EEE105 Tutorial Questions

The purpose of these sets of tutorial questions is for you to monitor your progress and ensure that you have understood the material presented in lectures. You should aim to complete the tutorials as the material is covered in the lectures. Information on the time you can attempt the tutorial and the time you should/must have completed it by is included here.

There is a continually assessed element to EEE105 and you will lose marks for this element if you have not completed all the relevant tutorial questions set by the tutorial session that you must complete it by.

In order to help your revision after the taught element of the module is completed you will find quite a large number of past examination papers with worked solutions on the module webpage. These are for you to use as you feel appropriate.

Fundamental Constants

Boltzman Constant, $k = 1.381\text{x}10^{-23}$ JK^{-1}
Charge on Electron, $q = 1.602\text{x}10^{-19}$ C
Mass of the Electron, $m_e = 9.11\text{x}10^{-31}$ kg
Planck's Constant, $h = 6.626\text{x}10^{-34}$ Js
Speed of Light in a Vacuum, $c = 3\text{x}10^{8}$ ms^{-1}
Mass of a Proton, $m_p = 1.673\text{x}10^{-27}$ kg
Permittivity of Free Space, $\varepsilon_0=8.85\text{x}10^{-12}$ Fm^{-1}

Tutorial Question Set 1: Electrons in a Vacuum

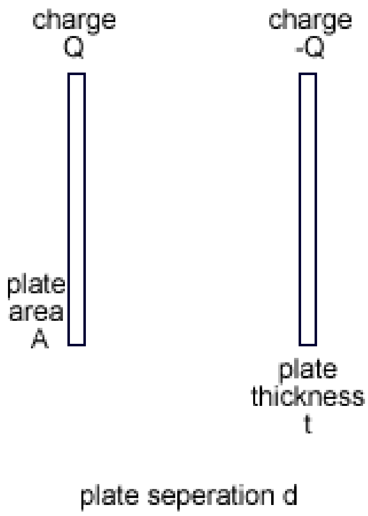
This question is based on lecture material completed in week 1
This question should be completed by the end of the tutorial in week 2
It must be completed by the beginning of the tutorial in week 3

1. A free electron travels through a distance of 0.1 mm over which 2 V is dropped. Calculate the velocity and kinetic energy after the electron travels the 0.1 mm starting from rest. Given that 1 eV= 1.6×10^{-19} J what is the kinetic energy in eV?

   (8.4×10^{5} ms^{-1}, 3.2×10^{-19} J or 2.0 eV)

Tutorial Question Set 2: Electric Fields
These questions are based on lecture material completed in week 2
These questions should be completed by the end of the tutorial in week 3
They must be completed by the beginning of the tutorial in week 4

1. Consider two plates of area A, of a thickness t, and separated by a distance d. The total charge on the left hand plate is Q and on the right hand plate is –Q. Assuming that the Electric Field = 0 on the left hand side of the left hand plate, use Poisson's equation to show that the field on the right hand side of the left hand plate = $Q/A\varepsilon$.



2. Apply Poisson's Equation again to show that the field between the plates is constant.

3 Show that the field on the right hand side of the right hand plate = 0, and hence plot the variation of E field as one passes from one side of the two parallel plates to the other.

4. If there is a field between the plates, then the two plates must be at a different potential. Show that the potential difference (i.e. the voltage) between the plates is $=Qd/A\varepsilon$

5. If we define a concept called capacitance which is equal to Q/(potential difference), show that the capacitance = $\varepsilon A/d$

Tutorial Question Set 3: Current in Solids

These questions are based on lecture material completed in week 3
These questions should be completed by the end of the tutorial in week 4
They <u>must</u> be completed by the beginning of the tutorial in week 5

1. Sketch the layout and calculate the largest resistance possible that would fit into an area of 90x90 μm^2 using a metal ribbon 0.01 μm thick with resistivity of 3.15×10^{-6} Ωm with the restriction that the metal track widths and gaps between them can be no smaller than 10 μm. (A 'spiral' geometry cannot be used because of access problems to one end of the resistor).

(15.4 kΩ)

2. A silver wire has a conductivity of $6.7\times10^7\ \Omega^{-1}m^{-1}$ at a specified temperature. If the electric field is 100 V/m calculate the average drift velocity of electrons, assuming there are 10^{29} free conduction electrons per cubic metre. Calculate also the mobility and mean free time between collisions. Use the free electron mass.

