Diode circuits –
DC analysis and models

GOAL:

Examine dc analysis techniques for diode circuits using various models to describe the diode characteristics

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- Diode is a two-terminal device with nonlinear i–v characteristics: nonlinear circuits

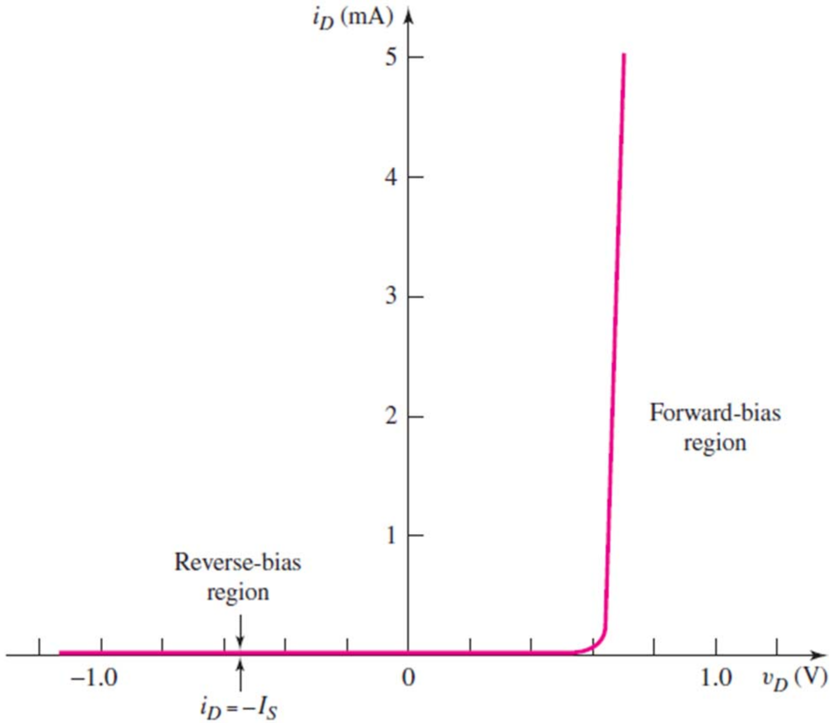
- Many electronic functions can only be implemented by nonlinear circuits such as, DC voltage generation from sinusoidal ones and implementation of logic functions

- Current-voltage characteristics of pn junction diode is considered to construct various circuit models (theoretical representation of circuit).

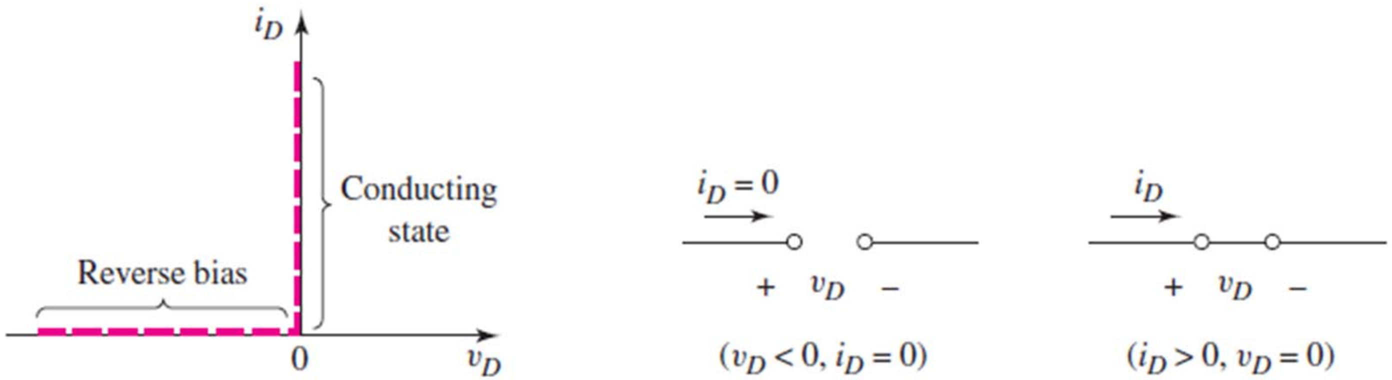
- Large signal models: considers behaviour of devices (diode) with relatively large changes in voltage and currents.

