EE335 Electronics

Homework-1, 27 Oct. 2016

* not to be collected and graded. ** solutions will be shared on course-online after a while

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Solution Sheet

Q1. (Chapter-1) The diode equation is known as $I_D = I_S\left(e^{\frac{V_D}{nV_T}} - 1\right)$, where thermal voltage is $V_T = \frac{kT}{q}$. (Note: Boltzman consant $k = 1.38 \times 10^{-23}\, JK^{-1}$, Electron charge $q = 1.6 \times 10^{-19}\, C$, Tempeture $T = 273^{\circ} + T_c$, Euler's number $e \cong 2.718$).

a) Calculate the thermal voltage V_T for a diode at a temperature of $T_c = 27°\text{C}$.
b) For the same diode of part (a), find the diode current I_D using the diode equation if $I_S = 1 \times 10^{-15} A = 1\, fA$, $n = 1$, and the applied bias voltage V_D is 0.70 V. $(fA\!: femto\ Amper)$

Solution:

a) A temperature of $T_c = 27°\text{C}$ (°C: Celcius birimi cinsinden sıcaklık) corresponds to $T = 273^{\circ} + T_c = 273^{\circ} + 27°\text{C} = 300°\text{K}$ (°K: Kelvin birimi cinsinden sıcaklık).

The thermal voltage is then;

$$V_T = \frac{kT}{q} = \frac{(1.38\times10^{-23})(300°\text{K})}{1.6\times10^{-19}} = \frac{(1.38)(300)}{1.6}\frac{(10^{-23})}{(10^{-19})} = 258.75 \times (10^{-23}10^{+19})$$
$$= 258.75 \times 10^{-23+19} = 258.75 \times 10^{-4}\ Volt.$$
$$= 258.75 \times 10^{-1}10^{-3}\ Volt.$$
$$= 25.875 \times 10^{-3}\ Volt.$$

$$\boxed{V_T = \mathbf{25.875\ mV}} \quad (milliVolt)$$

b) $I_D = I_S\left(e^{\frac{V_D}{nV_T}} - 1\right) = 10^{-15}\left(e^{\frac{0.70}{25.875\times10^{-3}}} - 1\right)$. The exponent term of the number e is $\frac{0.70}{25.875\times10^{-3}}$, and it is calculated as follows: $\frac{0.70}{25.875\times10^{-3}} = \frac{0.70\times10^{3}}{25.875} = \frac{0.70\times1000}{25.875} = \frac{700}{25.875} = 27.053$. Using this value we get,

$$I_D = I_S\left(e^{\frac{V_D}{nV_T}} - 1\right) = 10^{-15}\left(e^{\frac{0.70}{25.875\times10^{-3}}} - 1\right) = 10^{-15}\left(e^{\mathbf{27.053}} - 1\right)$$
$$= 10^{-15}\left(\mathbf{5.595 \times 10^{11}} - 1\right)$$

$\mathbf{5.595 \times 10^{11}}$ is very very larger than 1, so we can ignore 1, $(\mathbf{5.595 \times 10^{11}} - 1) \cong \mathbf{5.595 \times 10^{11}}$

$$I_D \cong 10^{-15}(5.595 \times 10^{11})$$
$$I_D \cong 5.595 \times 10^{11}10^{-15} = 5.595 \times 10^{11-15}$$
$$I_D \cong 5.595 \times 10^{-4} = 5.595 \times 10^{-1}10^{-3} = 0.5595 \times 10^{-3} A\ (A\!: Amper)$$

