Coulomb’s Law

Mari Martin
Lab Partner: Alcides Segovia

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Objective:

Calculate the relative charges on pith balls that are charged with combinations of 3 kinds of rod material and 4 kinds of cloth material using a triboelectric charge.

Theory:

Coulomb's law represents a non-contact force that is acted on charged objects (point charge) with some distance. Such a force is transmitted by the presence of an electric field.

Here, point charge represents a characteristic of a unit of matter that expresses the extent to which it has more or fewer electrons than protons. In an atom of matter, an electrical charge occurs whenever the number of protons in the nucleus differs from the number of electrons surrounding that nucleus. This electrical charge causes an attractive force or repulsive force.

Coulomb's law is expressed in the following equation.

$$\boldsymbol{F} = \mathrm{k}\frac{\boldsymbol{Q}_1\boldsymbol{Q}_2}{\mathrm{r}^2} \qquad \text{[Equation 1]}$$

k (proportionality constant) = 8.99×10^9 [$\mathrm{N \cdot m^2/C^2}$]

$\boldsymbol{Q_1}$, $\boldsymbol{Q_2}$ = point charges [C]

r = distance between two charges[m]

The force between two charges is directly proportional to the product of the two charges, and inversely proportional to the square of the distance between the two charges.

Proportionality constant **k** can be replaced with $\mathbf{1/4\pi\varepsilon_0}$, where ε_0 = permittivity of space.

In this experience, we used combinations of 3 kinds of rod material and 4 kinds of cloth material to obtain different charges.

In theory, the material is either donor or acceptor, and it is determined by its electronegativity. Thus, the greater the electronegativity between two materials, the greater the charge transferred, result in greater static charge.

Equipment List:

1. Pith-ball Electroscope
2. Pith balls
3. Acrylic rod
4. Rubber – black rod
5. PVC/Vinyl – white rod flat ended
6. Felt (acryl)
7. Silk
8. Wool (cashmere)
9. Rabbit fur
10. Ruler
11. String

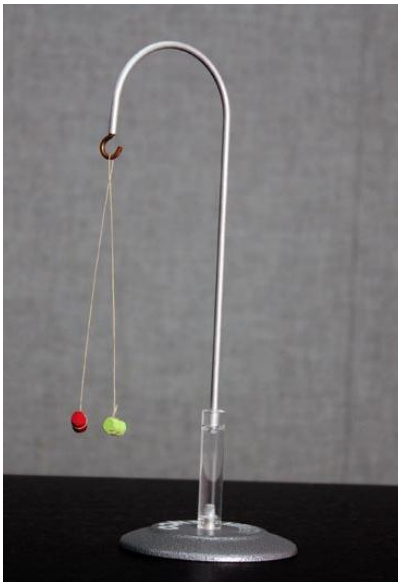

Figure1. Pith-ball Electroscope

Procedure:

We conducted the experiment to derive the relative charges on the pith balls. We prepared 3 kinds of rod material and 4 kinds of cloth material to compare each relative charge.

Steps:

1. Mount the Pith-ball Electroscope on a steady table.
2. Tie the two pith balls together using a string.
3. Measure the string distance.
4. Set the pith ball to two of the balls are adjacent to each other, I should be the same length of thread to the Electroscope as shown in Figure 1.
5. Rub one of the rod (Equipment List 3-5) using one of the cloth that is listed in previous section (Equipment List 6-9).
6. Induce the electric charge created by friction to the pith balls by holding a rod closed to them.
7. Measure the distance between two pith balls when the electric charges are induced completely.
8. Discharge the pith balls by touching them.
9. Repeat steps from 5 to 8 to complete all combinations of rod and cloth materials.

Data:

The length of string is **0.24m**, that is, from the hook to each pith ball is **0.12m**.

There were some cases that pith balls did not separate from each other. In this case are expressed as in N/A.

		Rod Materials		
		Acrylic Rod (+ + +)	**Rubber Black Rod (- - -)**	**PVC Plastic rod (- - - -)**
Cloth Materials	**Acryl Felt (+ + +)**	N/A	N/A	27mm
	Silk (neutral)	N/A	N/A	12mm
	Wool (+)	N/A	23mm	35mm
	Rabbit Fur (+ + + +)	15mm	20mm	35mm

Table 1. Separation Distance of Pith Ball

* Electronegativity shown in the parentheses.

