Chapter 10 Diodes

Chapter 10 Diodes

1**.** Understand diode operation and select diodes for various applications.

2**.** Analyze nonlinear circuits using the graphical load-line technique.

3. Analyze and design simple voltage-regulator circuits.

4. Solve circuits using the ideal-diode model and piecewise-linear models.

5. Understand various rectifier and wave-shaping circuits.

6. Understand small-signal equivalent circuits.

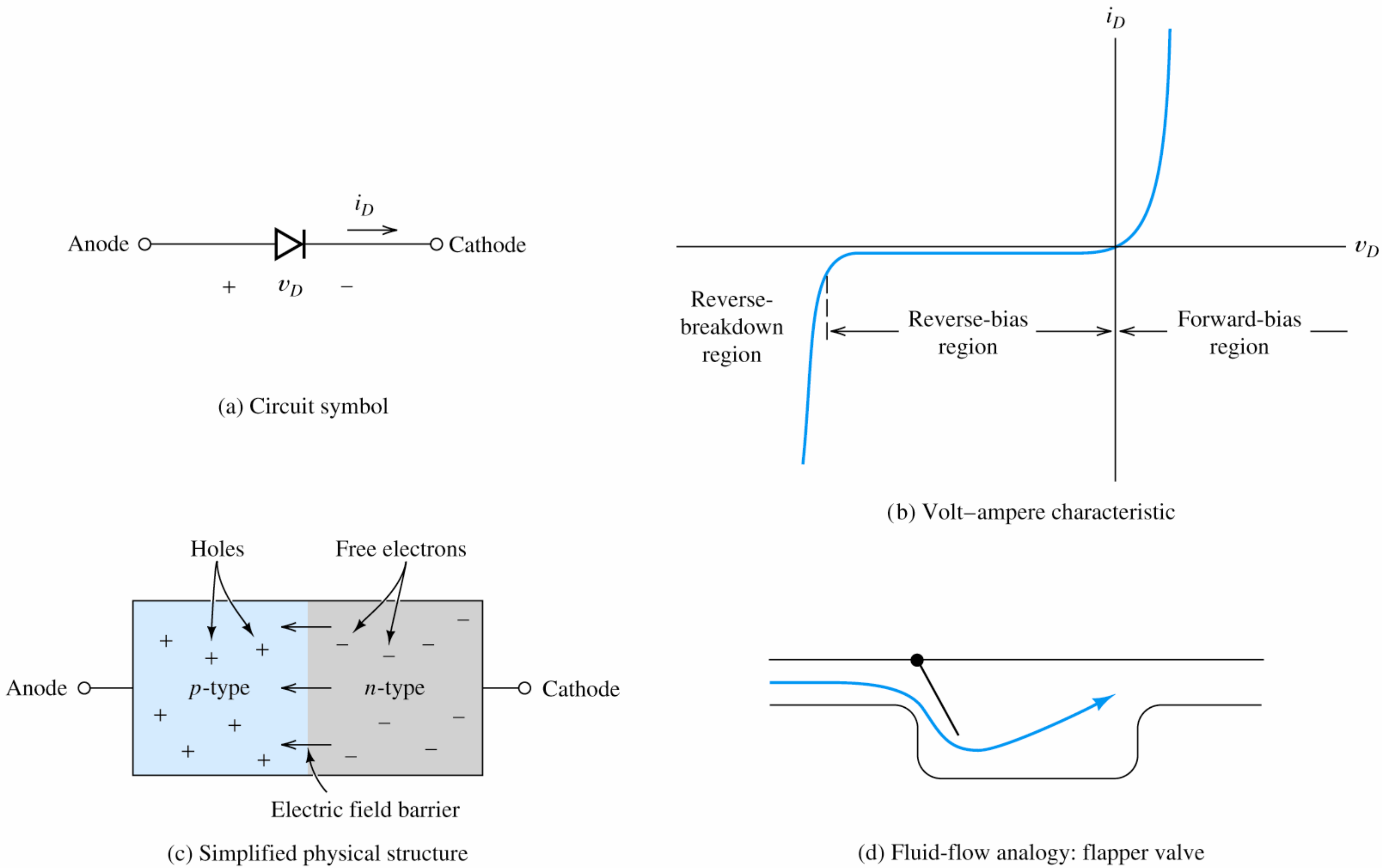


Figure 10.1 Semiconductor diode.

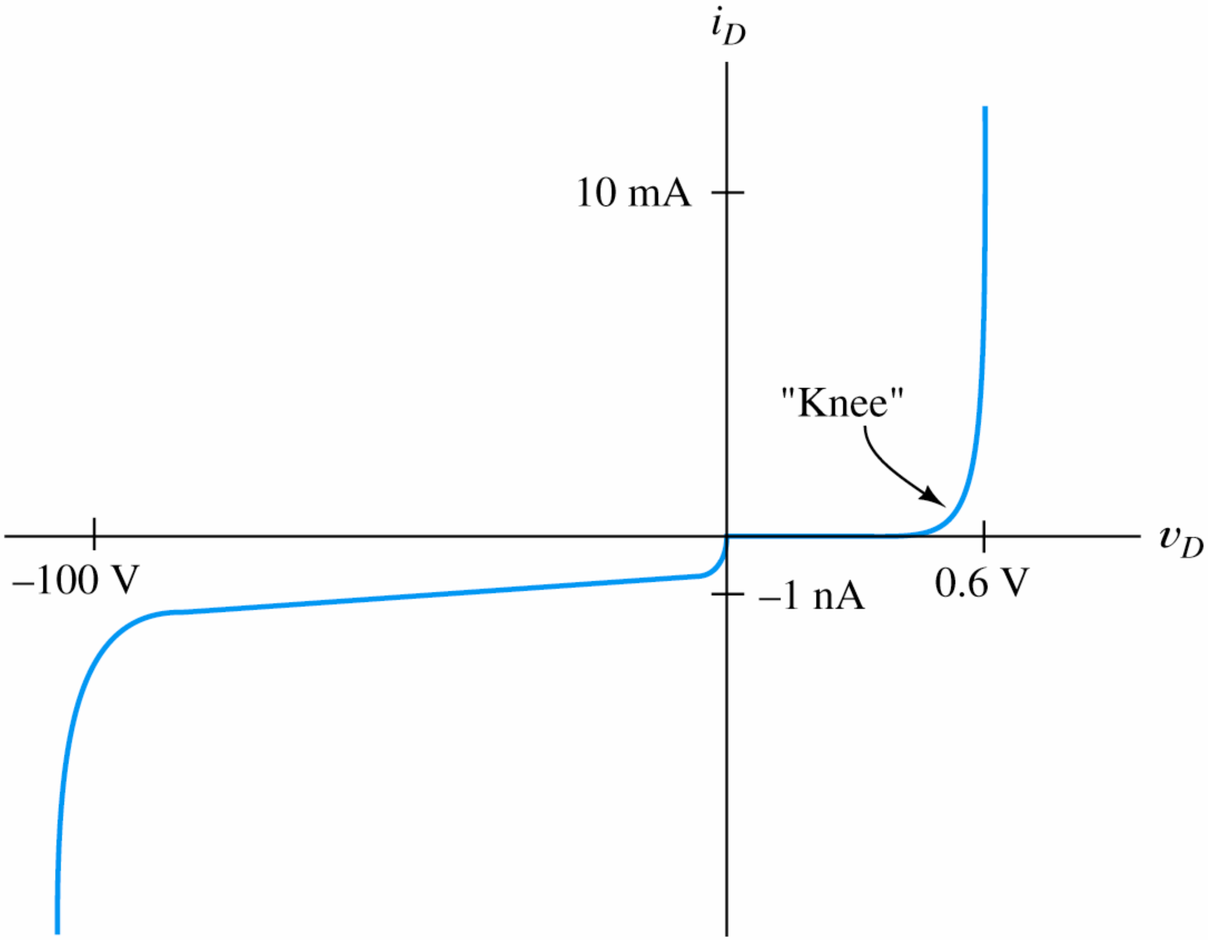


Figure 10.2 Volt–ampere characteristic for a typical small-signal silicon diode at a temperature of 300 K. Notice the change of scale for negative current and voltage.

Shockley Equation

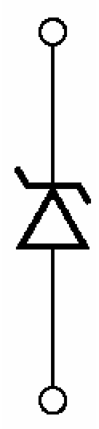
$$i_D = I_s\left[\exp\left(\frac{v_D}{nV_T}\right) - 1\right] \qquad V_T = \frac{kT}{q}$$

$k = 1.38 \times 10^{-23}$ J/K is Boltzmann's constant and $q = 1.60 \times 10^{-19}$ C is the magnitude of the electrical charge of an electron, n is the emission coefficient (between 1 and 2). Is is the saturation current. At a temperature of 300 K, we have

$$V_T \cong 26\,\text{mV}$$

Zener Diodes

Diodes that are intended to operate in the breakdown region are called **Zener diodes**.



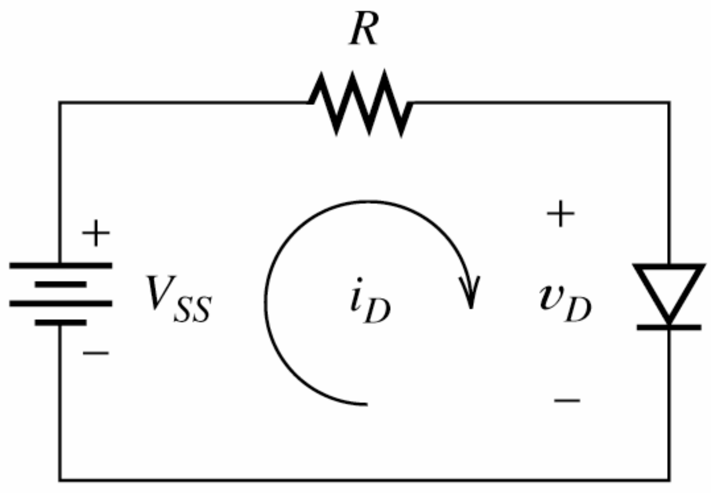
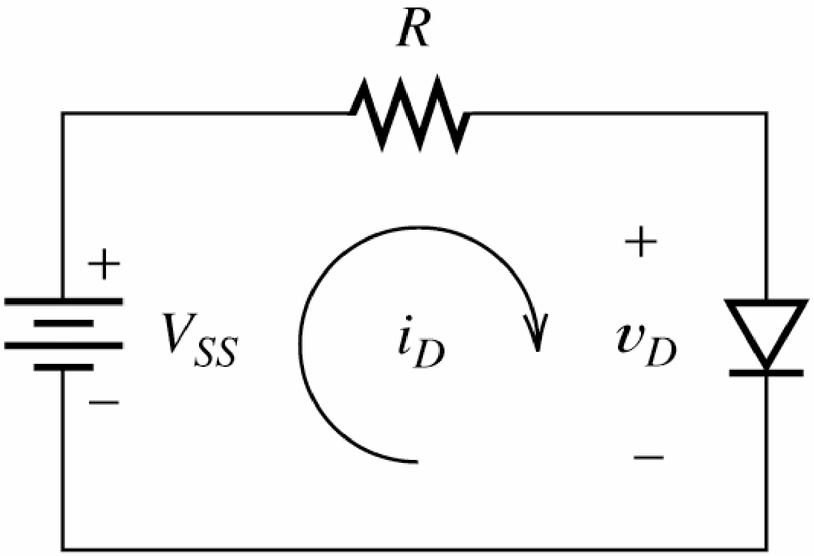


Figure 10.5 Circuit for load-line analysis.

