

Use the following information to answer written-response question 2.

A Millikan Experiment

A charged particle that has a mass of 2.8×10^{-16} kg accelerates upward at 3.6 m/s^2 in the electric field between two horizontal plates that have a separation of 0.10 m . The potential difference across the plates is $4.0 \times 10^2 \text{ V}$. The experiment is performed on Earth's surface at sea level.

2. a. Calculate the magnitude and direction of the electric force exerted upon the particle.

$$F_{\text{net}} = F_{\text{el}} - F_{\text{g}}$$

$$F_{\text{el}} = F_{\text{net}} + F_{\text{g}}$$

$$F_{\text{el}} = ma + mg$$

$$F_{\text{el}} = m(a + g)$$

$$= (2.8 \times 10^{-16}) (3.6 + 9.81)$$

$$F_{\text{el}} = 3.7548 \times 10^{-15} \text{ N}$$

$$3.8 \times 10^{-15} \text{ N up}$$

- b. Determine the charge on the particle. (If you were unable to answer part a, use the hypothetical value $F_{\text{e}} = 2.6 \times 10^{-15} \text{ N}$.)

$$F_{\text{el}} = qE$$

$$3.8 \times 10^{-15} = q \left(\frac{V}{d} \right)$$

$$3.8 \times 10^{-15} = q \left(\frac{400}{0.10} \right)$$

$$\frac{3.8 \times 10^{-15} \text{ N}}{4000 \text{ V/m}} = q$$

$$9.4 \times 10^{-19} \text{ C}$$

$$9.387 \times 10^{-19} \text{ C} = q$$

- c. Determine the time required for the particle to move from the lower to the upper plate when the particle begins at rest.

accelerated motion \Rightarrow don't use $t = \frac{d}{v}$

$$v_i = \phi$$

$$t = ?$$

$$a = 3.6 \text{ m/s}^2$$

$$d = 0.10 \text{ m}$$

$$d = v_i t + \frac{1}{2} a t^2$$

$$0.10 \text{ m} = \frac{1}{2} (3.6) t^2$$

$$0.2357 \text{ s} = t$$

$$\boxed{0.24 \text{ s}}$$

- d. Assume that the voltage applied to the plates can be varied. Calculate the minimum voltage needed to move the particle from the lower plate to the upper plate. (If you were unable to answer part b, use the hypothetical value $9.6 \times 10^{-19} \text{ C}$ as the charge on the particles.)

* Find Voltage needed TO SUSPEND drop
 assume voltage $>$ this will cause upward acceleration

$$F_{el} = F_g$$

$$q \frac{V}{d} = mg$$

$$V = \frac{mgd}{q}$$

$$= \frac{(2.8 \times 10^{-16})(9.81)(0.10)}{9.387 \times 10^{-19} \text{ C}}$$

$$V = 292.6 \text{ V}$$

\therefore Voltage must be $> 292.6 \text{ V}$

- e. Assume now that the particle is initially at rest between the plates. If the charges on the plates were inverted (negative plate becomes positive, and positive plate becomes negative), what would be the magnitude and direction of the net force on the particle?

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• at rest $\uparrow F_{el}$
 $\downarrow F_g$

$F_{el} = F_g$ equal and opposite

If $|\vec{E}|$ direction is reversed F_{el} is now = in magnitude and in the same direction as F_g \therefore

$$F_{net} = F_g \times 2$$

$$= mg \times 2$$

$$= (2.8 \times 10^{-16})(9.81) \times 2$$

$$= 5.5 \times 10^{-15} \text{ N down}$$

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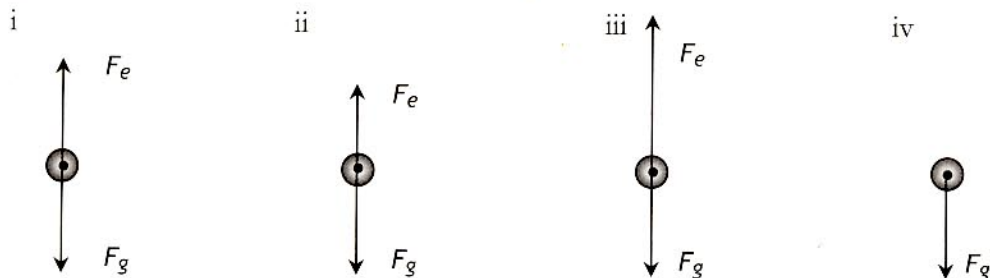
$\downarrow F_{el}$ $\downarrow F_g$

