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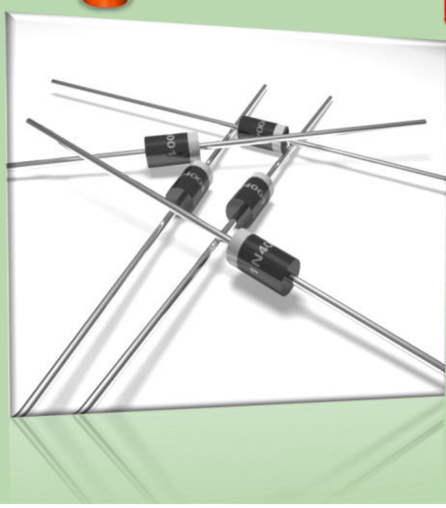


Electronic Fundamentals

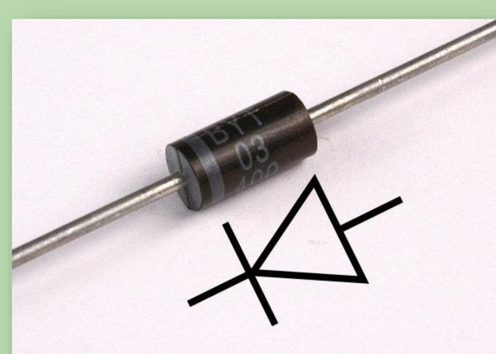
Circuits, Devices, and Applications

Diodes and Applications

Diode Models

Diodes and Applications

- Diode Operation
- *V-I* Characteristics of a Diode
- Diode Models
- Half-Wave and Full-Wave Rectifiers
- Power Supply Filters and Regulators
- Diode Limiters and Clampers
- Voltage Multipliers

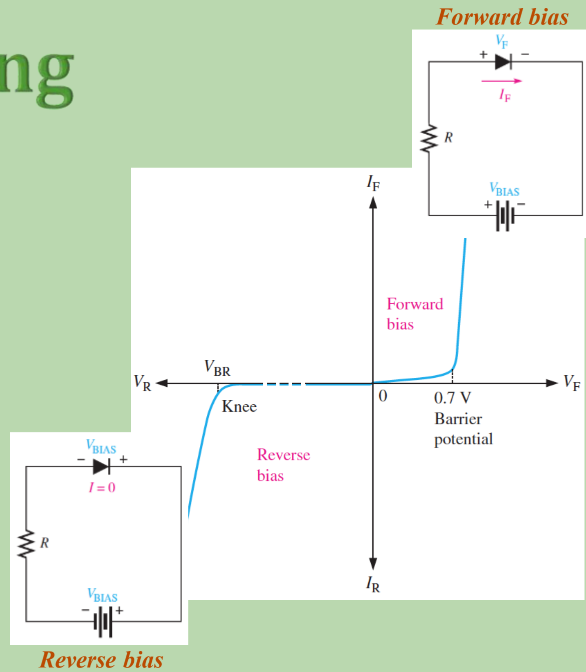


Diode modelling

In electronics, **diode modelling** refers to the mathematical models used to approximate the actual behavior of **real diodes** to enable calculations and circuit analysis.

A diode's I-V curve is nonlinear (it is well described by the Shockley diode law).

This nonlinearity complicates calculations in circuits involving diodes so simpler models are often required.



Shockley diode model

The Shockley diode equation relates the diode current (I_D) of a p-n junction diode to the diode voltage (V_D). This relationship is the diode *I-V characteristic*:

$$I_D = I_s(e^{kV_D/T_K} - 1)$$

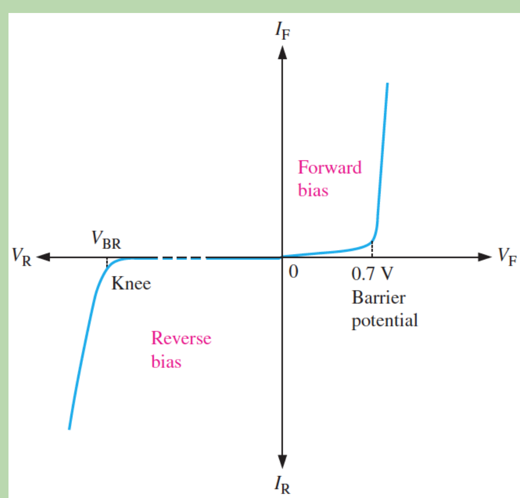
I_s = reverse saturation current

k = 11,600/η

η = 1 for Ge and **η = 2** for Si for below the knee of the curve,

η = 1 for both Ge and Si above the knee.