LOAD-LINE ANALYSIS OF DIODE CIRCUITS



$$V_{SS} = Ri_D + v_D$$

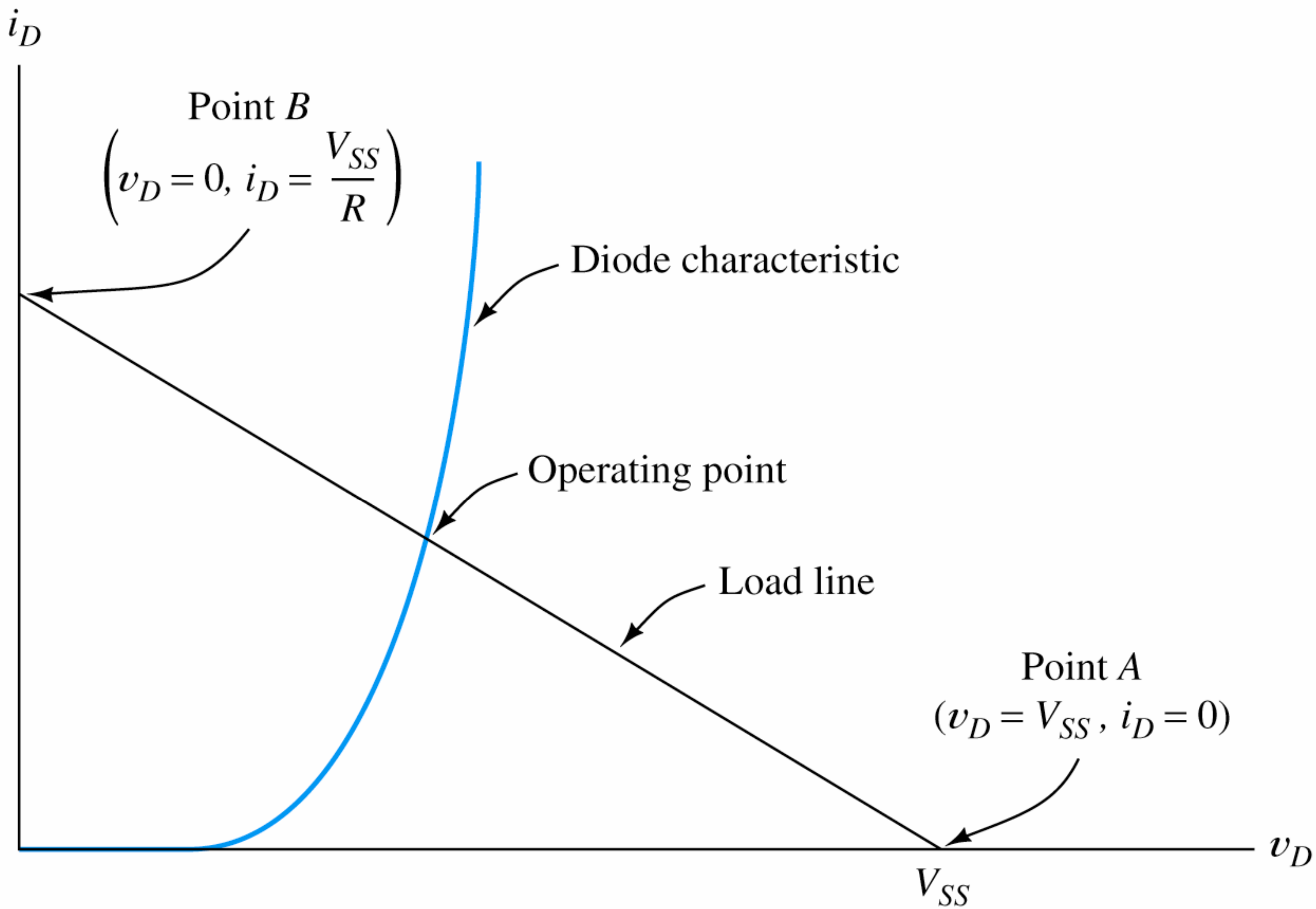


Figure 10.6 Load-line analysis of the circuit of Figure 10.5.

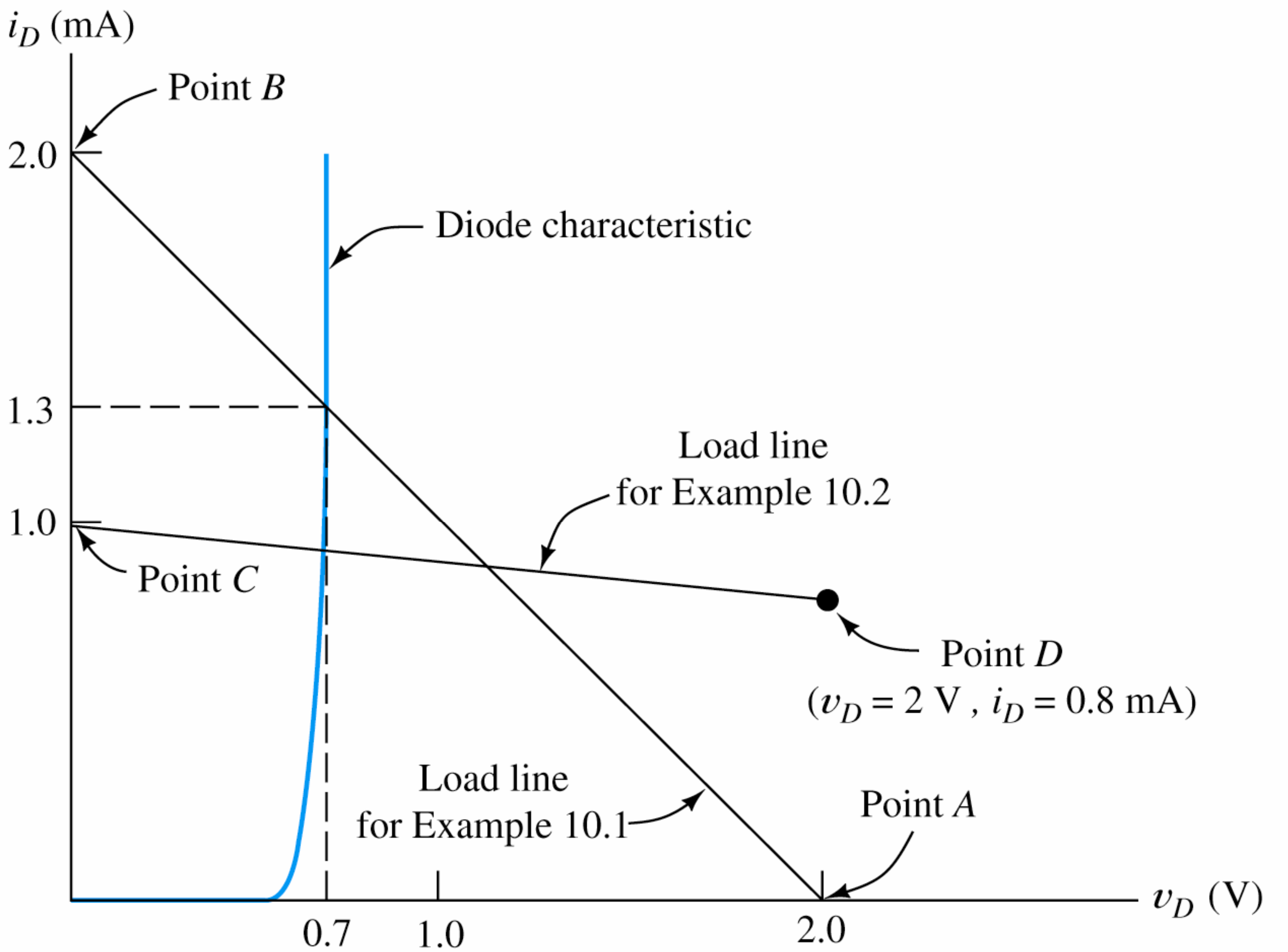


Figure 10.7 Load-line analysis for Examples 10.1 and 10.2.

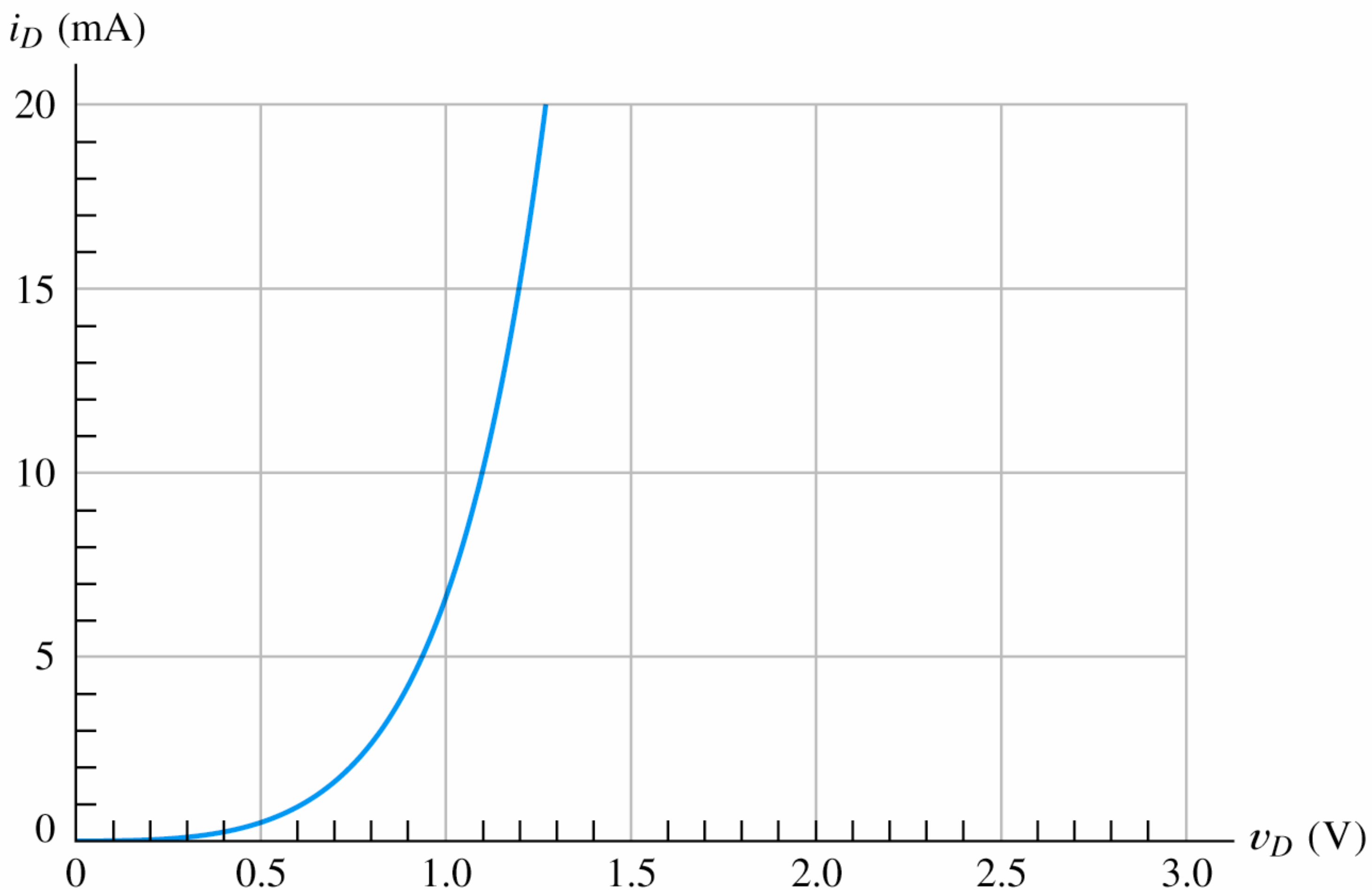


Figure 10.8 Diode characteristic for Exercise 10.3.

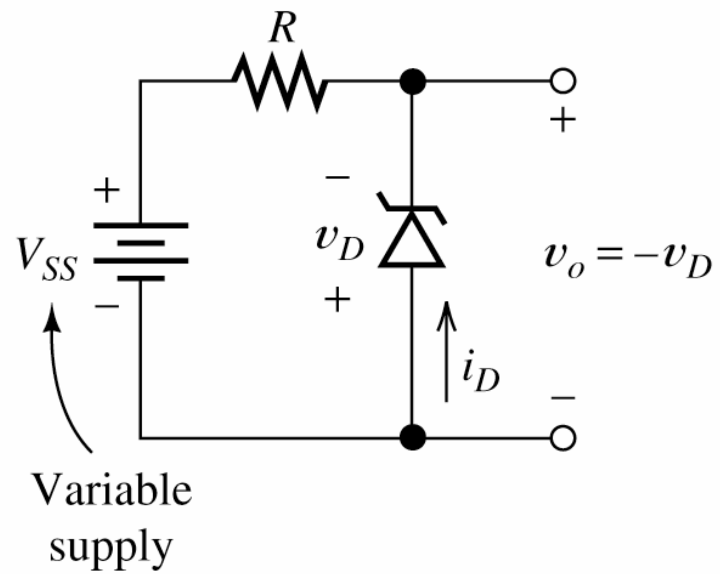
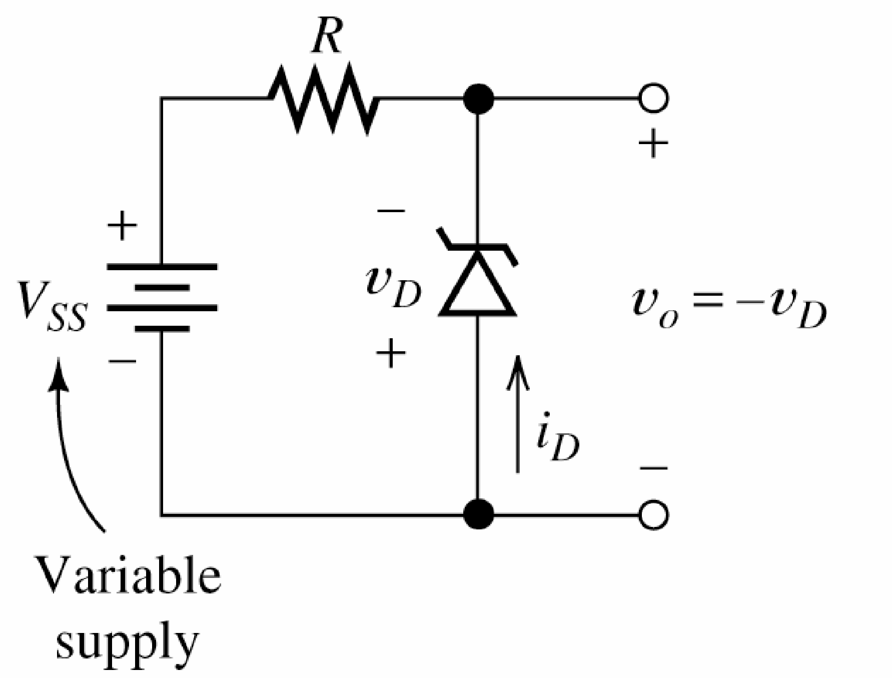


Figure 10.9 A simple regulator circuit that provides a nearly constant output voltage v_o from a variable supply voltage.

