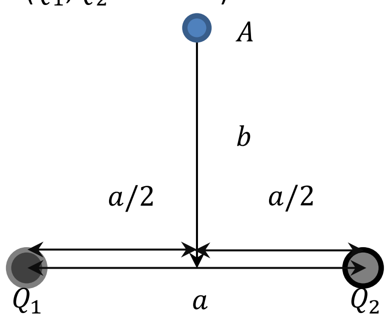
Name: ______________________________ DISC: ____________ Score: _____ / 20

Instructions:

- Do your own work.
- Answer the questions below in the space provided.
- Make sure you show all your work and any equations that you use.
- Please place a box around your answers.
- Remember to give the correct units with all numerical answers

Q1	Q2	Q3	Q4
10	10	5	5

1. Consider the following situation (Q_1, Q_2 are fixed):



a	b	Q_1	Q_2	k	ELECTRIC FIELD	FORCE
$5\ m$	$3\ m$	$+6.0\ \mu C$	$-3.5\ \mu C$	$9\times10^9 N\ m^2/C^2$	$E(r)=\frac{kq}{r^2}$	$F(r)=\frac{kq_1q_2}{r^2}=qE(r)$

a. Using the information in the table, find the electric field (magnitude and direction) at point A.

Potential (5 pts):

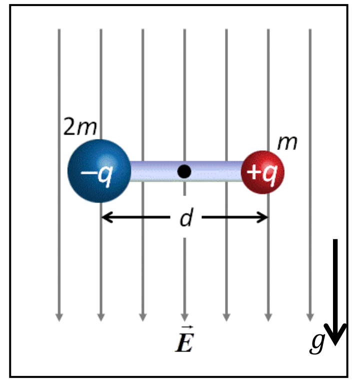
Charge	Magnitude of E from Charge	x-component of E	y-component of E
Q_1	$\frac{(9\times10^9\times6\times10^{-6})}{6.25+9} = \frac{(54\times10^3)}{15.25} = 3.54\times10^3\ N/C$	$3.54\times10^3\times\frac{2.5}{3.91}\frac{N}{C} = 2.26\times10^3\ N/C$ Along the +x-direction	$3.54\times10^3\times\frac{1.5}{3.91}\frac{N}{C} = 1.36\times10^3\frac{N}{C}$ Along the +y-direction
Q_2	$\frac{(9\times10^9\times3.5\times10^{-6})}{6.25+9} = \frac{(31.5\times10^3)}{15.25} = 2.07\times10^3\ N/C$	$2.07\times10^3\times\frac{2.5}{3.91}\frac{N}{C} = 1.32\times10^3\frac{N}{C}$ Along the +x-direction	$2.07\times10^3\times\frac{1.5}{3.91}\frac{N}{C} = 7.94\times10^2\frac{N}{C}$ Along the -y-direction
Total Field	**Magnitude**	**x-component**	**y-component**
E_{total}	$\sqrt{(3.58\times10^3)^2+(0.57\times10^3)^2}\frac{N}{C} = 3.63\times10^3\ N/C$	$(2.26+1.32)\times10^3\frac{N}{C} = 3.58\times10^3\frac{N}{C}$	$(1.36-0.794)\times10^3\frac{N}{C} = 5.7\times10^2\ N/C$
θ	$\tan\theta\frac{(5.7\times10^2)}{3.58\times10^3} = 0.159$ $\theta = 9.05°$		

b. What force (magnitude and direction) would a charge $q = 1.5\ \mu C$ experience at point A?

Work (5 pts):

$$F = qE = 1.5 \times 10^{-6} \times 3.63 \times 10^{3} = 5.45 \times 10^{-3} N\ at\ \theta = 9.05°$$

2. An electric dipole sits perpendicular to an downward-directed electric field, as shown. Gravity also acts downward on the dipole as shown in the diagram. The dipole can rotate about a frictionless axis located a distance $d/2$ from each charge.



a. What is the electric dipole moment $\vec{p}$ of this dipole? Does it depend on the mass of the charges?

Dipole moment (1 pts):
Mass dependence (1pt.):

$$\vec{p} = qd = 6 \times 10^{-6} \times 0.5 \times 10^{-2} = 3 \times 10^{-8}\ C\ m$$

along the +x-direction. The electric dipole moment does not depend on the mass.

b. Using the information in the table, find the torque on the dipole due only to the electric field.

Dipole Torque (2 pts):

Mechanical Torque	$\tau_M = rF \sin\theta$
Electric Dipole Torque due to Field	$\tau_d = pE \sin\theta$
Charge $\lvert q \rvert$	$6\ \mu C$
Separation Distance d	$0.5\ cm$
Electric Field E	$1000\ N/C$
Mass m	$5\ g$

$$\tau_{elec} = 3 \times 10^{-8} \times 1000 = -3 \times 10^{-5}\ Nm$$

c. Find the mechanical torque on this dipole due to gravity alone.

Dipole Torque (2 pts):

$$\tau_{mech} = (2 \times 5 \times 10^{-3}) \times 9.81 \times (0.25 \times 10^{-2}) - (5 \times 10^{-3}) \times 9.81 \times (0.25 \times 10^{-2})$$
$$= 12 \times 10^{-5}\ Nm$$

d. Does the dipole rotate in this electric field? What field strength would be required to prevent the rotation? (use page 3 to show your work—make sure your answer is clear).

Rotate (1 pts):
New Field (3 pts):

Because the sum of these two torques is not zero (i.e. the net torque is not zero), the diplole will rotate. Specifically, the mechanical torque on the dipole is larger than the electrical torque. We can find the electric field strength needed to keep the situation in equilibrium (prevent the rotation): $\tau_{mech} = \tau_{elec}$

$$\tau_{mech} = pE$$
$$E = \frac{\tau_{mech}}{p} = \frac{(12 \times 10^{-5}\ Nm)}{(3 \times 10^{-8}\ C\ m)} = 4 \times 10^{3}\ \frac{N}{C}$$

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