(0.42 m/s, 4.2×10^{-3} m^2/Vsec, 2.38×10^{-14} s)

Tutorial Question Set 4: Intrinsic Semiconductors

These questions are based on lecture material completed in week 4
These questions should be completed by the end of the tutorial in week 5
They <u>must</u> be completed by the beginning of the tutorial in week 6

1. The intrinsic free carrier concentration for Si at room temperature is 1.5 x 10^{16} m^{-3}. From this derive the pre-exponential term in the equation for n_i(see notes) that enables n_i to be calculated at all temperatures (W_g(Si) = 1.1 eV).
   Modify this equation for Ge (W_g=0.66 eV) and diamond (W_g=6 eV) calculating n_i for each (assume the pre-exponential term is the same). Which would be most useful as a thermistor for measuring temperature at or near room temperature?

(n_i(Ge) = 1x10^{20} m^{-3}, n_i(diamond) = 4x10^{-27} m^{-3})

(Note you may get a different answer here depending on your assumption of T for room temperature.
Temperatures around 290-300 K may be used, furthermore
it is also acceptable to use a value of 1/40 eV for kT at room temperature.
Remember, due to the exponent a small change in kT can make a large change in n_i)

2. A bar of intrinsic germanium has 2.5x10^{19} free electrons per m^3. Find the net current density when an electric field of 500 Vm^{-1} is applied. (Assume μ_h= 0.19, μ_e= 0.39 $m^2V^{-1}s^{-1}$).

(1160 Am^{-2})

Tutorial Question Set 5: Extrinsic Semiconductors
These questions are based on lecture material completed in week 4
These questions should be completed by the end of the tutorial in week 6
They must be completed by the beginning of the tutorial in week 8

1. n-type Si has a resistivity of 4.3×10^{-3} Ωm at room temperature and the free electron density is 1.2×10^{22} m^{-3}. Calculate the mobility from this data. What is the mean time between collisions (τ) appropriate to this mobility? Assume $m_e^*=0.98m_e$.

   (0.12 m^2/Vs, 6.7×10^{-13} s)

2. Using the Einstein relation calculate the room temperature electron diffusion coefficient for Si and Ge.

   (0.0031 m^2/s, 0.0093 m^2/s)

3. Germanium is doped with $1x10^{-2}$ atomic percent of antimony. Assuming that at room temperature all antimony atoms are ionised, compare the electron and hole densities. You may assume that the electron density is determined only by the donors. From this information, calculate the resistivity of the material. (Assume the density of Ge is $5.4x10^3$ kgm^{-3}, Ge atomic weight=72.6 a.m.u. (atomic mass units), μ_h=0.19, μ_e=0.39 $m^2V^{-1}s^{-1}$, $n_i=2.5x10^{19}$ m^{-3}).

   (4.45×10^{24} m^{-3}; $1.40x10^{14}$ m^{-3}; $3.60x10^{-6}$ Ωm)

4. A chip of Si is 1 mm x 2 mm in area and 0.1 mm thick. The material has one in every 10^8 atoms replaced by an atom of B (Assume the density of Si is $2.3x10^3$ kgm^{-3}, Si atomic weight=28.1 a.m.u.).
   (a) Is the doped material n-type or p-type. Why?
   (b) What is the density of majority and minority carriers. Can one be neglected
   (c) What voltage is required for a current of 2mA between the large faces?
   N.B. For Si n_i ~$1.5x10^{16}$ m^{-3}, μ_h=0.046 $m^2V^{-1}s^{-1}$.

   ((a) p-type, (b) p=$4.9x10^{20}$ m^{-3}, n=$4.6x10^{11}$ m^{-3}, yes -- n<<p, (c) 28 mV)

5. A rod of p-type germanium 6 mm long, 1 mm wide and 0.5 mm thick, has an electrical resistance of 120 ohms along its length. What is the impurity concentration? What proportion of the conductivity is due to electrons in the conduction band? (Assume μ_h=0.19, μ_e=0.39 $m^2V^{-1}s^{-1}$ and $n_i=2.5x10^{19}$ m^{-3})

   (3.29×10^{21} m^{-3}, 1 in $8.4x10^3$)

6. Pure silicon has a resistivity of 2000 Ωm at room temperature and a density of conduction electrons of $1.4x10^{16}$ m^{-3}. Calculate the resistivites of samples containing acceptor concentrations of 10^{21} and 10^{23} m^{-3}. Assume that the hole mobility remains the same as in pure silicon and that it equals 0.26 of the electron mobility.