ZENER-DIODE VOLTAGE-REGULATOR CIRCUITS

A voltage regulator circuit provides a nearly constant voltage to a load from a variable source.



$$V_{SS} + Ri_D + v_D = 0$$

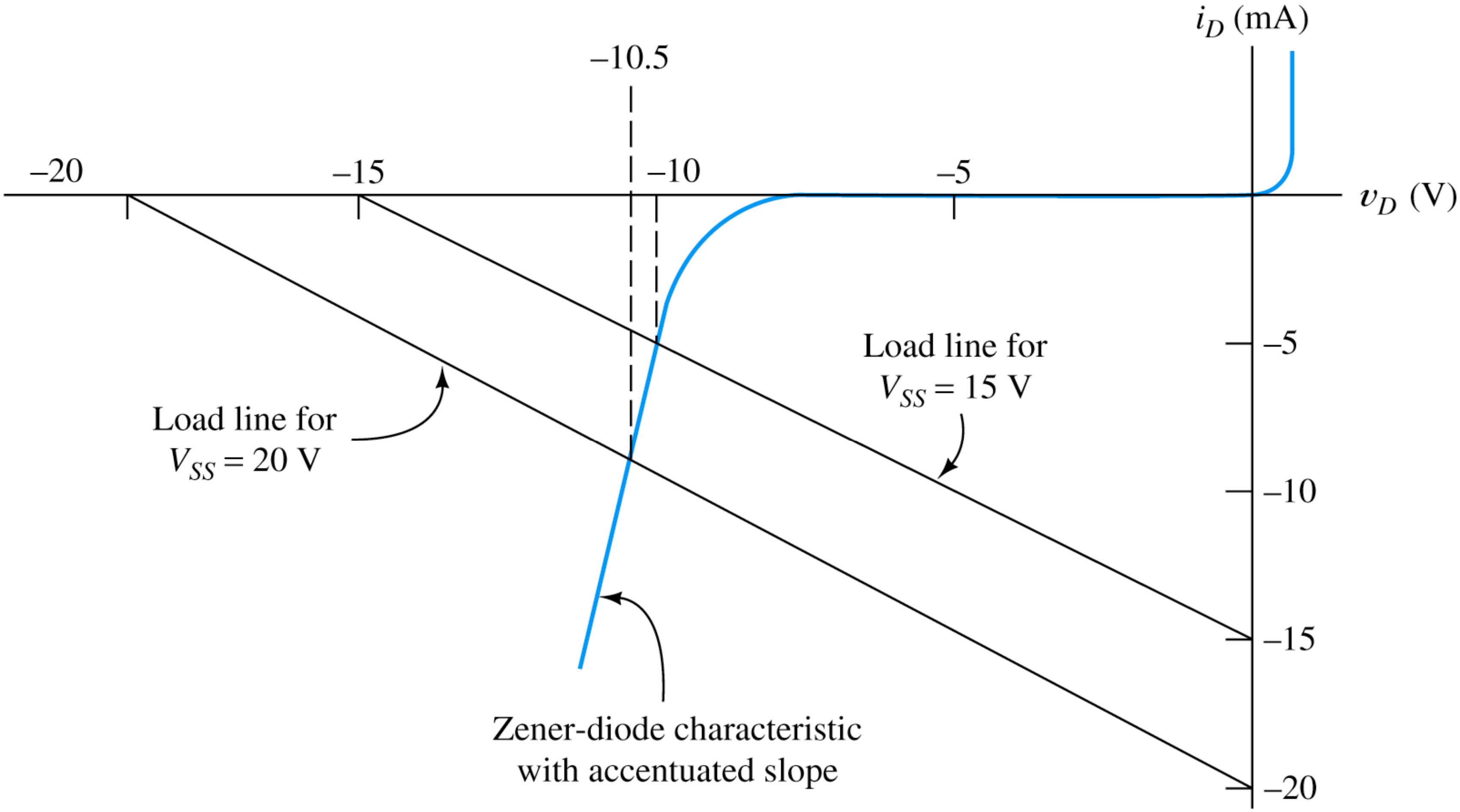


Figure 10.10 See Example 10.3.

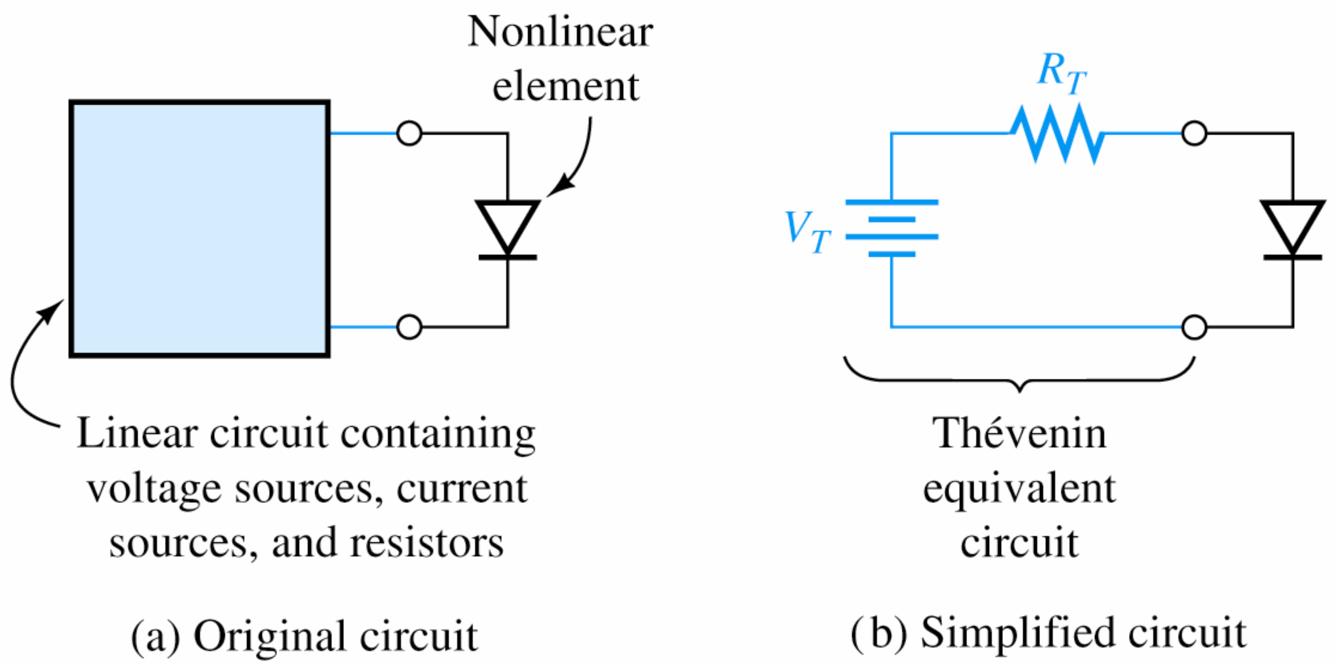
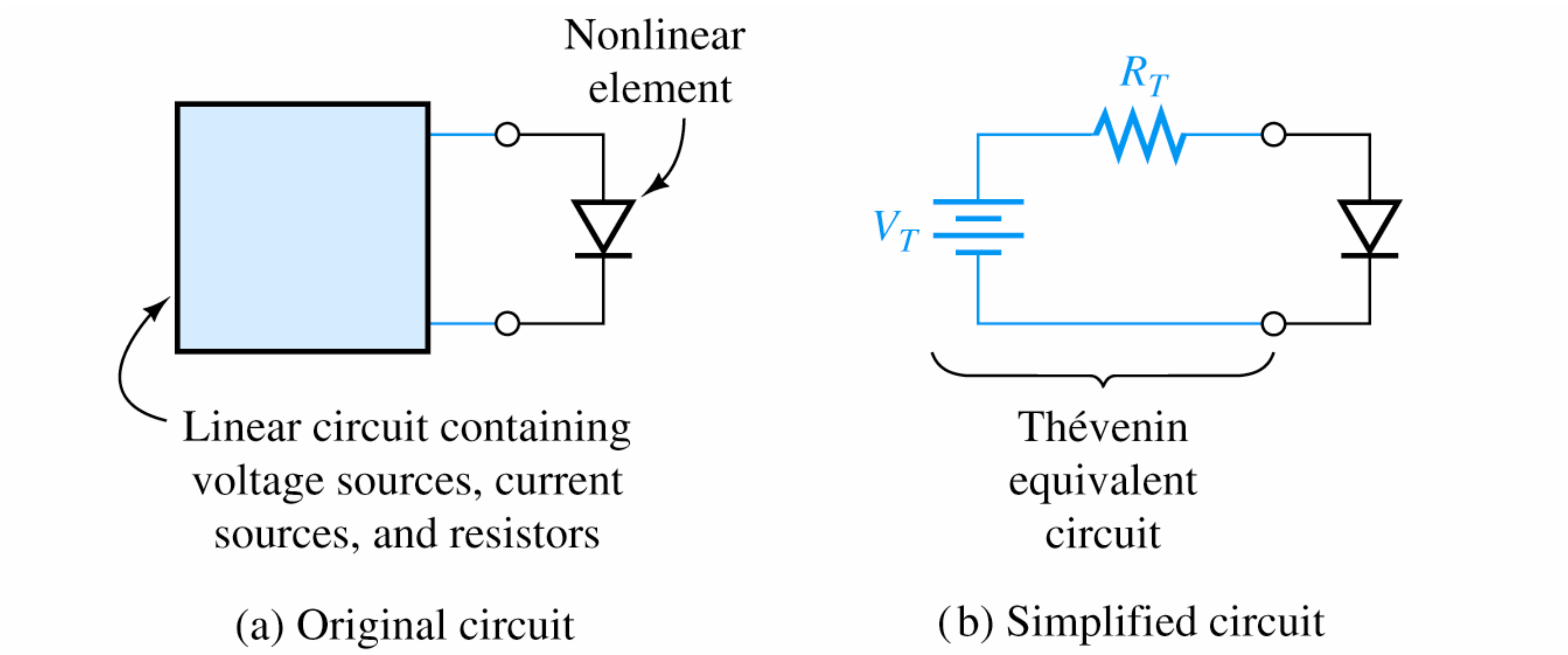


Figure 10.11 Analysis of a circuit containing a single nonlinear element can be accomplished by load-line analysis of a simplified circuit.

