Workshop Tutorials for Physics

Solutions to ER1: **Charge and Coulomb's Law**

A. Qualitative Questions:

1. The following effects are fundamentally electrical in nature:
a. tension in a spring – this is due to the distortion of bonds in the spring, which are electrical in nature.
b. "crackles" when you take clothes off – this is due to buildup of charge on the garment
c. "crackles" from walking on dry leaves – as in **a**, this is due to breaking and distortion of bonds in the leaves, so this is also electrical in nature.
e. nerve conduction – relies on the movement of ions across cell membranes
g. the auroras – are due to charged particles becoming trapped in the Earth's magnetic field.
h. pressure in a gas is due to the electrical repulsion of the molecules.
The following are **not** electrical in nature:
d. the spiral structure of galaxies – is due to gravitational forces
f. nuclear fission – the strong nuclear force holds nuclei together, although the energy released in nuclear fission comes from the electric force which drives the pieces apart.

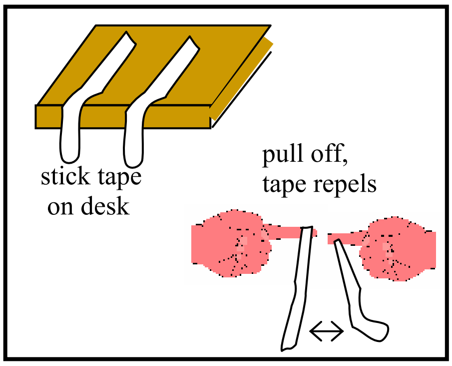
2. Coulomb's law for electrostatics: $F_E = \frac{kq_1q_2}{r^2}$.

The force on one electron in the helium atom due to the nucleus is $F = \frac{kq_1q_2}{r^2} = \frac{k(-e)(2e)}{r^2}$,
where r is the distance from the nucleus to the electron, $-e$ is the charge on the electron and $+2e$ is the charge of the nucleus due to the two protons it contains.

The force on that one electron due to the nucleus is $F = \frac{k(-e)(2e)}{r^2}$, which has *exactly the same magnitude* as the force on the nucleus due to that electron, not less. Note that this is also the case for the gravitational force, the force on the Earth due to the gravitational attraction of a thrown tennis ball is the same as the force on the ball due to the earth. These are action reaction pairs, and Newton's third law tells us that they must experience equal and opposite forces.

B. Activity Questions:

1. Tape Charge
Large organic molecules, such as are involved in sticky tape or combs and hair or glass/plastic and cloth/fur, break easily and leave these items charged. The tape pieces repel each other because they have picked up a net charge, hence there is an electric field between them due to the charges. Hence they can interact without touching.



2. Electroscope and electrophorus
Rubbing with the rubber gloves charges the lower plate of the electrophorus. The neutral metal conducting plate (with insulated handle) is placed on the lower plate and charges in the metal separate with the lower surface having a charge opposite in sign to the charged lower plate. The upper surface of the metal plate is then earthed (by touching with a finger), leaving a net charge on the metal plate. It can then be removed. When the upper plate of the electrophorus touches the electroscope, charge flows onto the cap, stem and leaves of the electroscope. Since the leaves have excess like charge they will repel each other. When the upper plate of the electrophorus is held near the uncharged electroscope, charge in the electroscope will separate and the cap will have the opposite charge to the electrophorus and the leaves the same charge as the electrophorus. Once again the leaves themselves will have like charge and so will repel each other.

3. Charged rods
The glass rods are charged by electrons moving to or from them from the fur or silk. The plastic rods are charged by organic molecules being broken and positively charged segments stripped from the rod.
You can accelerate the rod without touching or blowing on it by holding another charged rod close by: the charges on the rods interact via a field, and attract or repel, accelerating the rod balanced on the watch-glass.