$T_K = T_C + 273^o$



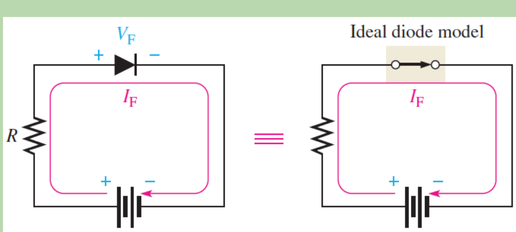
Diode Models

Diode Approximations
- *The Ideal Diode Model*
- *The Practical Diode Model*
- *The Complete Diode Model*

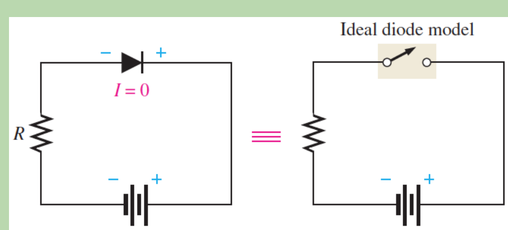
Barrier potential | **Reverse current** | **Dynamic resistance**

The Ideal Diode Model

- The ideal model of a diode is the least accurate approximation and can be represented by a **simple switch**.
- When the diode is forward-biased, it ideally acts like a closed (on) switch
- When the diode is reverse-biased, it ideally acts like an open (off) switch.



Forward bias



Reverse bias

The diode is assumed to have a zero voltage across it when forward-biased, as indicated by the portion of the curve on the positive vertical axis.

$$V_F = 0\ V$$

The forward current is determined by the bias voltage and the limiting resistor using Ohm's law.

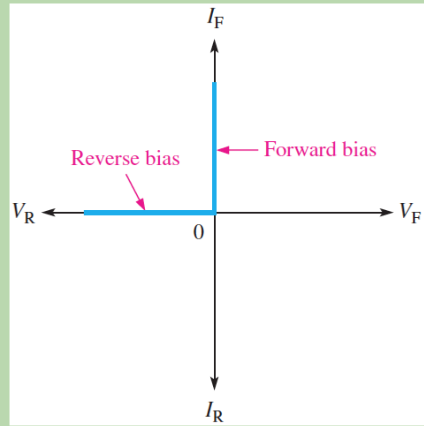
$$I_F = \frac{V_{BIAS}}{R_{LIMIT}}$$

The reverse current is neglected

$$I_R = 0\ A$$

The reverse voltage equals the bias voltage.

$$V_R = V_{BIAS}$$



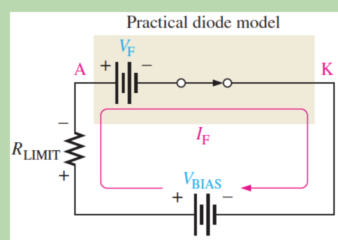
Ideal V-I characteristic curve

The Practical Diode Model

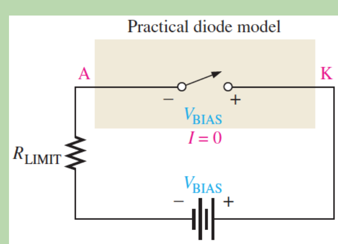
- The practical model includes the **barrier potential**.
- When the diode is **forward-biased**, it is equivalent to a closed switch in series with a small equivalent voltage source (V_F) equal to the barrier potential (0.7 V) with the positive side toward the anode.

Note: This equivalent voltage source represents the **barrier potential** that must be exceeded by the bias voltage before the diode will conduct and **is not an active source of voltage.**

- When conducting, a voltage drop of 0.7 V appears across the diode.
- When the diode is **reverse-biased**, it is equivalent to an open switch just as in the ideal model.