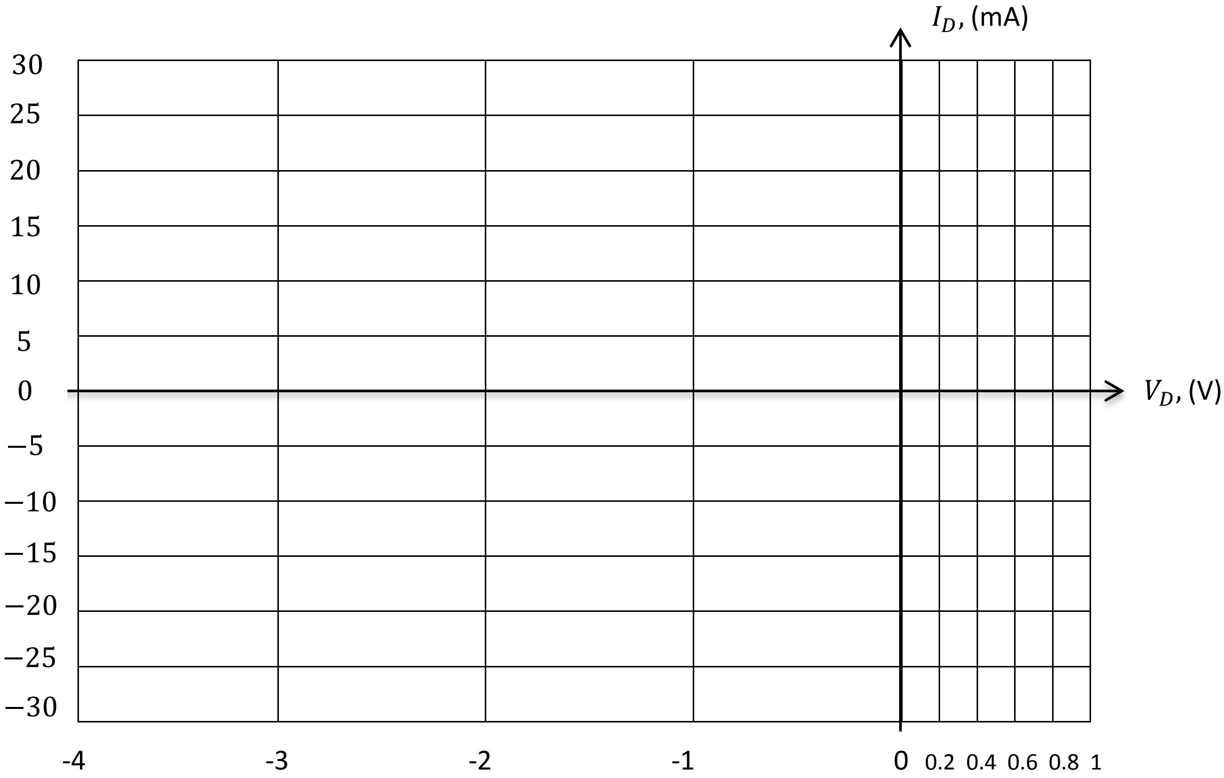
$$\boxed{I_D = \mathbf{0.5595\ mA}}$$

Q2. a) Repeat part (b) of Q1 (question 1) to calculate the diode current I_D for each diode voltage V_D given in the table below and fill the table with the calcuated current values.

V_D (V)	-3	-2	-1	0	0.30	0.50	0.60	0.70	0.75	0.80
I_D (mA)										
Diode status (ON or OFF)										

b) Write down the status of the diode as ON or OFF to the table. (Note: assume that the diode is ON when $I_D \geq 10^{-6}$A=1uA, and OFF when $I_D <$1uA).

c) Using the values filled in the table, plot $I_D - V_D$ characteristics of the diode on the graph below.



Solution:

a) Thermal voltage in Q1 was $V_T = 25.875\ mV$, so we will use this value for V_T.

For $V_D = -3\ V$:

$$I_D = I_S\left(e^{\frac{V_D}{nV_T}} - 1\right) = I_S\left(e^{\frac{-3}{25.875\times10^{-3}}} - 1\right) = I_S(4.43 \times 10^{-51} - 1) \cong -I_S$$ (because 4.43×10^{-51} is a very small number and can be taken zero). Thus, for $\boldsymbol{V_D = -3\ V: I_D \cong -I_S = -10^{-15}}$.

For $V_D = -2\ V$:

$$I_D = I_S\left(e^{\frac{V_D}{nV_T}} - 1\right) = I_S\left(e^{\frac{-2}{25.875\times10^{-3}}} - 1\right) = I_S(2.7 \times 10^{-34} - 1) \cong -I_S$$ (because 2.7×10^{-34} is a very small number and can be taken zero). Thus, for $\boldsymbol{V_D = -2\ V: I_D \cong -I_S = -10^{-15}}$.

