EE335 Electronics

Homework-2, 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. Suppose that the zener diode in the circuit of fig. 1.a has an approximated $I_D - V_D$ characteristics shown in the fig. 1.b. Resistors are given as $R = 1k\Omega, R_L = 320\ \Omega$.

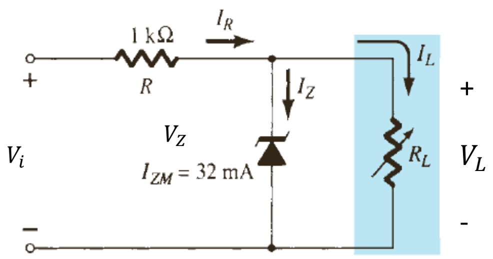


Fig. 1. a

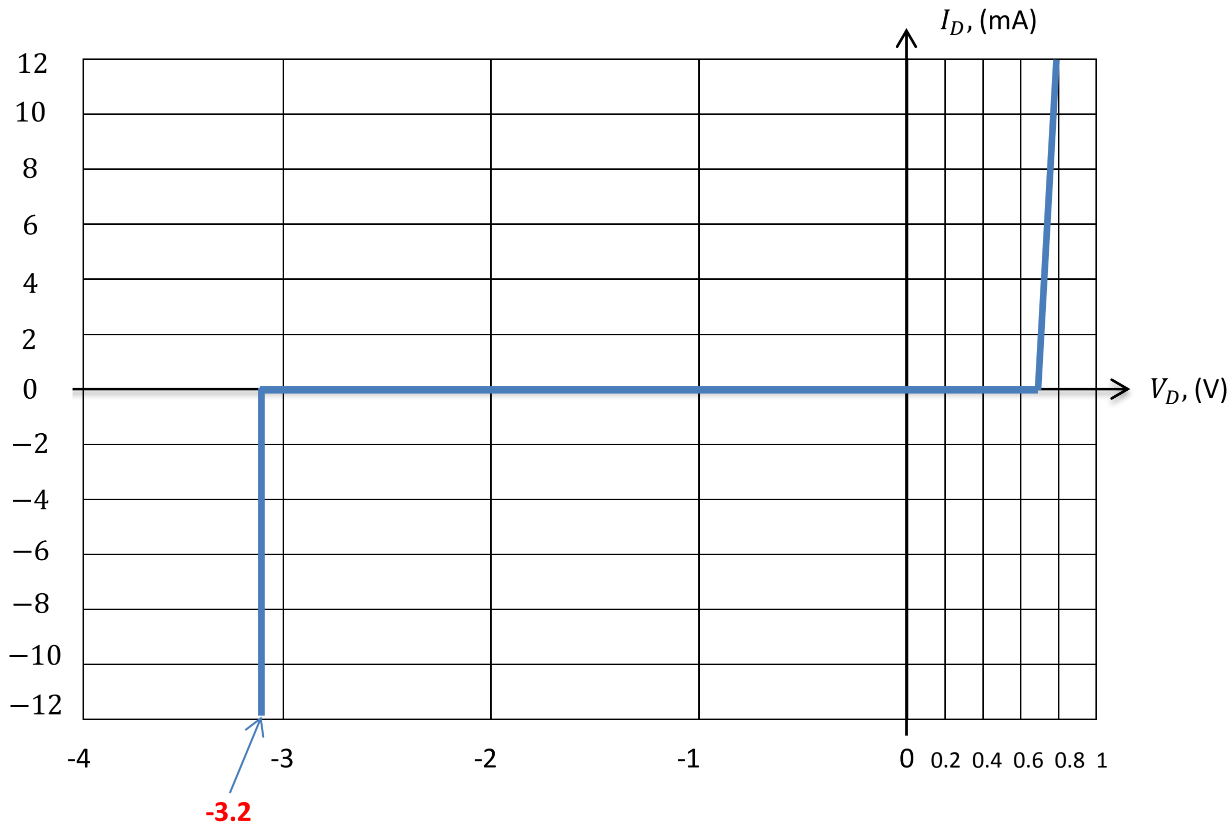


Fig. 1.b

a) According to the characteristics given in fig. 1.b, what is the zener voltage V_z ?

b) Fill the 1st line of the table below if an input voltage of $V_i = 23.2\ V$ is applied to the circuit.

