\text{electric field strength due to the other electron}}{\text{electric field strength due to the nucleus}}$$

Question 2

[2]

(d)(ii) Use your answer in **(d)(i)** to suggest and explain how the orbit of the electron is affected by the presence of the other electron. **[1]**

Question 2



Solution 2

(a)

Mark scheme

- (electric) force is (directly) proportional to product of charges **B1**
- force (between point charges) is inversely proportional to the square of their separation **B1**

Solution 2

(b)(i)

Mark scheme

- charge $= (+)2e$ **A1**

Solution 2

(b)(ii) Worked steps

Coulomb's law, with the nucleus's charge of $2e$ and the electron's e. This is a *show that*, so the substituted line has to be written out.

- $F = \dfrac{Q_1 Q_2}{4\pi\varepsilon_0 r^2} = \dfrac{2 \times (1.60 \times 10^{-19})^2}{4\pi \times 8.85 \times 10^{-12} \times (170 \times 10^{-12})^2}$
- The numerator is 5.12×10^{-38} and the denominator 3.22×10^{-30}.
- $F = 1.6 \times 10^{-8}$ N, as required.

Solution 2

Keep the factor of 2 from the nuclear charge outside the square — writing $(2e)^2$ doubles the answer. And keep the π in $4\pi\varepsilon_0$; leaving it out is a factor of about three.

Mark scheme

- F $=$ 2 $\times$ (1.60 $\times$ 10–19)2 / [4π $\times$ 8.85 $\times$ 10–12 $\times$ (170 $\times$ 10–12)2] $=$ 1.6 $\times$ 10–8 N **A1**

Solution 2

(c)(i) Worked steps

That electric force is what holds the electron in its circular path, so it **is** the centripetal force.

- $F = \dfrac{mv^2}{r}$, so $v = \sqrt{\dfrac{Fr}{m}}$
- $v = \sqrt{\dfrac{1.6 \times 10^{-8} \times 170 \times 10^{-12}}{9.11 \times 10^{-31}}}$
- $v = 1.7 \times 10^{6}\ \mathrm{m\,s^{-1}}$

Solution 2

The mass is the **electron's** — it is the thing going round. And take the square root: without it the answer is 3.0×10^{12}, which is faster than light and should be spotted on sight.

Mark scheme

- F = mv2 / r **C1**
- v = [(1.6 × 10–8 × 170 × 10–12) / (9.11 × 10–31)]½
- = 1.7 × 106 m s–1 **A1**

Solution 2

(c)(ii) Worked steps

With the speed known, the period is one circumference divided by it.

- $v = \dfrac{2\pi r}{T}$, so $T = \dfrac{2\pi r}{v} = \dfrac{2\pi \times 170 \times 10^{-12}}{1.73 \times 10^{6}}$
- $T = 6.2 \times 10^{-16}$ s

The same answer follows from $F = m\omega^2 r$ with $\omega = \dfrac{2\pi}{T}$, giving $T = \sqrt{\dfrac{4\pi^2 mr}{F}}$ — use whichever route you trust.

Carry the **unrounded** speed forward: 1.7 instead of 1.73 moves the period into the next significant figure. **Mark scheme**

Solution 2

- $F = mr\omega 2$ and $\omega = 2\pi$ / T
- $F = 4\pi 2mr$ / T2 **C1**
- $T = [\ (4\pi 2 \times 9.11 \times 10–31 \times 170 \times 10–12)\ /\ (1.6 \times 10–8)\ ]$½
- $= 6.2 \times 10–16$ s **A1**
- or $v = 2\pi r$ / T
- (C1)
- $T = (2\pi \times 170 \times 10–12)\ /\ (1.73 \times 106)$
- $= 6.2 \times 10–16$ s
- (A1)

Solution 2

(d)(i) Worked steps

A ratio question needs no constants — write the proportionality, form the ratio, and let everything common cancel.