- Small signal models: considers behaviour of devices (diode) with relatively small changes in voltage and currents.

Ideal I–V characteristics of a pn-junction diode

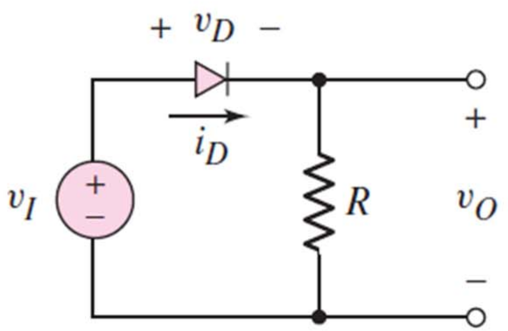


An ideal diode:

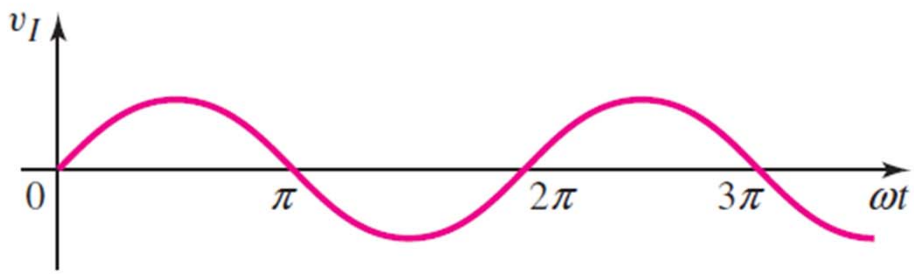


Rectifier:

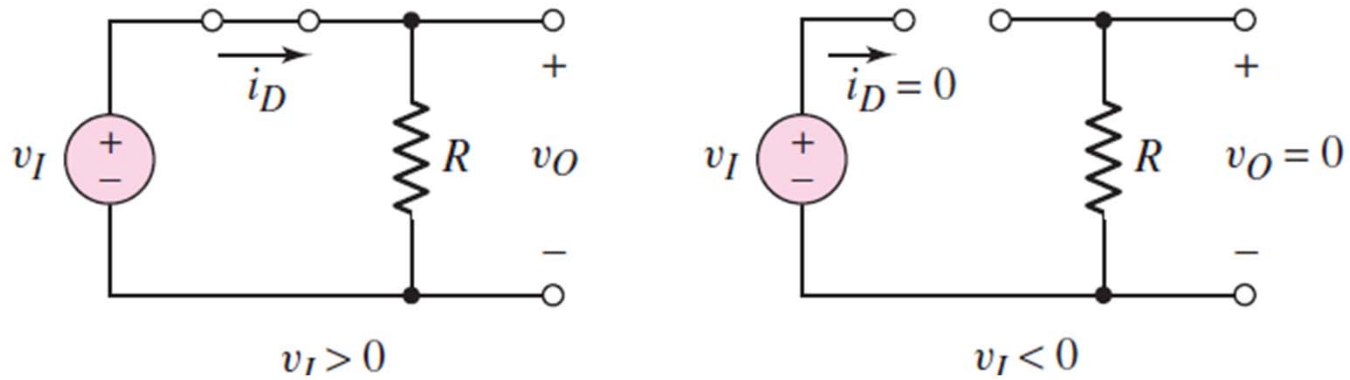
The circuit



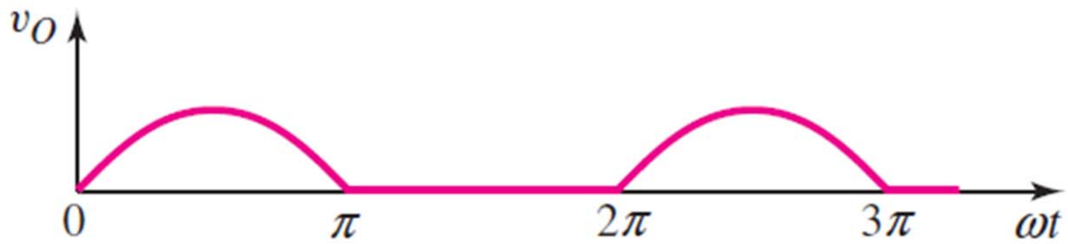
Sinusoidal voltage signal



Equivalent circuits



Output



The input signal is sinusoidal and has a zero average value; however, the output signal contains only positive values and therefore has a positive average value.

This circuit is said to rectify the input signal, which is the first step in generating a dc voltage from ac. A dc voltage is required in virtually all electronic circuits.

Four approaches to the dc analysis of diode circuits

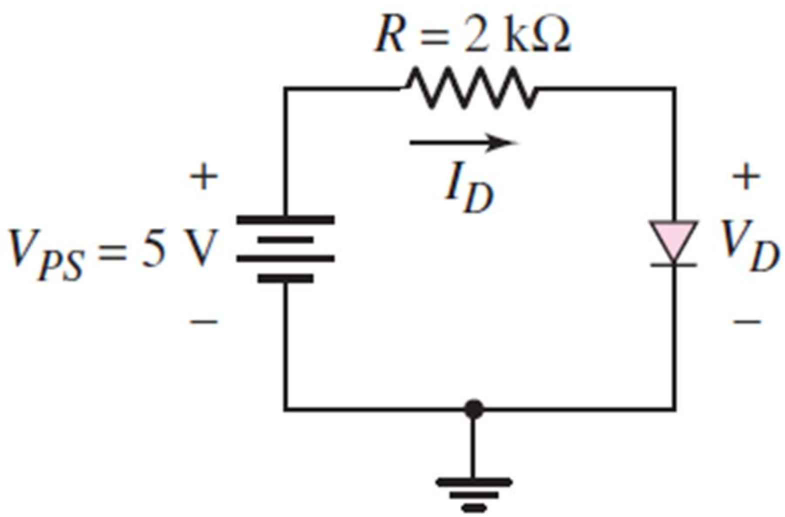
(a) iteration (b) graphical techniques

(c) a piecewise linear modelling method

(d) a computer analysis.

Iteration and Graphical Analysis Techniques:

- Iteration means using trial and error to find a solution to a problem
- Graphical analysis technique involves plotting two simultaneous equations and locating their point of intersection



Kirchhoff's voltage law-

$$V_{PS} = I_D R + V_D$$

$$I_D = \frac{V_{PS}}{R} - \frac{V_D}{R}$$

From diode characteristics:

$$I_D = I_S\left[e^{\left(\frac{V_D}{V_T}\right)} - 1\right]$$

$$V_{PS} = I_S R\left[e^{\left(\frac{V_D}{V_T}\right)} - 1\right] + V_D$$

V_D is the only unknown as I_S is considered known.
But the equation is transcendental.

$$5 = (10^{-13})(2 \times 10^3)\left[e^{\left(\frac{V_D}{0.026}\right)} - 1\right] + V_D$$

trial and error

Try V_D = 0.6 v, R.H.S is 2.7 v

Try V_D = 0.65 v, R.H.S is 15.1 v

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Try V_D = 0.619 v, R.H.S is 4.99v

