JULY 2021

AP CIE - 2 MODULE 3 SOLUTIONS

TYPED NOTES

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Semi-Conductor Devices

Module 3 Question Bank Solutions for CIE - 2

@ Vishnu Nadella

PART - A

11Q) Why do we need a suitable material for the Light Emitting Diode?

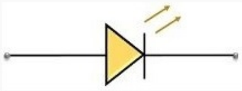
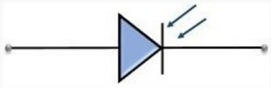
> Different semiconductor materials with different bandgaps produce different colors of light.
> The precise wavelength (color) can be tuned by altering the composition of the light-emitting, or active region.

12Q) Mention the different types of LED materials among with their radiant color.

> Main LED materials
> The main semiconductor materials used to manufacture LED's are:
> → Indium Gallium Nitride (InGaN): Blue, Green and ultraviolet(UV) high brightness LEDs
> → Aluminum Gallium Indium Phosphide (AlGaInP): Yellow, orange, and red high brightness LEDs.

→ Aluminum Gallium Arsenide (AlGaAs): Red and infrared LEDs
→ Gallium Phosphide (GaP): Yellow and green LEDs

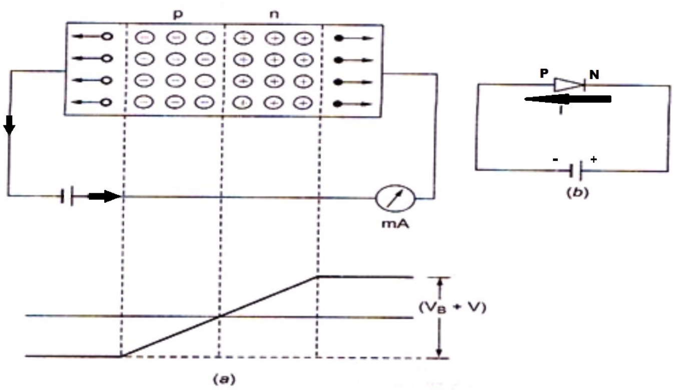
13Q) Illustrate any two differences between LED and Photo Diode

Parameter	LED	Photodiode
Definition	LED is a device that converts electric energy into light energy.	Photodiode is a device that converts light energy into electric energy.
Symbol		
Operating Principle	Electroluminance	Photoconduction
Function	It emits light.	It detects light.
Type of biasing	Forward biased	Reverse biased
Fabricated with	GaAs, GaAsP, GaP etc.	Si, InGaAs etc.
Application	In electronic display system, light display system etc.	Solar panel, logic circuits etc.

14Q) Compare the principle behind working of LED and solar diode.

Parameters	LED (Light Emitting Diode)	Photodiode
Working Principle	Works on the principle of Electro-luminance.	Works on the principle of Photoconduction.

15Q) Draw the circuit of a reverse biased PN junction diode



Reverse Biased Circuit

16Q) Mention any two advantages of Avalanche Photo Diode

> Advantages of Avalanche Photo Diode
> → Greater level of sensitivity
> → High performance
> → Fast response time

17Q) Mention the Industrial applications of Solar Cell.

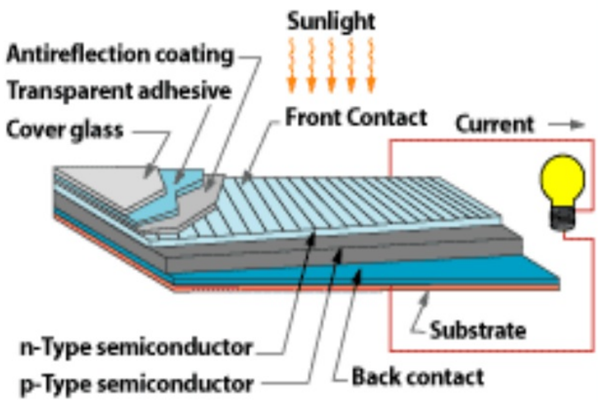
> → Can be used as the main source or backup source for electricity
> → Solar water heater to generate steam and run turbines
> → To reduce carbon emissions
> → Solar water pumps and lighting
> → Telecommunications and Remote area Surveillance units

