Physics 202

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Conductors vs insulators

- Electric charge remains where placed within or on the surface of an insulator such as glass or wood or plastic. (Forever, unless neutralized.)
- Electric charge moves freely within an electrical conductor such as a “metal” like copper.
- Excess electric charge on a conductor redistributes itself to minimize the forces of electrical repulsion. Charge redistribution occurs at close to light speed.
- Electrons, protons, and electric charge are conserved. Even in relativistic processes involving antimatter when electrons are not conserved, charge is conserved.

Charging by induction

- A negative charge is brought near a conducting sphere. It attracts positive charge and repels negative charge as shown.
- If the sphere is connected to a large conducting body (“ground”), some negative charge moves to that body.
- If the connection is broken, a net positive charge remains on the sphere.

Last time

- The stuff we call matter is held together by the force of electricity.
- We are simply bags of static electricity.
- We stand on atoms held together by electricity.
- “Everything” (OK, baryonic matter not dark matter etc) is electrical.
Polarization

- A charged balloon in proximity to an insulating wall repels like charge and attracts opposite charge “polarizing” individual molecules as if they were individually conductors.
- The opposite charges are closer than the like charges so a net attractive force results.
- Given sufficient charge, the balloon sticks to the wall.

Electric force

- The charged balloon induces a charge separation on the surface of the wall due to realignment of charges in the molecules of the wall.

The Xerox process

- Invented in a kitchen!
- Charging: cylindrical drum is electrostatically charged by a high voltage wire called a corona wire or a charge roller. The drum has a coating of a photoconductive material. A photoconductor is a semiconductor that becomes conductive when exposed to light.[2]
- Exposure: A bright lamp illuminates the original document, and the white areas of the original document reflect the light onto the surface of the photoconductive drum. The areas of the drum that are exposed to light become conductive and therefore discharge to ground. The area of the drum not exposed to light (those areas that correspond to black portions of the original document) remain negatively charged. The result is a latent electrical image on the surface of the drum.
- Developing: The toner is positively charged. When it is applied to the drum to develop the image, it is attracted and sticks to the areas that are negatively charged (black areas), just as paper sticks to a toy balloon with a static charge.
- Transfer: The resulting toner image on the surface of the drum is transferred from the drum onto a piece of paper with a higher negative charge than the drum.
- Fusing: The toner is melted and bonded to the paper by heat and pressure rollers.

Think about a long conductor

- Suppose we put some charge on a long copper wire starting in, say, Seattle.
- Charge distributes along the conductor. A signal may magically appear in, say, NYC.
- Many places are not yet electrified.
Rural electrification

1.4 billion people without electricity

Coulomb’s Law

- The electrical force between two point-like charges is proportional to the product of the charges and inversely proportional to the square of their separation.

- The forces are a) repulsive for like charges, b) attractive for unlike charges, and c) equal and opposite.

- It’s all rather like gravity!

Units

- The standard international unit of charge is the Coulomb.

- The charge of the electron is \( q_e = -e = -1.602 \times 10^{-19} \text{ C} \).

- The force constant is \( k_e = 9 \times 10^9 \text{ N m}^2 \text{ C}^{-2} \).

- Commit these two numbers to memory.
Question

- What is the charge of the electron in SI units?
- What is the value of the force constant in Coulomb’s Law in SI units?

The amount of charge in 1 kg of normal matter

- The mass of matter is that of its nucleons - electrons weigh very little.
- \( m_p = m_n >> m_e \) and there are roughly an equal number of \( n \) and \( p \) in any nucleus.
- The number of protons in one kg of matter is about \( N_p = 1 \text{ kg}/(2^*m_p) = 0.3 \times 10^{27} \) and equals the number of electrons for neutral matter.
- The total charge in protons is \( N_p * e = 0.3 \times 10^{27} \times 1.6 \times 10^{-19} \text{ C} = 0.5 \times 10^{8} \text{ C} \).
- This charge is always (almost) exactly balanced by equal and opposite negative electronic charge.

Superposition of electrical forces

- Given a collection of charges fixed in space, the electric force on any one is found by the vector superposition of the forces due to the others.
- In the example shown here, \( q_3 \) is attracted to \( q_2 \) and repelled by \( q_1 \). Add the components along \( x \) and \( y \) to get find the net force.

\[
F_x = k_e \frac{q_3q_2}{a^2} + \frac{1}{\sqrt{2}} k_e \frac{q_3q_2}{(\sqrt{2}a)^2}
\]
Example

- Where is the resultant force equal to zero?
- The magnitudes of the individual forces will be equal.
- Directions will be opposite.
- Will result in a quadratic equation
- Choose the root that gives the forces in opposite directions.

Electric field

- The ability of a charge to influence other charges is represented by a force field called the electric field.
- The electric field \( E \) at a point \( x \) is the force per unit charge on a test charge placed at \( x \).

\[ E(x) = F_{q_0}(x)/q_0 \]

Electric field of a point charge

- The electric field of a point charge is radial and points away from a positive charge and towards a negative charge.
- Think of + charges as sources of field and - charges as sinks of field.

\[ E_q(x) = F_{q_0}(x)/q_0 = k_e \frac{q}{r^2} \hat{r} \]

Electric field of a collection of point charges

- The total electric force on a test charge due to a collection of charges is the vector sum of the electric forces.
- The electric field due to a collection of charges is the vector sum of the electric fields of the individual charges.

\[ E(x) = \sum_i k_e \frac{q_i}{r_i^2} \hat{r}_i \]
Field lines

- Electric field lines are a way to visualize the field.
- The lines follow the flow of a hypothetical collection of test charges subject to the electric field and to drag such that the move always in the direction of the field.
- The density of lines is proportional to the field strength.

Dipoles

- A pair of equal and opposite charges are called an electric dipole. Field lines go from positive to negative. At large distances there is no electric field - the field from the + charge is equal and opposite to the field of the - charge.
- At large distances from two equal charges, the field is radial like that of a point charge.