For $V_D = -1\ V$:

$$I_D = I_S\left(e^{\frac{V_D}{nV_T}} - 1\right) = I_S\left(e^{\frac{-1}{25.875\times10^{-3}}} - 1\right) = I_S(1.64\times10^{-17} - 1) \cong -I_S$$ (because 1.64×10^{-17} is a very small number and can be taken zero). Thus, for $\boldsymbol{V_D = -1\ V: I_D \cong -I_S = -10^{-15}.}$

For $V_D = 0\ V$:

$$I_D = I_S\left(e^{\frac{V_D}{nV_T}} - 1\right) = I_S\left(e^{\frac{0}{25.875\times10^{-3}}} - 1\right) = I_S(1-1) = 0.$$ Thus, for $\boldsymbol{V_D = 0\ V: I_D = 0.}$

For $V_D = 0.30\ V$:

$$I_D = I_S\left(e^{\frac{V_D}{nV_T}} - 1\right) = I_S\left(e^{\frac{0.30}{25.875\times10^{-3}}} - 1\right) = I_S(1.085\times10^5 - 1) \cong I_S(1.085\times10^5)$$ (because 1.085×10^5 is a very larger than 1, $1.085\times10^5 - 1 \cong 1.085\times10^5$).

Then $I_D \cong I_S(1.085\times10^5) = 10^{-15}(1.085\times10^5) = 1.085\times10^{-10} = 0.1085\times10^{-9}\ A = 0.1085\ nA$ (nA: nanoAmper)

Thus, for $\boldsymbol{V_D = 0.30\ V: I_D = 0.1085\ nA}$

For $V_D = 0.50\ V$:

$$I_D = I_S\left(e^{\frac{V_D}{nV_T}} - 1\right) = I_S\left(e^{\frac{0.50}{25.875\times10^{-3}}} - 1\right) = I_S(2.47\times10^8 - 1) \cong I_S(2.47\times10^8)$$ (because 2.47×10^8 is a very larger than 1, $2.47\times10^8 - 1 \cong 2.47\times10^8$).

Then $I_D \cong I_S(2.47\times10^8) = 10^{-15}(2.47\times10^8) = 2.47\times10^{-7} = 0.247\times10^{-6} = 0.247\ uA$ (uA: microAmper)

Thus, for $\boldsymbol{V_D = 0.50\ V: I_D = 0.247\ uA}$

For $V_D = 0.60\ V$:

$$I_D = I_S\left(e^{\frac{V_D}{nV_T}} - 1\right) = I_S\left(e^{\frac{0.60}{25.875\times10^{-3}}} - 1\right) = I_S(1.17\times10^{10} - 1) \cong I_S(1.17\times10^{10})$$ (because 1.17×10^{10} is a very larger than 1, $1.17\times10^{10} - 1 \cong 1.17\times10^{10}$).

Then $I_D \cong I_S(1.17\times10^{10}) = 10^{-15}(1.17\times10^{10}) = 1.17\times10^{-5} = 11.7\times10^{-6} = 11.7\ uA$

Thus, for $\boldsymbol{V_D = 0.60\ V: I_D = 11.7\ uA}$

For $V_D = 0.70\ V$:

$$I_D = I_S\left(e^{\frac{V_D}{nV_T}} - 1\right) = I_S\left(e^{\frac{0.70}{25.875\times10^{-3}}} - 1\right) = I_S(5.61\times10^{11} - 1) \cong I_S(5.61\times10^{11})$$ (because 5.61×10^{11} is a very larger than 1, $5.61\times10^{11} - 1 \cong 5.61\times10^{11}$).

Then $I_D \cong I_S(5.61\times10^{11}) = 10^{-15}(5.61\times10^{11}) = 5.61\times10^{-4} = 0.561\times10^{-3} = 0.561\ mA$ (mA: milliAmper)

Thus, for $\boldsymbol{V_D = 0.70\ V: I_D = 0.561\ mA}$

For $V_D = 0.75\ V$:

$$I_D = I_S\left(e^{\frac{V_D}{nV_T}} - 1\right) = I_S\left(e^{\frac{0.75}{25.875\times10^{-3}}} - 1\right) = I_S(3.87\times10^{12} - 1) \cong I_S(3.87\times10^{12})$$ (because 3.87×10^{12} is a very larger than 1, $3.87\times10^{12} - 1 \cong 3.87\times10^{12}$).

Then $I_D \cong I_S(3.87\times10^{12}) = 10^{-15}(3.87\times10^{12}) = 3.87\times10^{-3} = 3.87\ mA$

Thus, for $\boldsymbol{V_D = 0.75\ V: I_D = 3.87\ mA}$

For $V_D = 0.80\,V$:

$$I_D = I_S\left(e^{\frac{V_D}{nV_T}} - 1\right) = I_S\left(e^{\frac{0.80}{25.875\times10^{-3}}} - 1\right) = I_S(2.67\times10^{13} - 1) \cong I_S(2.67\times10^{13})$$ (because 2.67×10^{13} is a very larger than 1, $2.67\times10^{13} - 1 \cong 2.67\times10^{13}$).