Load-Line Analysis of Complex Circuits



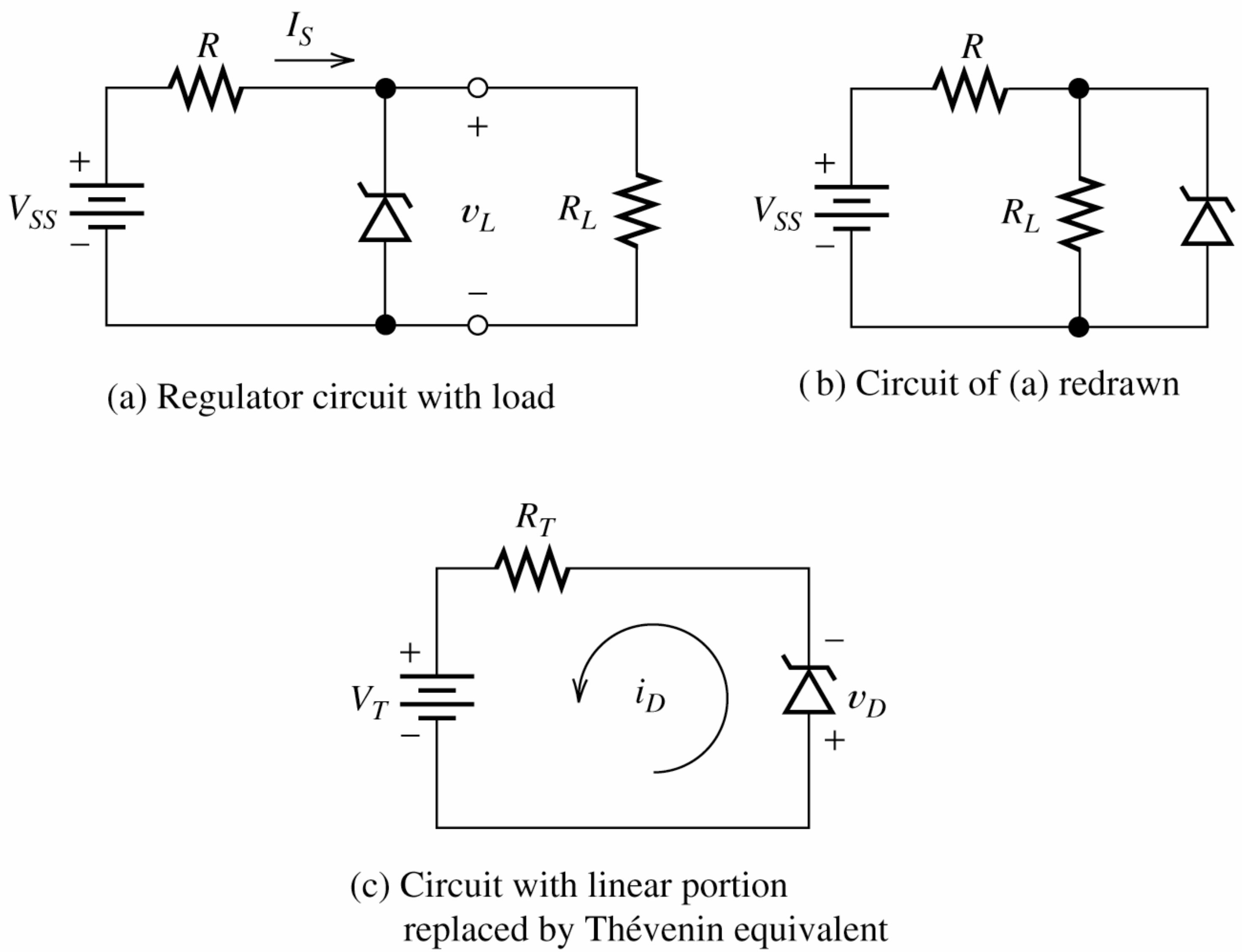


Figure 10.12 See Example 10.4.

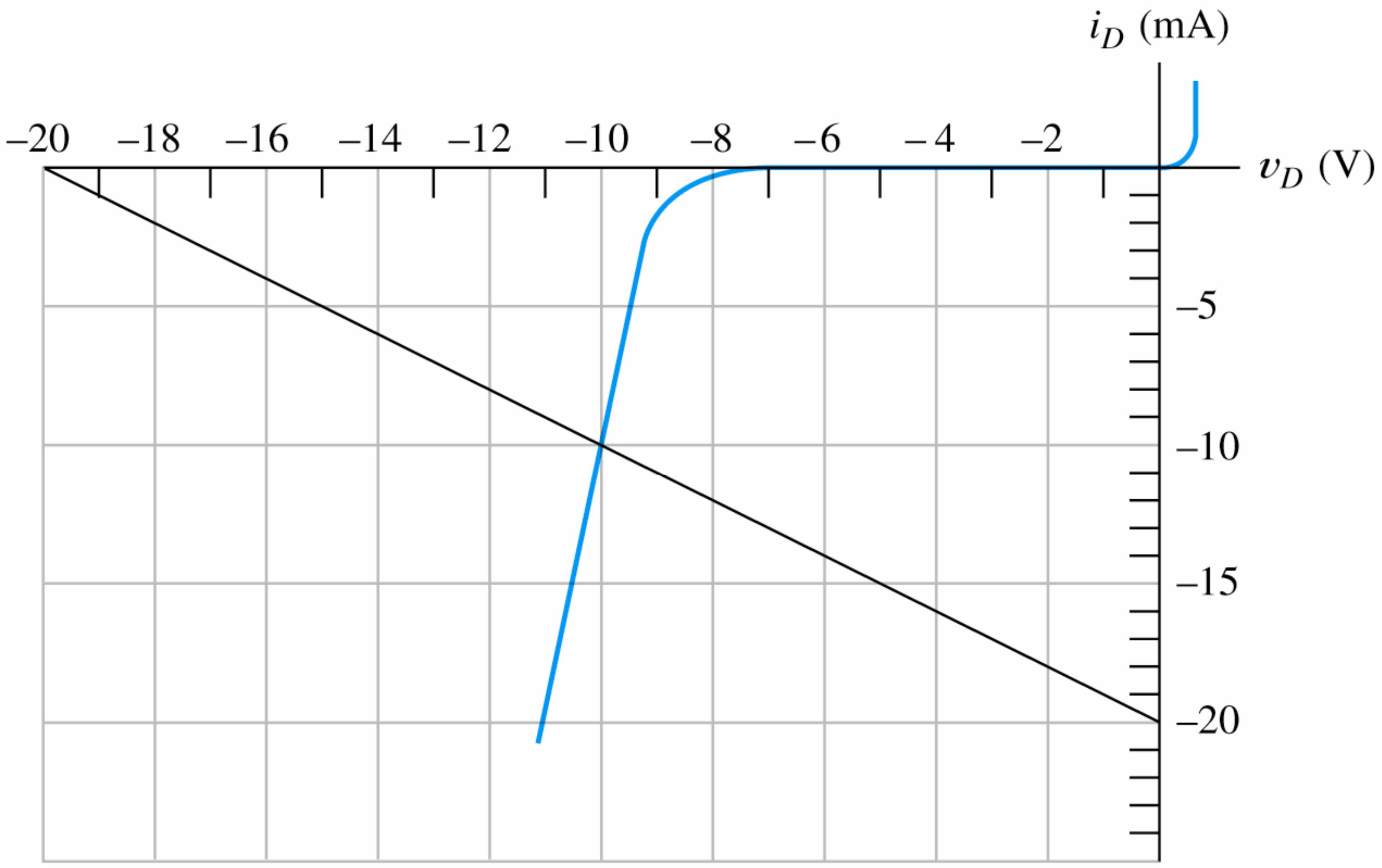


Figure 10.13 Zener-diode characteristic for Example 10.4 and Exercise 10.4.

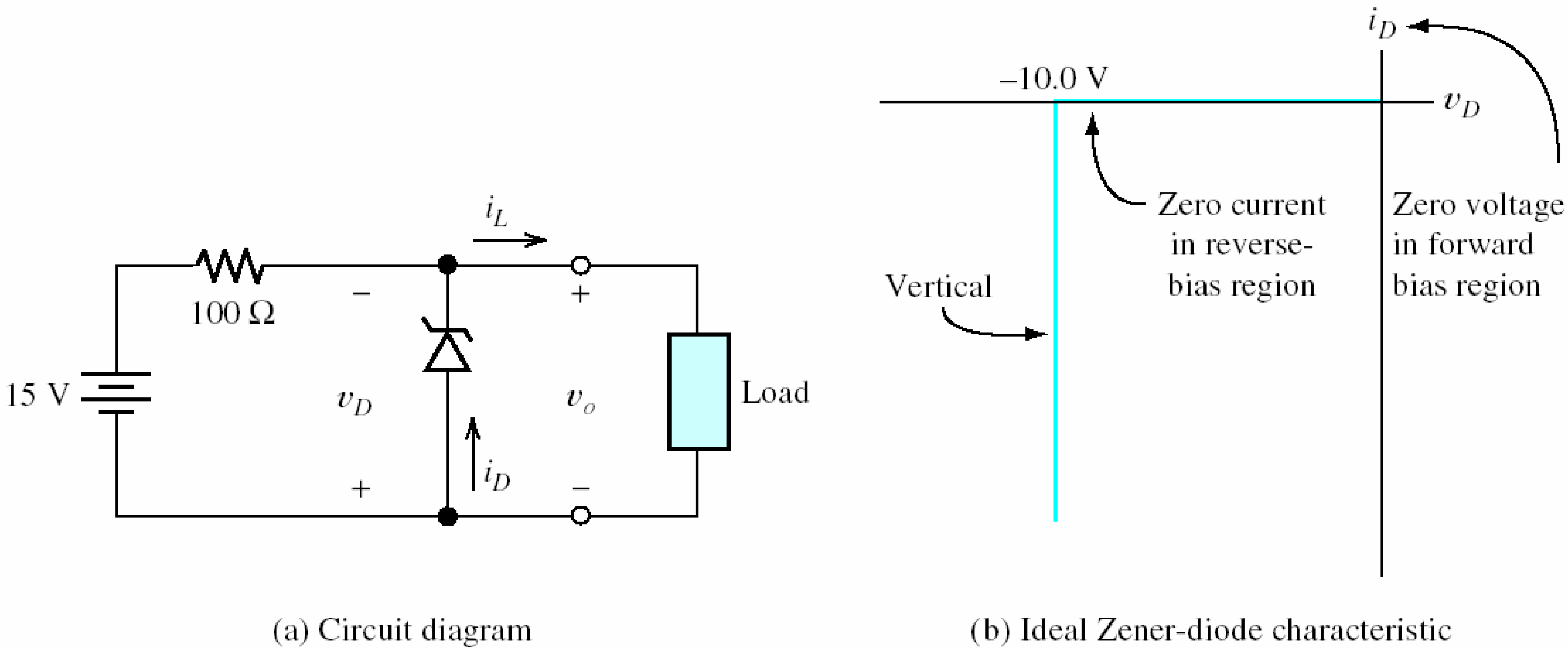


Figure 10.14 See Exercise 10.5.

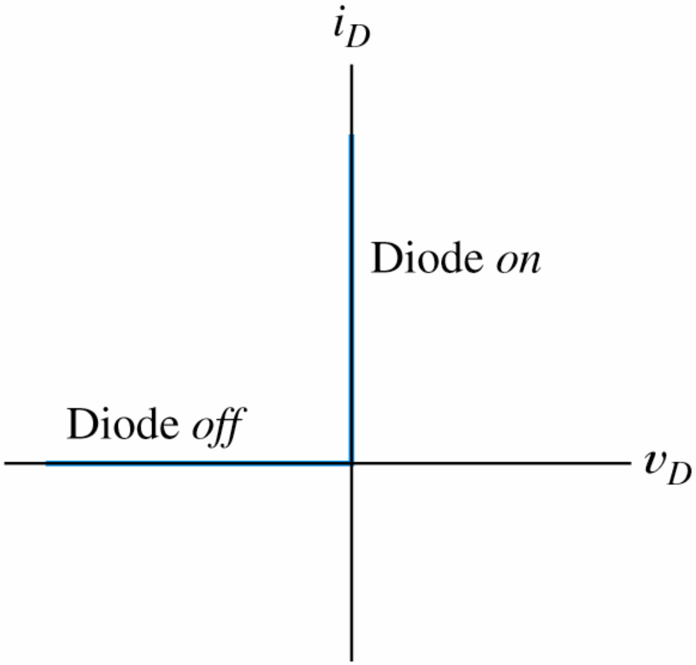
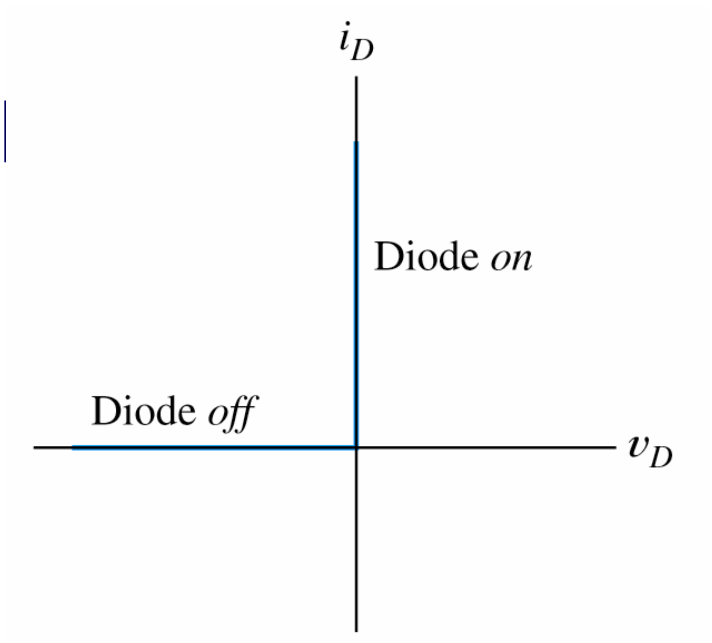


Figure 10.15 Ideal-diode volt–ampere characteristic.