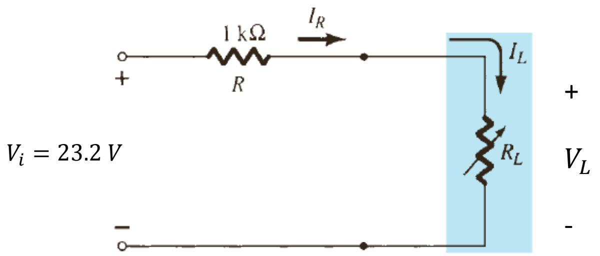
c) Fill the 2nd line of the table below if a maximum of $I_{ZM} = 32\ mA$ is to flow thru the zener diode.

V_i, (V)	I_R, (mA)	I_Z (mA)	I_L, (mA)	V_R, (V)	V_L, (V)
23.2					
		32			

Solution

a) According to the characteristics given in fig. 1.b, it is very easy to see that the zener voltage $\boldsymbol{V_z = 3.2\ V}$.

b) Let's check if the zener diode is ON or OFF. As you remember from the class lecture, to do this first we assume that the zener diode is removed from the circuit. Thus, the equivalent circuit becomes as follows:



i) **Solving the circuit:** Using KVL (Kirchoff's Voltage Law) for this circuit gives us

$$-V_i + RI_L + R_LI_L = 0 \quad (1) \quad \text{which yields}$$

$$I_L = \frac{V_i}{R+R_L} \quad (2)$$

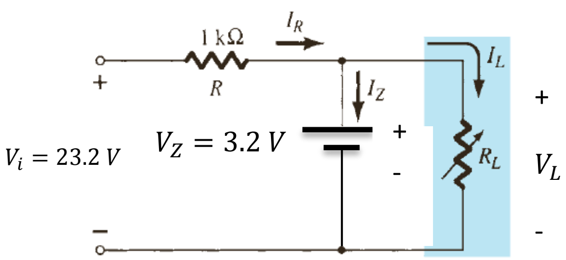
Substituting the given values in (2) we have $I_L = \frac{V_i}{R+R_L} = \frac{23.2}{1000+320} = 0.0176\ A = \boldsymbol{17.6\ mA}$**.** Now, let us find the load voltage; it is calculated as follows;

$$V_L = R_LI_L \quad (3)$$

Substituting the given values in (3) we have $V_L = R_LI_L = (320)(17.6mA) = (320)(17.6 \times 10^{-3}) = \boldsymbol{5.632\ V}$

Since this $V_L = \boldsymbol{5.632\ V}$ value is greater than the zener voltage $V_Z = \boldsymbol{3.2\ V}$**,** **the zener diode is ON.**

ii) Now, since we understood that the zener diode is ON, we must put the zener diode model as shown below. (You see that zener diode' model -when it is ON-, is just a DC voltage source of Vz=3.2 V.



Now, let us do the calculations:

$$V_L = V_Z = 3.2\ V$$

$$V_R = V_i - V_Z = 23.2 - 3.2 = 20\ V$$

Using Ohm's Law, we have $I_L = \frac{V_L}{R_L} = \frac{3.2}{320} = 0.010\ A = 10\ mA$

$$I_R = \frac{V_R}{R} = \frac{20}{1000} = 0.020\ A = 20\ mA$$

From the circuit schematic, we can easly see that the resistor current is the sum of the zener current and load current, i.e.,