Close enough

$$I_D = \frac{V_{PS} - V_D}{R} = \frac{5 - 0.619}{2} = 2.19 \text{ mA}$$

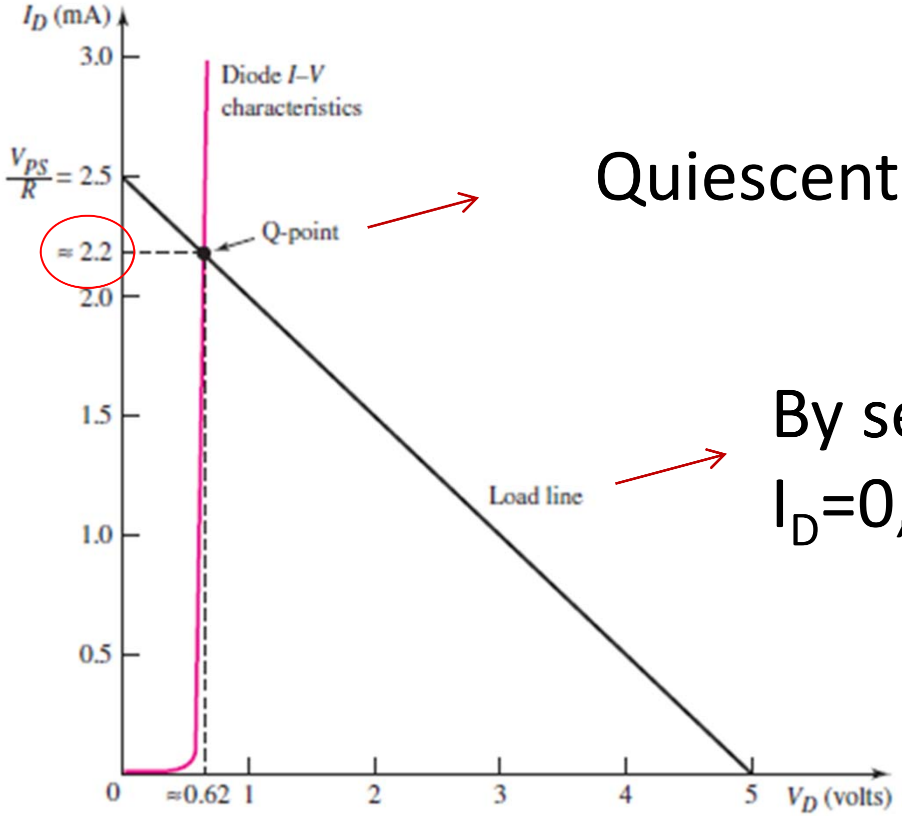
Used extensively in the analysis of diode and transistor circuits

