# Past-paper walk-through

## Electric Charge and the Process of Charging ▪ 8.2

eXercise

# Questions in this set

- 2021 Q2

# 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

2021 ▪ Q2

[Apparatus diagram: A fixed support holds an insulating string from which a Conducting Sphere (upper) hangs, labeled "Insulating String" at top. Directly below it, separated by a distance $d$, is a Conducting Sphere (lower) mounted on an "Insulating Rod," which rests on an "Electronic Balance" (drawn as a rectangular box). The two spheres are identical conducting spheres, vertically aligned with separation $d$ between their centers.]

Students perform an experiment to study the force between two charged objects using the apparatus shown above, which contains two identical conducting spheres. The upper sphere is attached to an insulating string, which can be used to move the sphere downward. The lower sphere sits on an insulating rod, which is on an electronic balance. The electronic balance is zeroed before the lower sphere and insulating rod are in place.

# Question 2

For the first trial, a charge of $Q$ is placed on each sphere and then the upper sphere is slowly moved downward. The students measure the distance $d$ between the centers of the spheres and the magnitude $F$ of the force that appears on the electronic balance. The recorded data are shown on the graph of $F$ as a function of $\frac{1}{d^2}$ shown below. [Graph: vertical axis $F$ $(\mu\text{N})$ ranging from 9000 to 13,000 in increments of 1000; horizontal axis $\frac{1}{d^2}\left(\frac{1}{\text{m}^2}\right)$ ranging from 0 to 100 in increments of 20; plotted data points (approximate): $(5, 9200)$, $(30, 9700)$, $(45, 10,300)$, $(65, 11,400)$, $(90, 12,900)$; no line of best fit drawn yet.]

**(a)(i)** Draw a line that represents the best fit to the points shown.

**(a)(ii)** Use the graph to calculate the charge $Q$.

# Question 2

**(a)(iii)** [Second, extended graph: vertical axis $F$ ($\mu$N) ranging from 9000 to 14,000 in increments of 1000; horizontal axis $\frac{1}{d^2}\left(\frac{1}{\text{m}^2}\right)$ ranging from 0 to 160 in increments of 20; a dashed best-fit line/curve is drawn through data points from the origin region up through about $(140, 13, 700)$; plotted data points (approximate): $(10, 9100)$, $(30, 9700)$, $(50, 10, 000)$, $(65, 11, 500)$, $(90, 12, 700)$, $(105, 13, 000)$, $(120, 13, 300)$, $(140, 13, 700)$, $(155, 13, 800)$.]

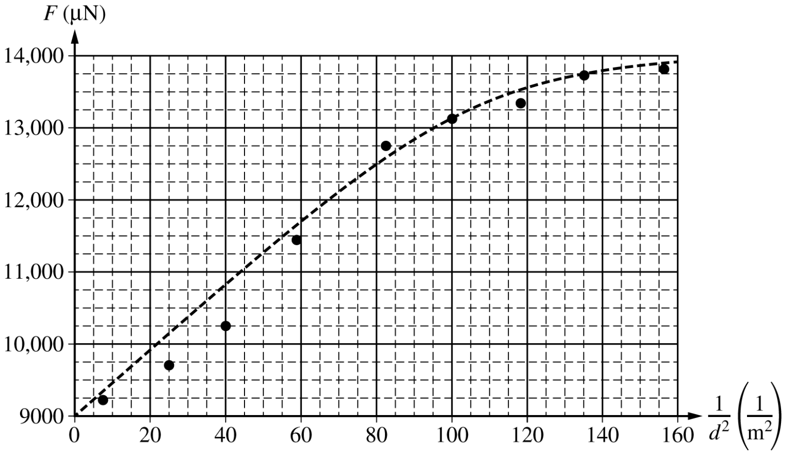
On the graph on the previous page, draw a circle around the data point that was taken when the distance between the centers of the spheres was the least.