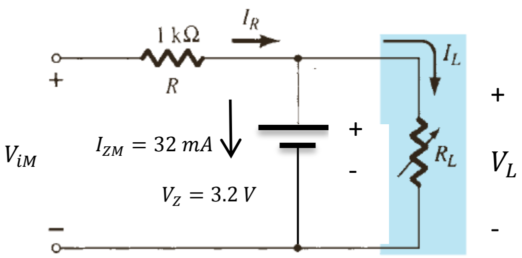
$I_R = I_Z + I_L$, **from this equation we can write,**

$I_Z = I_R - I_L$, **hence we get** $I_Z = I_R - I_L = 20\ mA - 10\ mA = 10\ mA$

As a result, with the calculated values above, the 1st line of the table would look like as follows.

V_i, (V)	I_R, (mA)	I_Z (mA)	I_L, (mA)	V_R, (V)	V_L, (V)
23.2	**20**	**10**	**10**	**20**	**3.2**

c) If a maximum of $I_{ZM} = 32\ mA$ is to flow thru the zener diode, the input voltage V_i must increase. Thus, we must find a maximum input voltage value of V_{iM} for this case. Let us draw the equivalent circuit schematic for this case.



$$V_L = V_Z = 3.2\ V$$

$$I_L = \frac{V_L}{R_L} = \frac{3.2}{320} = 0.010\ A = 10\ mA$$

$$I_{ZM} = 32\ mA$$

$$I_{RM} = I_{ZM} + I_L = 32\ mA + 10\ mA = 42\ mA$$

This I_{RM} current is the maximum current to flow thru the resistor R. Therefore, the maximum voltage drop over R will be,

$$V_{RM} = RI_{RM} = (1\ k\Omega)(42mA) = 42\ V$$

Then, the maximum allowed input voltage will be,

$$V_{iM} = V_{RM} + V_Z = 42 + 3.2 = 45.2\ V$$

As a result, with the calculated values above, the 2nd line of the table would look like as follows.

V_i, (V)	I_R, (mA)	I_Z (mA)	I_L, (mA)	V_R, (V)	V_L, (V)
23.2	**20**	**10**	**10**	**20**	**3.2**
45.2	**42**	**32**	**10**	**42**	**3.2**

Q2. (Load-Line Analysis)

1. a. Using the characteristics of Fig. 2.b , determine I_D , V_D , and V_R for the circuit of Fig. 2.a .
b. Repeat part (a) using the approximate model for the diode, and compare results.
c. Repeat part (a) using the ideal model for the diode, and compare results.