IDEAL-DIODE MODEL

The ideal diode acts as a s
circuit for forward currents
and as an open circuit with
reverse voltage applied.



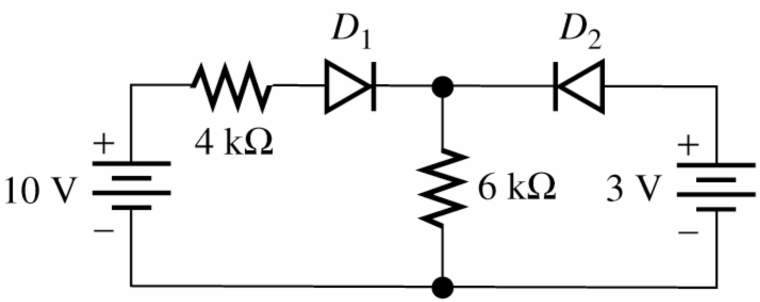
Assumed States for Analysis of Ideal-Diode Circuits

1. Assume a state for each diode, either on (i.e., a short circuit) or off (i.e., an open circuit). For *n* diodes there are 2^n possible combinations of diode states.

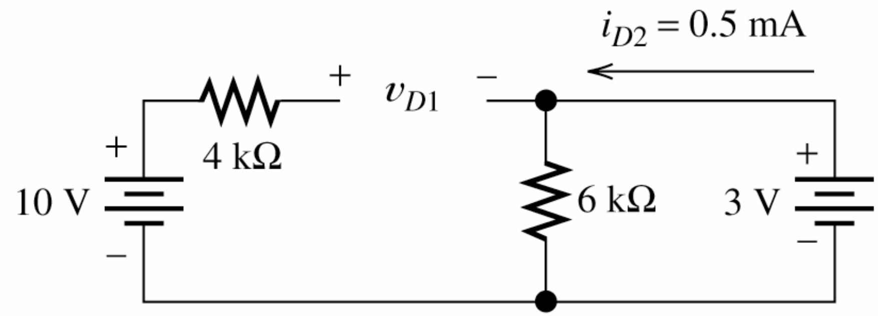
2. Analyze the circuit to determine the current through the diodes assumed to be on and the voltage across the diodes assumed to be off.

3. Check to see if the result is consistent with the assumed state for each diode. Current must flow in the forward direction for diodes assumed to be on. Furthermore, the voltage across the diodes assumed to be off must be positive at the cathode (i.e., reverse bias).

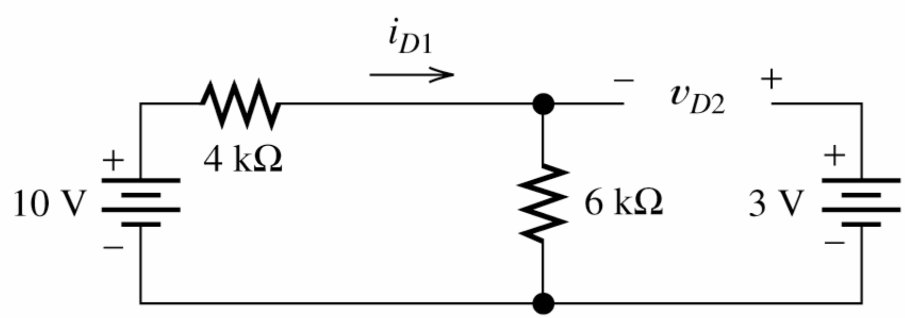
4. If the results are consistent with the assumed states, the analysis is finished. Otherwise, return to step 1 and choose a different combination of diode states.



(a) Circuit diagram



(b) Equivalent circuit assuming D_1 off and D_2 on (since $v_{D1} = +7$ V, this assumption is not correct)



(c) Equivalent circuit assuming D_1 on and D_2 off (this is the correct assumption since i_{D1} turns out to be a positive value and v_{D2} turns out negative)

Figure 10.16 Analysis of a diode circuit using the ideal-diode model. See Example 10.5.

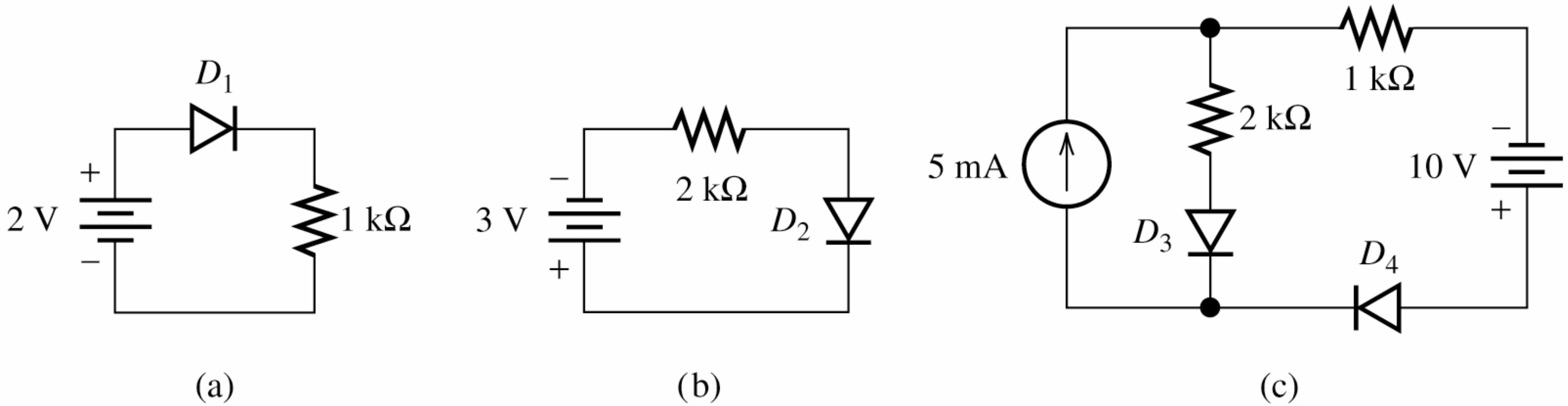
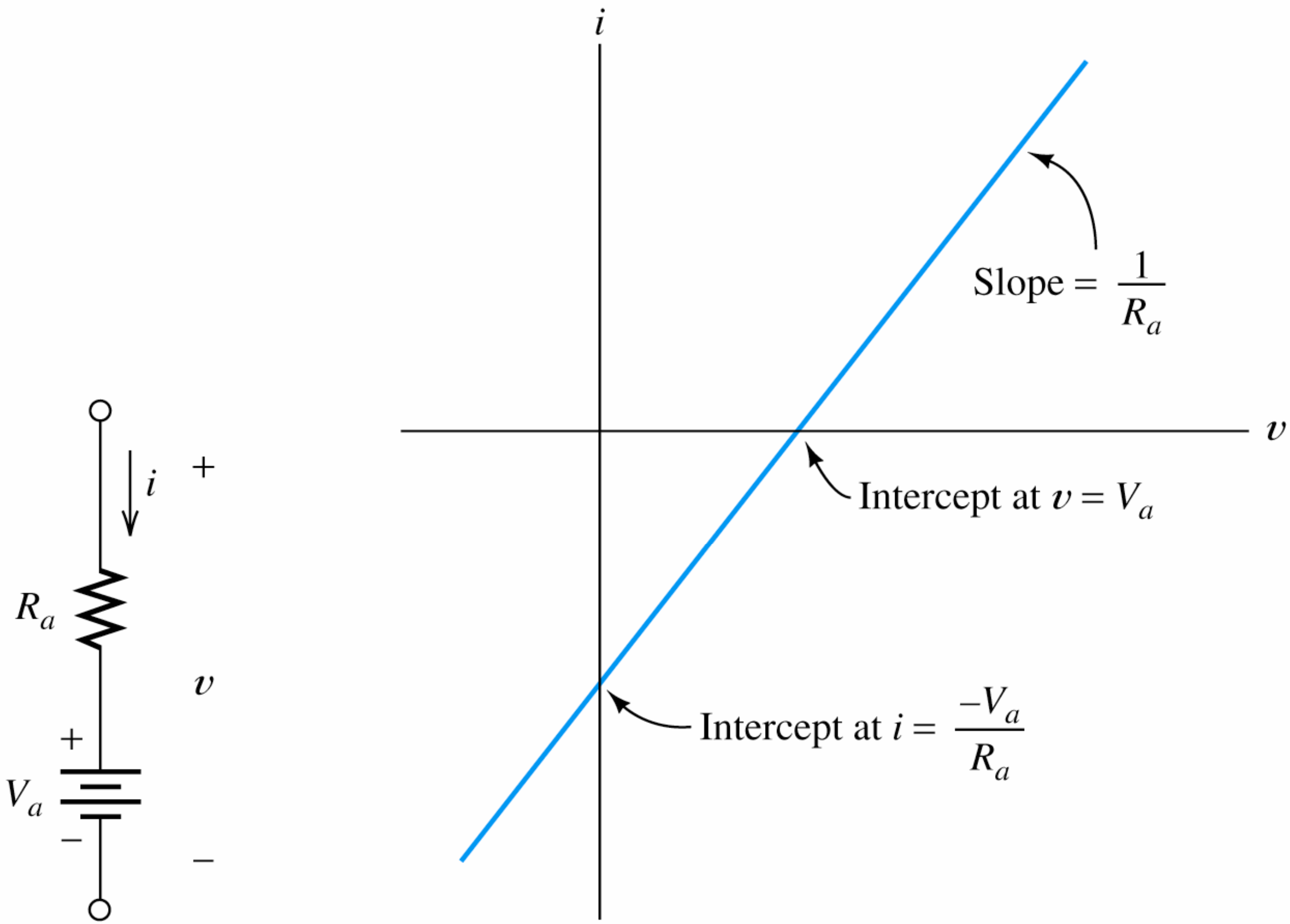


Figure 10.17 Circuits for Exercise 10.8.

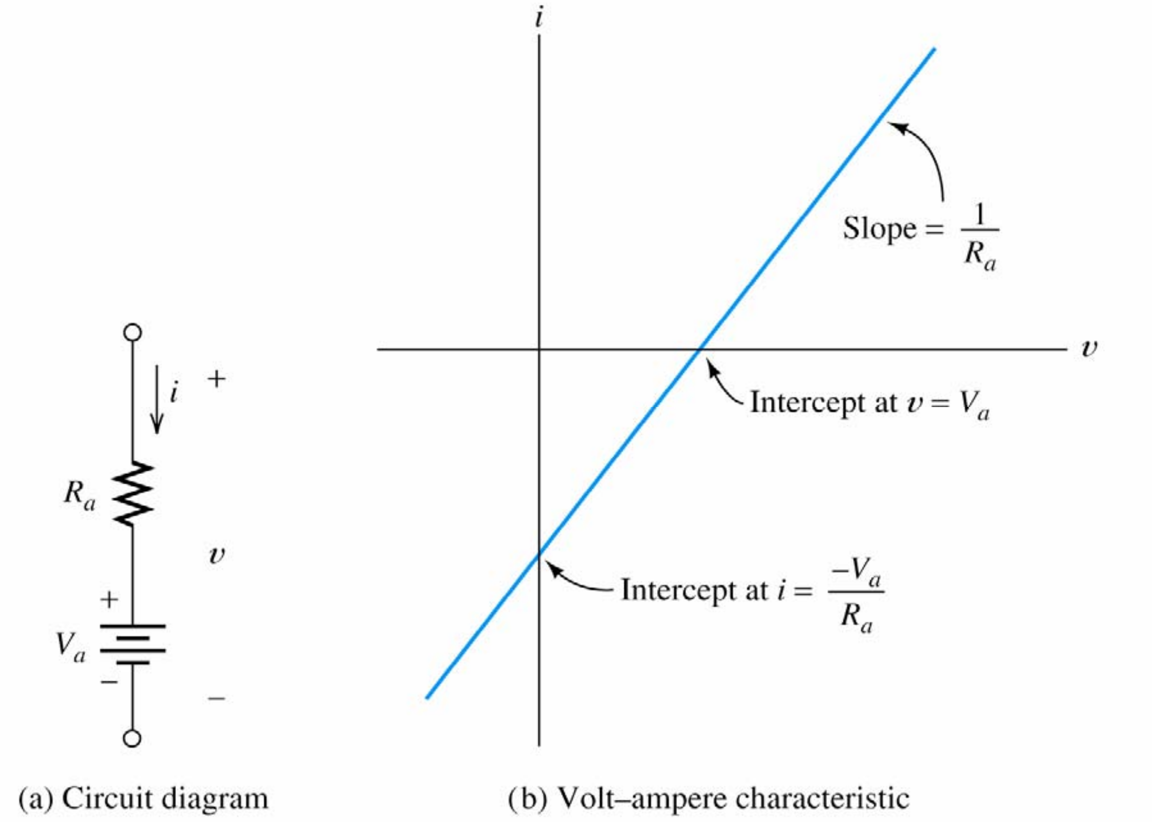


(a) Circuit diagram (b) Volt–ampere characteristic

Figure 10.18 Circuit and volt–ampere characteristic for piecewise-linear models.

