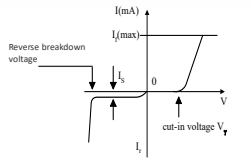
Voltage vs Current Characteristics



V - I characteristics of a diode

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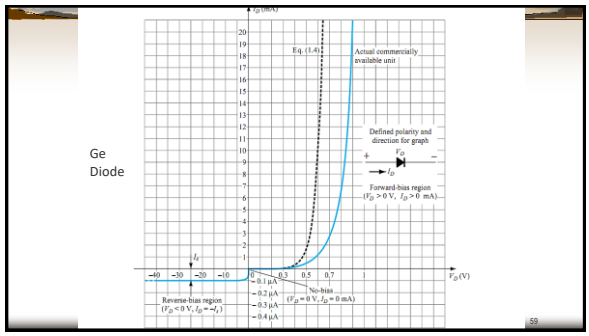

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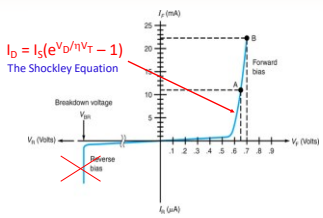
V-I Characteristic Curve



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The Shockley Equation

$$I_D = I_S(e^{V_D/\eta V_T} - 1)$$

- V_T is the thermal equivalent voltage. The equation to find V_T at various temperatures is:

$$V_T = \frac{KT}{q} \qquad \Rightarrow V_T = \frac{1.38 \times 10^{-23} \times 300}{1.6 \times 10^{-19}} = 2.6 \times 10^{-2} \text{Volt}$$

K = 1.38 x 10^{-23} J/K T = temperature in Kelvin q = 1.6 x 10^{-19} C

- V_T is approximately 26 mV at room temperature.

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The Shockley Equation

$$I_D = I_S(e^{V_D/\eta V_T} - 1)$$

- η is the emission coefficient(ideality/quality factor) of the diode. For a silicon diode η is around 1.
- When current is lowered it may rise above 1; even up to 2 in some diodes.
- It is determined by the way the diode is constructed. It also varies slightly with diode current.

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Use of Shockley Equation

If the Reverse saturation current of a given diode is 0.1 nA what will be the diode current when the forward voltage drop of the diode is 0.1V at 300K?

$$I = I_S(e^{\frac{V_D}{\eta V_T}} - 1)$$

$$\Rightarrow I = 1 \times 10^{-10} \times (e^{\frac{0.1}{2 \cdot 2.6 \cdot 10^{-2}}} - 1)$$

$$\Rightarrow 4.66 \times 10^{-9} A$$

Approximation...

$$I_D \approx I_S e^{V_D/\eta V_T}$$

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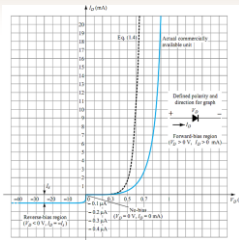
Resistances of a Diode



DC or static	$R_D = \frac{V_D}{I_D}$	Defined as a *point* on the characteristics
AC or dynamic	$r_d = \frac{\Delta V_d}{\Delta I_d} = \frac{26\text{ mV}}{I_D}$	Defined by a tangent line at the *Q*-point
Average ac	$r_{ac} = \frac{\Delta V_d}{\Delta I_d}$ p. to p.	Defined by a straight line between limits of operation

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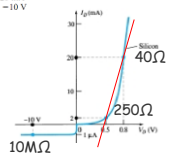
Exercise : DC Resistance of a Diode

Determine the dc resistance levels for the diode of Fig.
(a) $I_D = 2$ mA
(b) $I_D = 20$ mA
(c) $V_D = -10$ V



Exercise...
Find Average Resistance between the two points...

$$r_{av} = \left.\frac{\Delta V_d}{\Delta I_d}\right|_{\text{pt. to pt.}}$$

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Dynamic Resistance (rd)

$$I_D = I_S(e^{V_D/\eta V_T} - 1)$$

$$I = I_S\left[e^{\frac{V}{\eta V_T}} - 1\right]$$

$$\frac{dI}{dV} = I_S\left[\frac{1}{\eta V_T}e^{\frac{V}{\eta V_T}}\right]$$

$$\frac{dI}{dV} = \frac{I_S\, e^{\frac{V}{\eta V_T}}}{\eta V_T} = \frac{I}{\eta V_T}$$

$\frac{\eta V_T}{I_D}$

$$\frac{dV}{dI} = \frac{\eta V_T}{I}$$

$$\frac{dV_D}{dI_D} \cong \frac{0.026}{I_D}$$

$$r_d = \frac{26\text{ mV}}{I_D}$$ Ge,Si

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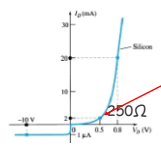
Exercise : DC Resistance of a Diode



Exercise...
Find Dynamic Resistance

$$\frac{dV_D}{dI_D} \cong \frac{0.026}{I_D}$$

$$r_d = \frac{26\text{ mV}}{I_D}$$ Ge,Si

Find average resistance between the two points.

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Block Resistance (r'd)

$$r'_d = \frac{26\text{ mV}}{I_D} + r_B$$

Resistance of the semiconductor material and the contact resistances at the terminals.