10. Thomas Edison became convinced that electrical charge is quantized when he used Millikan and Fletcher's oil drop apparatus. He had previously thought that charge could be any continuous variable. Define quantized [Appendix A]

Quantized means a distinct elemental value.

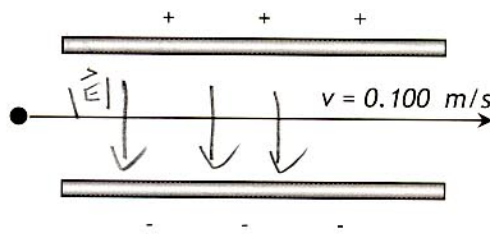
Use the information below to answer question 11.

A free-body diagram is a necessary part of the solution for oil drop problems. Four free-body diagrams for an oil drop are drawn below. [Appendix A]



11. Considering only the vertical dimension, identify the free-body diagram(s) that best describes an oil drop that is
- moving at a constant velocity. *i*
 - accelerating upwards. *ii*
 - accelerating downwards. *iv and ii*

12. A 5.80×10^{-9} kg oil droplet having a charge magnitude of 5.40×10^{-14} C enters the electric field between two horizontally charged plates that are 8.00 cm apart, as shown in the diagram. The oil drop passes through the plates undeflected at a uniform speed of 10.0 cm/s. (Ignore the effects of the nonuniform electric field at the ends of the plates.)



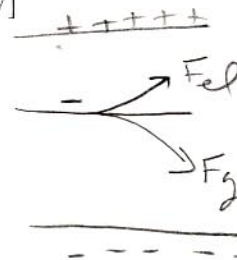
- Draw electric field lines between the plates in the diagram. [Appendix A]
- Identify the sign of the charge on the oil drop. [Appendix A] *negative*
- Determine the potential difference between the two plates. [84.3 kV]

$$c) F_{el} = F_g$$

$$q|E| = mg$$

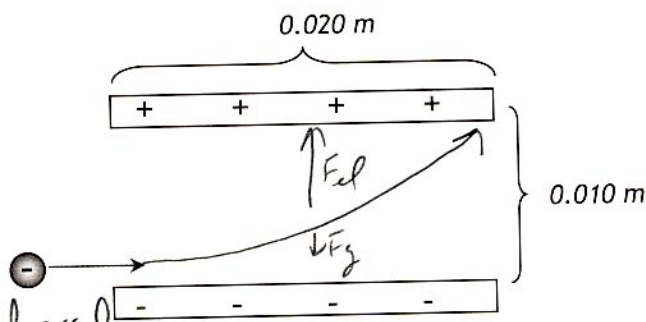
$$q \frac{V}{d} = mg$$

$$5.4 \times 10^{-14} \cdot \frac{V}{0.08} = (5.80 \times 10^{-9})(9.81)$$



13. A charged oil drop is sent in through the uniform electric field between two parallel plates as shown in the diagram below. The potential difference is adjusted so that the charged particle just contacts the upper right side of the positive plate. (Ignore the effects of the non-uniform electric field at the ends of the plates.) Determine the charge on the particle. [$1.4 \times 10^{-8} \text{ C}$]

