Physics 30 – Lesson 14
Coulomb's Law

Possible 99 / 93

Practice problems

1)

$r = 2.00cm = 0.0200m$

$q_1 = -4.00\mu C = -4.00\times10^{-6}C$

$q_2 = -3.00\mu C = -3.00\times10^{-6}C$

$F_E = ?$

$$\left|F_E\right| = \left|\frac{kq_1q_2}{r^2}\right|$$

$$\left|F_E\right| = \left|\frac{8.99\times10^9 \frac{N\cdot m^2}{C^2}(-4.00\times10^{-6}C)(-3.00\times10^{-6}C)}{(0.020m)^2}\right|$$

$$\left|F_E\right| = 270N$$

Since the charges are both negative they repel

$$\boxed{\vec{F}_E = 270N\ repulsion}$$

2)

$q_1' = q_1$

$q_2' = 2q_2$

$r' = 3r$

$$0.0620N = \frac{kq_1q_2}{r^2}$$

$$1.6\times10^{-2}N\times\frac{(2)}{3^2} = \frac{kq_1q_2}{r^2}\times\frac{(2)}{3^2}$$

$$\boxed{F_E' = 0.0138N}$$

3)

$r = 0.100m$

$F = 0.0340N$

$q_2 = 3q_1$

$$F_E = \frac{kq_1q_2}{r^2}$$

$$F_E = \frac{kq_1(3q_1)}{r^2}$$

$$F_E = \frac{3kq_1^2}{r^2}$$

$$q_1 = \sqrt{\frac{F_Er^2}{3k}}$$

$$q_1 = \sqrt{\frac{(0.0340N)(0.100m)^2}{3(8.99\times10^9\frac{N\cdot m^2}{C^2})}}$$

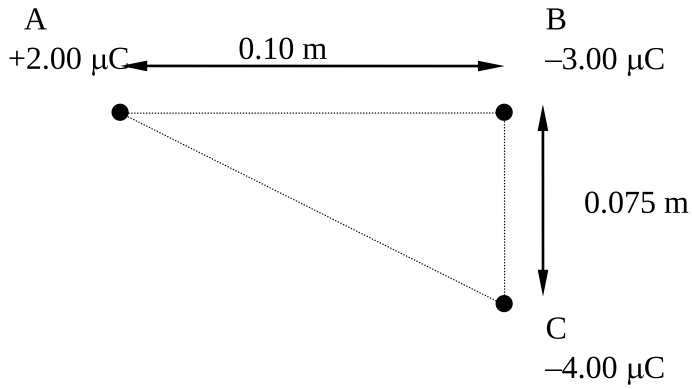
$$\boxed{q_1 = 1.12\times10^{-7}C}$$

$q_2 = 3q_1$

$q_2 = 3(1.12\times10^{-7}C)$

$$\boxed{q_2 = 3.36\times10^{-7}C}$$

4)



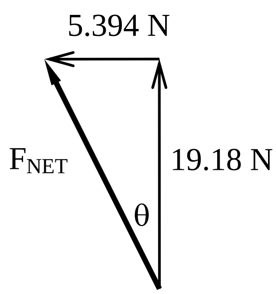
There are two forces acting on charge B: $F_{C\text{ on }B}$ and $F_{A\text{ on }B}$.

$$F_{C\,on\,B} = \left| k\ \frac{q_B\, q_C}{r^2} \right| \qquad F_{A\,on\,B} = \left| k\ \frac{q_A\, q_C}{r^2} \right|$$

$$F_{C\,on\,B} = \left| \frac{8.99\times10^{9}\ \frac{N\cdot m^2}{C^2}(3.00\times10^{-6}C)(4.00\times10^{-6}C)}{(0.075\,m)^2} \right| \qquad F_{A\,on\,B} = \left| \frac{8.99\times10^{9}\ \frac{N\cdot m^2}{C^2}(2.00\times10^{-6}C)(3.00\times10^{-6}C)}{(0.10\,m)^2} \right|$$

$$F_{C\,on\,B} = 19.18\,N \text{ away from C} \qquad F_{A\,on\,B} = 5.394\,N \text{ toward A}$$