- For a point charge, $E = \dfrac{Q}{4\pi\varepsilon_0 r^2}$, so $E \propto \dfrac{Q}{r^2}$.
- The other **electron** carries $e = 1.60 \times 10^{-19}$ C and sits 340×10^{-12} m away — twice the radius, since the two electrons are on opposite sides of the nucleus.
- The **nucleus** carries $2e = 3.2 \times 10^{-19}$ C and sits 170×10^{-12} m away.
- $\dfrac{E_{\text{electron}}}{E_{\text{nucleus}}} = \dfrac{1.60 \times 10^{-19} \times (170 \times 10^{-12})^2}{3.2 \times 10^{-19} \times (340 \times 10^{-12})^2}$
- $= \dfrac{1}{2} \times \left(\dfrac{1}{2}\right)^2 = 0.13$

Solution 2

Notice the two distances are **not** the same, and which one goes where: the *numerator's* field uses the *electron's* distance and the *denominator's* uses the nucleus's, so the squared distances swap sides when the fractions are divided. Getting that the wrong way round gives 8, which is the marked wrong answer.
The result says the nucleus dominates by about eight to one, which is why a one-electron model of the atom works at all.

Mark scheme

- $E \propto Q\ /\ r2$ C1
- $\text{ratio} = [1.60 \times 10–19 \times (170 \times 10–12)2]\ /\ [3.2 \times 10–19 \times (340 \times 10–12)2]$
- $= 0.13$ A1

Solution 2

(d)(ii)

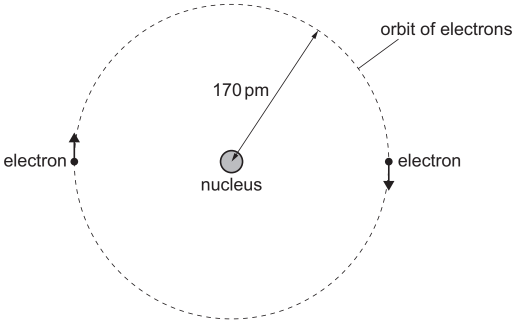
Mark scheme

- resultant force slightly less (than $1.6 \times 10–8$ N) so speed lower or resultant force slightly less (than $1.6 \times 10–8$ N) so period greater **B1**

Question 2

9702/43 J25 ▪ Q2 ▪ 11 marks

2 A helium atom may be modelled as a nucleus surrounded by two electrons in diametrically opposite circular orbits, each of radius 170 pm, as shown in Fig. 2.1.



Question 2

Fig. 2.1

(a) State Coulomb's law.

Question 2

(b) **(i)** State the charge on the nucleus, in terms of the elementary charge *e*.

Question 2

(ii) Show that the electric force between the nucleus and one of the electrons is 1.6×10^{-8} N.

Question 2

[1]

(c) Assume that the force in **(b)(ii)** is the only force on the electrons.

(i) Calculate the speed of the orbiting electrons.

Question 2

(ii) Calculate the period of the orbit of the electrons.

Question 2

(d) In practice, the orbit of each electron is affected by the presence of the other electron.

(i) For the position of one of the electrons, determine the ratio

$$\frac{\text{electric field strength due to the other electron}}{\text{electric field strength due to the nucleus}}.$$

Question 2

(ii) Use your answer in **(d)(i)** to suggest and explain how the orbit of the electron is affected by the presence of the other electron.

Question 2

[Total: 11]

Solution 2

(a)

Mark scheme

- (electric) force is (directly) proportional to product of charges
- force (between point charges) is inversely proportional to the square of their separation

Solution 2

(b)(i)

Worked steps

Helium has two protons, and the nucleus carries no electrons.

- Charge on the nucleus $= +2e = 2 \times 1.60 \times 10^{-19} = +3.2 \times 10^{-19}$ C

The **sign** is part of the answer — a nucleus is positive, and the question is setting up an attraction in the next part.

Mark scheme

- charge $=$ $(+)$2e

Solution 2

(b)(ii) Worked steps

Coulomb's law, with the nucleus's $2e$ and the electron's e.

- $F = \dfrac{Q_1 Q_2}{4\pi\varepsilon_0 r^2} = \dfrac{2 \times (1.60 \times 10^{-19})^2}{4\pi \times 8.85 \times 10^{-12} \times (170 \times 10^{-12})^2}$
- The numerator is 5.12×10^{-38} and the denominator 3.22×10^{-30}.
- $F = 1.6 \times 10^{-8}$ N

Solution 2

Keep the 2 from the nuclear charge and square only *e* — writing $(2e)^2$ doubles the answer. And note the $4\pi\varepsilon_0$: leaving the π out is a factor of about three.

