Name: **Section:** **Date:**

Physics 2121
Lab Physics for Science & Engineering II
<u>Coulomb's Law</u>

THEORY

Purpose

Students will verify Coulomb's Law and demonstrate that: (i) the electrostatic force between two charged particles varies as an inverse square law with distance, and (ii) the electrostatic force is directly proportional to the electric charge.

Introduction

When charged particles are in proximity to one another, the effect of the electric charge is that the particles exert a force on each other. You may recall that opposite charges (one positive and one negative) attract and like charges (both negative or both positive) repel.

For charged particles at rest, the resulting electrostatic force between depends on the magnitude of the charges and the distance between them. A quantitative measure of the electrostatic force $\vec{F}$ on a charge q_1 due to a charge q_2 separated by a distance r is given by *Coulomb's Law*

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

where $\hat{r}$ is a unit vector pointing from q_2 to q_1 and the constant $k = 1/4\pi\epsilon_0$ (known as Coulomb's constant) has the value $8.987 \times 10^9 N \cdot m^2 \cdot C^{-2}$. Using this expression, we can obtain the electrostatic force between any two point charges at rest if we know the magnitude of the charges and their separation distance.

The expression for Coulomb's Law (1) shows that the electrostatic force is directly proportional to the individual charges q_1 and q_2. This relationship captures the physical intuition that the force is greater if there is more charge present. The direction of the force depends on the signs of the charges (+/-), so we can see that Coulomb's Law also accounts for the attraction of opposite charges and the repulsion of like charges.

A distinctive feature of Coulomb's Law is the inverse square relationship between force and distance. If we compare the force between two charges separated by a distance r_1 with the force between the same charges separated by a greater distance r_2 (so that $r_1 < r_2$), we see by Coulomb's Law that the force becomes weaker when the charges are separated by a larger distance.

It's important to note that Coulomb's Law in this form involves *point charges* which are mathematical points that have no spatial extent. In the real world where charged objects have definite size, we can often approximate charged objects with point charges when the separation distances are much larger than the size of the objects; however, this approximation fails at short distances or when the separation between the charged objects is small compared to their spatial extent.