   (0.136 and 0.00136 Ωm)

7. A hole current of 10 mA flows into a circular injecting contact of 5mm diameter on one face of a thick block of n-type Si with a minority carrier lifetime of 25 μs. Assuming one-dimensional flow and a diffusion coefficient for holes of 0.0015 m^2s^{-1}, calculate the increase in carrier densities at the contact face and 0.1 mm and 1 mm from it. (Hint: use the exponential dependence of minority carriers with distance, differentiate at x=0 and solve for the hole concentration there.)

   (4.16×10^{20} m^{-3}, 2.48×10^{20} m^{-3}, 2.47×10^{18} m^{-3})

Tutorial Question Set 6: Introduction to pn Junctions

These questions are based on lecture material completed in week 7 (most by week 6)

These questions should be completed by the end of the tutorial in week 8

They <u>must</u> be completed by the beginning of the tutorial in week 9

1. A germanium p-n junction has a bulk resistivity of 4.2×10^{-4} and 2.08×10^{-2} Ωm for the p- and n-type material respectively. If $\mu_e = 0.3$, $\mu_h = 0.15$ m^{2}V^{-1}s^{-1} for this material, and n_i=2.5×10^{19} m^{-3} at room temperature, calculate the height of the potential barrier at the junction.

   (0.3 V)

2. The minority carrier lifetimes of the p and n-type material of the junction of problem 1 are 150 and 75 μs respectively, and the sample has a cross-sectional area of 1×10^{-6} m^2. Assuming that there is a large thickness of semiconductor on each side of the junction, calculate the saturation current. What proportion of the saturation current is carried by holes?

   (0.72 μA, 99% carried by holes)

3. For the same p-n junction as in problem 1, calculate the hole density at the interface between the depletion layer and the n-type material when forward and reverse voltages of 25, 50 and 100 mV are applied to the junction. What forward voltage would have to be applied for the injected hole density to equal 10% of the normal electron density? What is the effective conductivity at the edge of the depletion layer in this case?

   (Forward: 1.7×10^{18}, 4.52×10^{18}, 3.27×10^{19} m^{-3}.
   Reverse: 2.3×10^{17}, 8.64×10^{16}, 1.19×10^{16} m^{-3}.
   128 mV, 50.4 Sm^{-1})

Tutorial Question Set 7: Reverse Biased Junctions

These questions are based on lecture material completed in week 7

These questions should be completed by the end of the tutorial in week 9

They must be completed by the beginning of the tutorial in week 10

1. A particular germanium junction has the following properties at room temperature:

hole mobility	$0.17\ m^2V^{-1}s^{-1}$
electron mobility	$0.36\ m^2V^{-1}s^{-1}$
conductivity of p-type	$1\times10^4\ Sm^{-1}$
conductivity of n-type	$1\times10^2\ Sm^{-1}$
intrinsic density	$2.4\times10^{19}\ m^{-3}$

Find:

a) the contact potential at room temperature,

b) the density of holes injected into the n side of the junction when a forward bias of 0.1 V is applied.

(0.35 V, $1.8\times10^{19}\ m^{-3}$)

2. The current flowing in a certain p-n junction at room temperature is 1 μA when a reasonably large reverse bias voltage is applied. Find the applied voltage corresponding to a forward current of 10 mA.
The diode is constructed with p-type material of conductivity 2000 Sm^{-1} and n-type of 500 Sm^{-1}. Each region is l mm long and 1 x 0.5 mm in cross-section. Calculate the total voltage drop across the terminals of the diode when 10 mA flows. Comment on the result.

(0.23 V, 0.28 V)

3. In what wavelength range will a GaAs photodiode respond to incident light?
Note that the energy of a photon is hc/λ, where h is Planck's constant and c is the speed of light. Wg for GaAs is 1.42 eV.
What happens if light outside this wavelength range is incident?