Forward bias



Reverse bias

Since the **barrier potential** is included, the diode is assumed to have a voltage across it when forward-biased, as indicated by the portion of the curve to the right of the origin.

$$V_F = 0.7V$$

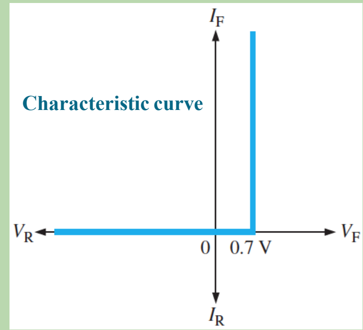
The **forward current** is determined as follows by first applying Kirchhoff's voltage law

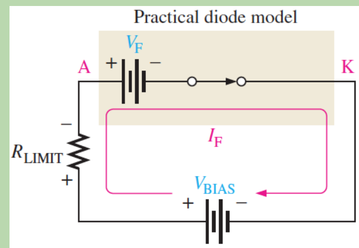
$$I_F = \frac{V_{BIAS} - V_F}{R_{LIMIT}}$$

The diode is assumed to have zero reverse current, as indicated by the portion of the curve on the negative horizontal axis.

$$I_R = 0\text{ A}$$

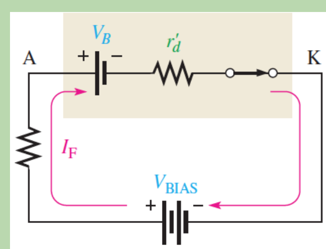
$$V_R = V_{BIAS}$$

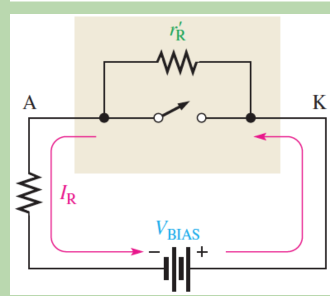




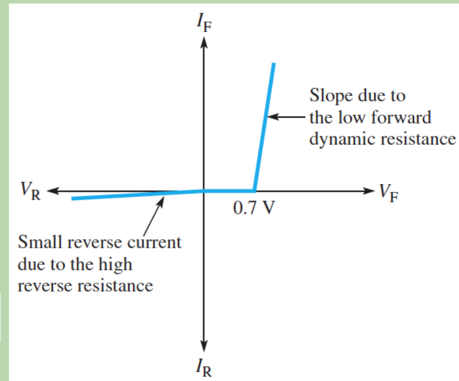
The Complete Diode Model

- When the diode is forward-biased, it acts as a closed switch in series with the equivalent **barrier potential voltage (V_B)** and the small forward **dynamic resistance (r'_d)**.
- When the diode is reverse-biased, it acts as an open switch in parallel with the large internal reverse resistance (r'_R).
- The barrier potential does not affect reverse bias, so it is not a factor.



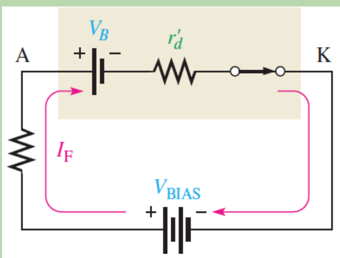


The curve slopes because the voltage drop due to dynamic resistance increases as the current increases.



The characteristic curve for the complete diode model

$$V_F = 0.7\text{ V} + I_F r'_d$$

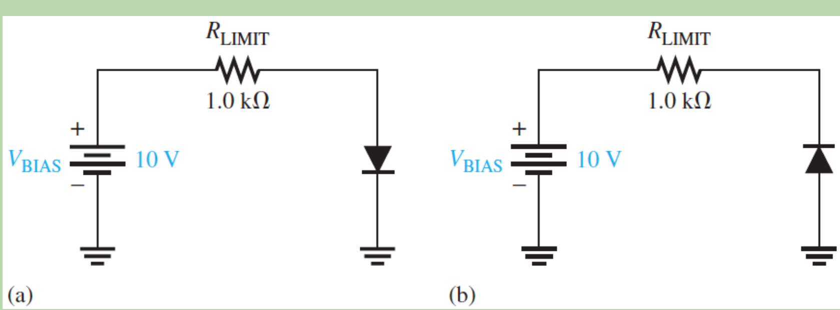


$$I_F = \frac{V_{BIAS} - 0.7\text{ V}}{R_{LIMIT} + r'_d}$$

Example

(a) Determine the **forward voltage** and **forward current** for the diode in Figure (a) for each of the diode models. Also find the voltage across the limiting resistor in each case. Assume r'_d = 10 ohm at the determined value of forward current.

(b) Determine the **reverse voltage** and **reverse current** for the diode in Figure (b) for each of the diode models. Also find the voltage across the limiting resistor in each case. Assume I_R = 1 *u*A.