Mass of oil drop: $5.0 \times 10^{-5} \text{ kg}$
 Initial velocity of particle: 0.70 m/s , directly to the right
 Electric field between plates: 120 kV/m



i) find upward accel

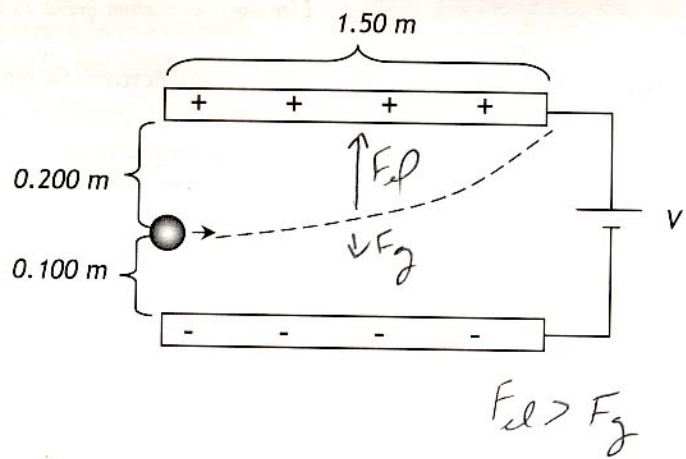
x	y
$v_x = \frac{dx}{dt}$	$d = v_x t + \frac{1}{2} a t^2$
$t = \frac{0.020 \text{ m}}{0.70 \text{ m/s}}$	$0.010 \text{ m} = \frac{1}{2} a (0.028 \dots)^2$
$t = 0.02857 \text{ s}$	$a = 24.5 \text{ m/s}^2$

ii) $F_{\text{net}} = F_{\text{el}} - F_g$
 find q) $ma = q|\vec{E}| - mg$

$$\frac{m(a+g)}{|\vec{E}|} = q$$

$$\frac{(5.0 \times 10^{-5})(24.5 + 9.81)}{120000} = q$$

14. A 1.20×10^{-6} kg particle having a charge of $-0.500 \mu\text{C}$ is travelling horizontally at 5.00 m/s when it enters the region between two charged plates as shown in the diagram. The particle strikes the top plate at its extreme right end. Determine the potential difference between the plates. (Ignore the effects of the nonuniform electric field at the ends of the plates.) [10.3 V]



i)

x	y
$v_x = \frac{d_x}{t}$	$d = v_x t + \frac{1}{2} a t^2$
$5.00 \text{ m/s} = \frac{1.50 \text{ m}}{t}$	$0.200 = \frac{1}{2} a (0.30)^2$
$t = 0.30 \text{ s}$	$a = 4.44 \text{ m/s}^2$

ii) $F_{\text{net}} = F_{\text{el}} - F_g$

$$ma = q|\vec{E}| - mg$$

$$(1.20 \times 10^{-6} \cdot 4.44 \text{ m/s}^2) = .5 \times 10^{-6} \cdot |\vec{E}| - (1.20 \times 10^{-6} \cdot 9.81)$$

$$5.333 \times 10^{-6} = .5 \times 10^{-6} \cdot |\vec{E}| - 1.1772 \times 10^{-5}$$

$$1.710 \times 10^{-5} = .5 \times 10^{-6} |\vec{E}|$$

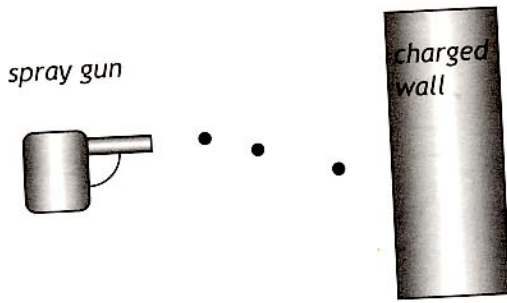
$$34.21 = \frac{V}{m} = |\vec{E}|$$

iii) $|\vec{E}| = \frac{V}{d}$

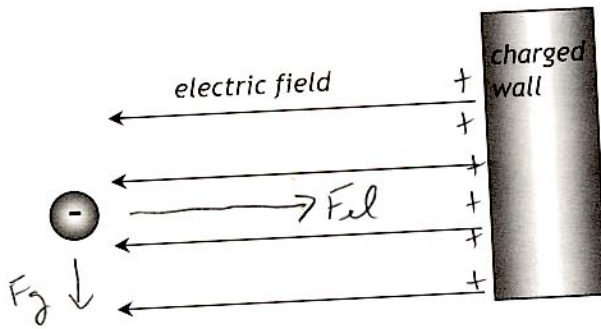
$$34.21 = \frac{V}{0.30 \text{ m}}$$

$$V = 10.3 \text{ V}$$

Paint may be applied to a surface using electrostatic principles. This process was invented by Ransburg in 1938. Negatively charged paint particles are sprayed at low speed to a charged surface which attracts the charged particles. This method of painting has the advantage of wasting much less paint than conventional painting methods. [Appendix A]