The following is an old examination question

4.a) Sketch out the disposition of space charge in and around the depletion region of a p^+n junction diode. By using arguments of equality of this charge on either side of the junction, show that the depletion depths are inversely proportional to the respective doping densities. Roughly draw the shape of the magnitude of the electric field with distance across this region and illustrate what happens to this field and the depletion depth under both forward and reverse bias. **(10 mrks)**

b) It can be shown that the depletion depth dependence on reverse bias of a "one-sided" (i.e. p^+>>n) abrupt junction is given by

$$d_j=(2\varepsilon V_j/eN_d)^{0.5}$$

where V_j is the applied plus the built-in voltage(≈0.7 V) and N_d is the donor concentration. Write down the expression for the capacitance per unit area of the diode assuming parallel plate geometry. **(3 mrks)**

c) Modern large scale silicon integrated circuits have supply voltages of 3 V. What *relative* range of capacitance values are possible for this voltage? Calculate the donor doping level required to achieve a maximum capacitance of $2\times10^{-6}\ Fm^{-2}$. You may assume the relative permittivity of Si to be 12. **(7 mrks)**

Tutorial Question Set 8: Field Effect Transistors

These questions are based on lecture material completed in week 9

These questions should be completed by the end of the tutorial in week 10

They must be completed by the beginning of the tutorial in week 11

1. A JFET is to be operated in the low drain voltage mode as a voltage controlled attenuator. When the gate voltage is 1 V the drain resistance is 2 kΩ and when $V_g = 2$ V, the drain resistance is 3 kΩ.
   Find the pinch-off voltage for the device and estimate its drain resistance when $V_g = 3$ V.
   (5.03 V, 4.87 kΩ)

2. In a particular single sided p-channel silicon JFET, the width of the channel with no gate voltage applied, is 2 μm. If the resistivity of the channel is 0.1 Ωm, find the pinch-off voltage of the device, V_p. (It may be assumed that the hole mobility for silicon is 0.05 $m^2V^{-1}s^{-1}$ and its bulk relative permittivity is 12.)
   Also find the channel half-width when the gate voltage equals $V_p/2$ and the drain current is zero.
   (3.8 V, 0.59 μm)

Tutorial Question Set 9: Bipolar Transistors

These questions are based on lecture material completed in week 10
These questions should be completed by the end of the tutorial in week 11
They <u>must</u> be completed by the beginning of the tutorial in week 12

1. A certain n-p-n bipolar transistor has the following properties:

emitter resistivity	$3\times10^{-4}\ \Omega m$
base resistivity	$6\times10^{-3}\ \Omega m$
cross-sectional area	$10^{-8}\ m^2$
electron mobility	$0.13\ m^2V^{-1}s^{-1}$
hole mobility	$0.05\ m^2V^{-1}s^{-1}$
intrinsic carrier density	$1.5\times10^{16}\ m^{-3}$

The transistor is operated at 20°C with a base-emitter applied voltage of 0.65 V and a collector voltage of 10 V.

Determine:
(a) the carrier concentrations in base and emitter
(b) the built-in potential at the base-emitter junction
(c) the base-emitter junction current, assuming a saturation current density of 1 μAm^{-2}
(d) the approximate ratio of electron to hole currents flowing across the base-emitter junction
(e) the collector current, neglecting recombination in the base and leakage current

((a)$n_n = 1.6\times10^{23}\ m^{-3}$, $p_n= 1.4\times10^{9}\ m^{-3}$, $p_p = 2.1\times10^{22}\ m^{-3}$, $n_p=1.1\times10^{10}\ m^{-3}$, (b)0.77 V, (c)1.52 mA, (d) 20:1, (e)1.45 mA)

The following is an old examination question

2.a) What are the two main contributions to the base current in a bipolar transistor and what two single parameters describe these effects on the current gain? Briefly state the device design features usually used to reduce these. **(10 mrks)**

b) The ratio of electron current and hole current across a pn junction is approximately given by the ratio of the conductivities of the n and p regions respectively. If the doping in the emitter of a device is ten times that of the base and the mobility of electrons is ten times that of the holes, calculate the common emitter current gain if 98% of the injected electrons reach the collector. **(6 mrks)**

c) Sketch the distribution of electrons across the base of a bipolar transistor for the two cases of the width of the base being much larger and much smaller than the electron diffusion length. **(4 mrks)**