Results:

Some of the cases could not get the result because two pith balls did not separate from each other. However, those pith balls were repelled or attracted to the charged rod. Thus, I can assume that some of the electrons of pith balls were induced or transferred and it was composed a polar structure by inducing with charged rod.

According to the theory, the greater the electronegativity between two materials, the greater the charge transferred. Thus, the result becomes greater static charge. As expected, the results showed this phenomenon.

Figure 2. shows a free diagram of the one of the pith ball when it was induced by charged rod.

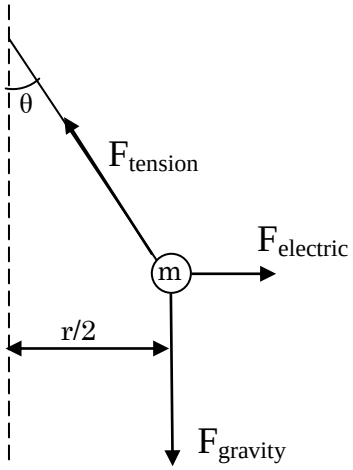

Figure 2. Free diagram of the one of the pith ball

The force that one small charged object exerts on a second one expressed in Equation 1.

The equation that was applied the Figure 2. to the Equation 1 is expressed in the following equation.

$$\boldsymbol{F}_{electric} = k\frac{\boldsymbol{Q}_1\boldsymbol{Q}_2}{\left(\frac{r}{2}\right)^2} \qquad \text{[Equation 2]}$$

$\boldsymbol{F}_{gravity}\cdot\sin\theta$ is equivalent to the repulsive force. That is $\boldsymbol{F}_{electric}$ and $\boldsymbol{F}_{gravity}\cdot\sin\theta$ are equivalent and it can be expressed in the following equation.

$$\boldsymbol{F}_{electric} = \boldsymbol{F}_{gravity}\cdot\sin\theta \qquad \text{[Equation 3]}$$

This can be expressed as the following equation since $\mathbf{Q}_1$ and $\mathbf{Q}_2$ are assumed be the same charge.

$$mg\cdot\sin\theta = k\frac{\boldsymbol{Q}^2}{\left(\frac{r}{2}\right)^2} \qquad \text{[Equation 4]}$$

From this equation, since ***k*** and ***mg*** are constant, we can see the relationship when the greater the distance ***r*** the greater the charge.

The charge on the pith balls for each rod/cloth material combination can be solved using Equation 4.

For example, for combination of PVC Plastic rod and Rabbit Fur, electric charge on the pith ball was **1.53119E-09 C.** Divide this number by elementary charge ***e***, we can derive the numbers of electrons reside on each pith ball which was **9,556,768,840 ≈ 9.6 billion**.

Error Analysis:

There are some concerns which may have caused some numerical error.

1. Charge remains on the Electroscope

   The electric charge may remain on the pith ball when we conducted several different combinations. We couldn't tell if the electroscope had totally released the charge.

2. Rubbing rods with clothes

   When we rubbed a rod using a cloth, we didn't count how many times we rubbed. This may be affected to the charge amount for the each rod. Thus, electric charge may be varied by this factor.

3. The way of transferring electric charge

   When we conducted this experiment, we tried to transfer the charge by holding a rod closed to the metal hoop supporting the threads. However, it didn't work so we tried to do that by holding a rod close to the pith balls directly. This may become a factor of un-uniform charge to the pith balls and may result in polar charge.

4. Measuring the distance between the pith balls

   When we conducted this experiment, we used a ruler to measure the distance between the pith balls. The pith balls were constantly moving and it was difficult to measure and depending on the angle to see the ball, the distance may have been measure inaccurately.

Conclusion:

We determined the relative charges on the pith balls that are charged by combinations of 3 kinds of rod material and 4 kinds of cloth material using a triboelectric charge. It was difficult to measure the distance of the two pith balls and in some of the cases they could not get separated. Nevertheless, we got some evidence that there were differences of electric charge on the pith balls depending on the combinations of different materials.