Mark scheme

- F = 2 × (1.60 × 10–19)2 / [4π × 8.85 × 10–12 × (170 × 10–12)2] = 1.6 × 10–8 N

Solution 2

(c)(i) Worked steps

That Coulomb force is what keeps the electron in its circular path, so it *is* the centripetal force.

- $F = \dfrac{mv^2}{r}$, so $v = \sqrt{\dfrac{Fr}{m}}$
- $v = \sqrt{\dfrac{1.6 \times 10^{-8} \times 170 \times 10^{-12}}{9.11 \times 10^{-31}}}$
- $v = 1.7 \times 10^{6}\ \mathrm{m\,s^{-1}}$

Solution 2

The mass here is the **electron's**, not the atom's — the electron is the thing moving in a circle. And take the square root at the end: forgetting it gives 3.0×10^{12}, which is faster than light and should be caught by inspection.

Mark scheme

- F = mv2 / r
- v = [(1.6 × 10–8 × 170 × 10–12) / (9.11 × 10–31)]½
- = 1.7 × 106 m s–1

Solution 2

(c)(ii) Worked steps

With the speed known, the period is one circumference divided by it.

- $v = \dfrac{2\pi r}{T}$, so $T = \dfrac{2\pi r}{v}$
- $T = \dfrac{2\pi \times 170 \times 10^{-12}}{1.73 \times 10^{6}}$
- $T = 6.2 \times 10^{-16}$ s

Solution 2

The same answer comes from $F = m\omega^2 r$ with $\omega = \frac{2\pi}{T}$, giving $T = \sqrt{\frac{4\pi^2 mr}{F}}$ — use whichever you are surer of.

Carry the **unrounded** speed forward: using 1.7 instead of 1.73 shifts the period into the next significant figure. **Mark scheme**

- F = mrω2 and ω = 2π / T
- F = 4π2mr / T2
- T = [(4π2 × 9.11 × 10–31 × 170 × 10–12) / (1.6 × 10–8)]½
- = 6.2 × 10–16 s
- or

Solution 2

- $v = 2\pi r / T$
- (C1)
- $T = (2\pi \times 170 \times 10–12) / (1.73 \times 106)$
- $= 6.2 \times 10–16\,s$
- (A1)
- 9702/43
- May/June 2025

Solution 2

(d)(i) Worked steps

A ratio needs no constants — write the proportionality and let everything common cancel.

- For a point charge $E \propto \dfrac{Q}{r^2}$.
- The other **electron** carries $e = 1.60 \times 10^{-19}$ C and is 340×10^{-12} m away — twice the orbital radius, since the two electrons sit on opposite sides of the nucleus.
- The **nucleus** carries $2e = 3.2 \times 10^{-19}$ C and is 170×10^{-12} m away.
- $\dfrac{E_{\text{electron}}}{E_{\text{nucleus}}} = \dfrac{1.60 \times 10^{-19} \times (170 \times 10^{-12})^2}{3.2 \times 10^{-19} \times (340 \times 10^{-12})^2} = \dfrac{1}{2} \times \left(\dfrac{1}{2}\right)^2 = 0.13$

Solution 2

The squared distances **swap sides** when the two fractions are divided, so the numerator carries the nucleus's distance. Getting that the wrong way round gives 8.

Mark scheme

- $E \propto Q \, / \, r2$
- $\text{ratio} = [1.60 \times 10\text{–}19 \times (170 \times 10\text{–}12)2] \, / \, [3.2 \times 10\text{–}19 \times (340 \times 10\text{–}12)2]$
- $= 0.13$

Solution 2

(d)(ii) Worked steps

The two forces on an electron act in opposite directions, so the second electron **reduces** the pull towards the nucleus.

- The resultant force is slightly **less** than the 1.6×10^{-8} N used earlier.
- From $F = \frac{mv^2}{r}$ at the same radius, a smaller force means a **lower speed** — and therefore a **longer period**.

Solution 2

Either consequence earns the mark, but say which quantity you mean. The size of the effect is the 0.13 from (d)(i): about a 13% reduction, so the correction is real but small — which is why the one-electron model of part (c) was worth doing at all.