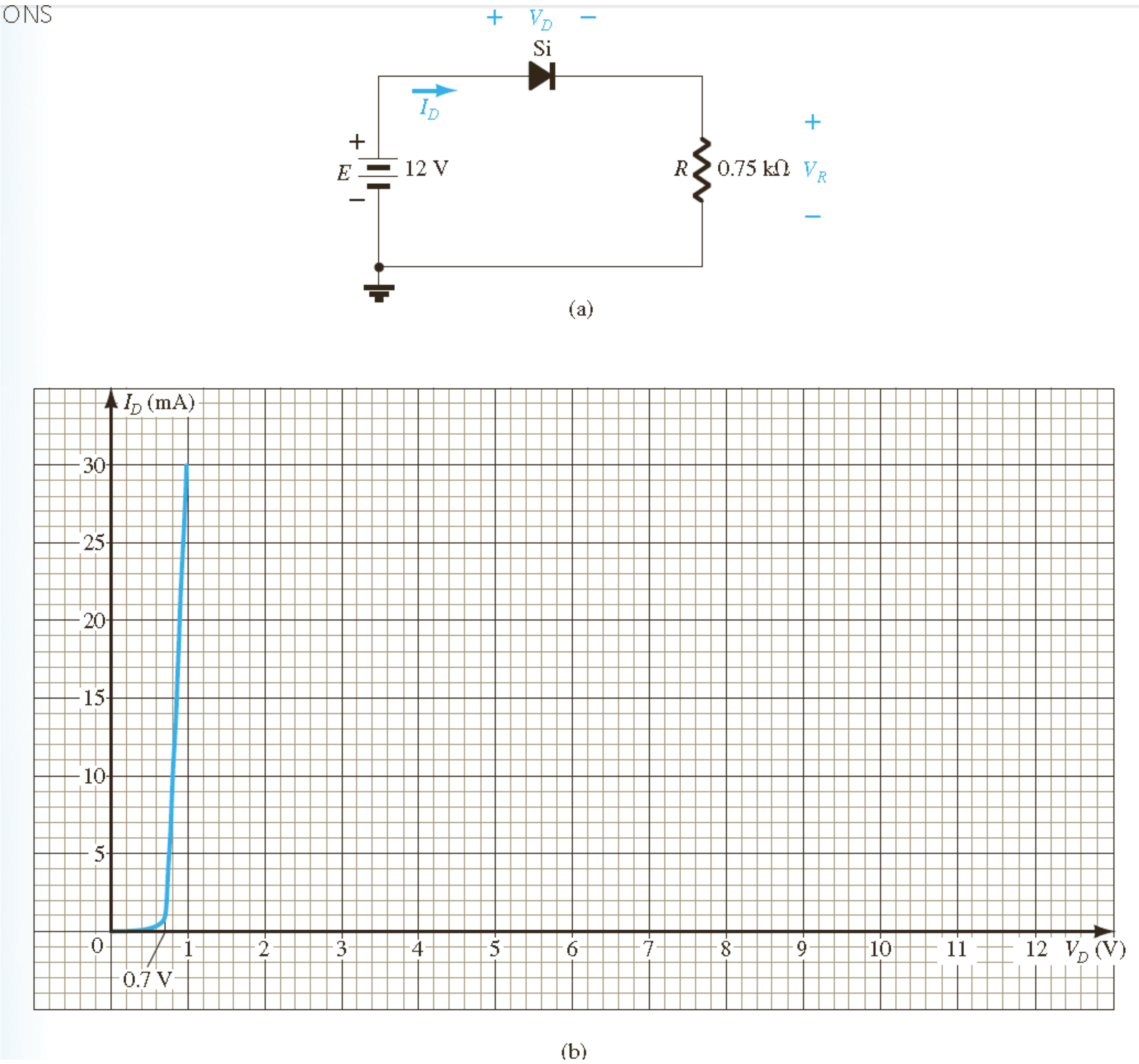


Fig. 2.

Solution:

a) Using the KVL (Kirchoff's Voltage Law), we can write the following equation,

$$-\boldsymbol{E} + \boldsymbol{V_D} + \boldsymbol{R I_D} = \mathbf{0} \quad \textbf{(1)}$$

Finding the intersection point at the y-axis ($\boldsymbol{I_D}$ axis)**:** for this, we must set $V_D = 0$ in (1), thus,

$$-E + (0) + RI_D = 0 \text{ -> then } \boldsymbol{I_D} = \frac{\boldsymbol{E}}{\boldsymbol{R}} \; (2)$$

