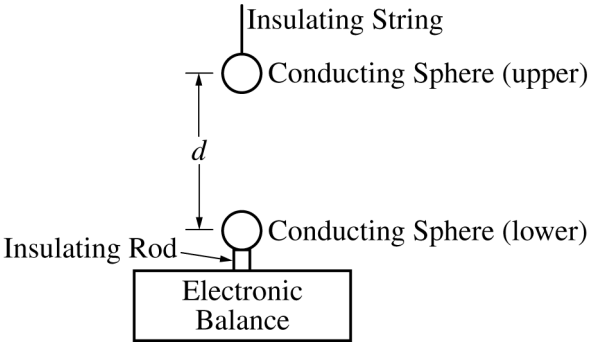
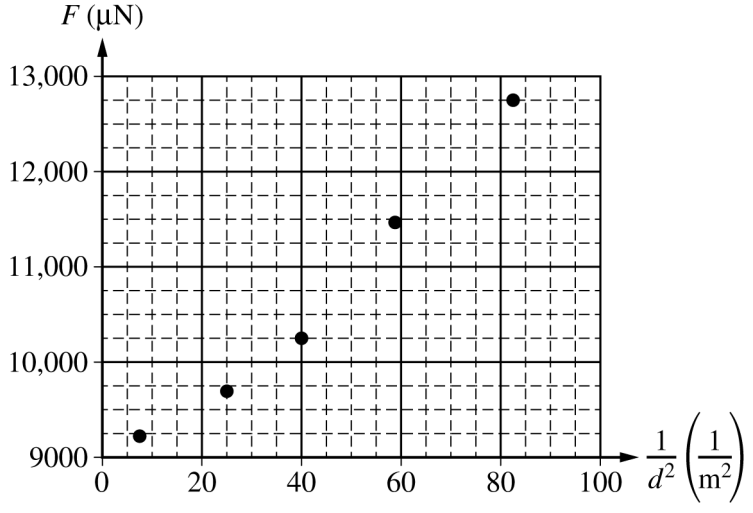
Begin your response to **QUESTION 2** on this page.



2. 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 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.



(a)

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

ii. Use the graph to calculate the charge Q.

GO ON TO THE NEXT PAGE.

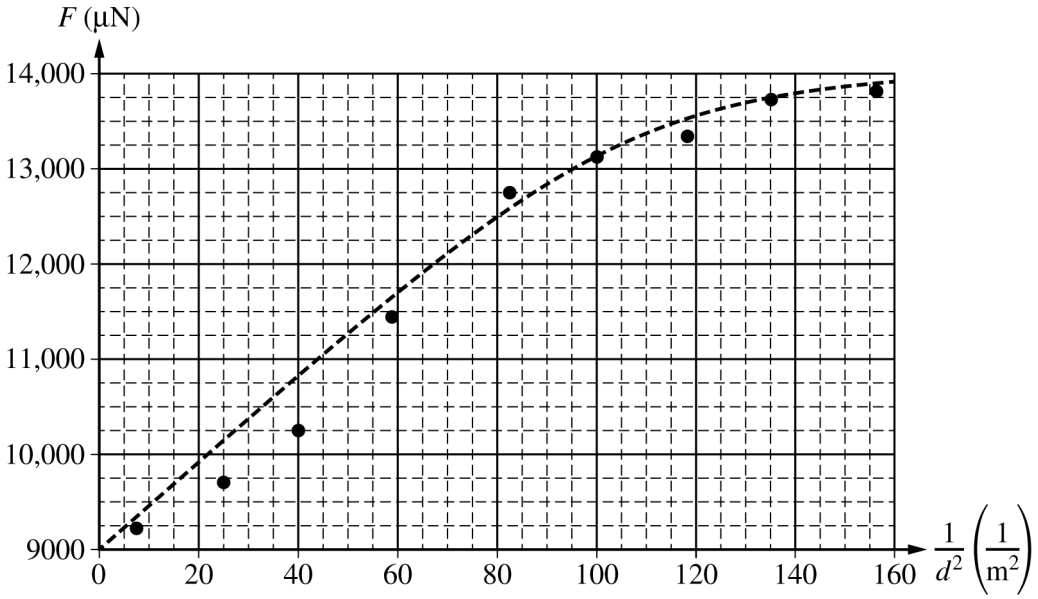
Continue your response to **QUESTION 2** on this page.

iii. 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.

iv. Determine the distance between the centers of the spheres for the data point indicated above.

v. What physical quantity does the vertical intercept represent?

Justify your answer.



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.

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

____ Yes _____ No

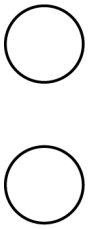
Justify your answer.

GO ON TO THE NEXT PAGE.

Continue your response to **QUESTION 2** on this page.

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

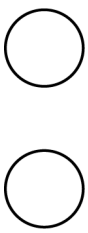
i. On the circles representing the spheres below, use a single "+" sign on each sphere to represent the locations of highest concentration of the excess positive charges.



ii. Explain how this rearrangement could be responsible for the discrepancy.

(d) 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.

i. 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.



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?

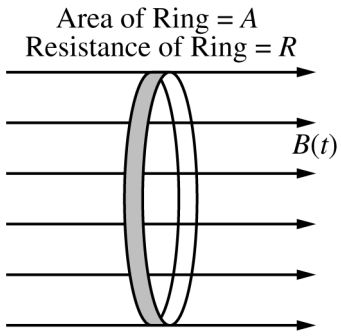
_____ Greater than _____ Less than _____ Equal to

Justify your answer.

GO ON TO THE NEXT PAGE.

Use a pencil or pen with black or dark blue ink only. Do NOT write your name. Do NOT write outside the box.