Mark scheme

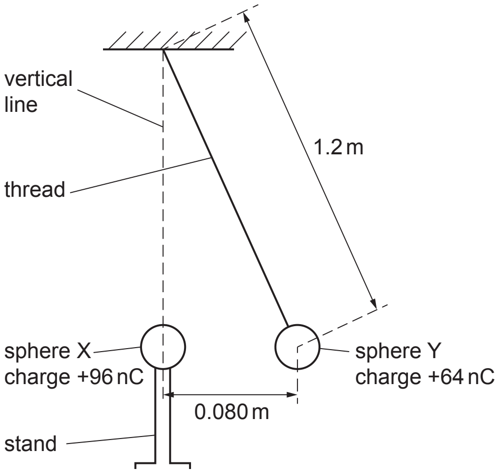
- resultant force slightly less (than 1.6×10–$8\,N$) so speed lower
- or
- resultant force slightly less (than 1.6×10–$8\,N$) so period greater
- 9702/43
- May/June 2025

Question 4

9702/42 M23 ▪ Q4 ▪ 12 marks

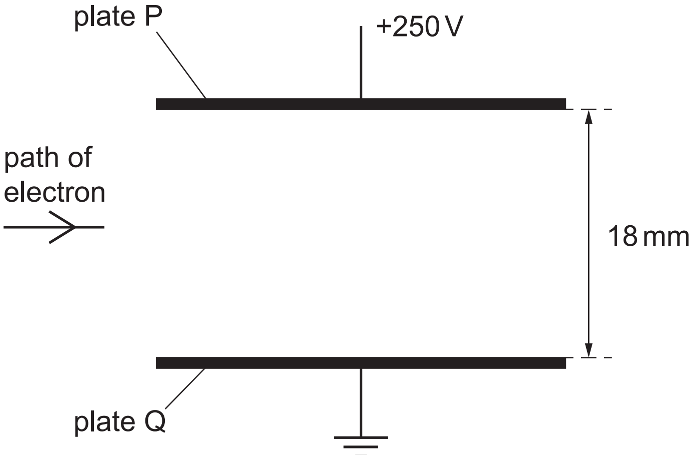
(a) State Coulomb's law. **[2]**
(b)(i) On Fig. 4.2, draw and label all the forces acting on sphere Y. **[1]**
(b)(ii) Determine the mass of sphere Y. **[4]**
(b)(iii) Calculate the total electric potential energy stored between X and Y. **[1]**
(c)(i) State the direction of the electric force on the electron when between the plates. **[1]**
(c)(ii) Determine the magnitude of the force acting on the electron due to the electric field. **[2]**
(c)(iii) Explain why the electron does not follow a circular path. **[1]**

Question 4

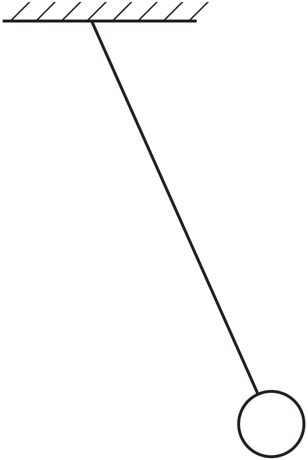


vertical line
thread
1.2 m
sphere X
charge +96 nC
sphere Y
charge +64 nC
0.080 m
stand

Question 4



Question 4



Solution 4

(a)

Mark scheme

- (electric) force is (directly) proportional to product of charges
- force (between point charges) is inversely proportional to the square of their separation

Solution 4

(b)(i) Worked steps

Know. Sphere Y hangs on a string and is pushed sideways by the other charged sphere. Three forces act on it, and each needs an arrow **and** a label.

Draw.

- **Tension** in the string, along the string, pointing **up** towards the support.
- **Electric force**, **horizontal**, pointing away from sphere X (the charges repel).
- **Weight**, **vertically down**.

Solution 4

Check. All three labels are needed for the mark. Adding a fourth arrow such as "reaction" is wrong: nothing touches the sphere except the string.

Mark scheme

- arrows showing tension upwards in direction of string, electric force horizontally to the right and weight vertically downwards and all three labelled

Solution 4

(b)(ii) Worked steps

Know. Sphere Y is in equilibrium under three forces, so the string is tilted at exactly the angle at which the tension's two components balance the weight and the electric force.