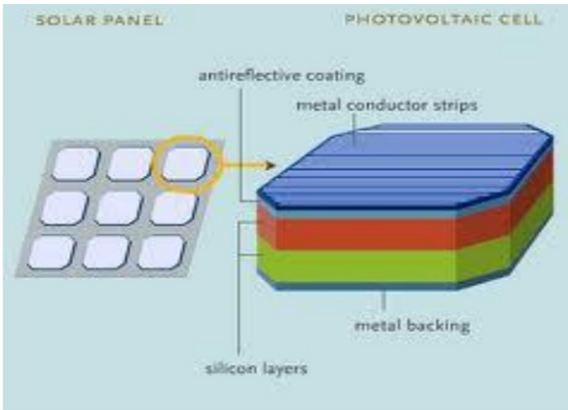
18Q) What are the materials used for fabrication of a solar cell?

> A typical solar cell consists of a glass or plastic cover, an anti-reflective coating, a front contact to allow electrons to enter a

circuit, a back contact to allow them to complete the circuit, and the semiconductor layers where the electrons begin and complete their journey

#NOTE: Below Picture is for reference only

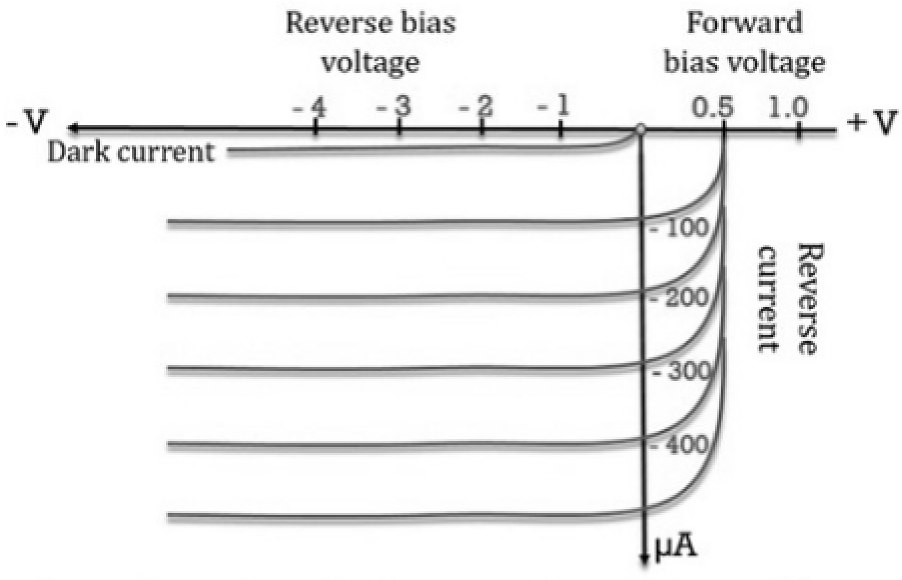




19Q) Define the efficiency of a solar cell.

> Solar cell efficiency refers to the portion of energy in the form of sunlight that can be converted via photovoltaics into electricity by the solar cell.
> The usual efficiency range of solar cells 11-15%.

20Q) Draw the V-I characteristics of photo diode



Characteristics

PART - B

11Q) Write a note on Avalanche photo diode. Review the parameters that are commonly used to assess the performance of a detector

> An Avalanche Photodiode (APD) is a highly sensitive semiconductor photodiode that exploits the photoelectric effect to convert light into electricity.
>
> **Responsivity :**
>
> The responsivity of a detector is given as the ratio of the generated photocurrent ( ) to the amount of optical power ( ) incident on the detector
>
> **Quantum Efficiency :**
>
> A detector is not capable of collecting all the photons and convert them to electron-hole pairs. The number of electrons produced per incident photon is defined as the quantum efficiency.