PIECEWISE-LINEAR DIODE MODELS

$$v = R_a i + V_a$$



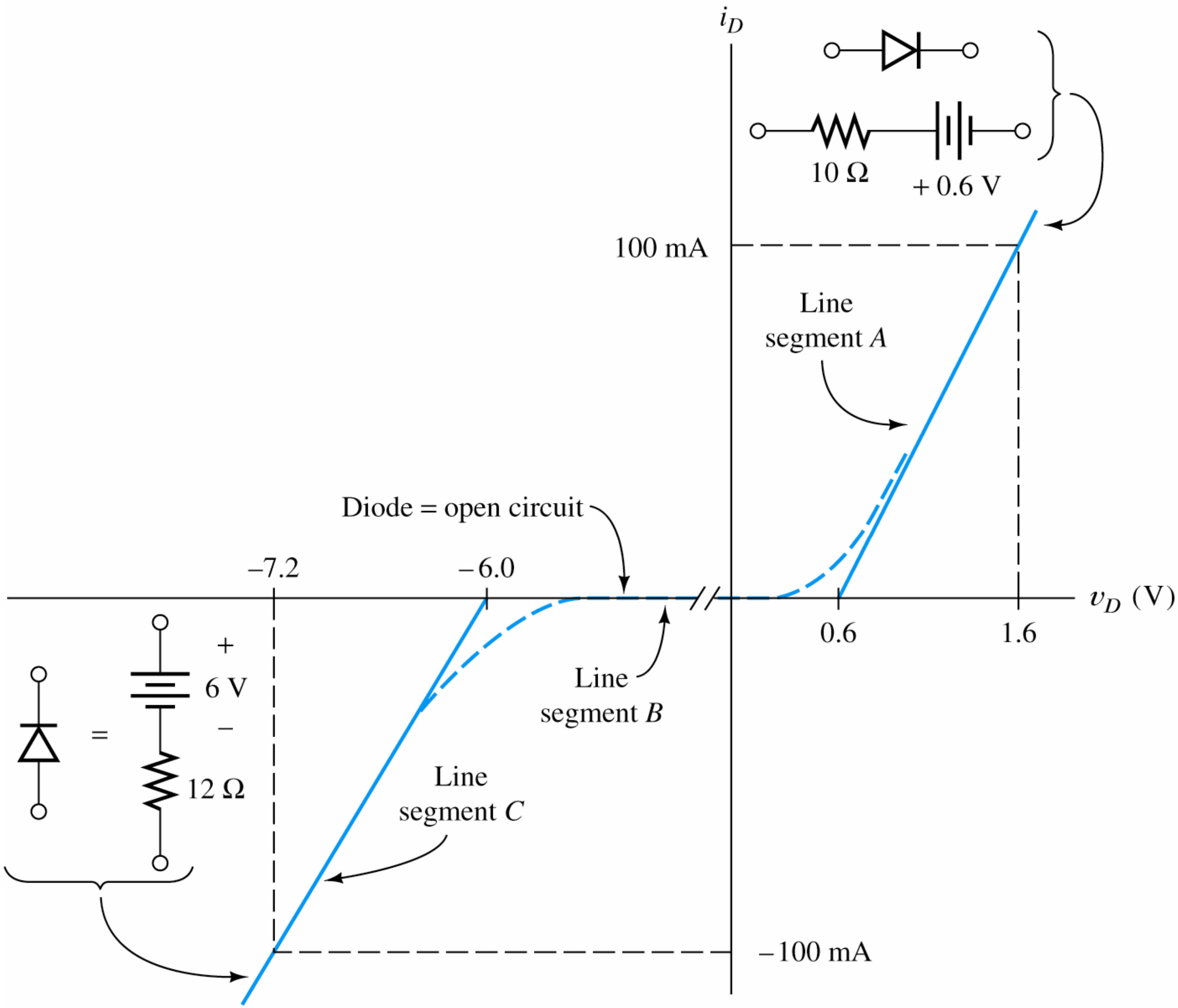
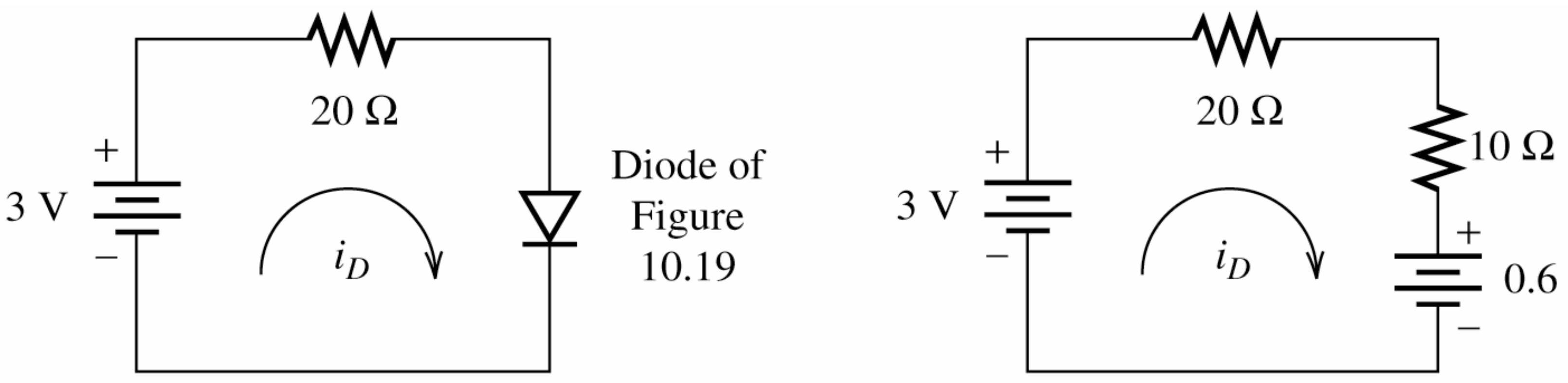


Figure 10.19 Piecewise-linear models for the diode of Example 10.6.



(a) Circuit diagram

(b) Circuit with diode modeled by the equivalent circuit for the forward-bias region

Figure 10.20 Circuit for Example 10.7.

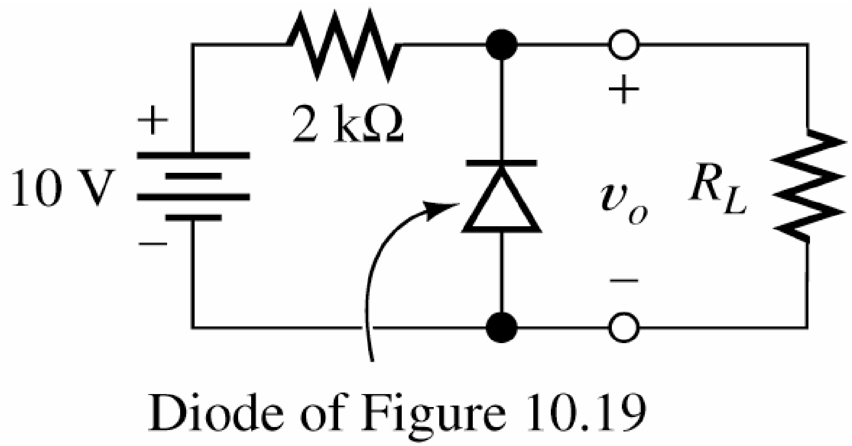


Figure 10.21 Circuit for Exercise 10.9.

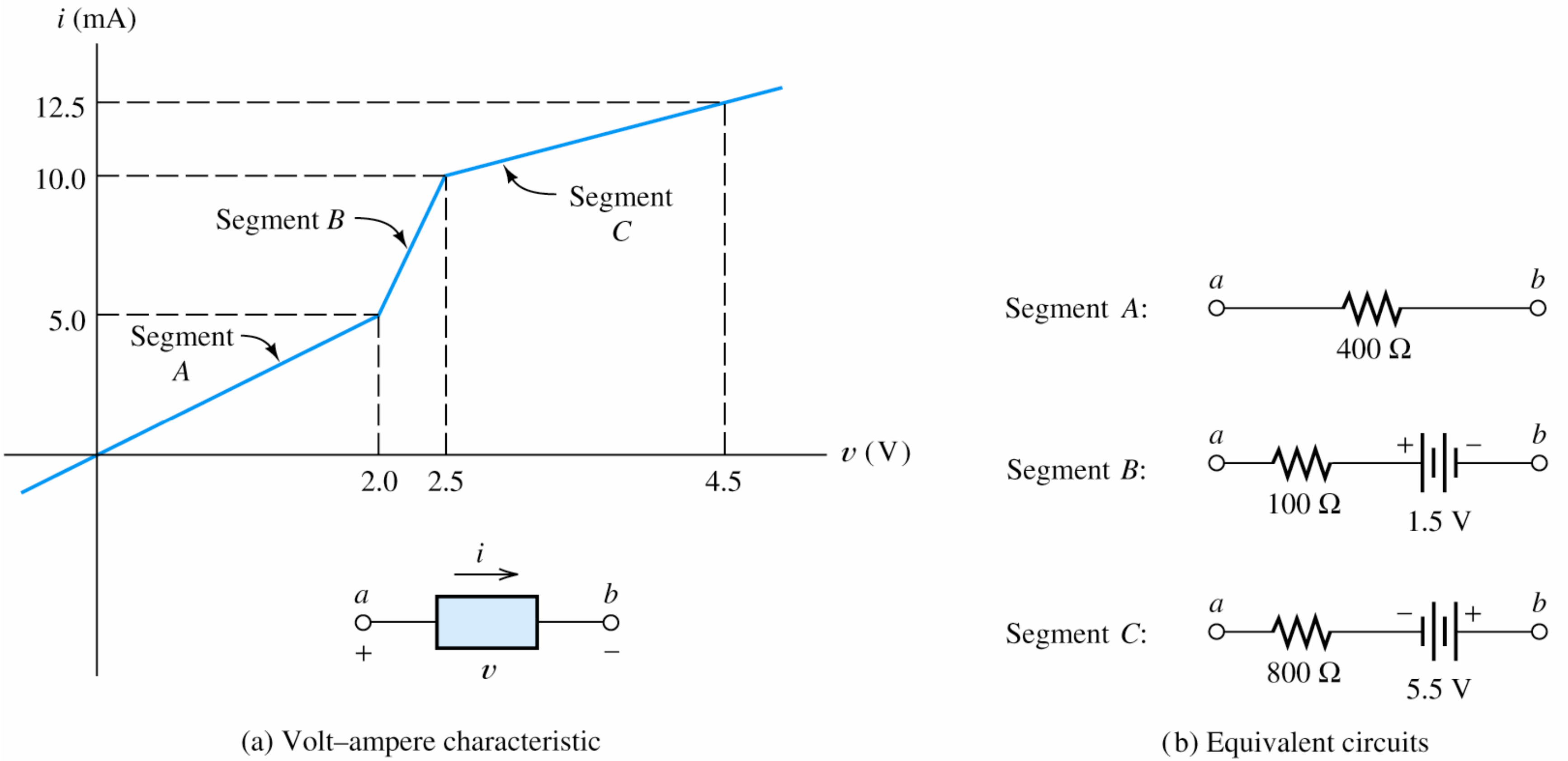


Figure 10.22 Hypothetical nonlinear device for Exercise 10.10.