**(a)(iv)** Determine the distance between the centers of the spheres for the data point indicated above.

**(a)(v)** What physical quantity does the vertical intercept represent?

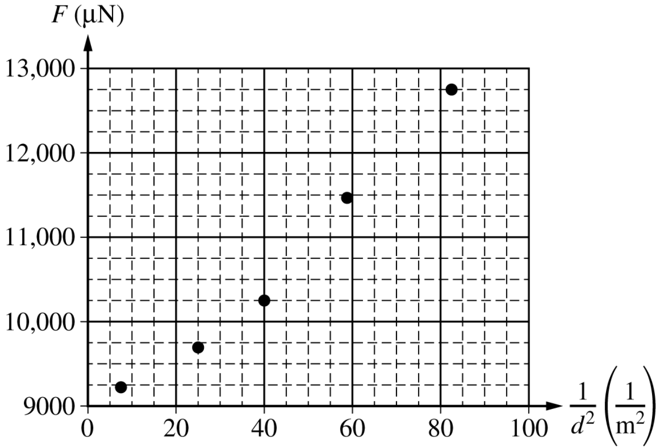
Justify your answer.

# Question 2

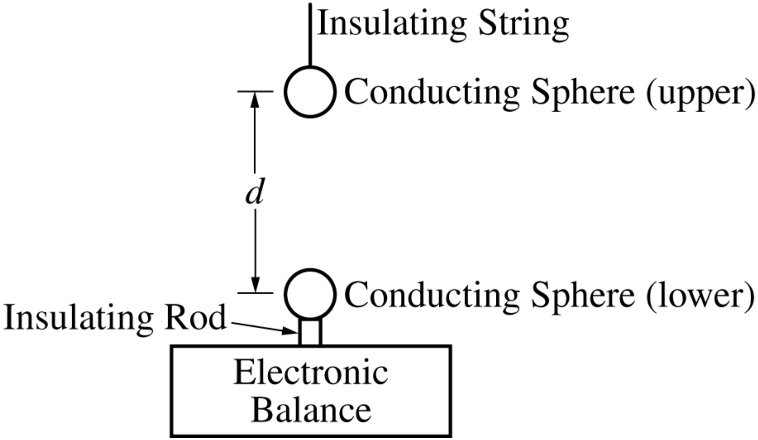


$F$ (μN)
14,000
13,000
12,000
11,000
10,000
9000
0
20
40
60
80
100
120
140
160
$\frac{1}{d^2}\left(\frac{1}{\mathrm{m}^2}\right)$

# Question 2



# Question 2


Insulating String
Conducting Sphere (upper)
d
Conducting Sphere (lower)
Insulating Rod
Electronic
Balance

# Question 2

2021 ▪ Q2

[Apparatus diagram: A fixed support holds an insulating string from which a Conducting Sphere (upper) hangs, labeled "Insulating String" at top. Directly below it, separated by a distance $d$, is a Conducting Sphere (lower) mounted on an "Insulating Rod," which rests on an "Electronic Balance" (drawn as a rectangular box). The two spheres are identical conducting spheres, vertically aligned with separation $d$ between their centers.]

Students perform an experiment to study the force between two charged objects using the apparatus shown above, which contains two identical conducting spheres. The upper sphere is attached to an insulating string, which can be used to move the sphere downward. The lower sphere sits on an insulating rod, which is on an electronic balance. The electronic balance is zeroed before the lower sphere and insulating rod are in place.

For the first trial, a charge of $Q$ is placed on each sphere and then the upper sphere is slowly moved downward. The students measure the distance $d$ between the centers of the spheres and

# Question 2

the magnitude $F$ of the force that appears on the electronic balance. The recorded data are shown on the graph of $F$ as a function of $\frac{1}{d^2}$ shown below.

[Graph: vertical axis $F$ ($\mu$N) ranging from 9000 to 13,000 in increments of 1000; horizontal axis $\frac{1}{d^2}\left(\frac{1}{\text{m}^2}\right)$ ranging from 0 to 100 in increments of 20; plotted data points (approximate): $(5, 9200)$, $(30, 9700)$, $(45, 10, 300)$, $(65, 11, 400)$, $(90, 12, 900)$; no line of best fit drawn yet.]

**(b)** The experiment is extended by collecting additional data points, which appear on the right side of the graph shown above. The new data points do not follow the linear pattern seen with the first points. The group of students tries to explain this discrepancy.

One student suspects that charge is slowly leaking off the top sphere. Could this explain the discrepancy?

_______ Yes _______ No

# Question 2

Justify your answer.