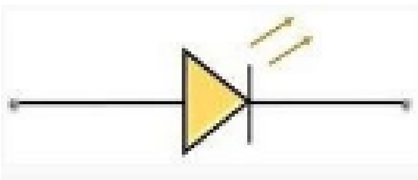
Spectral Response :

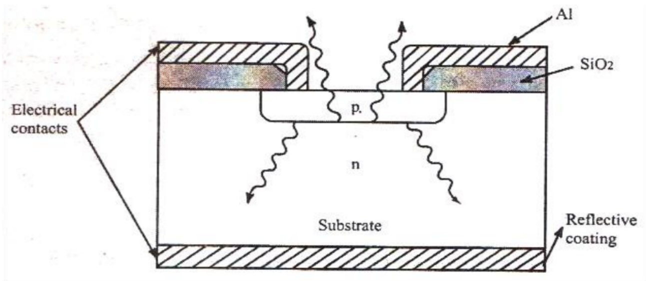
The spectral response of a detector is given by the manner in which the output signal of the detector varies with the change in the wavelength of the incident radiation.

12Q) Illustrate the construction and working of LED. What are the advantages and disadvantages of LEDs in electronic display?

Construction of LED

The recombination of the charge carrier occurs in the P-type material, and hence P-material is the surface of the LED. For the maximum emission of light, the anode is deposited at the edge of the P-type material. The cathode is made of gold film, and it is usually placed at the bottom of the N-region. This gold layer of cathode helps in reflecting the light to the surface.





Construction of typical LED

Working of LED

The LED is connected in the forward-biased, which allows the current to flows in the forward direction. The flow of current is because of the movement of electrons in the opposite direction. The recombination shows that the electrons move from the conduction band to the valence band and they emit

> electromagnetic energy in the form of photons. The energy of photons is equal to the gap between the valence and the conduction band.

Advantages

- Lifetime
- Low maintenance
- Efficiency
- Brightness

Disadvantages

- very expensive
- blue light (Eye Damage)
- thermal instability
- Potential color shift over lamp life

13Q) Compare and contrast the functioning of Light Emitting diode and photo diode

Light Emitting Diode (LED)

- Two terminal device which converts electrical energy to electrical energy.
- Works on the principle of Electro-Luminance.
- Forward Bias only
- Indicator in AC circuits, Alphanumeric and Numeric display, etc.
- Direct band gap Semi-Conductor
- Gallium Arsenide Phosphide (GaAsP) or Gallium Phosphide (GaP). (Semiconductor used)

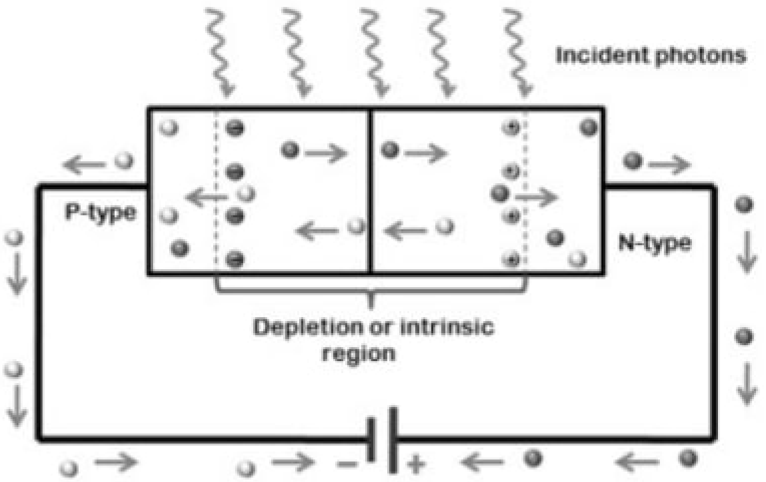
Photo Diode (PD)

- Two terminal device which converts light energy into electrical energy
- Works on the principle of Photoconduction
- Reverse Bias only
- Switching, high speed counting, ac coupled signaling, etc.
- Indirect band gap Semi-Conductor
- Germanium (Ge) or Silicon (Si) (Semiconductor used)

14Q) Give the theory of junction photo diode with a neat diagram. Discuss the factors which limit the speed of response

of photodiodes.