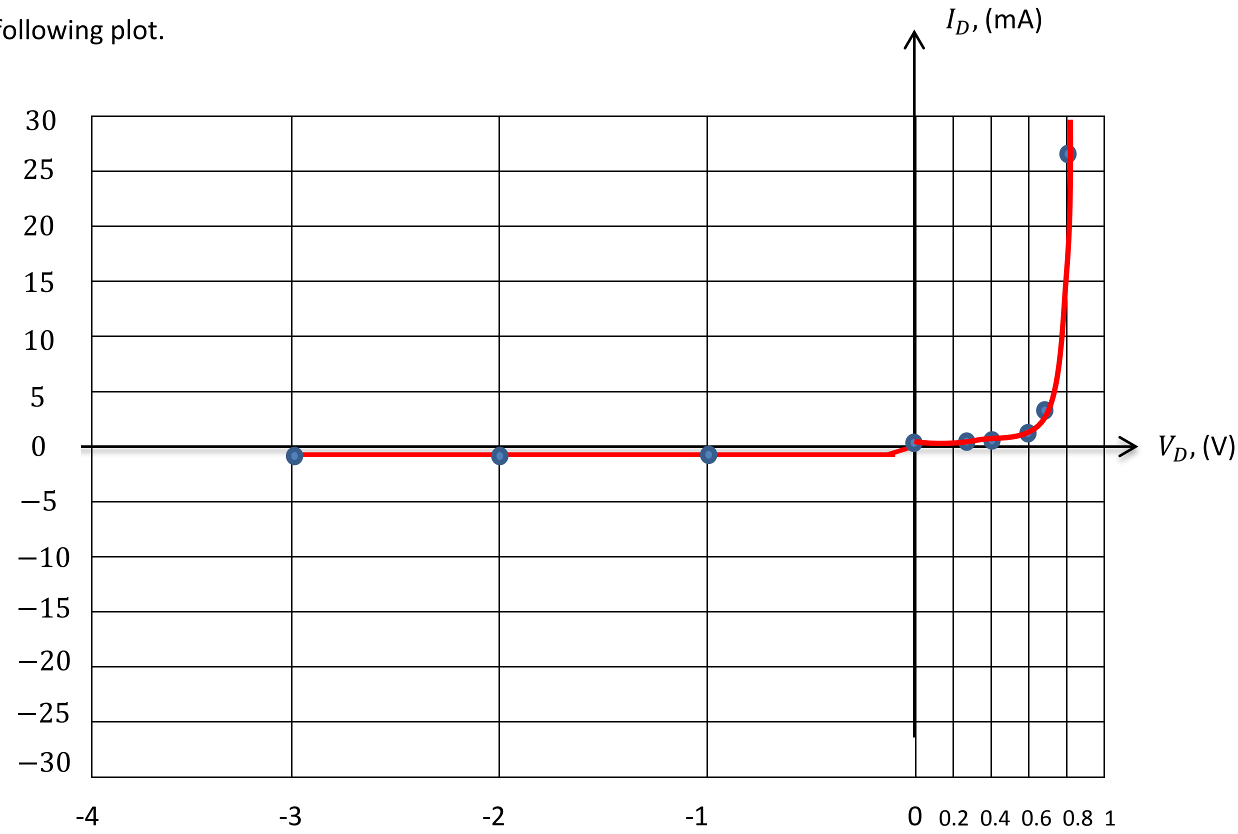
Then $I_D \cong I_S(2.67\times10^{13}) = 10^{-15}(2.67\times10^{13}) = 2.67\times10^{-2} = 26.7\times10^{-3} = 26.7\ mA$

Thus, for $\boldsymbol{V_D = 0.80\,V}$: $\boldsymbol{I_D = 26.7\ mA}$

V_D (V)	-3	-2	-1	0	0.30	0.50	0.60	0.70	0.75	0.80
I_D	-10^{-15}	-10^{-15}	-10^{-15}	**0**	**0.108 nA**	**0.247 uA**	**11.7 uA**	**0.561 mA**	**3.87 mA**	**26.7 mA**
Diode status (ON or OFF)	**OFF**	**OFF**	**OFF**	**OFF**	**OFF**	**OFF**	**ON**	**ON**	**ON**	**ON**

b) See the filled table above.

c) Using the filled table values above, $I_D - V_D$ characteristics of the diode will be similar to the following plot.