Graphical

$$I_D = \frac{V_{PS}}{R} - \frac{V_D}{R}$$ → Circuit load line

V_D and I_D are linearly related

Graph



Quiescent point

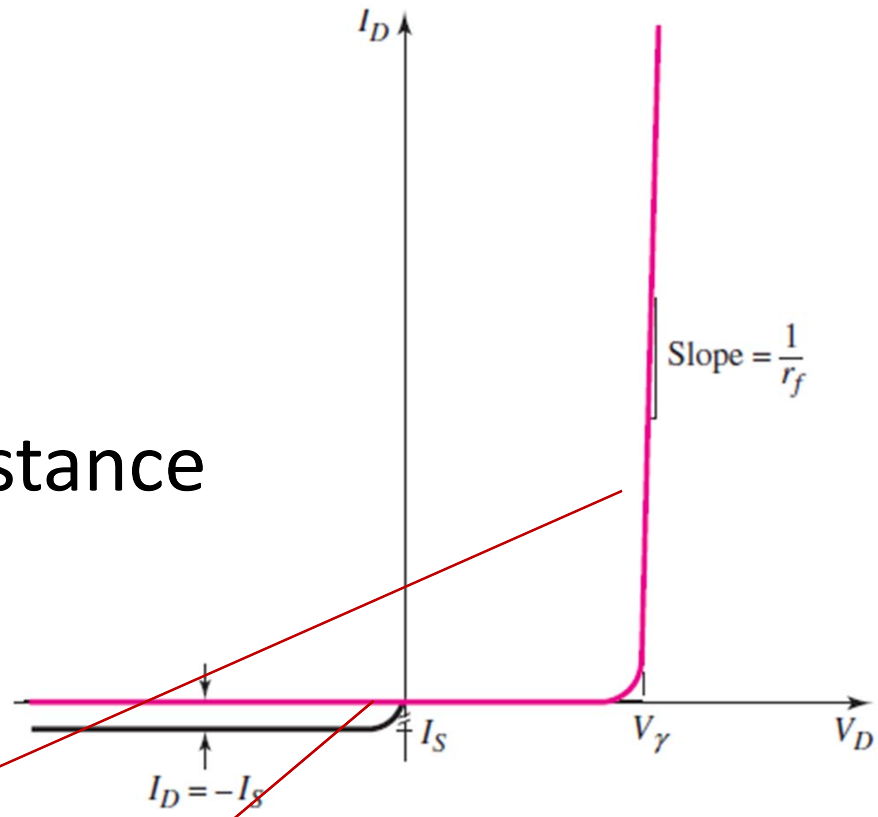
By setting $I_D=0$, $V_D=0$

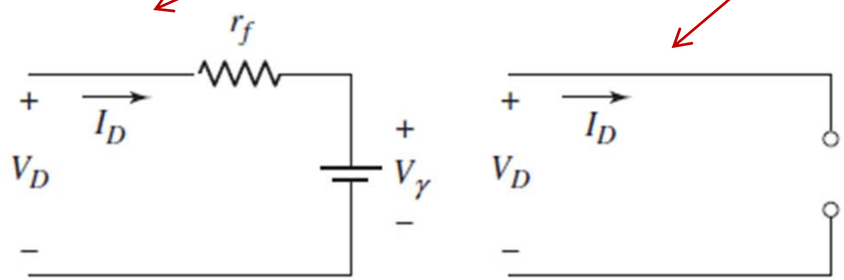
Cumbersome, but visualizing is easier

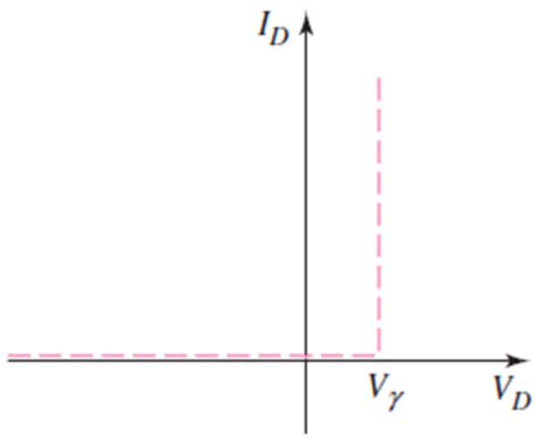
Piece-wise linear model:

V_γ →cut-in voltage

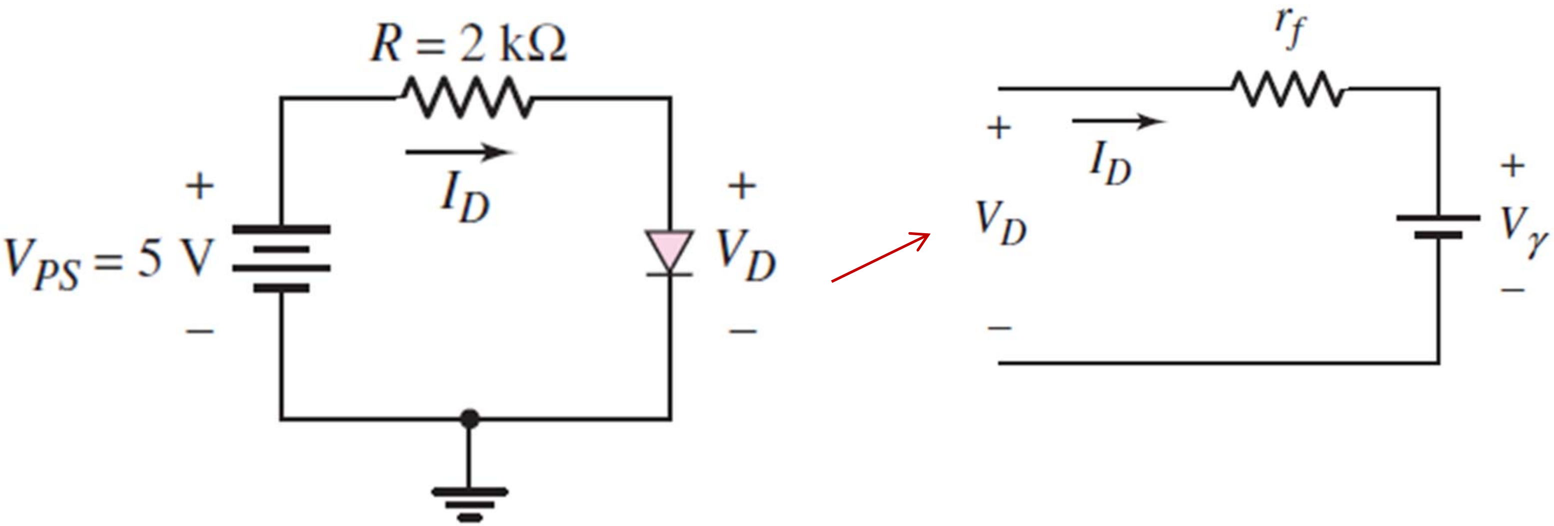
r_f →forward diode resistance







$r_f = 0$



$$I_D = \frac{V_{PS} - V_\gamma}{R + r_f} = \frac{5 - 0.6}{2 \times 10^3 + 10} \Rightarrow 2.19\,\text{mA}$$

$$V_D = V_\gamma + I_D r_f = 0.6 + (2.19 \times 10^{-3})(10) = 0.622\,\text{V}$$

$$P_D = I_D V_D$$

$$P_D = (2.19)(0.622) = 1.36\,\text{mW}$$

Resistance r_f is much smaller than the circuit resistance R, so the diode current I_D is essentially independent of the value of r_f

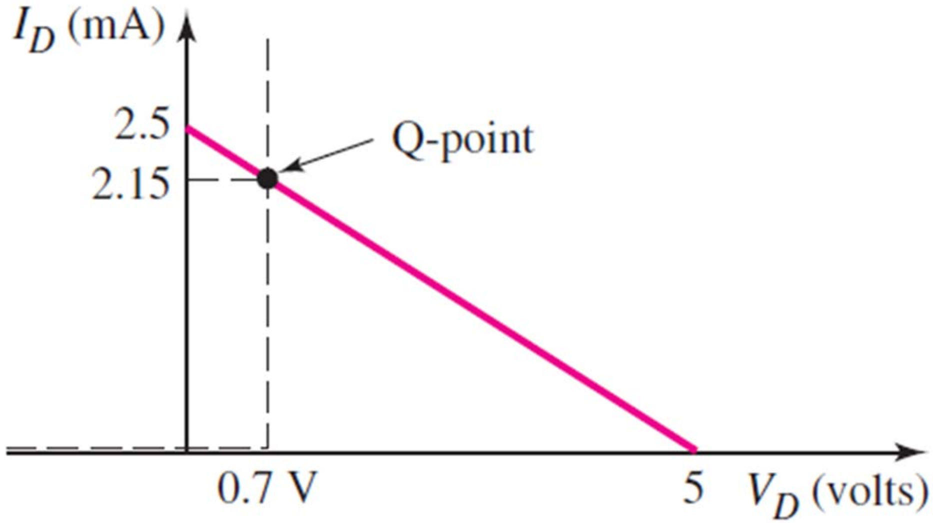
Also calculated diode current is not a strong function of the cut-in voltage. Cut-in voltage of 0.7 V is taken for silicon pn junction diodes

Load line and the piecewise linear model can be combined:

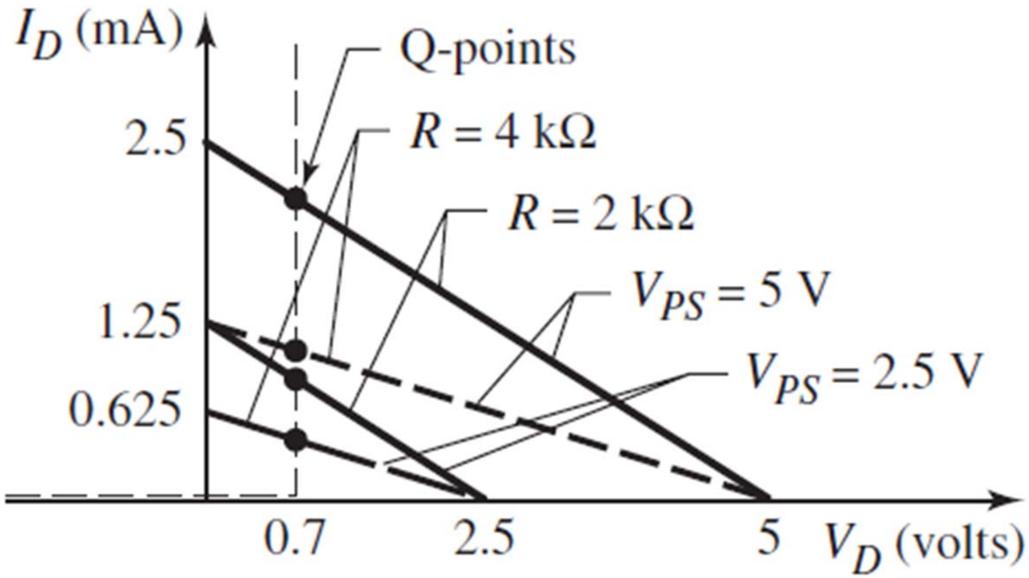
$$V_{PS} = I_D R + V_\gamma \qquad r_f = 0$$

Also represented by

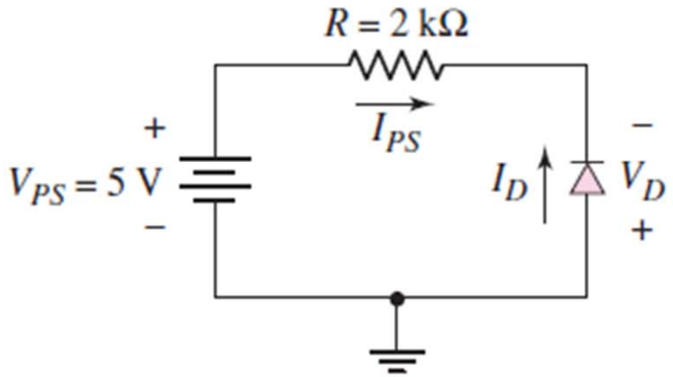
$$V_{PS} = 5\text{ V}, \quad R = 2\,\text{k}\Omega$$



Similarly:

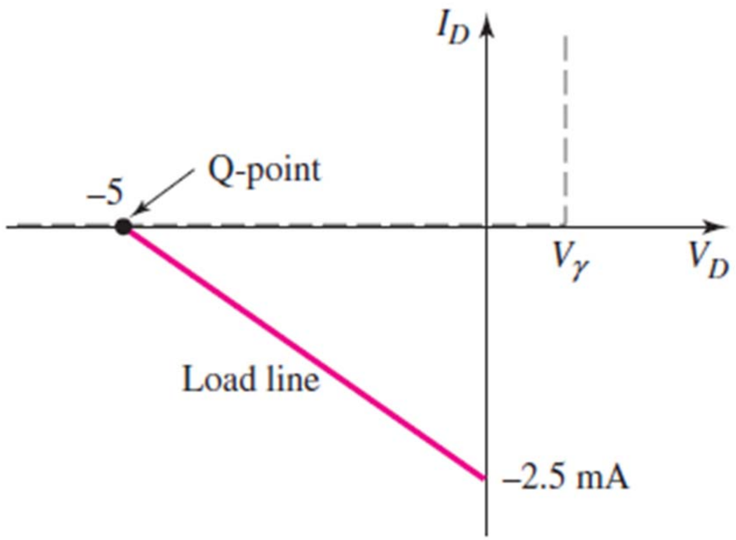


The load line concept is also useful when the diode is reverse biased.