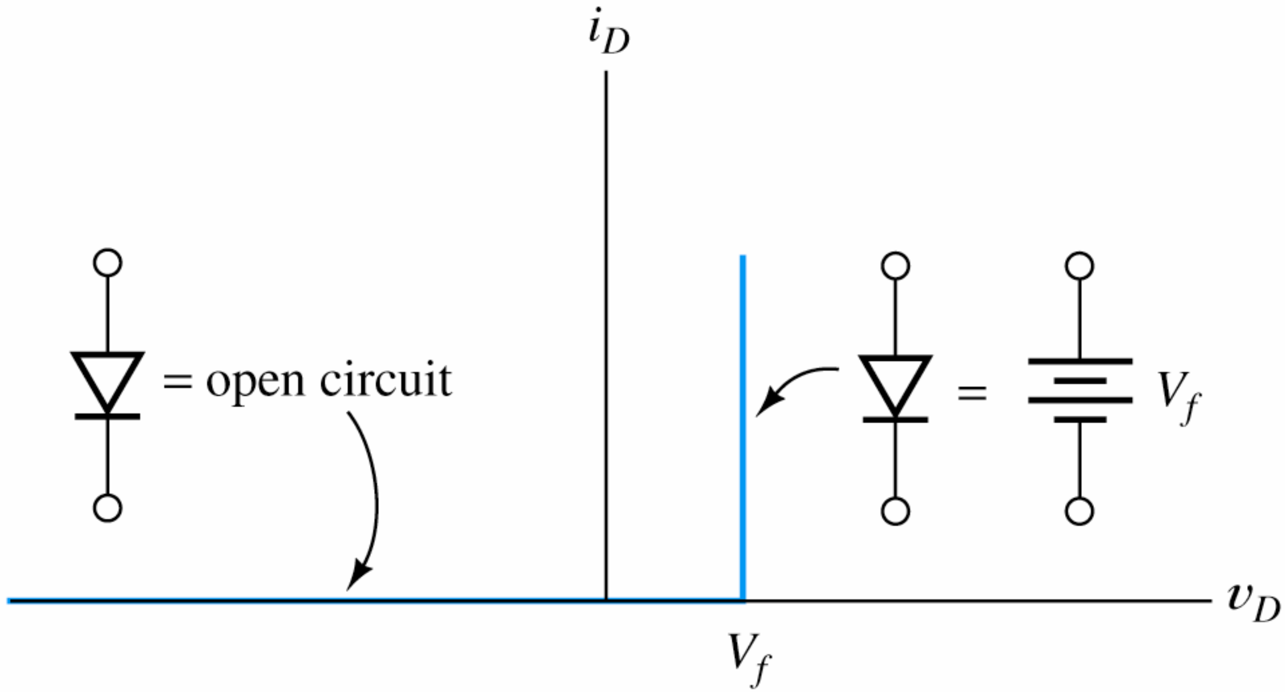


Figure 10.23 Simple piecewise-linear equivalent for the diode.

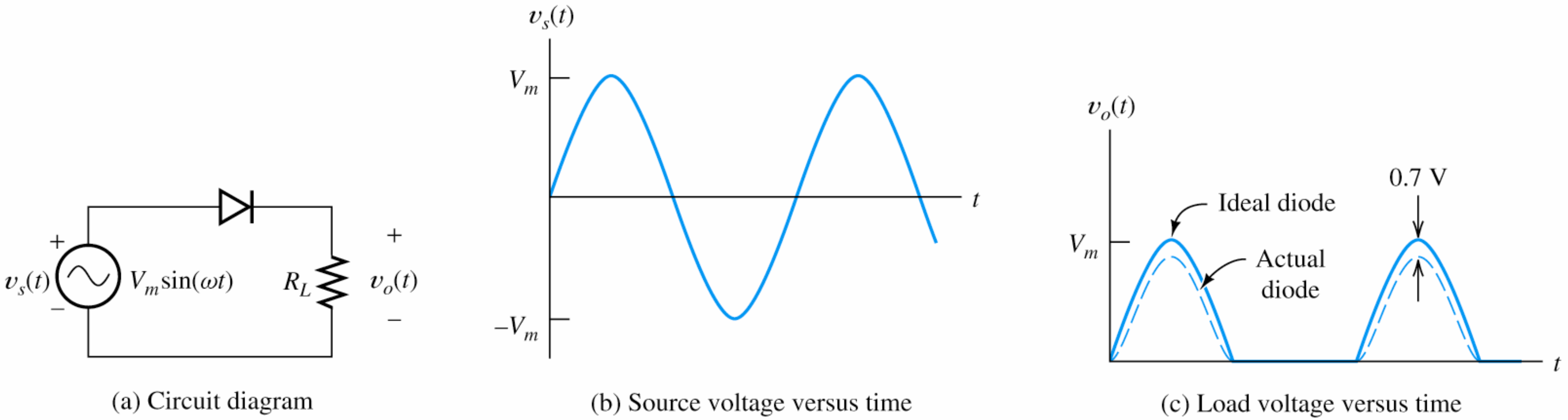


Figure 10.24 Half-wave rectifier with resistive load.

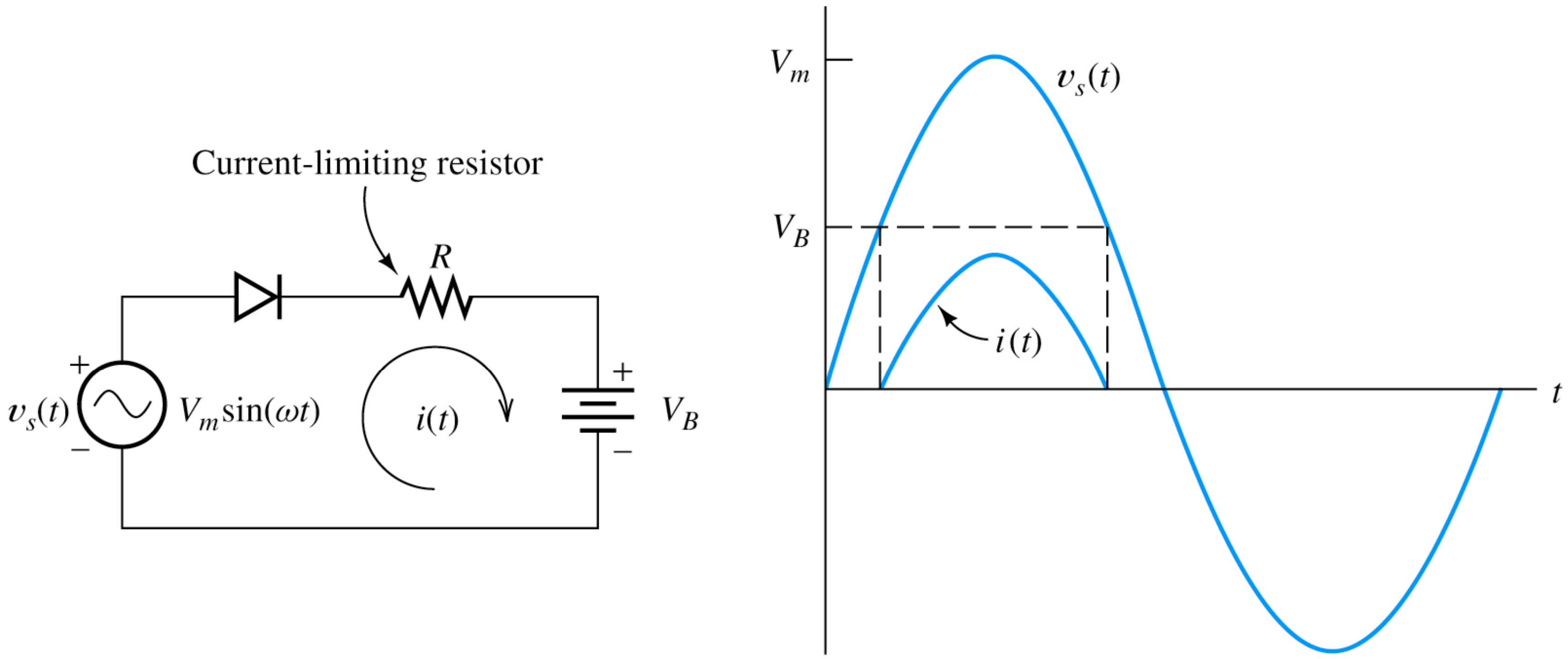


Figure 10.25 Half-wave rectifier used to charge a battery.

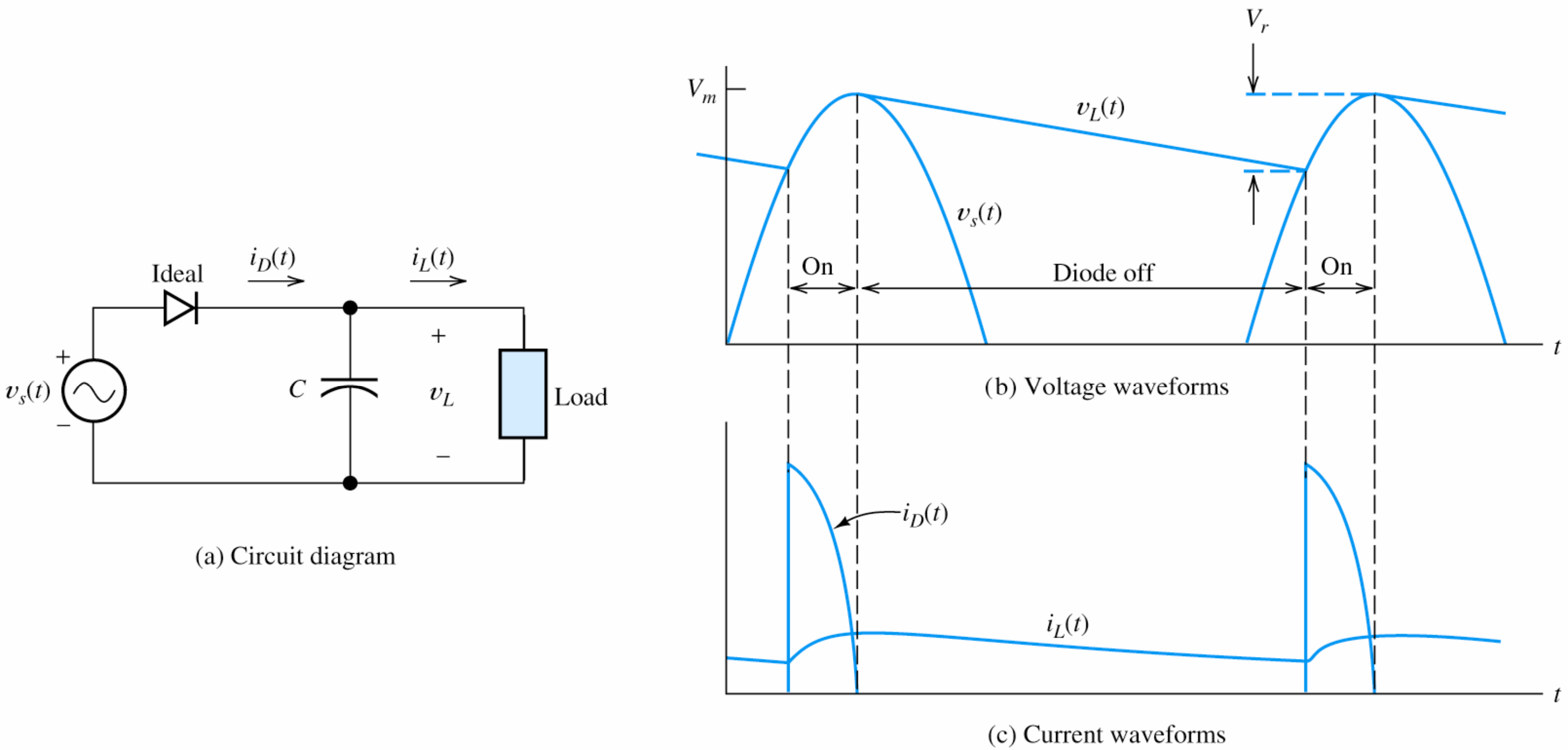
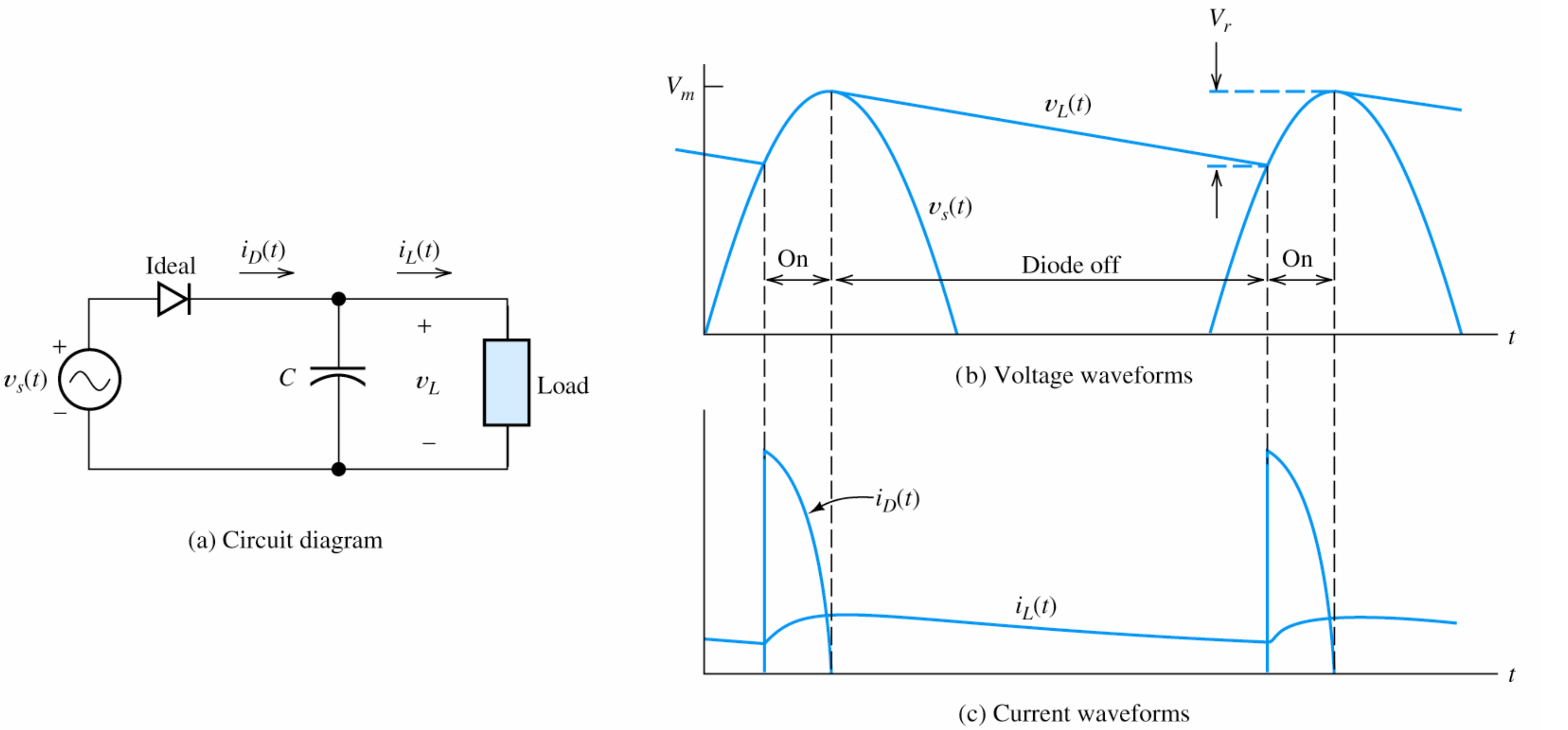