Typical value: 0.1 Ω for high power diodes
2 Ω for low power diodes

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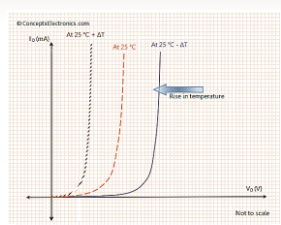
Effect of Temperature



Effect of temperature on forward characteristics

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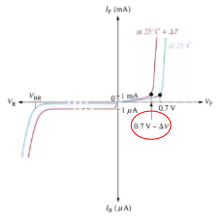
Effect of Temperature



The curve shifts to the left at the rate of -2.5 mV per degree centigrade change in temperature.

Eg. If the temperature increases from room temperature (25° C) to 80° C, the voltage would drop by...

(80-25) x 2.5 mV = 137.5 mV.

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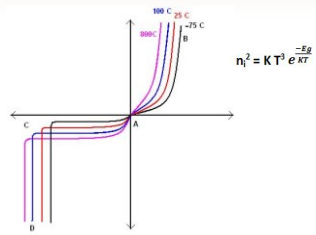
Effect of Temperature



$$n_i^2 = K T^3 e^{\frac{-Eg}{KT}}$$

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Effect of Temperature on Reverse Saturation Current

- Si Diode
  - 7% increase per degree C
  - Doubles at every 10 degree C increase

$$I_{02} = I_{01}\, x\, 2^{\left[\frac{T_2 - T_1}{10}\right]}$$

- Ge Diode
  - 12% increase per degree C
  - Doubles at every 6 degree C increase

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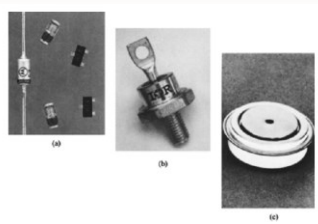
Diodes made for handling different power levels



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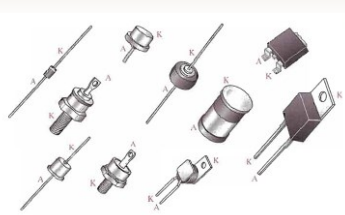
Appearance...



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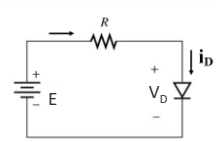
Circuit Solutions



$$E - V_D - V_R = 0$$

$$E = V_D + I_D R$$

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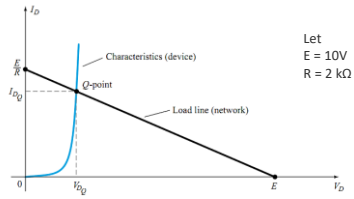
DC Load Line and the Operating Point



Let
E = 10V
R = 2 kΩ

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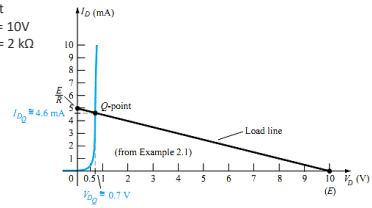
DC Load Line and the Operating Point

Let
E = 10V
R = 2 kΩ



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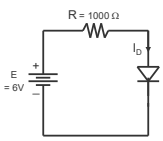
Graphical Solution for the Q Point

Tutorial Question :

Find the equation of the DC load line.



$$I_D = \frac{E - V_D}{R}$$

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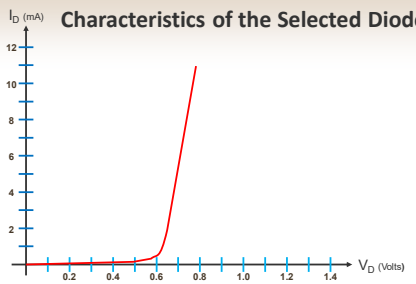
Characteristics of the Selected Diode



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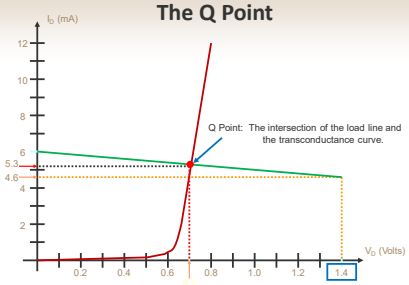
The Q Point



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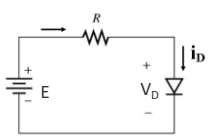
Mathematical Solution



$$E - V_D - V_R = 0$$

$$E - V_D - I_D R$$

$$I = I_S\left[e^{\frac{V_D}{\eta V_T}} - 1\right]$$

$$I = I_S\left[e^{\frac{V_D}{\eta V_T}} - 1\right]$$

$$\frac{I}{I_S} = e^{\frac{V_D}{\eta V_T}} - 1$$

$$\frac{I}{I_S} + 1 = e^{\frac{V_D}{\eta V_T}}$$

$$\frac{V_D}{\eta V_T} = \ln\left[\frac{I}{I_S} + 1\right]$$

$$V_D = \eta V_T \ln\left[\frac{I}{I_S} + 1\right]$$

$$V_D + IR = E$$

$$I = \frac{E - V_D}{R}$$

$$V_D = \eta V_T \ln\left[\frac{I}{I_S} + 1\right]$$

$$V_D = \eta V_T \ln\left[\frac{(E - V_D)}{R.I_S} + 1\right]$$

Iterative Solution

Or use Lambert W function (Omega function) to get the explicit solution

https://en.wikipedia.org/wiki/Diode_modelling#Iterative_solution

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