> The photodiode is operated under a moderate reverse bias. This keeps the depletion layer free of any carriers and normally no current will flow. However when a light photon enters the intrinsic region it can strike an atom in the crystal lattice and dislodge an electron. In this way a hole-electron pair is generated. The hole and electron will then migrate in opposite directions under the action of the electric field across the intrinsic region and a small current can be seen to flow. It is found that the size of the current is proportional to the amount of light entering the intrinsic region. The more light, the greater the numbers of hole electron pairs that are generated and the greater the current flowing.
>
> NOTE: (In below diagram dark ones are: electrons (or -ve charged particles) and light ones are: holes (or +ve charged particles))



Photodiode Working Principle

> There are basically three limiting factors to the speed of a photo detector:

> → diffusion of carriers
> → drift transit time in the depletion region
> → capacitance of the depletion region

15Q) Summarize how a photo diode can be converted into PIN and Avalanche photodiode

> **PIN Diode:**
> Pin diode can be constructed in two different structures: Mesa structure and Planar structure.
> In mesa structure, layers that are already doped are grown onto the substrate (intrinsic layer). The amount of doping and thickness of the layer can be controlled as per the requirement.
> In a planar structure, a very thin epitaxial layer is fabricated on the P-type substrate. This epitaxial layer consists of P+ regions. Similarly, an epitaxial layer is fabricated on an N-type substrate, and that will be comprised of the N+ region. And in between these semiconductors, a layer of intrinsic material of width 10-200 microns and resistivity 0.1 Ω-m is introduced. The semiconductor layer provides ohmic contacts.

> **Avalanche Diode:**
> Avalanche diodes are generally made from silicon or other semiconductor materials. The construction of avalanche diode is similar to Zener diode but the doping level in avalanche diode differs from Zener diode.
> Zener diodes are heavily doped. Therefore, the width of the depletion region in the Zener diode is very thin. Because of this thin depletion layer or region, reverse breakdown occurs at lower voltages in the Zener diode.

> On the other hand, avalanche diodes are lightly doped. Therefore, the width of the depletion layer in the avalanche diode is very wide compared to the Zener diode. Because of this wide depletion region, reverse breakdown occurs at higher voltages in the avalanche diode. The breakdown voltage of the avalanche diode is carefully set by controlling the doping level during manufacture.

16Q) In what respect is an LED different from an ordinary p-n junction diode? State applications of LEDs. Why should LEDs preferred over conventional incandescent lamps.

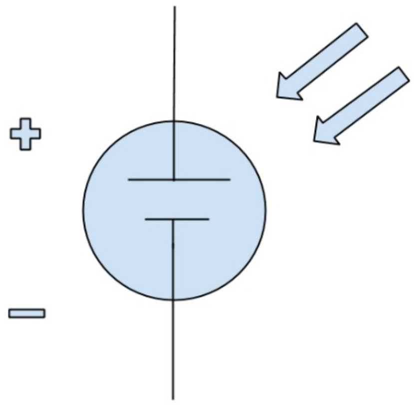
> The LED emits light, whereas PN junction diode cannot emit light.
> LEDs are impure or Extrinsic or compound semiconductors whereas PN are pure or intrinsic or elemental Semiconductors
> Applications:
> → night lighting
> → art lighting
> → outdoor lighting
> → electronics
> → automotives
> → signage
> LEDs are extremely energy efficient and consume up to 90% less power than incandescent bulbs. Since LEDs use only a fraction of the energy of an incandescent light bulb there is a dramatic decrease in power costs. Also, money and energy is saved in maintenance and replacement costs due to the long LED lifespan. LEDs have a lifespan of up to 60,000 hours compared to 1,500 hours for incandescent bulbs

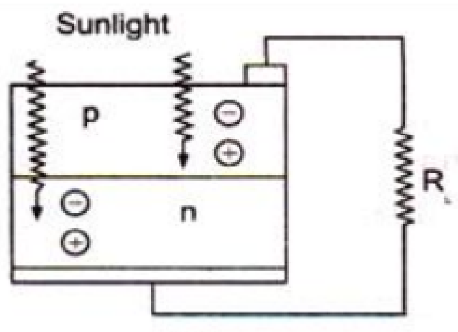
17Q) Explain with a neat sketch the construction, working and V-I characteristics of solar cell

Construction:

There are several technologies to construct a solar cell. One of them is Quantum Dot (QD) Solar Cells. These are built up of a semiconductor (silicon) coated with a very thin layer of Quantum dots. Quantum dots are just a fancy name of crystals in the size range typically a few nanometers in diameter. These crystals are mixed into a solution and placed on a piece of silicon which is rotated really fast. The crystals are then spread out due to the centrifugal force. The reason these quantum dots are given so much attention is that normally one photon will excite one electron creating one electron-hole pair.