Electric force. $F_E = \dfrac{Q_1 Q_2}{4\pi\varepsilon_0 r^2} = \dfrac{(96 \times 10^{-9})(64 \times 10^{-9})}{4\pi(8.85 \times 10^{-12})(0.080)^2} = 8.63 \times 10^{-3}$ N.

Angle. The sphere hangs 0.080 m sideways on a string of length 1.2 m, so $\theta = \sin^{-1}\left(\dfrac{0.080}{1.2}\right) = 3.82^\circ$ from the vertical.

Resolve. Horizontally $T\sin\theta = F_E$ and vertically $T\cos\theta = mg$, so dividing gives $\tan\theta = \dfrac{F_E}{mg}$ and $mg = \dfrac{F_E}{\tan\theta} = \dfrac{8.63 \times 10^{-3}}{\tan 3.82^\circ} = 0.129$ N.

Solution 4

Answer. $m = \dfrac{0.129}{9.81} = 0.013$ kg.

Check. Use r^2, the **separation squared**, not the string length. And because the angle is small, $\tan\theta \approx \dfrac{0.080}{1.2}$, which is the shortcut the mark scheme's second route takes: $m = \dfrac{1.2 \times F_E}{0.080 \times 9.81}$, same answer. **Mark scheme**

- $F_E = \frac{96\times10^{-9}\times64\times10^{-9}}{4\pi\times8.85\times10^{-12}\times0.080^2}$
- $(= 8.63 \times 10^{-3}$ N$)$
- **either** angle to vertical $= \sin^{-1}(0.080/1.2)$
- $(= 3.82°)$

Solution 4

- weight $= F_E/\tan 3.82 = 8.63 \times 10^{-3}/\tan 3.82$
- $(= 0.129$ N)
- mass $= 0.129/9.81$
- $= 0.013$ kg
- **or** $T \sin\theta = mg$ and $T\cos\theta = F_E$ or $\tan\theta = mg/F_E$
- $\tan\theta = 1.2/0.080$
- $m = (1.2 \times 8.63 \times 10^{-3})/(0.080 \times 9.81)$
- $= 0.013$ kg

Solution 4

(b)(iii) Worked steps

Know. Electric potential energy between two point charges uses r, not r^2. It is the force equation with one power of r removed.

Equation. $E_p = \dfrac{Q_1 Q_2}{4\pi\varepsilon_0 r}$.

Substitute. $E_p = \dfrac{(96 \times 10^{-9})(64 \times 10^{-9})}{4\pi(8.85 \times 10^{-12})(0.080)}$.

Answer. $E_p = 6.9 \times 10^{-4}$ J.

Solution 4

Check. Both charges are positive, so the energy is **positive**: work had to be done to bring them this close. A quick numerical check is that $E_p = F_E \times r$ here, which is exactly what removing one power of r does.

Mark scheme

- $$E_p = \frac{Q_1 Q_2}{4\pi\varepsilon_0 r} = \frac{96 \times 10^{-9} \times 64 \times 10^{-9}}{4 \times \pi \times 8.85 \times 10^{-12} \times 0.080}$$
- $$= 6.9 \times 10^{-4}\ \text{J}$$

Solution 4

(c)(i)

Mark scheme

- towards the top of the page / towards plate P

Solution 4

(c)(ii) Worked steps

Know. Between parallel plates the field is uniform, so the field strength is the p.d. divided by the plate separation. The force then follows from the charge.

Equations. $E = \dfrac{V}{d}$ and $F = QE$, so $F = \dfrac{QV}{d}$.

Substitute. $F = \dfrac{(1.6 \times 10^{-19})(250)}{0.018}$.

Answer. $F = 2.2 \times 10^{-15}$ N.

Solution 4

Check. Keep the separation in metres. Note also that this force is the **same everywhere** between the plates, unlike the point-charge force in part (b), which fell off as $\frac{1}{r^2}$.

Mark scheme

- $F = QE$ and $E = V/d$
- $F = 1.6 \times 10^{-19} \times 250/0.018$
- $$= 2.2 \times 10^{-15} \text{ N}$$