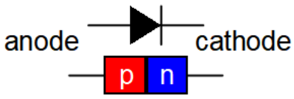
Diode

The diode is a passive, non-linear electronic component consisting of a p-n junction. The lead connected to the p junction is called the anode, while the one connected to the n junction is called the cathode. The reference of the leads on the real component is given by a black or silver line which indicates the cathode.

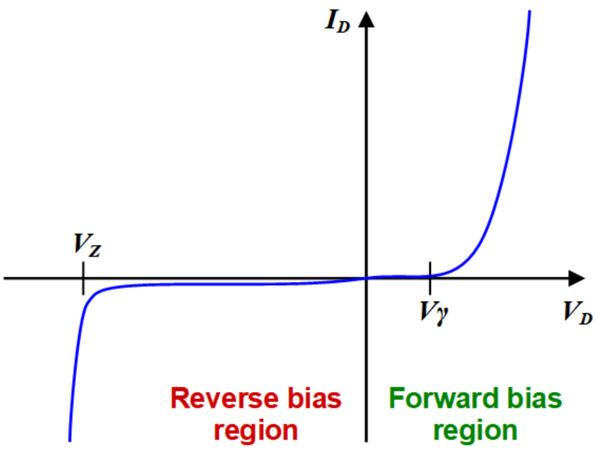
The circuit symbol is:



Similarly to the operating principle of the p-n junction, the ideal function of the diode is to allow the flow of electric current from the anode to the cathode and to block it in the opposite direction. The diode conducts electric current if the voltage at its ends, or the voltage on the anode with respect to the cathode, is positive.

Therefore, the diode is said to be forward-biased if the voltage on the anode with respect to the cathode is positive, while it is said reverse-biased if the voltage on the anode with respect to the cathode is negative.

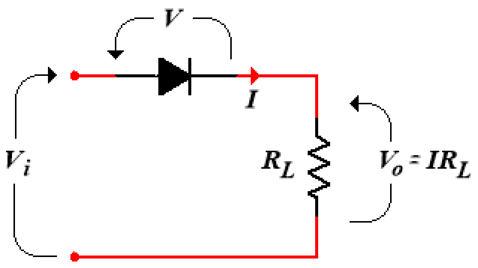
The real behavior of a diode is represented by the volt-amperometric characteristic curve. It graphically expresses the trend of the current in the diode (I_D) as the voltage between the anode and cathode (V_D) varies.



For positive voltages of V_D, the diode conducts electric current in an appreciable way only if the voltage V_D exceeds the threshold voltage ($V\gamma$). The threshold voltage value depends on the semiconductor used and is approximately 0.7V for silicon diodes and approximately 0.2V for germanium diodes.

For negative voltages of V_D, a very low reverse saturation current flows in the diode. For a given negative voltage value, breakdown voltage (V_Z), usually quite high (tens or hundreds of volts), the breakdown of the p-n junction occurs.

In the following circuit, the diode is placed in series with a load R_L and represents the simplest and most common application of this component.



To obtain the instantaneous values of the current I and of the voltage V on the diode when a given signal V_i is applied to the input, the equation on the mesh can be used:

$$V_i = V + IR_L \quad \rightarrow \quad V = V_i - IR_L$$

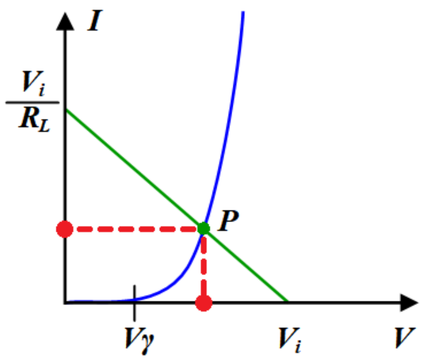
This last equation represents the load line on the diode. Rewriting it:

$$I = -\frac{1}{R_L}V + \frac{V_i}{R_L}$$

To trace the load line, we find the points of intersection with the axes by setting:

$$\begin{cases} V = 0 & \rightarrow \quad I = \dfrac{V_i}{R_L} \\ I = 0 & \rightarrow \quad V = V_i \end{cases}$$

