Coulomb's Law

PHYS 296

Your name____________________ **Lab section____________________**

PRE-LAB QUIZZES

1. What is the purpose of this lab?

2. Two conducting hollow balls of diameter *3.75* cm are both initially charged by a bias voltage of *+5000* V. When they are brought to a center-to-center distance of *10.0* cm, what is the electrostatic force between them? Hint: see Lab II manual for the net charge on each ball and assume the charge is uniformly distributed on the surface of each ball.

3. For the torsion balance, write down the relationship between the exerted force and the angle of rotation.

4. For the two conducting balls as described in problem 2, when one ball is attached to a torsion balance (as shown in Figure 1) the wire is twisted by a torsional angle of 1°. Assuming the length of the lever arm as *10.0 cm*, find the torsion constant of the wire. Show the calculation.

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Name__________________________ **Lab section**____________________

Lab partner's name(s)____

Purpose

In this lab, we investigate the law governing the electrostatic force between electric charges.

Background

In 1785, Coulomb conducted a series of experiments investigating the electrostatic force between electric charges. Similar to Cavendish's experimental approach to measure gravitational force, Coulomb employed a torsion balance to determine electrostatic force. As Coulomb discovered, the magnitude of the electrostatic force (F) between two charged objects, which are separated by a distance of r and bear electrical charges q_1 and q_2, follows Equation (1):

$$F = k\frac{q_1 q_2}{r^2}, \tag{1}$$

where $k = 9.0 \times 10^9\ N\ m^2/C^2$. In this lab, we use the torsion balance as depicted in Figure 1 to measure electrostatic force and to verify Coulomb's law.

In this lab, the electrostatic force (F) is exerted on the conducting hollow ball with charge q_1 as shown in Figure 1 by a second conducting hollow ball of charge q_2. The second ball is not shown in Figure 1 and can move along a sliding track to change the distance, r, between q_1 and q_2. As shown, the first ball is attached to an insulation stick which is tightly fixed with the torsion wire. This way, the ball, the stick, and the wire rotate together under the electrostatic force which is exerted by the second ball and passes through the center of the first ball and along the direction perpendicular to the wire. The force produces a torque on the wire described by

$$T = FL, \tag{2}$$

where L is the lever arm, i.e., the distance between the center of the ball and the wire. We determine the torque T exerted on the wire by measuring the twisted angle of the torsion wire (θ). The relationship between θ and T is given by

$$T = K\theta. \tag{3}$$

K is the torsion constant of the wire. Thus, Equations (1), (2), and (3) lead to

$$\theta = \frac{FL}{K} = \frac{L}{K}\cdot k\frac{q_1 q_2}{r^2}. \tag{4}$$

Because L and K are constants, θ and F bear the same dependence on the interacting charges and their distance. Therefore, through measuring the dependences of θ on r, q_1, and q_2, we can determine the dependences of F on them.

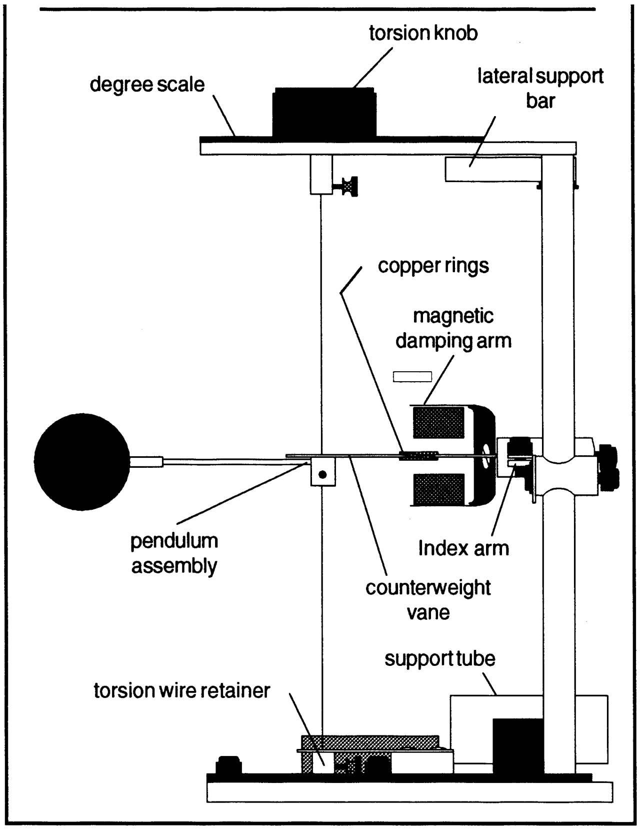

Figure 1 The schematics of the torsion balance. The graphite-coated ball, attached to the torsion wire, is balanced by the counterweight vane. Before the experiment, make sure the ball and the counterweight vane are properly balanced; use the copper rings if needed. Rotate the torsion dial until the white marker line on the dial is aligned with the *0°* mark. Then rotate the thumbscrew of the torsion wire retainer, which is used to fix the bottom position of the torsion wire, around the vertical axis until the black marker line on the counterweight vane aligns with the black marker line on the supporting frame. **Do not loosen or tighten the thumbscrew!** A second graphite-coated ball (not shown) is attached to a supporting rod which can slide along the sliding track (not shown). The center-to-center distance between the two balls can be varied by moving the supporting rod along the sliding track. The ruler attached to the sliding track (scale: centimeter) should read *3.75* cm (the diameter of the ball) when the two balls are in contact.