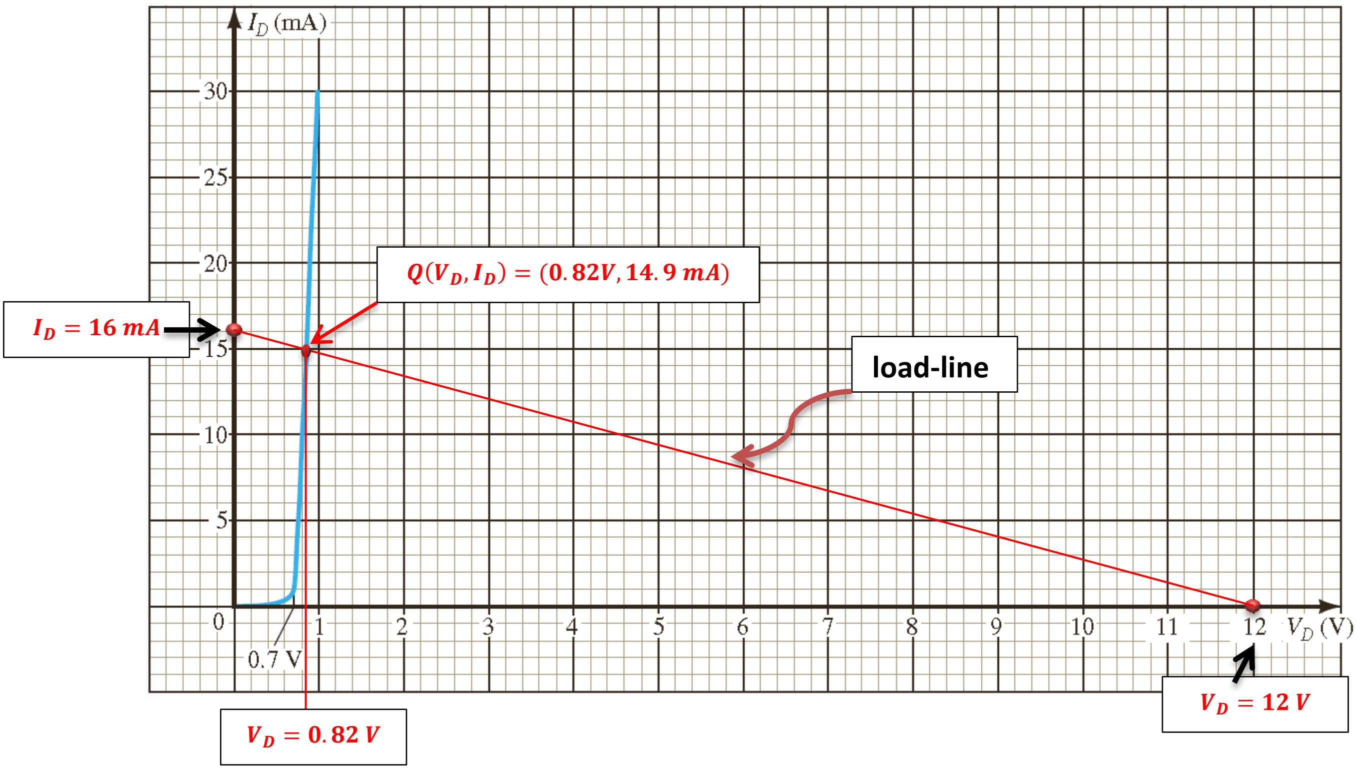
Finding the intersection point at the x-axis ($\boldsymbol{V_D}$ axis)**:** for this, we must set $I_D = 0$ in (1), thus,

$$-E + V_D + R(0) = 0 \text{ -> then } \boldsymbol{V_D = E} \;\; (3)$$

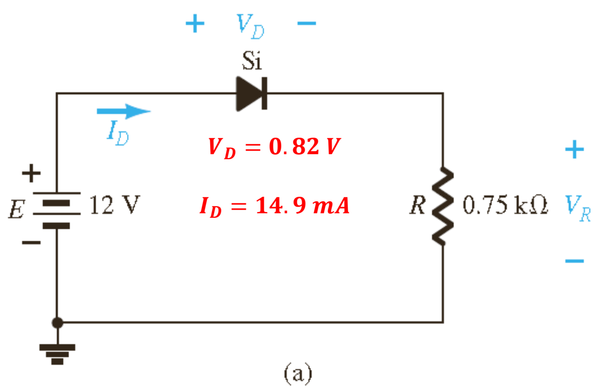
Let us now mark those points determined by (2) and (3) which are, $\boldsymbol{I_D = \frac{E}{R} = \frac{12}{0.75\ k\Omega} = 16\ mA}$ **and** $\boldsymbol{V_D = E = 12\ V}$. Please have a look at the graph below to see these points. Now, draw the **load-line** from one point to the other.