$$V_{PS} = I_{PS}R - V_D = -I_D R - V_D$$

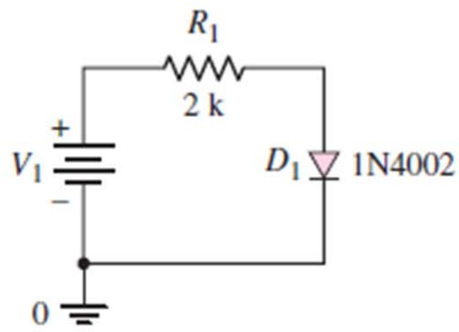
$$I_D = -\frac{V_{PS}}{R} - \frac{V_D}{R}$$



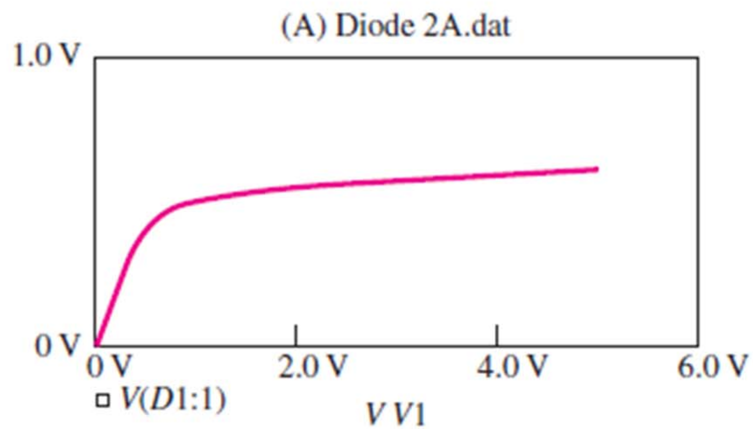
Although the piecewise linear model may yield solutions that are less accurate than those obtained with the ideal diode equation, the analysis is much easier.

Computer Simulation and Analysis

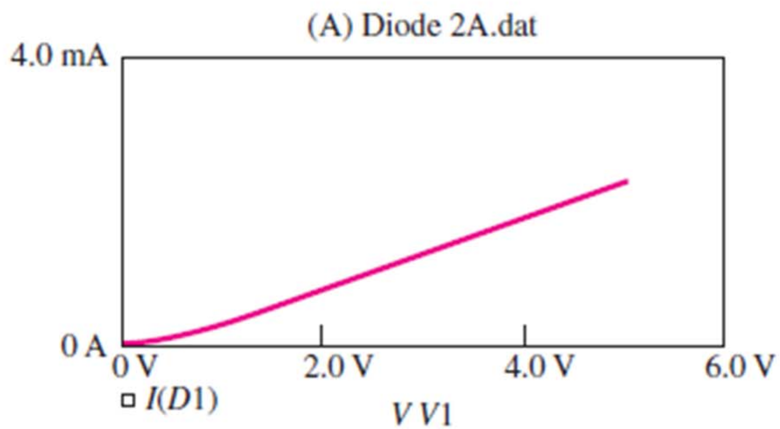
simulation program with integrated circuit emphasis (SPICE) --> PSpice



(a)



(b)



(c)

Summary:

The two dc diode models used in the hand analysis of diode circuits are: the ideal diode equation and the piecewise linear approximation.

For the ideal diode equation, the reverse-saturation current I_S must be specified. For the piecewise linear model, the cut-in voltage V_γ and forward diode resistance r_f must be specified.