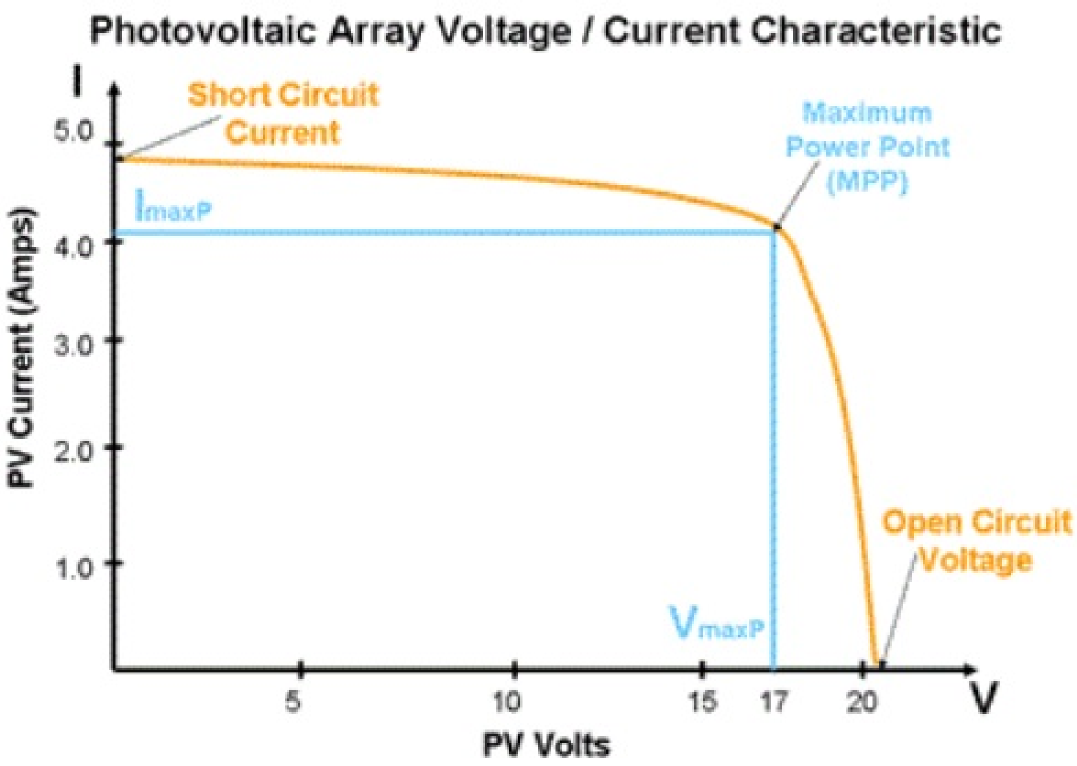
The energy loss is the original energy of the photon minus the energy needed to excite the electron (also called the band gap [energy loss = original energy - energy needed]). However, when a photon hits a quantum dot made of the same material, there may be several electron-hole pairs created, typically 2-3, but 7 has been observed.





Working principle:

The solar cell is basically a p – n junction diode that converts sunlight directly to electricity. The working principle of solar cells is based on the photovoltaic effect. In general, the photovoltaic effect means the generation of a potential difference at the junction of two different materials in response to visible or other radiation.



18Q) Compare and contrast the functioning of Light Emitting diode and solar cell.

Light Emitting Diode (LED)	Solar Cell (SC)
• LED emits light.	• Solar cell generates Electricity.
• Electrical energy is converted into Light energy.	• Light energy is converted into Electrical Energy.
• Works on the principle of Electro-Luminance.	• Works on the principle of photovoltaic effect.

- In-Direct Band Gap semi-conductor materials.
- Indicator in AC circuits, Alphanumeric and Numeric display, etc.
- Gallium Arsenide Phosphide (GaAsP) or Gallium Phosphide (GaP). (Semi conductor used)

- Direct Band Gap semi-conductors materials.
- Used for generating electricity
- Germanium (Ge) or Silicon (Si) (Semiconductor used)

🚫 No need of writing this JUST FOR UNDERSTANDING PURPOSE
#NOTE - Solar cells are been optimized to generate current and they differ from Photo Diode in terms of functionality

19Q) Give the properties of silicon and gallium arsenide based on band theory.