# Question 2

2021 ▪ Q2

[Apparatus diagram: A fixed support holds an insulating string from which a Conducting Sphere (upper) hangs, labeled "Insulating String" at top. Directly below it, separated by a distance $d$, is a Conducting Sphere (lower) mounted on an "Insulating Rod," which rests on an "Electronic Balance" (drawn as a rectangular box). The two spheres are identical conducting spheres, vertically aligned with separation $d$ between their centers.]
Students perform an experiment to study the force between two charged objects using the apparatus shown above, which contains two identical conducting spheres. The upper sphere is attached to an insulating string, which can be used to move the sphere downward. The lower sphere sits on an insulating rod, which is on an electronic balance. The electronic balance is zeroed before the lower sphere and insulating rod are in place.
For the first trial, a charge of $Q$ is placed on each sphere and then the upper sphere is slowly moved downward. The students measure the distance $d$ between the centers of the spheres and

# Question 2

the magnitude $F$ of the force that appears on the electronic balance. The recorded data are shown on the graph of $F$ as a function of $\frac{1}{d^2}$ shown below.

[Graph: vertical axis $F$ ($\mu$N) ranging from 9000 to 13,000 in increments of 1000; horizontal axis $\frac{1}{d^2}\left(\frac{1}{\mathrm{m}^2}\right)$ ranging from 0 to 100 in increments of 20; plotted data points (approximate): $(5, 9200)$, $(30, 9700)$, $(45, 10, 300)$, $(65, 11, 400)$, $(90, 12, 900)$; no line of best fit drawn yet.]

**(c)(i)** A second student suspects that the excess charges have rearranged themselves, polarizing the spheres.

On the circles representing the spheres below, use a single "$+$" sign on each sphere to represent the locations of highest concentration of the excess positive charges.

[Two blank circles are shown, stacked vertically, representing the upper and lower spheres, for the student to mark.]

**(c)(ii)** Explain how this rearrangement could be responsible for the discrepancy.

# Question 2

2021 ▪ Q2

[Apparatus diagram: A fixed support holds an insulating string from which a Conducting Sphere (upper) hangs, labeled "Insulating String" at top. Directly below it, separated by a distance $d$, is a Conducting Sphere (lower) mounted on an "Insulating Rod," which rests on an "Electronic Balance" (drawn as a rectangular box). The two spheres are identical conducting spheres, vertically aligned with separation $d$ between their centers.]

Students perform an experiment to study the force between two charged objects using the apparatus shown above, which contains two identical conducting spheres. The upper sphere is attached to an insulating string, which can be used to move the sphere downward. The lower sphere sits on an insulating rod, which is on an electronic balance. The electronic balance is zeroed before the lower sphere and insulating rod are in place.

For the first trial, a charge of $Q$ is placed on each sphere and then the upper sphere is slowly moved downward. The students measure the distance $d$ between the centers of the spheres and

# Question 2

the magnitude $F$ of the force that appears on the electronic balance. The recorded data are shown on the graph of $F$ as a function of $\frac{1}{d^2}$ shown below.

[Graph: vertical axis $F$ ($\mu$N) ranging from 9000 to 13,000 in increments of 1000; horizontal axis $\frac{1}{d^2}\left(\frac{1}{\text{m}^2}\right)$ ranging from 0 to 100 in increments of 20; plotted data points (approximate): $(5, 9200)$, $(30, 9700)$, $(45, 10, 300)$, $(65, 11, 400)$, $(90, 12, 900)$; no line of best fit drawn yet.]

**(d)(i)** A third student suggests that the experiment be modified so that the top sphere is given a negative charge that is equal in magnitude to the positive charge given to the bottom sphere.

On the circles representing the spheres below, use a single "$+$" sign on the bottom sphere to represent the location of highest concentration of the excess positive charges. Use a single "$-$" sign on the top sphere to represent the location of the highest concentration of the excess negative charges.

# Question 2

[Two blank circles are shown, stacked vertically, representing the upper (top) and lower (bottom) spheres, for the student to mark.]

**(d)(ii)** For a separation distance equal to that of the data point indicated in part (a)(iii), would the magnitude of the force reading with spheres of opposite charges be greater than, less than, or equal to the magnitude of the force reading with spheres of the same charges?

_______ Greater than _______ Less than _______ Equal to

Justify your answer.

# Solution 2

## (a)(i)

**Mark scheme**

- Draw a single straight best-fit line through the plotted data points (approximately through the trend from the lower-left points near $(10, 9100)$ up through the upper-right points near $(140, 13700)$), balancing points above and below the line rather than connecting the dots.