15. A 2.30×10^{-10} kg negatively charged paint droplet of 9.25×10^{-14} C is travelling towards the wall where it enters the wall's uniform electric field of 4.50×10^4 N/C shown below.
- Draw the forces (i.e., free-body diagram) acting on the charged particle below.
 - Identify the charge (positive, negative or neutral) on the wall's surface. +
 - Determine the net force acting on the particle. [4.74 nN, 28.5° down from the horizontal]



$$F_g = mg$$

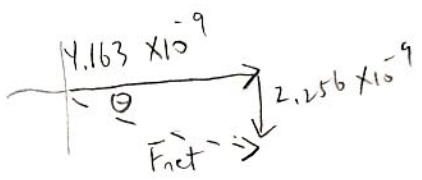
$$= (2.30 \times 10^{-10}) (9.81)$$

$$= 2.256 \times 10^{-9} \text{ N}$$

$$|E| = \frac{F_{el}}{q}$$

$$4.50 \times 10^4 = \frac{F_{el}}{9.25 \times 10^{-14} \text{ C}}$$

$$F_{el} = 4.163 \times 10^{-9} \text{ N}$$



$$F_{net} = \sqrt{(4.163 \times 10^{-9})^2 + (2.256 \times 10^{-9})^2}$$

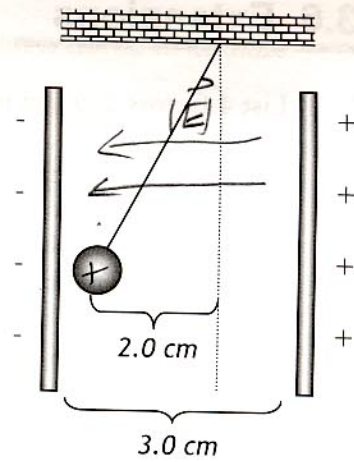
$$= 4.7349 \times 10^{-9} \text{ N}$$

$$\tan \theta = \frac{\text{opp}}{\text{adj}}$$

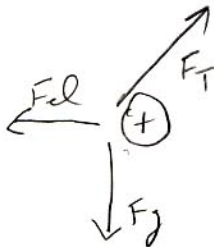
$$= 28.5^\circ$$

$$4.74 \text{ nN}$$

16. A 4.20×10^{-3} kg pith ball, having a charge magnitude of $2.40 \mu\text{C}$, is suspended on a 90.0 cm long string between two oppositely charged parallel plates as shown in the diagram. The pith ball is 2.00 cm from its original vertical position before the plates were charged. [Appendix A]
- Identify the sign of the charge on the pith ball. $+$
 - Use arrows to draw the electric field direction between the two charged plates on the diagram.
 - Draw a free-body diagram for the pith ball.
 - Determine the magnitude of the electric field between the plates. [381 N/C]
 - Determine the potential difference between the two charged plates. [11.4 V]



c)

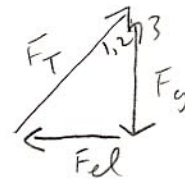


suspended... so F_T and $F_{el} + F_g$ balance

$$d) \quad |E| = \frac{F_{el}}{q} = \frac{9.15 \times 10^{-4}}{2.40 \times 10^{-6} \text{ C}}$$

$$= 381.49$$

$$= 381 \text{ N/C}$$



$$\tan 1.273 = \frac{F_{el}}{F_g}$$



$$\sin \theta = \frac{2}{90}$$

$$\theta = 1.273^\circ$$

$$\tan 1.273 = \frac{F_{el}}{4.2 \times 10^{-3} \times 9.81}$$

$$F_{el} = 9.15578 \times 10^{-4} \text{ N}$$

$$e) \quad |E| = \frac{V}{d}$$

$$381.49 = \frac{V}{0.03}$$

$$V = 11.44 \text{ V}$$

$$11.4 \text{ V}$$