EEE105 - Electronic Devices
Lecture 2

Poisson's Equation Example.

Last time we discussed the Poisson's Equation, which we can use to relate the Electric Field, Potential Difference (Voltage) and density of charges. Let us consider a simple example.

Let us consider a layer of material which is 1 mm thick and which is of infinite cross-sectional area. There is a density of fixed positive charges in the layer giving, ρ_1 = 2x10^{-3} Cm^{-3}. Assuming at the left hand surface of the layer that E and V =0, calculate the value of electric field and voltage on the right hand surface. The relative permittivity of the material making up the layer is 8.

Next, what are the electric field and voltage at a distance of one 1mm away from it on either side (assume that in these regions the charge density is zero and the relative permittivity is 1).

Finally plot the variation of field and voltage through the layer and extending 1 mm to either side.

Answer

First we must set up the problem – so lets draw the structure:

Note lets set the problem up so that the left hand surface of the layer is at x=0 (This means that E,V=0 @ x=0)

Next calculate the permittivity:

For the layer let us first calculate the field at the RHS:

$\dfrac{dE}{dx} = \dfrac{\rho}{\varepsilon}$ and therefore the formula for $E(x) = \displaystyle\int \frac{\rho}{\varepsilon}dx = \frac{\rho x}{\varepsilon} + C_1$

where C_1 is a constant. From the way we have defined the problem we can say that E=0 at x=0 and hence C_1=0.

Now as the layer is 1mm thick we can simply substitute into the equation for E to get its value on the right hand side of the layer, which will be 2.82x10^4 Vm^{-1}

Next we want to calculate the voltage across the layer:

$\dfrac{dV}{dx} = -E = -\dfrac{\rho x}{\varepsilon}$ and therefore $V = -\displaystyle\int \frac{\rho x}{\varepsilon}dx = -\frac{\rho x^2}{2\varepsilon} + C_2$

where C_2 is a constant. From the boundary condition that V=0 at x=0 we get C_2=0

We can now calculate the voltage on the right hand side to be –14.1 V, and clearly as we go from x=0 to x=0.001 the change in voltage will be parabolic in shape.

Let us now consider what happens to *E(x)* and *V(x)* outside the layer:

For the left hand side things are quite simple.

ρ =0 hence E must be a constant. We also know that E(0)=0 Vm^{-1}. Thus E(-1 mm)=0 Vm^{-1}

For the voltage it is similar: as E is a constant and equal to zero, V must be a constant and from the boundary condition that V(0)=0 V we have V(-1 mm)=0 V

For the right hand side:

As ρ =0 again E must be constant and as E(1 mm)=2.82x10^4 Vm^{-1}, at one millimetre away we have E(1 mm)=2.82x10^4 Vm^{-1}.

For the voltage the situation is as follows:

Hence we can now plot E and V through the structure

Electronic Devices in a Vacuum

(CAL: valves - Electronic Valves)

There are a whole family of electronic devices based on electrons moving in a vacuum. In fact many of the very earliest computers were based on them! Nowadays these devices are only rarely used in specialist applications (e.g. high power).

Here we will consider one device as an example: The triode valve:

In this diagram the grid is normally placed very close to the cathode. Electron is thermionically emitted from the cathode and accelerated by the electric field towards the grid. The amount of electron emission (or current) is controlled by the grid voltage. The higher the voltage on the grid the higher the emission from the cathode (ie the cathode current is higher). Most electrons miss the grid and are accelerated on to the anode.

Hence the anode current is ***controlled*** by the grid voltage.

The semiconductor device that replicates this behaviour is the (see later)

If the voltage between the anode and the cathode is 1 V then the electron will gain 1 eV (electron volt) of Energy in moving from the cathode to the anode.

However, valve are big and difficult to make. Furthermore, historically they have often been unreliable. This is why transistors, or other solid state devices, are used today.

Solids

(CAL: solids – Types of Solid)

All solids contain electrons. Their electrical properties depend on how easily the electrons can move. On this basis we can split these materials into three main classes:

INSULATORS

e.g.

In these materials the electrons are strongly bound up in the chemical (crystal) bonds and essentially are unable to move in an electric field. Such materials can be used in applications such as:

METALS

e.g.

The bonding is of a very different type in metals and the electrons are essentially free to move wherever they want. This means a large current can flow when a voltage is applied. They can be used in:

SEMICONDUCTORS

e.g.

The electrons are bound in bonds (as per an insulator) BUT can easily be released from the bond by applying some energy

The electrical properties can be strongly modified by the presence of small quantities of impurities. These materials for the key part of many devices such as:

WE CAN CLASS solids by their resistivity, ρ .

	ρ
Insulator	10^{11}-10^{18} Ωm
Semiconductor	10^{-3}-10^{-1} Ωm
Metal	~10^{-8} Ωm

Note the 26 orders of magnitude difference! In distance terms this is the equivalent of going across the diameter of an atom to travelling 100 light years!!!!

Key Points to Remember:

1. If there are no charges present the Electric field must be constant in one-dimension, the voltage will be a linear function with distance (which if the E-field is zero will be a constant value)
2. In a valve device we can control a large current between the cathode and anode with a voltage (and small current) appied to a grid. This behaviour can be replicated in a semiconductor device called a transistor
3. The ability of a solid to conduct depends how strongly the electrons are tied into the bonds.
   a) In Insulators electrons are strongly tied up in bonds and only a very few are free to conduct electricity
   b) In Metals many electrons are essentially free to move between atoms and hence conduct electricty
   c) In semiconductors HEAT or LIGHT can give sufficient energy for electrons to escape from the bond and become free to conduct electricity.