# Solution 2

## (a)(ii) Mark scheme

- Using two points on the best-fit line, the slope is $m = \frac{\Delta y}{\Delta x} = \frac{(12{,}000 - 10{,}500)\ \mu\text{N}}{(72 - 40)\ \text{m}^{-2}} = 4.7 \times 10^{-5}\ \text{N} \cdot \text{m}^2$. Since $F = \frac{kQ^2}{r^2} = kQ^2 \cdot \frac{1}{d^2}$, the slope of $F$ vs $1/d^2$ equals $kQ^2$. Solving for the charge: $Q = \sqrt{\frac{\text{slope}}{k}} = \sqrt{\frac{4.7 \times 10^{-5}\ \text{N} \cdot \text{m}^2}{9 \times 10^9\ \text{N} \cdot \text{m}^2/\text{C}^2}} = 7.2 \times 10^{-8}\ \text{C}$. Points: (1) correctly calculating the slope from two points on the best-fit line, (2) correctly relating the slope to the charge (slope $= kQ^2$), (3) correctly calculating $Q = 7.2 \times 10^{-8}$ C consistent with that slope.

# Solution 2

## (a)(iii)

**Mark scheme**

- Circle the data point corresponding to $1/d^2 \approx 82.5$ m$^{-2}$ (the point near $F \approx 12{,}900$ $\mu$N that is used in part (a)(iv) to determine the separation distance $d$).

## (a)(iv)

**Mark scheme**

- From the graph, the circled data point corresponds to $1/d^2 = 82.5$ m$^{-2}$, so $d = \sqrt{1/82.5 \text{ m}^{-2}} = 0.11$ m.

# Solution 2

## (a)(v) Mark scheme

- The vertical ($F$) intercept represents the weight of the (lower) conducting sphere and insulating rod, i.e. the balance/scale reading with no electric force present. Justification: When the spheres are infinitely far apart ($1/d^2 \to 0$), there is no electric force between them, so the only force recorded by the balance is the weight of the lower sphere and insulating rod — equivalently, the scale is zeroed before the rod and lower sphere are placed on it, so the nonzero y-intercept is their weight. Points: (1) indicating the intercept is the weight of the sphere/rod, (2) a correct justification.

# Solution 2

**(b)**

**Mark scheme**

- Yes. Justification: Because the later force measurements fall below the values predicted by extrapolating the best-fit line, a decrease in charge (charge slowly leaking off the top sphere over the course of the experiment, so $Q$ — and hence $F \propto Q^2$ — decreases) could explain the discrepancy seen in the data.

# Solution 2

## (c)(i) Mark scheme

- On each sphere, mark a single '+' at the point farthest from the other sphere (e.g. at the top of the upper sphere and the bottom of the lower sphere). Since both spheres carry excess positive charge, the mutual repulsion between the two spheres' charge distributions pushes each sphere's own excess positive charge toward the side away from the other sphere. Points: (1) correctly indicating the position of the excess positive charges (concentrated away from the other sphere on each), (2) correctly indicating the net charge on each sphere is positive (a single '+' marked, not a mix of signs).

# Solution 2

## (c)(ii)

**Mark scheme**

- On a conductor, excess charges are free to move and repel each other; the excess (same-sign) charges on each sphere rearrange until they are as far apart as possible from the charge on the other sphere. This polarization/redistribution increases the effective separation between the charge concentrations (beyond simply using the center-to-center distance $d$), which reduces the actual force below the $F = kQ^2/d^2$ prediction — explaining why the closer-spacing data points fall below the best-fit line.

# Solution 2

## (d)(i)

**Mark scheme**

- Mark a single '$-$' on the top sphere at the point closest to the bottom sphere, and a single '$+$' on the bottom sphere at the point closest to the top sphere. Because the spheres now carry opposite charges, they attract; unlike charges concentrate on the sides nearest each other.

# Solution 2

## (d)(ii)

**Mark scheme**

- Less than. Justification: The oppositely charged spheres attract each other, and this attractive force pulls the lower sphere upward (toward the upper sphere), decreasing the upward normal force the scale must exert to support it; thus the force (scale) reading with opposite charges is less than the reading obtained with spheres of the same (like) charge, which repelled and increased the reading. Points: (1) selecting 'Less than' and attempting a relevant justification, (2) a fully correct justification.