Finding Operating Point: It is so easy ! As you see from the plot, the operating point (**Q-point**) is the point where **load-line** and the **diode curve** intersect. As you see, it is the point where the vertical line of $\boldsymbol{V_D = 0.82V}$ and the horizontal line of $\boldsymbol{I_D = 14.9\ mA}$ intersect. Therefore, the Q point is

$$\boldsymbol{Q(V_D, I_D) = (0.82V, 14.9\ mA)}$$



Finding I_D, V_D, and V_R for the circuit of Fig. 2.a using the characteristics: It is very easy ! Let us write the Q-point values on the schematic as follows:



(a)

If we write the equation by KVL, $-E + V_D + V_R = 0.$

Finding V_R from this equation gives us $V_R = E - V_D = 12 - 0.82 = 11.18\,V$

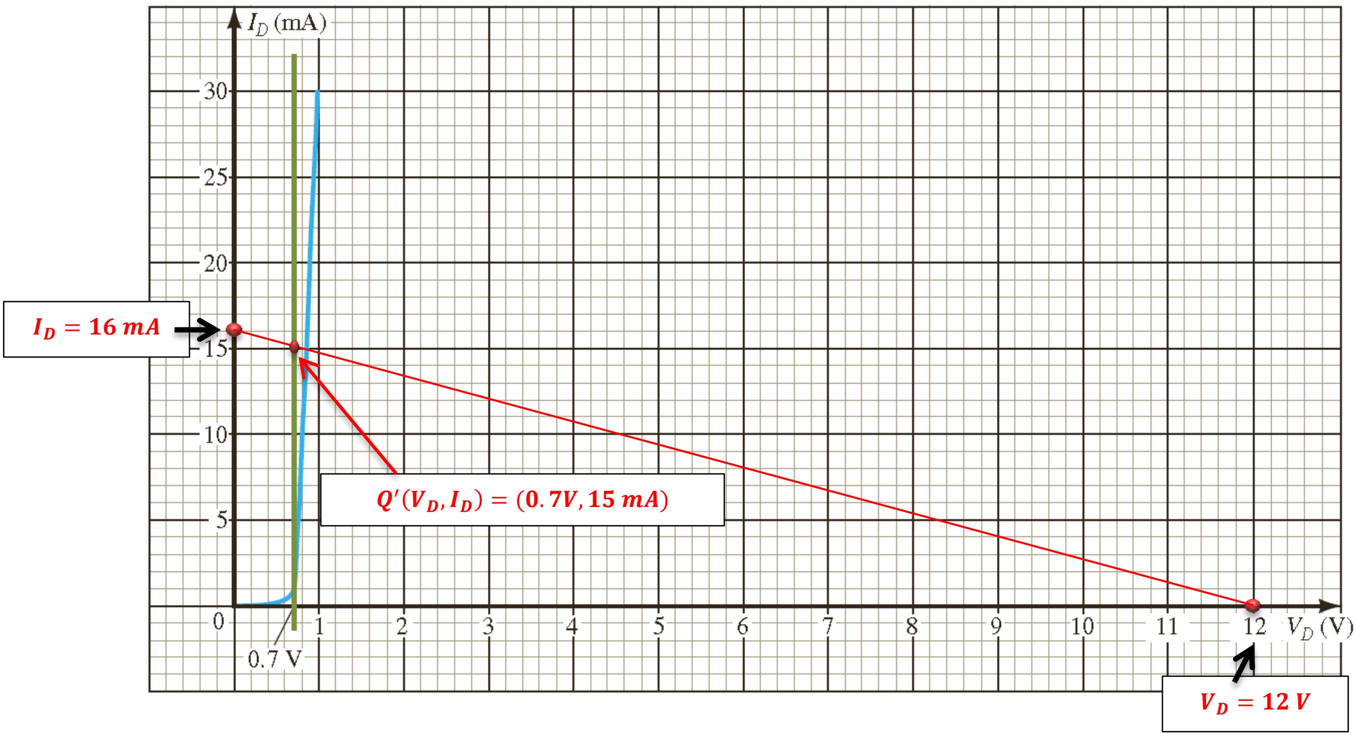
The current **I_R that is flowing thru R, hence, is found to be $I_R = \frac{V_R}{R} = \frac{11.18}{0.75\,k\Omega} = 14.907\,mA.$**