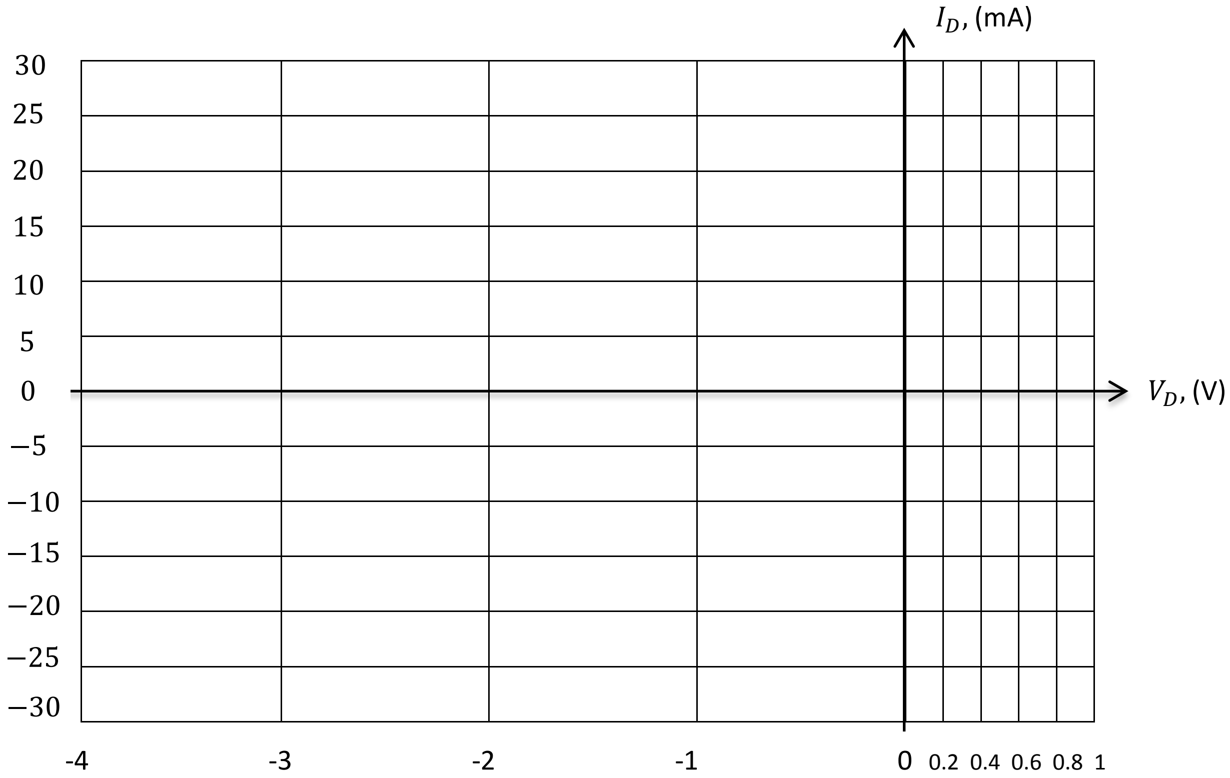
Q3. Assume that we have a zener diode with a zener voltage of $V_z = 2.1\,V$ which has the exact **forward-bias** features of the diode in Q1.

a) Repeat part (b) of Q1 (question 1) to calculate the diode current I_D for each diode voltage V_D given in the table below and fill the table with the calcuated current values.

V_D (V)	-3	-2	-1	0	0.30	0.50	0.60	0.70	0.75	0.80
I_D (mA)										
Diode status (ON or OFF)										

b) Write down the status of the diode as ON or OFF to the table. (Note: assume that the diode is ON when $I_D \geq 10^{-6}$A=1uA, and OFF when $I_D <$1uA).

c) Using the values filled in the table, plot $I_D - V_D$ characteristics of the diode on the graph below.



Solution:

a) and **b)** All the calculations will be the same as Q2's solution, except there will be a zener region less than -2.1 V. So, plot of $I_D - V_D$ characteristics of the diode will be different in Zener region but will be the same in diode region. This is seen in the following graph.

c) Using the filled table values above, $I_D - V_D$ characteristics of the diode will be similar to the following plot.