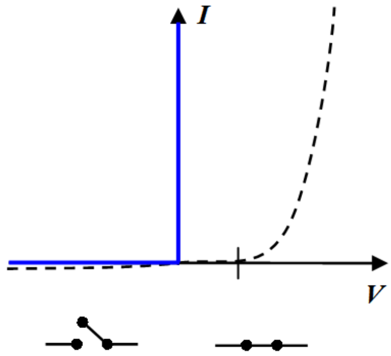
The intersection between the diode characteristic and the load line identifies the point of operation or static work (P), that is, it provides the values of I and V for that particular diode, in that circuit, with that value of R_L and with a given voltage V_i.



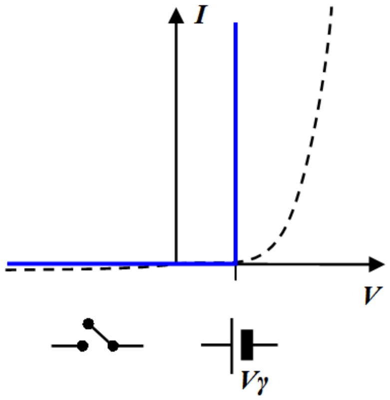
Having obtained I and V (in red) for the diode, it is now possible to calculate V_o.

The use of the diode characteristic for the circuit solution is very impractical, also because the characteristics of the real diodes are not always available.

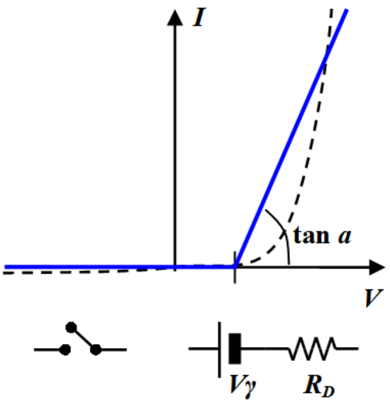
Diode circuit models are commonly used by introducing more or less drastic approximations depending on the type of application. In this way, the characteristic curve is also reduced to a broken line that interpolates the real characteristic.



Model A: diode as a switch. Having to qualitatively evaluate the operation of a circuit that includes one or more diodes, the simplest model is often used, which wants the diode in reverse bias as an open switch and the diode in forward bias as a closed switch or a short circuit.



Model B: diode as battery. While it is legitimate to consider the reverse bias diode as an open circuit, in many cases it is necessary to take into account the non-zero voltage drop (threshold voltage) across the forward bias diode. The diode in forward bias is therefore represented as a battery with a value of Vγ = 0.7V.

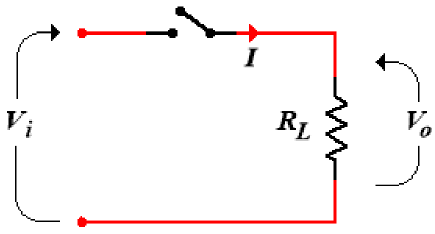


Model C: diode as battery and resistor. It is a more precise model that also allows to consider the voltage variation across the diode as the circulating current varies where Vγ = 0.7V and the resistance R_D is assigned a value ranging from a few Ω to a few tens of Ω.

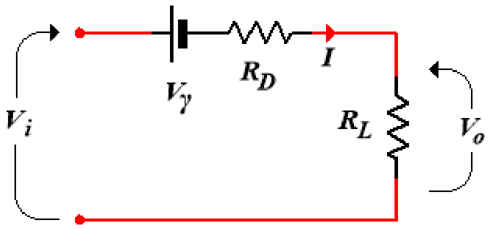
$$\tan \alpha = \frac{1}{R_D}$$

We apply model C to the previous circuit in order to avoid the calculation of the load line and simplify the study of V_o.