As you see, this value of I_R current is very very close (almost equal) to the diode current $I_D = 14.900\,mA$ read from the plot at the Q-point.

As a result the found values are as filled in the table follows:

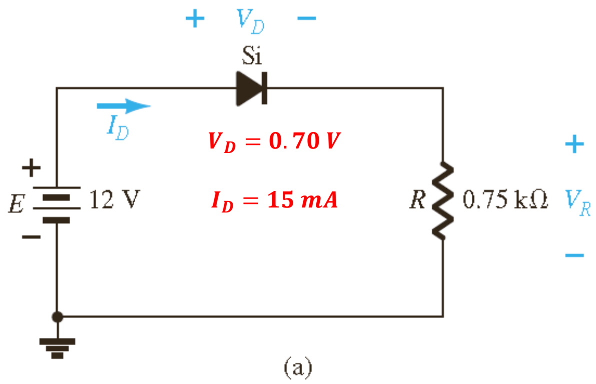
Diode model	*I_D (mA)*	*V_D (V)*	*V_R (V)*
Original model	14.9	0.82	11.18

b) Repeat part (a) using the approximate model for the diode, and compare results.
For this, we draw the **"approximate model for the diode"** on the same plot as follows. The **approximate model is formed by a vertical line (the green line on the plot) that intersects the x-axis at $V_D = 0.7\,V$.**



From the above plot, we see that the operating point Q' for the approximate model is read as $Q'(V_D, I_D) = (0.7V, 15\,mA)$

Finding I_D , V_D , and V_R for the circuit using the characteristics: Let us write the Q'-point values on the schematic as follows:



(a)

$$V_R = E - V_D = 12 - 0.70 = 11.30\ V$$

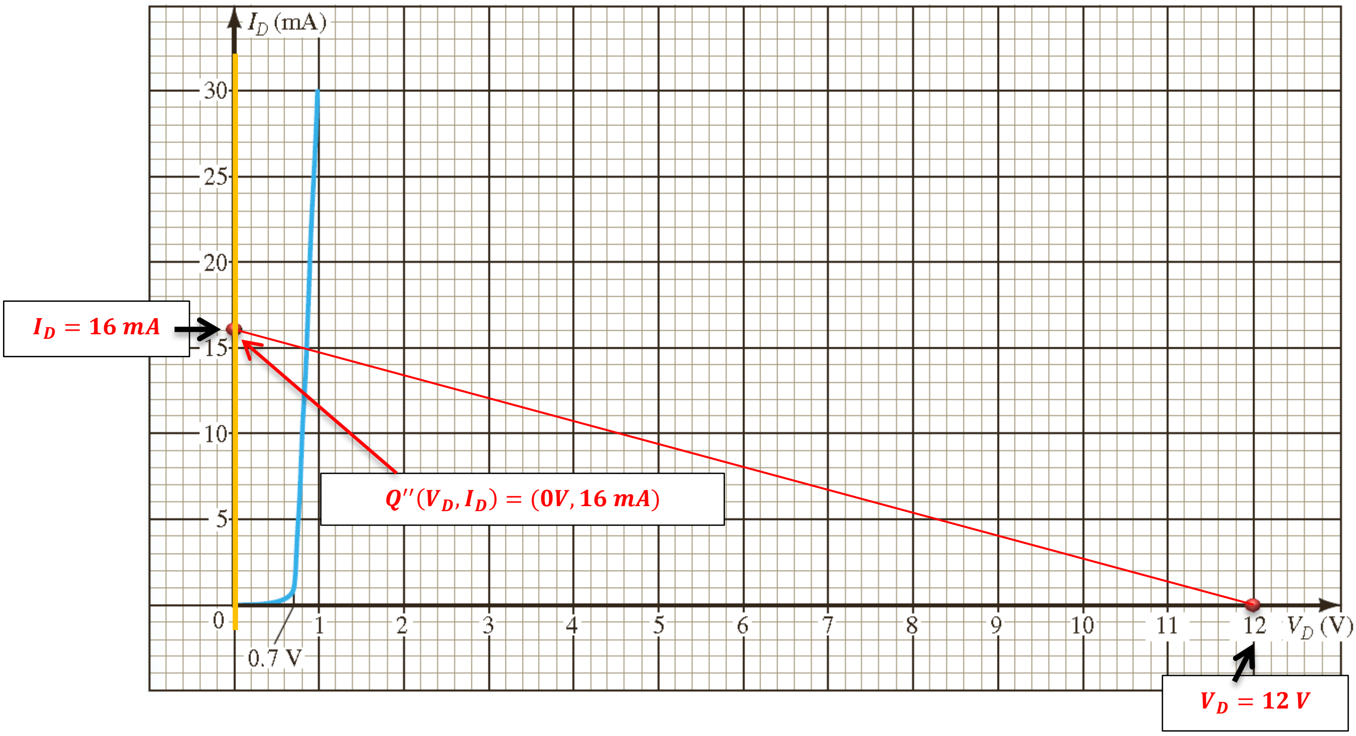
$$I_R = \frac{V_R}{R} = \frac{11.30}{0.75\ k\Omega} = 14.933\ mA.$$