> **Silicon (Si):**
> For intrinsic semiconductors like silicon, the Fermi level is essentially halfway between the valence and conduction bands. Although no conduction occurs at 0 K, at higher temperatures a finite number of electrons can reach the conduction band and provide some current.
> At finite temperatures, the number of electrons that reach the conduction band and contribute to current can be modeled by the Fermi function. That current is small compared to that in doped semiconductors under the same conditions.

> **Gallium Arsenide (GaAs):**
> This is a direct bandgap semiconductor with Band Gap(Eg) = 1.443ev (λg= 860 nm); p-n junctions are readily formed, when GaAs is doped with silicon, based on growing condition, either

> silicon can replace Ga or As. On Replacing Ga it acts as a donor and on As replacement, it acts as an acceptor. In silicon doped diodes the emission lies between 910 and 1020 nm. This has high quantum efficiency. These diodes have become standard near – IR emitting devices.
>
> #Sir Doubt is this enough or is there anything to add or its wrong

20Q) What are the main requirements of a LED material? Infer advantages of LED

> To break it down a little further, the semiconductor material itself is made of crystalline material and needs impurities in order to conduct electricity. However, these impurities are added to the semiconductor material later on in the manufacturing process.

> The main semiconductor materials used to manufacture LEDs are:
> → **Indium gallium nitride (InGaN):** blue, white, green, and ultraviolet high-brightness LEDs
> → **Aluminum gallium indium phosphide (AlGaInP):** yellow, orange, and red high-brightness LEDs
> → **Aluminum gallium arsenide (AlGaAs):** red and infrared LEDs
> → **Gallium phosphide (GaP):** yellow and green LEDs
> Finally, in order to power the diodes, electrical wires must be added. Gold and silver compounds are often used in LED wires, as they can handle being soldered and heat well. Lastly, to finish it off, the diodes are encased in transparent plastic, not glass (like traditional bulbs), making them durable and long-lasting.

Advantages of LED:

💡 LED Light Lifespan
💡 LED Energy Efficiency
💡 Improved Safety with LEDs
💡 LED Lights are Physically Small
💡 LEDs Have Great Color Rendering Index (CRI)
💡 LEDs Generate Directional Emissions
💡 LEDs Have Tremendous Design Flexibility
💡 LEDs are Solid State Lights (SSLs)

PART - C

6Q) Calculate the wavelength of emitted radiation from a LED made up of GaAs with a band gap of 1.52eV

Energy gap of a semi conductor is given by:

$E_g = \frac{hc}{\lambda}$

here;

h is planks constant = $6.626 * 10^{-34} m^2 kg/sec$

c is speed of light = $3.0 * 10^8 m/s$

λ is the wavelength of radiation $=?$

Given;

$E_g = 1.52eV$

$1eV = 1.602 * 10^{-19} J$

$1.52eV = 2.43 * 10^{-19} J$

So,$\lambda = \frac{hc}{E_g} = \frac{6.626*10^{-34}*3.0*10^8}{2.43*10^{-19}} = 8.18 * 10^{-7} m = 818nm$

Hence, the wavelength of the emitted radiation Gallium Arsenide(GaAs) which has a bandgap of $1.52eV$ is $818nm$.

7Q)A semiconductor diode laser has a wavelength of 1.65µm. Find its band gap in eV

> Energy gap (E_g) of a semi conductor is given by:
> $E_g = \frac{hc}{\lambda}$
> here;
> h is planks constant $= 6.626 * 10^{-34} m^2 kg/sec$
> c is speed of light $= 3.0 * 10^8 m/s$
> λ is wave length of radiation $= 1.65 \mu m$
> $E_g =$ Energy gap $= ?$
> Given,
> $\lambda = 1.65 \mu m$
> $\lambda = 1.65 * 10^{-6}$
> So,$E_g = \frac{hc}{\lambda} = \frac{6.626*10^{-34}*3.0*10^8}{1.65*10^{-6}*1.6*10^{-19}} eV = 0.7529 eV$
>
> Hence, the band gap in eV of a semiconductor which has a wavelength of $1.65 \mu m$ is $0.7529 eV$

8Q) Find the temperature at which a diode current is $2mA$ for a diode which has reverse saturation current of $10^{-9} A$. The ideality factor is 1.4 and the applied voltage is $0.6V$ forward bias.