The free body diagram is:



$$F_{NET} = \sqrt{19.18^2 + 5.394^2}$$
$$F_{NET} = 19.9\,N$$
$$\theta = \tan^{-1}\left(\frac{5.394}{19.18}\right)$$
$$\theta = 16^\circ\ W\ of\ N$$

$$\boxed{\vec{F}_{NET} = 19.9\,N\ \left[16^o\ W\ of\ N\right]}$$

5)

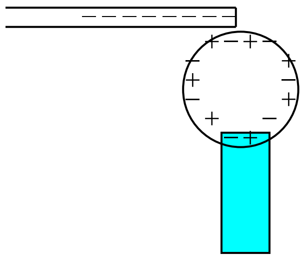
$$r = 0.350m$$
$$q_1 = -2.00\mu C = -2.00\times10^{-6}C$$
$$q_2 = -3.00\mu C = -3.00\times10^{-6}C$$
$$m = 2.00\times10^{-5}kg$$
$$a = ?$$

$$|F_E| = \left| \frac{kq_1q_2}{r^2} \right|$$
$$|F_E| = \left| \frac{8.99\times10^{9}\ \frac{N\cdot m^2}{C^2}(-2.00\times10^{-6}C)(-3.00\times10^{-6}C)}{(0.350m)^2} \right|$$
$$|F_E| = 0.44N$$

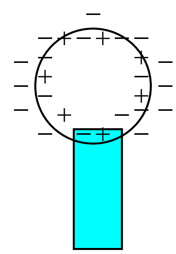
$$a = \frac{F_{NET}}{m}$$
$$a = \frac{0.44N}{2.00\times10^{-5}kg}$$
$$\boxed{a = 2.20\times10^{4}\ {}^{m}\!/\!{}_{s^2}}$$

Assignment

Part A - Electrostatics

1) 

A negatively charged rod brought into contact with a conducting object results in negative charges being transferred to the object.



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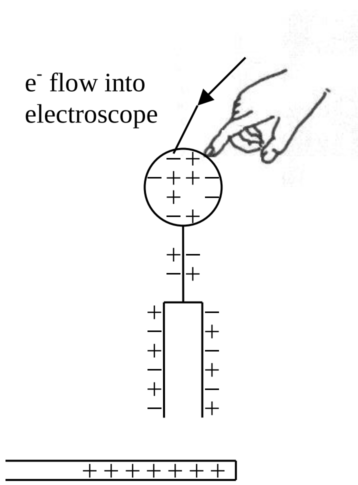


A positively charged rod brought near a conducting object along with a ground results in negative charges being pulled into the object by induction.

2) Static means not moving. Rubbing a conductor does not produce a static charge since the electrons are free to move away from one another in the conductor. A static charge is produced on an insulator since the electrons are not free to move and therefore they remain static in one spot.

/2

3)

$$q = N \cdot e^-$$

/2

$$q = (-1.0\times10^{10}\, e^-)(1.60\times10^{-19}\,\tfrac{C}{e^-})$$

$$\boxed{q = -1.6\times10^{-9}\,C}$$

4)

$$q = N \cdot e^-$$

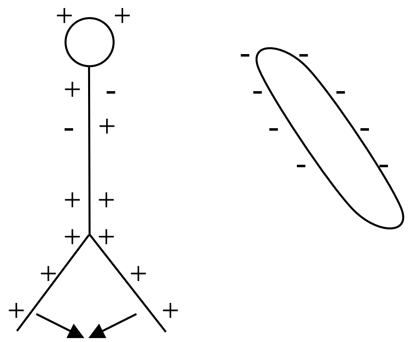
/2

$$q = (+1.0\times10^{12}\, p^+)(1.60\times10^{-19}\,\tfrac{C}{p^+})$$

$$\boxed{q = +1.6\times10^{-7}\,C}$$

5)