For $V_i < V\gamma$ the diode is reverse biased, so it is an open circuit, I = 0, $V_o = IR_L = 0$.



For $V_i \geq V\gamma$ the diode is directly biased, so $V_o = IR_L$.



Using the mesh equation, we obtain:

$$I = \frac{V_i - V_\gamma}{R_D + R_L}$$

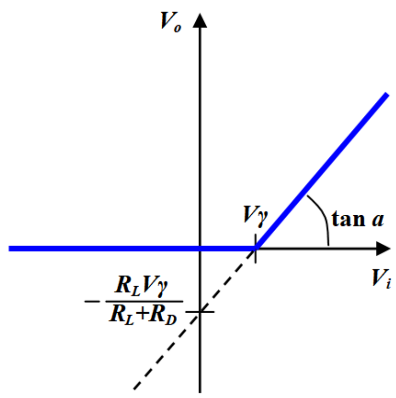
for which

$$V_o = IR_L = \frac{V_i - V_\gamma}{R_D + R_L} R_L = \left(\frac{R_L}{R_D + R_L}\right) V_i - \frac{R_L V_\gamma}{R_D + R_L}$$

The condition of $V_o = 0$ (per $V_i < V\gamma$) together with the newly obtained equation of V_o (per $V_i \geq V\gamma$), represent the trans-characteristic of the circuit, that is, they describe the value of V_o as V_i varies with the presence of the diode.

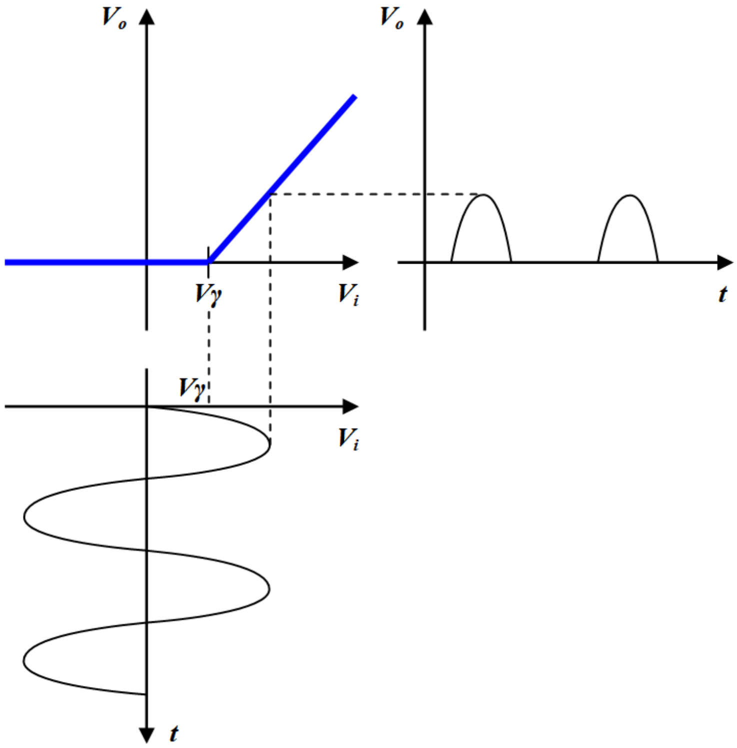
To trace the line (for $V_i \geq V\gamma$), we use the known value of Vγ as the first point (the line passes through this point as decided in model C, in fact if we set $V_o = 0$ we have $V_i = V\gamma$) and we obtain the second point by setting $V_i = 0$:

$$V_o = -\frac{R_L V_\gamma}{R_L + R_D}$$



$$\tan\alpha = \frac{R_L}{R_L + R_D}$$

If we assume the presence of a sinusoidal alternating signal at the input, the output response can be obtained through the trans-characteristic as follows:



The values of the input signal below Vγ will be canceled by the trans-characteristic. Only the pieces of positive half-waves equal to or greater than Vγ will be transferred to the output.