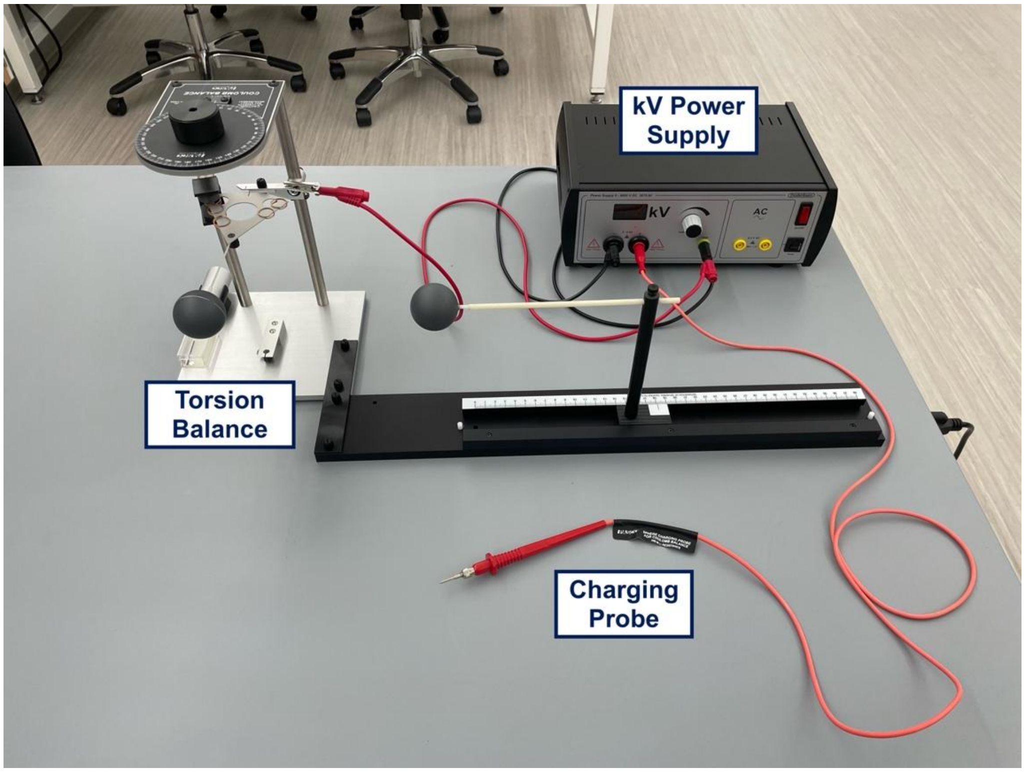

Figure 1: Coulomb's Law experiment apparatus

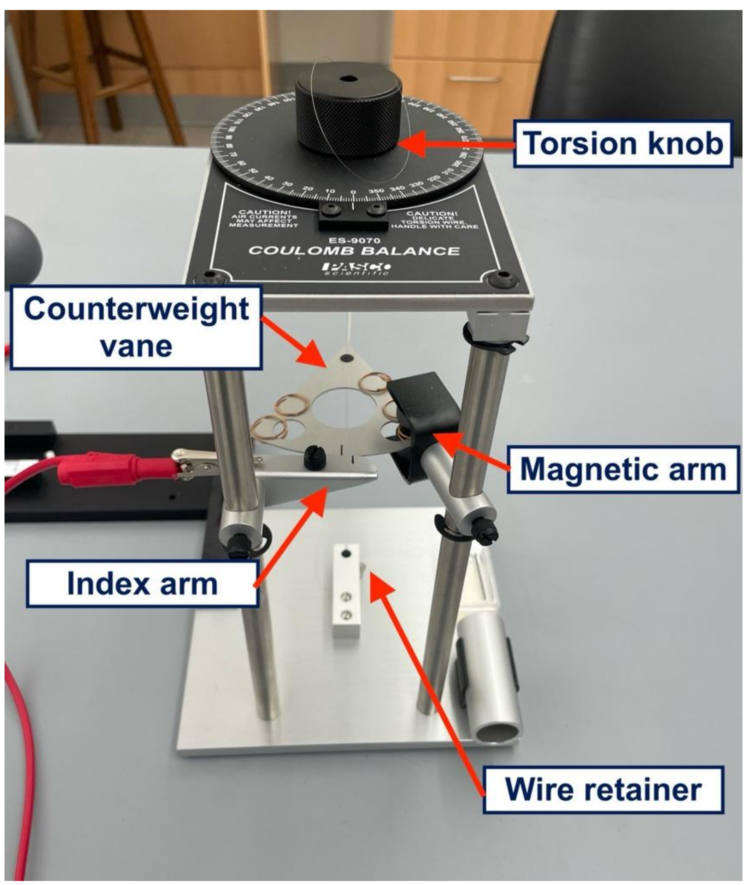

Figure 2: Torsion balance diagram

PROCEDURE

Caution: This experiment uses a high voltage power source to supply electric charge. Read and follow all safety instructions to ensure safe use of the equipment.

Calibrating the Torsion Balance

Ensure that the torsion balance is properly calibrated by locating and aligning the index markings on the counterweight vane and the index arm.

Warning: The torsion wire is fragile and should not be touched during any part of the experiment.