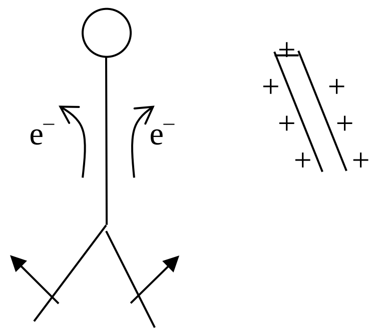
/3



Negative charges in the knob of the electroscope are repelled by the charged rod. The negatives flow down to the leaves, neutralizing them, and causing the leaves to come together.

6)

/3



Electrons are attracted to the charged rod. Since the leaves are becoming less negative and they spread apart, the electroscope must have been positive!

7)

/2

The spheres are conductors which will allow the free flow of charges. The charges will repel one another and will therefore move to the outside of the sphere regardless of whether the sphere is hollow or solid.

8)

/3

$$q = \tfrac{1}{2} q_T$$

$$q = \tfrac{1}{2} 7.75\times10^{19}\, p^+ \times 1.60\times10^{-19}\, \tfrac{C}{p^+}$$

$$\boxed{q = 6.2\,C \text{ each}}$$

9)

1) Touch the glass rod to the electroscope (conduction)
2) Use the silk (negatively charged) to charge the electroscope by induction.
3) Yes, either by induction with the glass rod or by conduction using the silk cloth.

/3

Part B – Coulomb's Law

1)

/4

$$F_g = \frac{Gm_1m_2}{r^2}$$

$$F_E = \frac{kq_1q_2}{r^2}$$

similar

- both obey inverse square law with distance
- both are linear with respect to mass / charge

different

- one depends on mass, the other on charge
- F_g is always present, F_E exists between charged items only
- F_g is always attractive, F_E can also be repulsive
- F_g is much smaller than F_E

2)

/3

$q_1 = +100\mu C$

$q_2 = 5.0\mu C$

$r = 0.500m$

$F_E = ?$

$$F_E = -\frac{kq_1 q_2}{r^2}$$

$$F_E = \frac{-8.99\times10^9 \frac{N\cdot m^2}{C^2}(100\times10^{-6}C)(5.00\times10^{-6}C)}{(0.500m)^2}$$

$$\boxed{F_E = -18.0N}$$

3)

/3

$$F_E = -\frac{kq_1 q_2}{r^2}$$

$$310N\times\frac{4}{(\frac{1}{2})^2} = -\frac{kq_1 q_2}{r^2}\times\frac{4}{(\frac{1}{2})^2}$$

$$F_E' = 310N\times16$$

$$\boxed{F_E' = 4.96\times10^3 N}$$

4)

/3

$Q = ?$

$r = 0.040m$

$q_1 = 80nC = 80\times10^{-9}C$

$F_E = +0.015N$

$$F_E = -\frac{kq_1 Q}{r^2}$$

$$Q = \frac{F_E r^2}{kq_1}$$

$$Q = \frac{0.015N(0.040m)^2}{8.99\times10^9 \frac{N\cdot m^2}{C^2}(80\times10^{-9}C)}$$

$$\boxed{Q = 3.3\times10^{-8}C}$$

5)

/5

$$q' = \frac{q_1+q_2}{2}$$

$$q' = \frac{+4.00\mu C + (-1.00\mu C)}{2}$$

$$q' = +1.5\mu C$$

$$F_E = +\frac{kq'q'}{r^2}$$

$$F_E = +\frac{8.99\times10^9 \frac{N\cdot m^2}{C^2}(1.5\times10^{-6}C)^2}{(0.200m)^2}$$

$$\boxed{F_E = +0.506N}$$

6)