Begin your response to **QUESTION 3** on this page.



3. A thin, conducting ring of area A and resistance R is aligned in a uniform magnetic field directed to the right and perpendicular to the plane of the ring, as shown. At time $t = 0$, the magnitude of the magnetic field is B_0. At $t = 1\,\text{s}$, the magnitude of the magnetic field begins to decrease according to the equation $B(t) = \frac{\beta}{t}$, where β has units of T·s.

(a) Derive an equation for the magnitude of the induced current I in the ring as a function of t for $t > 1\,\text{s}$. Express your answer in terms of β, A, R, t, and physical constants, as appropriate.

Assume $A = 0.50\,\text{m}^2$, $R = 2.0\,\Omega$, and $\beta = 0.50\,\text{T}\cdot\text{s}$.

(b) Calculate the electrical energy dissipated in the ring from $t = 1\,\text{s}$ to $t = 2\,\text{s}$.

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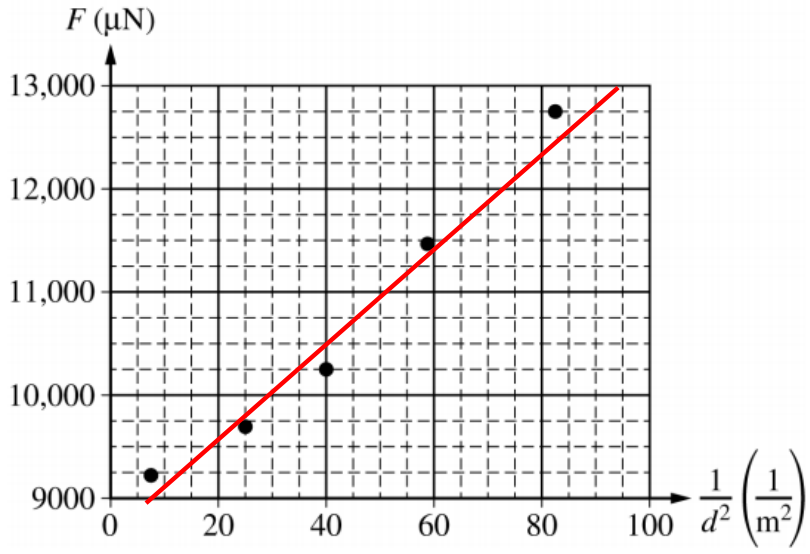
Question 2: Free-Response Question — 15 points

(a) i. For drawing an appropriate best-fit line **1 point**

Example response for part (a)(i)



ii. For calculating the slope using two points from the best-fit line **1 point**

$$slope = m = \frac{\Delta y}{\Delta x} = \frac{(12{,}000 - 10{,}500)\ \mu\text{N}}{(72 - 40)\ \text{m}^{-2}} = 4.7 \times 10^{-5}\ \text{N•m}^2$$

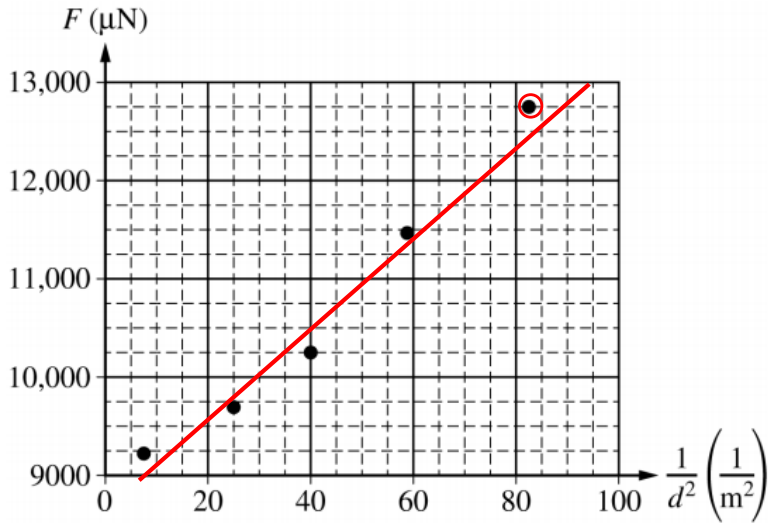
For correctly relating the slope to the charge **1 point**

$$F = \frac{kQ^2}{r^2} \therefore \text{slope} = kQ^2$$

For correctly calculating the charge consistent with the slope from the best-fit line **1 point**

$$Q = \sqrt{\frac{\text{slope}}{k}} = \sqrt{\frac{\left(4.7 \times 10^{-5}\ \text{N•m}^2\right)}{\left(9 \times 10^{9}\ \text{N•m}^2/\text{C}^2\right)}} = 7.2 \times 10^{-8}\ \text{C}$$

(a)	**iii.**	For drawing a circle around the appropriate data point	**1 point**



	iv.	For a correct answer From the graph, $\frac{1}{d^2} = 82.5\ \text{m}^{-2}$ $d = 0.11\ \text{m}$	**1 point**
	v.	For indicating that the *y*-intercept should be the weight of the conducting sphere and insulating rod	**1 point**
		For a correct justification	**1 point**

Example responses for part (a)(v).

When the spheres are infinitely far apart, there is no electric force between them. The only force recorded by the balance must be the weight of the lower sphere and insulating rod.

OR

The scale is zeroed before the insulating rod, and lower sphere are placed on it, so the nonzero y-intercept is their weight.

	Total for part (a)	**8 points**
(b)	For selecting "Yes" and providing a correct justification	**1 point**

Example response for part (b)

Because the later force measurements are lower than the expected values on the best-fit line, then a decrease in charge could explain the discrepancy seen in the data.