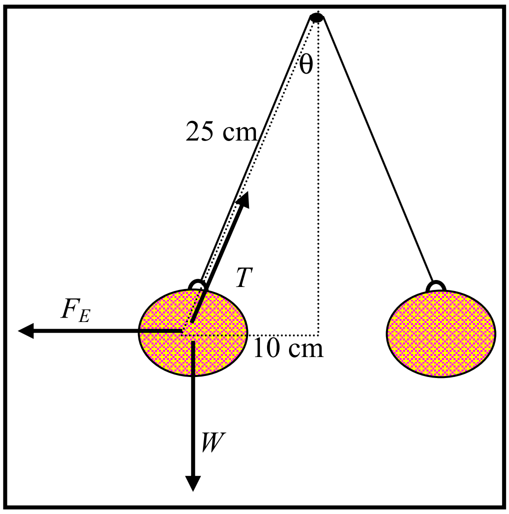
C. Quantitative Questions:

1. Comparison of gravitation and electrostatic force.
a. Newton's law of gravitation says that the force between any two masses is proportional to the size of the masses and decreases with the square of the distance between them: $F_G = \frac{Gm_1m_2}{r^2}$.
Coulomb's law for electrostatics says that the force between any two charges is proportional to the size of the charges and decreases with the square of the distance between them: $F_E = -\frac{kq_1q_2}{r^2}$.
Both have the same basic form in that the force varies inversely with r^2 and directly with either the product of the masses or the product of the charges of the objects. Note also that there is only one sort of mass, positive mass and that the gravitational interaction is always attractive, whereas in the case of electric charge there are both positive and negative charges and the interaction can be either attractive or repulsive.
b. An electron in a hydrogen atom orbits the nucleus at a mean distance of 5.29×10^{-11} m. The nucleus (a proton) has a mass of 1.67×10^{-27} kg and the electron has a mass of 9.11×10^{-31} kg.
The ratio of the forces is:

$$F_E / F_G = -\frac{kq_1q_2}{r^2} \Big/ \frac{Gm_1m_2}{r^2} = -\frac{kq_1q_2}{Gm_1m_2} = \frac{8.99\times10^9\,\text{N.m}^2.\text{C}^{-2}\times1.6\times10^{-19}\,\text{C}\times1.6\times10^{-19}\,\text{C}}{6.67\times10^{-11}\,\text{N.m}^2.\text{kg}^{-2}\times1.67\times10^{-27}\,\text{kg}\times9.11\times10^{-31}\,\text{kg}} = 2\times10^{39}$$

Hence the electrostatic force is 39 orders of magnitude stronger than the gravitational force between the electron and proton in a hydrogen atom!

2. The string that holds the balls is 40 cm long, and the balls have a radius of 5 cm, so the center of the ball is 25 cm from the pin, and 10 cm from the mid point between the balls (directly beneath the pin).



a. The following forces act on each of the balls: The force exerted by the string, T, the electrostatic force, F_E, and the weight $W = mg$. See diagram opposite.
b. Since the balls are stationary, the sum of forces acting on each one must be zero.
In the x direction: $F_E + T\sin\theta = 0$ (1)
In the y direction: $mg + T\cos\theta = 0$ (2)
From the dimensions given, $\sin\theta = 10/25$, so $\theta = 23.58^{\circ}$.
Combining (1) and (2) gives $\tan\theta = F_E/mg$,
So $kq_1q_2/r^2 = mg\tan\theta$ or $q_1q_2 = mg\tan\theta\, r^2/k$
But $q_1 = q_2 = q$ as charge will distribute evenly over the identical balls,

$$q = \sqrt{\frac{mg\tan\theta\, r^2}{k}} = \sqrt{\frac{.01\text{kg}\times9.888\,\text{m.s}^{-2}\times0.436\times(0.2\,\text{m})^2}{8.99\times10^9\,\text{N.m}^2.\text{C}^{-2}}} = 0.44\mu\text{C}.$$

c. In time the ions in the air will neutralize the charge on the balls and they would not stay apart. On a humid day this would happen fairly quickly.