/3

$$q_1' = \tfrac{1}{2}q_1$$
$$q_2' = \tfrac{1}{2}q_2$$
$$r' = 2r$$

$$1.6\times10^{-2}\,N = \frac{kq_1q_2}{r^2}$$

$$1.6\times10^{-2}\,N\times\frac{\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)}{2^2} = \frac{kq_1q_2}{r^2}\times\frac{\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)}{2^2}$$

$$\boxed{F_E' = 0.0010\,N}$$

7)

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$$q_1 = q_2 = 1.60\times10^{-19}\,C$$
$$r = 5.3\times10^{-11}\,m$$
$$m_1 = 1.67\times10^{-27}\,kg$$
$$m_2 = 9.1\times10^{-31}\,kg$$
$$F_E = ?$$
$$F_g = ?$$
$$v = ?$$
$$T = ?$$

a)

$$F_E = -\frac{kq_1q_2}{r^2}$$

$$F_E = \frac{-8.99\times10^9\,\frac{N\cdot m^2}{C^2}(1.60\times10^{-19}\,C)^2}{(5.3\times10^{-11}\,m)^2}$$

$$\boxed{F_E = -8.2\times10^{-8}\,N}$$

b)

$$F_g = \frac{-Gm_1m_2}{r^2}$$

$$F_g = \frac{-6.67\times10^{-11}\,\frac{N\cdot m^2}{kg^2}(1.67\times10^{-27}\,kg)(9.1\times10^{-31}\,kg)}{(5.3\times10^{-11}\,m)^2}$$

$$\boxed{F_g = -3.6\times10^{-47}\,N}$$

c)

$$ratio = \frac{F_E}{F_g}$$

$$ratio = \frac{8.2\times10^{-8}\,N}{3.6\times10^{-47}\,N}$$

$$ratio = \frac{2.3\times10^{39}}{1}$$

$$\boxed{2.3\times10^{39} : 1}$$

d) Since F_g is insignificant compared to F_E, F_E is responsible for F_c

e)

$$F_c = \frac{mv^2}{r}$$

$$v = \sqrt{\frac{F_cr}{m}}$$

$$v = \sqrt{\frac{8.2\times10^{-8}\,N(5.3\times10^{-11}\,m)}{9.1\times10^{-31}\,kg}}$$

$$\boxed{v = 2.2\times10^6\,\tfrac{m}{s}}$$

$$T^2 = \frac{4\pi^2mR}{F_c}$$

$$T = \sqrt{\frac{4\pi^2(9.1\times10^{-31}\,kg)(5.3\times10^{-11}\,m)}{8.2\times10^{-8}\,N}}$$

$$\boxed{T = 1.5\times10^{-16}\,s}$$

8)

a)

$$\vec{F} = \vec{F}_{1onT} + \vec{F}_{2onT}$$

$$\vec{F} = \left(-\frac{kq_1 q_T}{r_{1onT}^2}\right) + \left(+\frac{kq_2 q_T}{r_{2onT}^2}\right)$$

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$$\vec{F} = kq_T\left(-\frac{q_1}{r_{1onT}^2}\right) + \left(+\frac{q_2}{r_{2onT}^2}\right)$$

$$\vec{F} = (8.99\times10^9\ \tfrac{N\cdot m^2}{C^2})(2.5\times10^{-6}C)\left(-\frac{4.0\times10^{-5}C}{(0.36m)^2} + \frac{1.8\times10^{-5}C}{(0.12m)^2}\right)$$

$$\vec{F} = +21N \boxed{= 21N \text{ to the right}}$$

b)

$$\vec{F} = \vec{F}_{1onT} + \vec{F}_{2onT}$$

$$\vec{F} = \left(+\frac{kq_1 q_T}{r_{1onT}^2}\right) + \left(-\frac{kq_2 q_T}{r_{2onT}^2}\right)$$

$$\vec{F} = kq_T\left(+\frac{q_1}{r_{1onT}^2}\right) + \left(-\frac{q_2}{r_{2onT}^2}\right)$$

$$\vec{F} = (8.99\times10^9\ \tfrac{N\cdot m^2}{C^2})(2.5\times10^{-6}C)\left(+\frac{4.0\times10^{-5}C}{(0.12m)^2} - \frac{1.8\times10^{-5}C}{(0.36m)^2}\right)$$

$$\vec{F} = +59N \boxed{= 59N \text{ to the right}}$$

9)