As you see, this value of I_R current is very very close (almost equal) to the diode current $I_D = 15\ mA$ read from the plot at the Q'-point.

As a result the, found values are as follows:

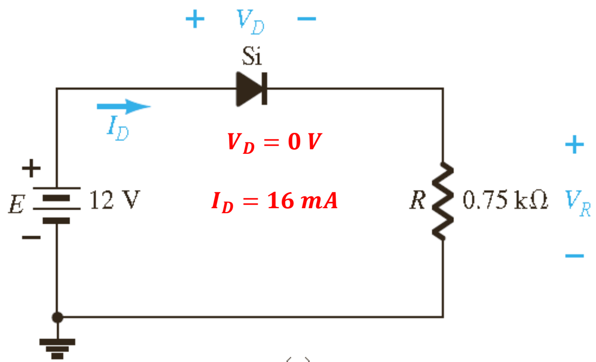
Diode model	*I_D (mA)*	*V_D (V)*	*V_R (V)*
Original model	14.9	0.82	11.18
Approximate model	15	0.70	11.30

c) Repeat part (a) using the **ideal model** for the diode, and compare results.
For this, we draw the **"ideal model for the diode"** on the same plot as follows. The **ideal model is formed by a vertical line** (**the orange line on the plot**) **that intersects the x-axis at $V_D = 0\ V$.**



From the above plot, we see that the operating point Q'' for the ideal model is read as $Q''(V_D, I_D) = (0V, 16\ mA)$

Finding I_D , V_D , and V_R for the circuit using the characteristics: Let us write the Q''-point values on the schematic as follows:



(a)

$$V_R = E - V_D = 12 - 0 = 12\ V$$

$$I_R = \frac{V_R}{R} = \frac{12}{0.75\ k\Omega} = 16\ mA.$$

As you see, this value of I_R current is the same as the diode current $I_D = 16\ mA$ read from the plot at the Q''-point.

As a result the, found values are as follows:

Diode model	I_D *(mA)*	V_D *(V)*	V_R *(V)*
Original model	14.9	0.82	11.18
Approximate model	15	0.70	11.30
İdeal model	16	0	12

Conclusion: All three diode models give reasonably close results. They can be used in solving diode circuits.