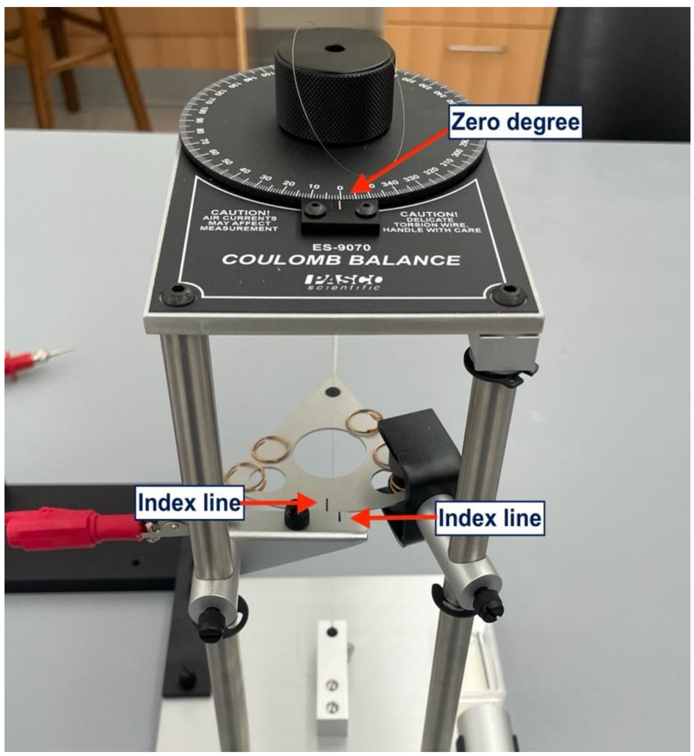

Figure 3: Calibrating torsion balance

1. Set the torsion dial to the zero degree mark using the torsion knob.

2. Locate the index line marking on the counterweight vane and the index line marking on the index arm. They should be aligned with each other. Refer to Figures 2 and 3.

3. If the index markings are not aligned (as in Figure 3), rotate the wire retainer at the bottom of the torsion wire, but do not loosen or tighten the thumbscrew. This will rotate the starting position of the counterweight vane.

Once the index markings on the counterweight vane and the index arm are aligned, have your TA verify that your balance is properly calibrated before proceeding.

Part 1: Force vs. Charge

Data Collection

We can verify the relationship between force and electric charge in Coulomb's Law by holding two conductive spheres at a fixed distance and varying the amount of electric charge. When the two charged spheres are brought close to each other, the suspended sphere will be displaced away from its initial position.

<u>Warning: Avoid touching the metallic end of the conducting probe during the experiment. Read all instructions before taking data and ask your TA if you are unsure how to proceed.</u>

1. Ensure the torsion balance is calibrated, and the torsion dial is set to the zero degree mark. You may need to adjust the wire retainer if the index markings are not aligned.

2. Move the sliding sphere along the slide assembly until the sliding sphere and the suspended sphere are as far away from each other as possible.

3. Ensure that the spheres have been completely discharged by gently touching each sphere with the grounding cable (attached to the torsion balance with an alligator clip). After discharging the conductive spheres, reattach the grounding cable to the torsion balance by clamping the alligator clip to the index arm.

4. Turn down the voltage dial on the power supply before turning it on (rotate counterclockwise). Once the voltage dial has been zeroed completely, turn on the power supply and set the initial voltage to 6.00 kV.

5. Use the charging probe to charge both conducting spheres. Gently touch each sphere with the metallic end of the charging probe to charge the spheres. After the spheres have been charged, turn down the voltage knob to 0.00V and then turn off the power supply.

    a. When charging the spheres, hold the charging probe near the end of the handle so that your hand is as far from the sphere as possible. If your hand is too close to the sphere, it will have a capacitive effect that will increase the amount of charge on the sphere for a given voltage.

6. Move the sliding sphere along the slide assembly to the 5cm position. (Note: the markings on the slide assembly represent the center-to-center distance between the spheres). If these steps have been done correctly, you should notice that the spheres repel each other.

7. Use the torsion knob to bring the index markings on the counterweight vane and the index arm back into alignment. Record the angle θ from the torsion dial. You should not adjust the wire retainer during this step.

8. Repeat steps 1-7 and charge the spheres to $5kV$, $4kV$, $3kV$, and $2kV$. Record the displacement angle each time.

Analysis

You should have several data points of voltage and angle V, θ. We would first like to express our measurements in terms of the familiar variables of charge q and force F. The charge of the spheres is related to the voltage, and the force is related to the displacement angle.

1. Use the formula $q = CV$ to convert your voltage measurements V to charge measurements q. The constant of proportionality $C = 2.11 \times 10^{-12}\ Coulombs/V$ is the capacitance of an isolated conducting sphere.

2. Use the formula $F = (1.45 \times 10^{-6}\ N/deg) \cdot \theta$ to convert your angle measurements θ into units of force (Newtons).

3. Use plotting software (Excel, Google Sheets, etc.) to plot your data for F vs. q^2. Apply a linear fit to obtain a line-of-best-fit through your data.

    a. Include a title, axis labels (with units), and the equation of the trendline from your data fitting. Print your graph.