$r = 0.040m$

$F = 0.90N$

/4

$q_2 = \frac{q_1}{4}$

$$F_E = \frac{kq_1 q_2}{r^2}$$

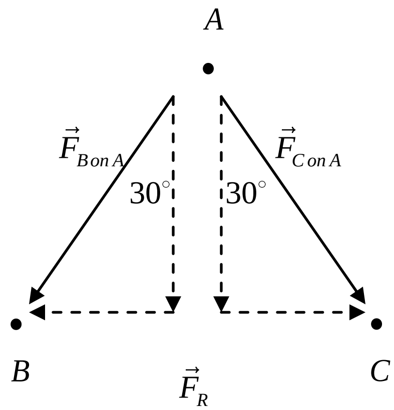
$$F_E = \frac{kq_1^2}{4r^2}$$

$$q_1 = \sqrt{\frac{4F_E r^2}{k}}$$

$$q_1 = \sqrt{\frac{4(0.90N)(0.040m)^2}{8.99\times10^9\ \frac{N\cdot m^2}{C^2}}}$$

$$\boxed{q_1 = 8.0\times10^{-7}C}$$

10)



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$$F_{B\,on\,A} = F_{C\,on\,A} = \frac{kq_{B/C}q_A}{r^2}$$

$$F_{B/C} = \frac{8.99\times10^9\ \frac{N\cdot m^2}{C^2}(0.20\times10^{-6}C)(0.30\times10^{-6}C)}{(0.10m)^2}$$

$$F_{B/C} = 0.05394N$$

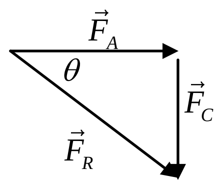
note: the horizontal components of F_B *and* F_C are equal and opposite

$$\therefore F_R = 2\times F_{B/C}\cos 30^\circ$$

$$F_R = 2\times 0.05394\cos 30^\circ$$

$$\boxed{\vec{F}_R = 0.093\,N[S]}$$

11)



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$$F_A = \frac{kq_Aq_B}{r^2}$$

$$F_A = \frac{8.99\times10^9\ \frac{N\cdot m^2}{C^2}(3.0\times10^{-6}C)(4.0\times10^{-6}C)}{(0.60m)^2}$$

$$F_A = 0.300N$$

$$F_C = \frac{kq_Cq_B}{r^2}$$

$$F_C = \frac{8.99\times10^9\ \frac{N\cdot m^2}{C^2}(4.0\times10^{-6}C)^2}{(0.60m)^2}$$

$$F_C = 0.400N$$

$$F_R = \sqrt{0.300^2 + 0.400^2}$$

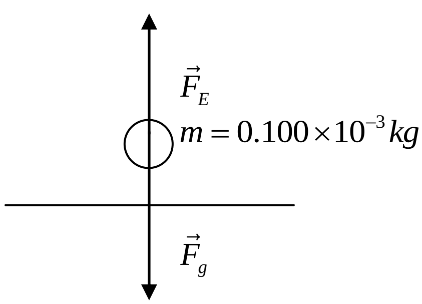
$$F_R = 0.500N$$

$$\theta = \tan^{-1}\frac{0.400}{0.300}$$

$$\theta = 53^\circ$$

$$\boxed{\vec{F}_R = 0.500N[53^\circ\ S\ of\ E]}$$

12)