> $I = I_o * (e^{(\frac{V}{\eta * V_T})} - 1)$
> here,
> $I =$ current $= 2mA$
> $I_o =$ reverse saturation current $= 10^{-9} A$
> $\eta =$ ideality factor $= 1.4$

> V_T = Thermal voltage =?
> V = applied voltage $= 0.6V$
> So, we know that
> $I = I_o * (e^{(\frac{V}{\eta * V_T})} - 1)$
> $(I/I_o) + 1 = e^{(\frac{V}{\eta * V_T})}$
> applying natural log on both sides
> $ln((I/I_o) + 1) = ln(e^{(\frac{V}{\eta * V_T})})$
>
> $$V_T = \frac{V}{\eta ln((\frac{I}{I_o})+1)} = \frac{0.6}{1.4 * ln(2 * (\frac{10^{-3}}{10^{-9}})+1)} = 0.02953V$$
>
> Since,
> $V_T = T * k / 11600$
> Since k is Boltzmann constant
> $T = V_T * 11600 = 0.02953 * 11600 = 342.548^\circ K = 69.65^\circ C$
> Therefore, the temperature is $69.65^\circ C$

**9Q) Consider a silicon diode with η=1.2. Estimate the change in voltage if the
current changes from 0.1mA to 10mA**

> $I = I_o * (e^{(\frac{V}{\eta * V_T})} - 1)$
> I = current $= 10mA$
> I_O = reverse saturation current $= 0.1mA = 0.1 * 10^{-3}A$
> η =ideality factor $= 1.2$
> V_T = thermal voltage = 0.026V
> ΔV = change in applied voltage =?
> So, we know that

> $I = I_o * (e^{(\frac{V}{\eta * V_T})} - 1)$
> $(I/I_o) + 1 = (e^{(\frac{V}{\eta * V_T})})$
> applying natural log on both sides
> $ln((I/I_o) + 1) = ln(e^{(\frac{V}{\eta * V_T})})$
> $\Delta V = \eta * V_T * ln(\frac{I}{I_o}) = 1.2 * 0.026 * ln(10 * \frac{10^{-3}}{0.1 * 10^{-3}}) = 0.1436V$
> Therefore, the applied voltage is $0.143V$

10Q) What will be the ratio of final current to initial current of a diode if voltage of a diode changes from 0.7V to 872.5 mV? Take ideality factor as 1.5

> We know that;
> $I = I_o * (e^{(\frac{V}{\eta * V_T})} - 1)$
> $I =$ current $=?$
> $I_o =$ reverse saturated current $=?$
> $\eta =$ ideality factor $= 1.5$

$V_2 = 872.5mV = 872.5 * 10^{-3}V = 0.8725V$

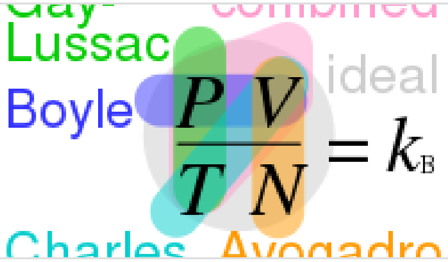
$\Delta V = V_2 - V_1 = 0.8725 - 0.7 = 0.1725$

Since there is no data available to calculate the terminal voltage let,
$V_T =$ terminal voltage $= 26mV = 0.026V$
(If you want to know more, click on the link below to know more and scroll down to the last paragraph)

Boltzmann constant - Wikipedia

The Boltzmann constant (or k) is the proportionality factor that relates the average relative kinetic energy of particles in a gas with the thermodynamic temperature of the gas. It occurs in the

W https://en.wikipedia.org/wiki/Boltzmann_constant



$$\frac{I}{I_o} = e^{\frac{\Delta V}{\eta * V_T}} - 1 = e^{\frac{0.1725}{1.5*0.026}} - 1 = 83.352 * 10^8$$

Therefore the ratio of currents is $51.9 * 10^8$