PART I THE DEPENDENCE ON DISTANCE

PROCEDURES

1. To prepare the torsion balance, first set the angle on the dial to *0°*. Next, look for the two black marker lines, one on the supporting frame, the other near the edge of the counterweight vane. To adjust the pendulum, rotate the thumbscrew (used to tighten the wire) of the wire retainer at the bottom until the two black marker lines are parallel to each other. NOTE: do not loosen or tighten the thumbscrew, only rotate it around the vertical axis.
2. Calibrate the distance. The distance between the charges on the balls can be approximately taken as (not exactly, as shown below) the center-to-center distance between the balls. Since the diameter of the ball is *3.75* cm, when the second ball contacts the first ball the ruler should read *3.75* cm. If not, adjust the horizontal rod holding the second ball (this should already be set correctly by the TA).
3. Slide the second ball to a distance of *6* cm. Charge both balls by touching the red probe of the DC power supply (see Lab 2) to each ball for a few seconds (first charging the ball on the sliding track). The DC bias voltage is set to *5* kV. (The black ground cable of the power supply should be grounded all the time. **Immediately turn off the power supply after charging the balls.)** After charging, the two balls repel each other and the first ball will move away.
4. Immediately, rotate the torsion dial by angle θ to produce a torque to counterbalance the torque induced by the electrostatic force, which brings the pendulum and the first ball back to the initial position such that the two black marker lines are again parallel to each other. The rotation angle of the torsion knob (along with the dial) is θ. However, during this process some charge may leak from the balls. For correction, leave the dial in its present position. Then, recharge the balls and adjust the torsion knob following the same procedure described above. This may lead to a new rotation angle θ. Repeat the procedure until the pendulum stops moving when you recharge the balls. Record the torsion angle θ at equilibrium in Table 1.
5. Repeat steps 3-4 for r = *5, 7, 8, 9, 10, 11,* and *12* cm.
6. Use Excel to tabulate the data, making columns for θ, r, and r^{-2}.
7. Plot θ versus r^{-2}. The rationale of plotting this way is that $\theta \propto x^n$ if we denote $x = r^{-2}$. Because $\theta \propto \frac{q_1 q_2}{r^2}$ (Coulomb's Law), n should equal *1*. Thus, the curve of θ versus r^{-2} should be a straight line.

You will notice that the data points corresponding to the small values of r do not fit well with $\theta \propto r^{-2}$. Instead, the curve bends up off the straight line. The deviation at small r is because the charged balls cannot be treated as two point charges at short distance. For a charged conducting ball isolated from other objects, the charge is uniformly distributed on the surface. It can be treated as a point charge located at the center of the ball in calculating the electrostatic force. When two charged balls are within a distance comparable to the diameter of the balls, however, the charge on each ball will redistribute on the surface so as to minimize the electrostatic energy. You may think this way: the charges on the two balls have the same sign and repel each other when they are brought close. Therefore, the charges tend to move to the opposite sides of the balls. As a result, the distance between the charges increases and the electrostatic force decreases. It means that the electrostatic force between the balls is less than that would be if the charge of each ball were located at the respective center. The deviation can be corrected by multiplying θ by *1/B* and the correction factor (B) is

$$B = 1 - \frac{4R^3}{r^3}, \qquad (5)$$

where R is the radius of the balls and r is the center-to-center distance between the balls. In steps (8)-(10), use Equation (5) to correct the data and re-plot the data.

8. Use Excel to calculate the correction factor (B) for each r.
9. Multiply the measured θ values by the corresponding $1/B$ value and record the corrected data of $\theta_{CORRECTED}$ as a new column.
10. Plot $\theta_{corrected}$ versus r^{-2} and the curve of θ versus r^{-2} on the same graph. Print the graph with an appropriate title, the axis labels, and different marks and legends for the two curves.

TABLE 1

Distance r (cm)	Torsion Angle θ
12	
11	
10	
9	
8	
7	
6	
5	

QUESTIONS

1. When increasing the level arm (L), do you expect the sensitivity of your measurement increase or decrease? Why?

PART II THE DEPENDENCE ON CHARGE

As seen in Lab 2, the graphite-coated ball can be charged by touch a high-voltage probe and the acquired charge is proportional to the voltage. In this lab, when the two balls are charged at the identical voltage, according to Equation (1) the electrostatic force between them will be proportional to the square of the voltage and, according to Equation (4), so does the torsion angle (θ).

PROCEDURES

1. Re-calibrate the torsion balance if it is needed.

2. Discharge the balls but gently hold them by bare hands. Set the distance of the moveable ball to *5.5* cm. Measure the torsion angle when you increase the bias voltage from *1.0* kV to *5.5* kV with each step increasing *0.5* kV. Record the data in Table 2.

3. Use Excel to plot θ versus V^2. Fit the curve and print out the graph with an appropriate title, labels, and the formula of fitting.

TABLE 2

Voltage (kV)	Angle θ
1.0	
1.5	
2.0	
2.5	
3.0	
3.5	
4.0	
4.5	
5.0	
5.5	

QUESTIONS

1. Is the curve of θ versus V^2 a straight line? Discuss how it supports Coulomb's law.

2. If you charge one ball to *5.0* kV while charging the other ball to a varying voltage V. What kind of relationship between θ and V do you expect?