Part 2: Force vs. Distance

Data Collection

We can also verify the relationship between force and distance by holding the spheres at a fixed charge and varying the distance between them. We should observe that the electrostatic force gets weaker as the charged sphere are separated by larger distances.

Warning: Avoid touching the metallic end of the conducting probe during the experiment. Read all instructions before taking data and ask your TA if you are unsure how to proceed.

1. Ensure the torsion balance is calibrated, and the torsion dial is set to the zero degree mark. You may need to adjust the wire retainer if the index markings are not aligned.

2. Move the sliding sphere along the slide assembly until the sliding sphere and the suspended sphere are as far away from each other as possible.

3. Ensure that the spheres have been completely discharged by gently touching each sphere with the grounding cable (attached to the torsion balance with an alligator clip). After discharging the conductive spheres, reattach the grounding cable to the torsion balance by clamping the alligator clip to the index arm.

4. Turn down the voltage dial on the power supply before turning it on (rotate counterclockwise). Once the voltage dial has been zeroed completely, turn on the power supply and set the initial voltage to 6.00 kV.

5. Use the charging probe to charge both conducting spheres. Gently touch each sphere with the metallic end of the charging probe to charge them. After the spheres have been charged, turn down the voltage knob to 0.00V and then turn off the power supply.

a. When charging the spheres, hold the charging probe near the end of the handle so that your hand is as far from the sphere as possible. If your hand is too close to the sphere, it will have a capacitive effect that will increase the amount of charge on the sphere for a given voltage.

6. Move the sliding sphere along the slide assembly to the 5cm position. (Note: the markings on the slide assembly represent the center-to-center distance between the spheres). If these steps have been done correctly, you should notice that the spheres repel each other.

7. Use the torsion knob to bring the index markings on the counterweight vane and the index arm back into alignment. Record the angle θ from the torsion dial. You should not adjust the wire retainer during this step.

8. Repeat this measurement (steps 1-7) for a total of 4 trials at the $5cm$ separation distance. Take turns adjusting the torsion dial with your lab partners for these trials so that each student completes one trial.

9. Repeat steps 1-8 for the following positions of the sliding sphere: $6cm$, $7cm$, $8cm$, $10cm$, $12cm$, $15cm$, and $20cm$. You should have a total of 32 angle measurements (4 trials for each of 8 distances) after completing this step.

Analysis

You should have several measurements of distance and angle (r, θ). We will perform a graphical analysis to demonstrate the $F \propto 1/r^2$ dependence of Coulomb's Law.

1. For each separation distance r, take the average of the 4 trial angles to obtain an average displacement angle $\bar{\theta}$.

2. Use the formula $F = (1.45 \times 10^{-6}\, N/deg) \cdot \theta$ to convert your average angle measurements $\bar{\theta}$ into units of force (Newtons).

3. Convert your separation distances r from centimeters to meters.

4. Use plotting software (Excel, Google Sheets, etc.) to make a plot of F vs. r. Apply a power-law fit to the data to obtain an estimate for the power-law dependence of force and distance (ie. $1/r^2$).

   a. Include a title, axis labels (with units), and the equation of the trendline from your data fitting. Print your graph.

   b. Find the percent error between your fitting exponent from the power-law fit and the exponent -2 from the r^{-2} dependence of Coulomb's Law. (For example, if your fitting gave a functional form $F = Ar^{-2.173}$, find the percent error between 2.173 and 2).

5. Use plotting software to make a plot of F vs. $1/r^2$. If you used Excel or Google Sheets, you can quickly create a calculated column of $1/r^2$ data from your r distances. Apply a linear fit to the data to obtain a line-of-best-fit.

a. Include a title, axis labels (with units), and the equation of the trendline from your data fitting. Print your graph.

Cleanup Procedure

1. Ensure that the power supply dial is turned to zero and the switch is turned off. Unplug the power supply from the power strip.

2. Discharge the conducting spheres by touching them with the grounding cable. Move the sliding sphere to its largest separation distance (37cm).

3. Return the torsion dial to the zero degree mark.

4. Have your TA sign your work to verify that you have completed the exit steps.