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$$\vec{F}_{net} = \vec{F}_E + \vec{F}_g$$

$$0 = F_E - F_g$$

$$F_E = F_g$$

$$F_E = F_g$$

$$\frac{kq^2}{r^2} = mg$$

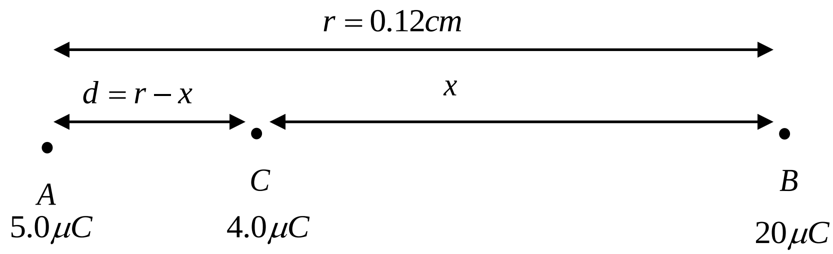
$$q^2 = \frac{mgr^2}{k}$$

$$q = \sqrt{\frac{mgr^2}{k}}$$

$$q = \sqrt{\frac{0.100\times10^{-3}kg(9.81\,{}^{m}/{}_{s^2})(0.02m)^2}{8.99\times10^9\ \frac{N\cdot m^2}{C^2}}}$$

$$\boxed{q = 6.6\times10^{-9}C}$$

13)



$$F_{AC} = F_{BC}$$

$$\frac{kq_A q_C}{(r-x)^2} = \frac{kq_B q_C}{x^2}$$

$$\frac{q_A}{(r-x)^2} = \frac{q_B}{x^2}$$

/5

$$\sqrt{\frac{x^2}{(r-x)^2}} = \sqrt{\frac{q_B}{q_A}}$$

$$\frac{x}{r-x} = \sqrt{\frac{q_B}{q_A}} = \sqrt{\frac{20\mu C}{5.0\mu C}} = 2$$

$$x = 2(r-x)$$

$$x = 2r - 2x$$

$$3x = 2r$$

$$x = \frac{2}{3}r$$

$$x = \frac{2}{3}(12cm)$$

$$\boxed{x = 8cm}$$

14)

a)

$F_E' = 1.0\times10^{-5}N$

$r = 0.30m$

$q' = ?$

$$F_E' = \frac{kq'^2}{r^2}$$

$$q' = \sqrt{\frac{F'r^2}{k}}$$

$$q' = \sqrt{\frac{1.0\times10^{-5}N(0.30m)^2}{8.99\times10^9\ \frac{N\cdot m^2}{C^2}}}$$

$$q' = 1.0\times10^{-8}C$$

b)

$F_E = -8.0\times10^{-5}N$

$r = 0.30m$

$q_1 = ?$

$q_2 = ?$

When two charges are brought together and separated the charge on each sphere is:

$$q' = \frac{q_1 + q_2}{2}$$

$$2q' - q_1 = q_2$$

$$F_E = \frac{kq_1 q_2}{r^2}$$

Bonus
/8

$$F_E = \frac{kq_1(2q' - q_1)}{r^2}$$

$$-8.0\times10^{-5}N = \frac{8.99\times10^9\ \frac{N\cdot m^2}{C^2}\, q_1\left[2(1.0\times10^{-8}C) - q_1\right]}{(0.30m)^2}$$

$$-8.0\times10^{-16} = 2.0\times10^{-8}q_1 - q_1^2$$

$$q_1^2 - 2.0\times10^{-8}q_1 - 8.0\times10^{-16} = 0$$

$$(q_1 - 4.0\times10^{-8})(q_1 + 2.0\times10^{-8}) = 0$$

$$\boxed{q_1 = \pm4.0\times10^{-8}C}$$

$$\boxed{q_2 = \mp2.0\times10^{-8}C}$$