Electromagnetism discussion problem 3 notes

(i) Explain why a bird landing on an overhead electricity wire does not receive an electric shock

An electric shock is the sensation experienced when an electric current passes through the body of an animal. For a current to pass from one point on the animal's body to an other, there must be a potential difference between the two points. Electric potential has no absolute value and must be defined to some reference point. Usually the potential of the Earth's ground is defined as zero, and the "high voltage" of overhead power cables is at a different potential (though time varying between negative and positive) with the adjective "high" implying that the PD between the cable and the ground is likely to be large enough to cause damage when bridged by animals and objects.

But if a bird lands on a cable it has no electrical connection between it and the ground and it simply takes the potential of the single cable is it standing on. There is no electrical connection to the ground and thus no potential difference to drive a current. If a human could jump high enough to grab the wire (with one or both hands) then they would also experience no shock.

Animals do get shocks from electricity cables though; a bird big enough for its wings to touch two adjacent cables simultaneously will be in trouble as the wires don't usually have the PDs operating in phase, and any animal climbing the pylon receives a shock when simultaneously touching the tower and the cable.

(ii) Explain why dielectric materials are usually placed between the plates of capacitors. Go on to explain what the characteristics of the perfect dielectric would be.

Any two conducting objects separated by an insulating medium is a capacitor. A dielectric is any insulating material placed between the two conductors. In practical electronics the dielectric serves three main practical purposes which are well described by considering a parallel plate capacitor viz. an arrangement of two parallel plates with a space in between them. In these arrangements the capacitance is directly proportional to the area of the plates and inversely proportional to the distance between them.

(i) The dielectric material increases the capacitance of the arrangement (relative to having a vacuum in between) thereby allowing more charge – and thus electrostatic energy - to be stored for a given potential difference between the plates.

(ii) The dielectric material placed between the plates like the filling of a sandwich allows the plates to be kept separate

(iii) If the dielectric material is an insulator it prevents any charge passing between the plates.

A good dielectric therefore needs to be a good insulator and be capable of being made as thin as possible to allow the plates to have a small distance between them. It also needs to be made of a material with a high dielectric constant; properties of such material are that the molecules or colloids making the material have a high electric dipole moment so although they don't conduct electricity the dipoles align with the field between the plates thus lowering the field strength in the dielectric.

Furthermore an ideal dielectric should be malleable and resistant to tearing. All in all there always has to some compromise made in dielectric material as no one material possesses all these qualities.

(iii) Is it possible to make a conservative force field with a frictional force?

Conservative force fields obey the following qualities:

- The curl of the field strength is zero

- The work done in moving a material in a closed path in the field is exactly zero

- The work done in moving from one point to another in the field is independent of the route taken

- The field strength has a related scalar potential.

Each of the above qualities implies the others are true.

Regarding the work done in moving in a closed path if can quickly be deduced that a frictional force field can never be conservative. Frictional forces oppose motion by definition and serve to dissipate energy; moving an object in a closed loop when a frictional force is present must include a constant input of energy from somewhere thus the work done is non-zero and a frictional force field is non-conservative.

(iv) If we refer to the direction of a current as being in the direction of the flow of a positive charge (or opposite to the direction of flow of a negative charge) why do we also say that current is a scalar quantity?

Electric current is defined as the rate of flow of charge through a surface. This must be a scalar: electric charge is a scalar quantity, and thus the amount of charge passing through a surface must also be scalar. As charge can be positive or negative the current can also be positive or negative but it is neither necessary nor possible to specify a direction. This can be further confirmed by realising that adding two currents together works by scalar addition: A rate of flow of charge of $\mathbf{1\ amp}$ through a surface where the charge carriers are moving north added to a rate of flow of charge through the same volume of $\mathbf{1\ amp}$ with the charge carriers moving east amounts to a total rate of flow of charge through the volume of $\mathbf{1\ amp}$, not $\sqrt{2}\ \mathbf{amp}$. Even though the charge carriers move with a velocity which does have a direction the current doesn't.

The addition example considers current moving in a 2D or maybe 3D environment, but often current is simply considered along the axis of a wire. This essentially renders discussion of the current in a circuit as a 1D problem, and in this case it does make sense to refer to the direction of the current, and without angles and components scalar and vector additions and subtractions work in the same way. In 1D it doesn't really matter whether current is a scalar or a vector.

Current density however is a vector and this will be covered formally in lecture 12.

(v) What can Gauss's law be useful for in (a) its differential form and (b) its integral form?

The differential form of Gauss's law states that the divergence of a electrostatic field is proportional to the charge density at a point. "At a point" is key to this: it means that in the whole of the 3D volume under consideration, if the divergence is zero there is no source of sink of charge, if the divergence is positive then there is a positive charge i.e. a source of electrostatic field and if the divergence is negative then there is a negative charge i.e. a sink of electrostatic field. Points where the divergence is infinite indicates the presence of point charges.

The integral form of Gauss's law states that total electric flux through any volume is directly proportional to the charge enclosed. Broadly speaking this has two uses. (i) if one observes a charge distribution then it is possible, in principle, to calculate the electric field strength at any point due to the charges. (ii) if the electric field strength is measured at every point around a closed surface then it is possible to know the total charge contained within.