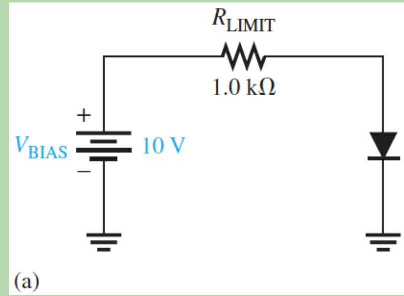
Solution (a)

- **Ideal model:**

$V_F = \mathbf{0\ V}$

$$I_F = \frac{V_{BIAS}}{R_{LIMIT}} = \frac{10\ V}{1.0\ k\Omega} = \mathbf{10\ mA}$$

$$V_{R_{LIMIT}} = I_F R_{LIMIT} = (10\ mA)(1.0\ k\Omega) = \mathbf{10\ V}$$



- **Practical model:**

$V_F = \mathbf{0.7\ V}$

$$I_F = \frac{V_{BIAS} - V_F}{R_{LIMIT}} = \frac{10\ V - 0.7\ V}{1.0\ k\Omega} = \frac{9.3\ V}{1.0\ k\Omega} = \mathbf{9.3\ mA}$$

$$V_{R_{LIMIT}} = I_F R_{LIMIT} = (9.3\ mA)(1.0\ k\Omega) = \mathbf{9.3\ V}$$

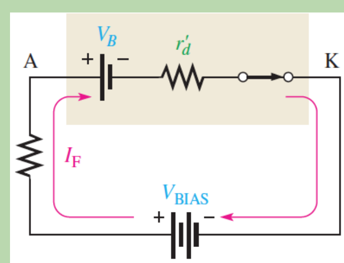
Solution (a)

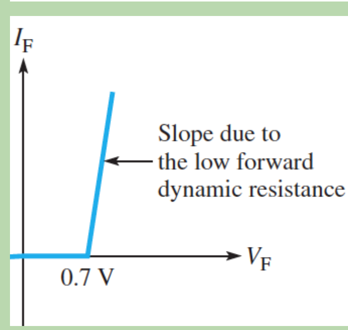
- **Complete model:**

$$I_F = \frac{V_{BIAS} - 0.7\ V}{R_{LIMIT} + r'_d} = \frac{10\ V - 0.7\ V}{1.0\ k\Omega + 10\ \Omega} = \frac{9.3\ V}{1010\ \Omega} = \mathbf{9.21\ mA}$$

$$V_F = 0.7\ V + I_F r'_d = 0.7\ V + (9.21\ mA)(10\ \Omega) = \mathbf{792\ mV}$$

$$V_{R_{LIMIT}} = I_F R_{LIMIT} = (9.21\ mA)(1.0\ k\Omega) = \mathbf{9.21\ V}$$





Solution (b)

- **Ideal model:**

$I_R = \mathbf{0\,A}$

$V_R = V_{BIAS} = \mathbf{10\,V}$

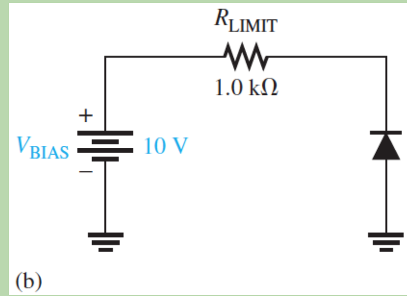
$V_{R_{LIMIT}} = \mathbf{0\,V}$

- **Practical model:**

$I_R = \mathbf{0\,A}$

$V_R = V_{BIAS} = \mathbf{10\,V}$

$V_{R_{LIMIT}} = \mathbf{0\,V}$

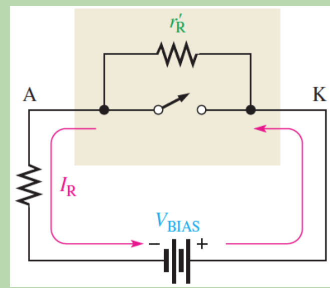


- **Complete model:**

$I_R = \mathbf{1\,\mu A}$

$V_{R_{LIMIT}} = I_R R_{LIMIT} = (1\,\mu A)(1.0\,k\Omega) = \mathbf{1\,mV}$

$V_R = V_{BIAS} - V_{R_{LIMIT}} = 10\,V - 1\,mV = \mathbf{9.999\,V}$



Exercise

1. Determine whether each silicon diode in Figure is forward-biased or reverse-biased.
2. Determine the voltage across each diode in Figure, assuming the practical model.
3. Determine the voltage across each diode in Figure, assuming an ideal diode.
4. Determine the voltage across each diode in Figure, using the complete diode model with r'_d = 10 ohm, r'_R = 100 Mohm.