Figure 10.26 Half-wave rectifier with smoothing capacitor.



(a) Circuit diagram

(b) Voltage waveforms

(c) Current waveforms

$$C = \frac{I_L T}{V_r}$$

$$V_L \cong V_m - \frac{V_r}{2}$$

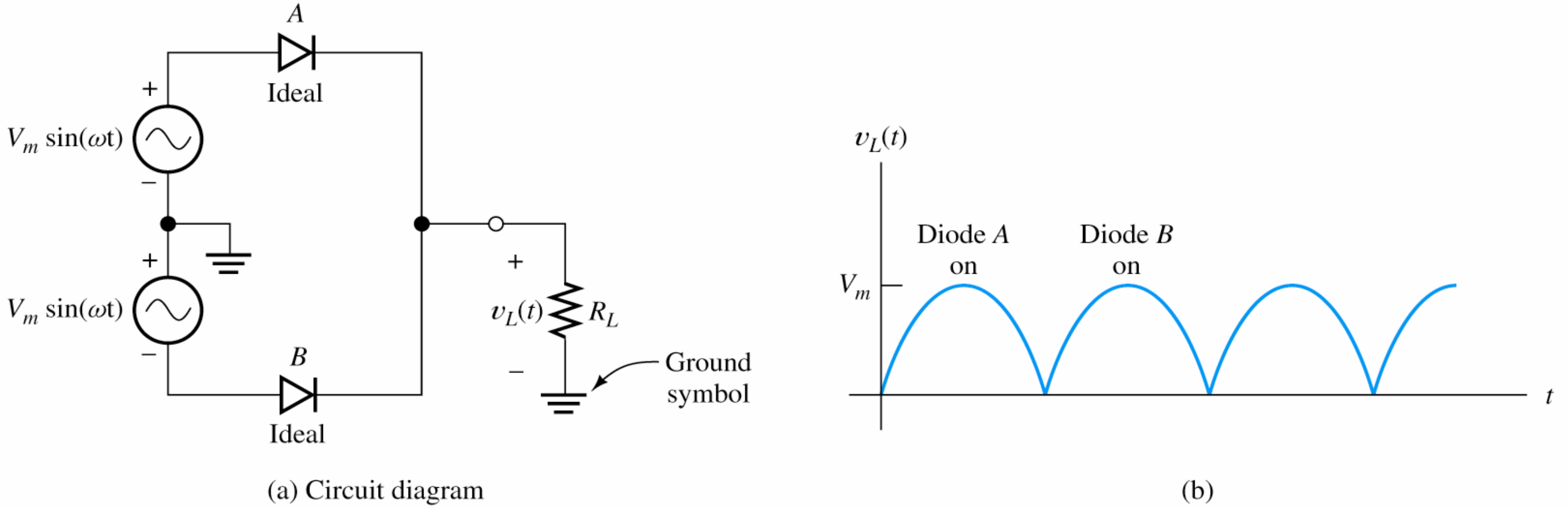


Figure 10.27 Full-wave rectifier.

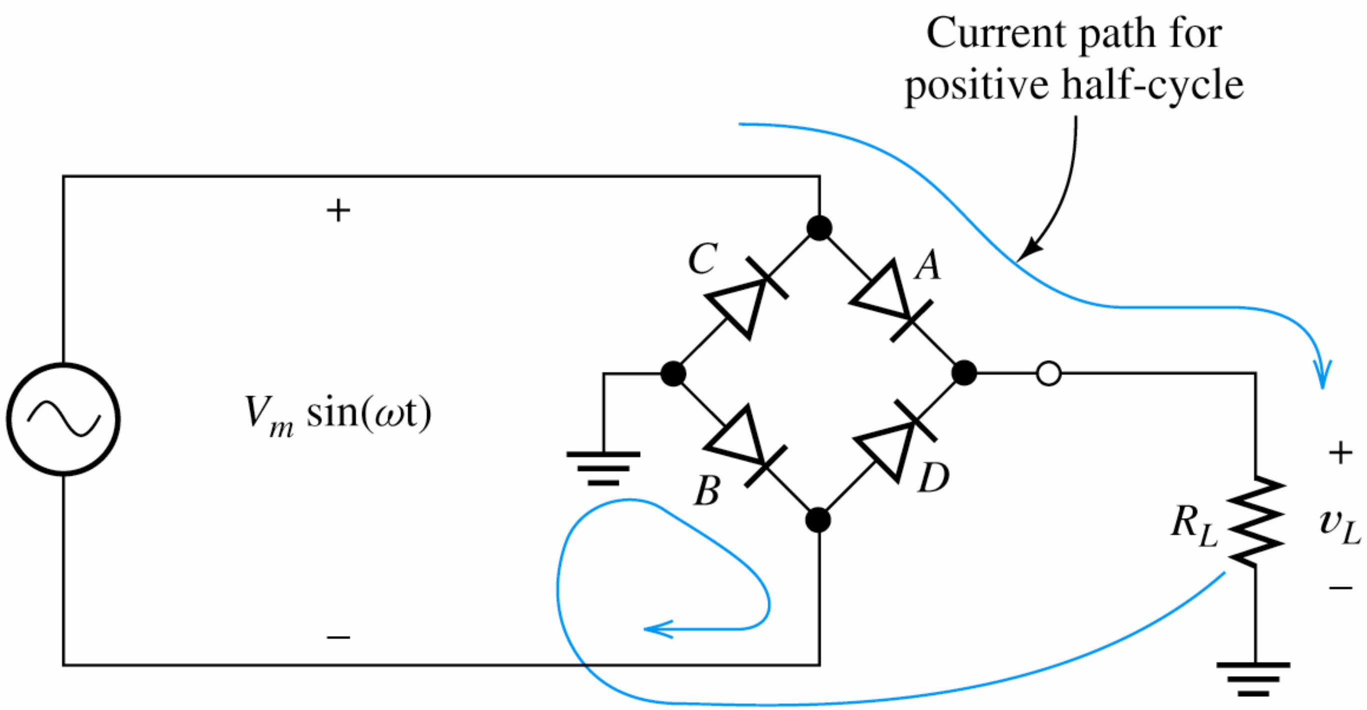


Figure 10.28 Diode-bridge full-wave rectifier.

Peak Inverse Voltage

An important aspect of rectifier circuits is the **peak inverse voltage** (PIV) across the diodes.

The capacitance required for a full-wave rectifier is given by:

$$C = \frac{I_L T}{2V_r}$$

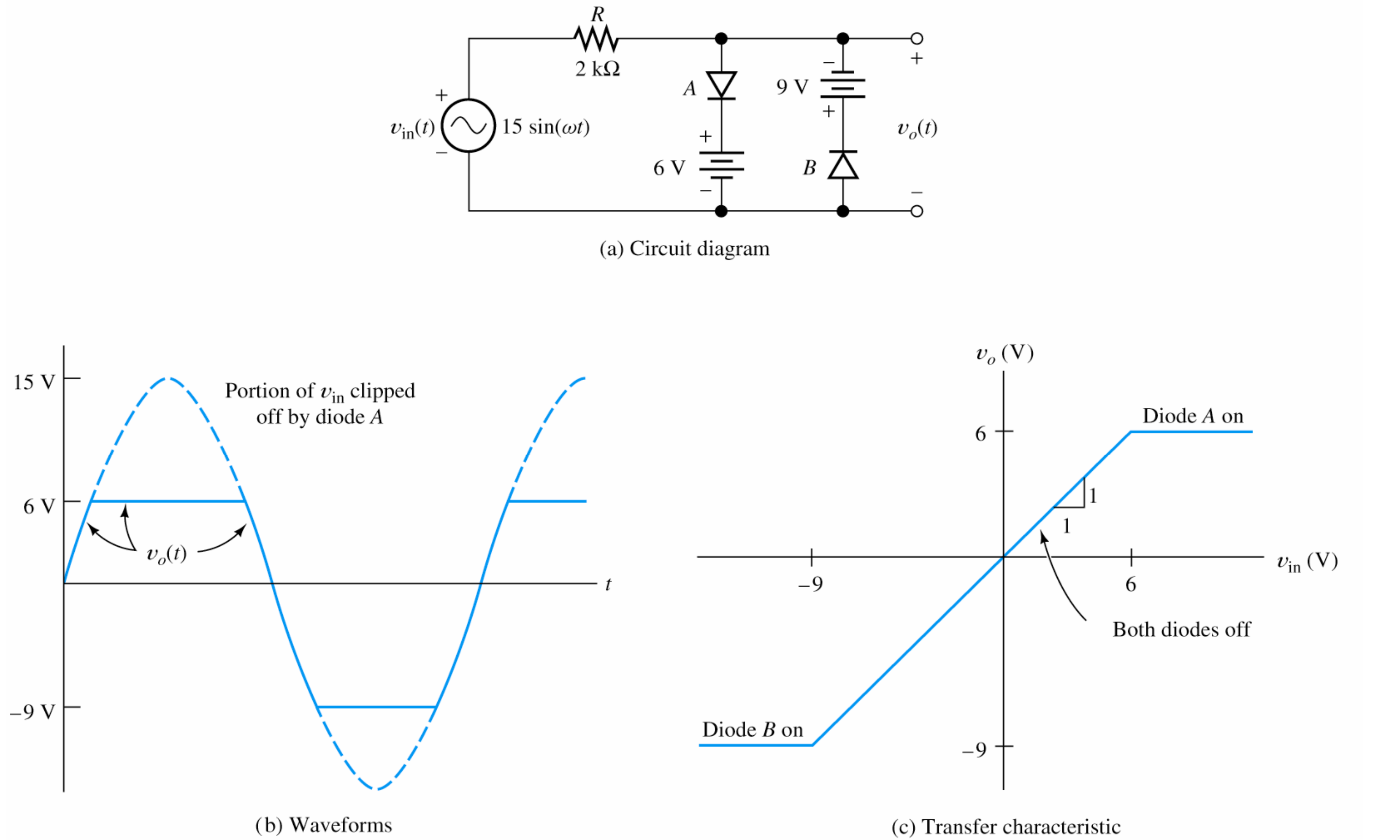
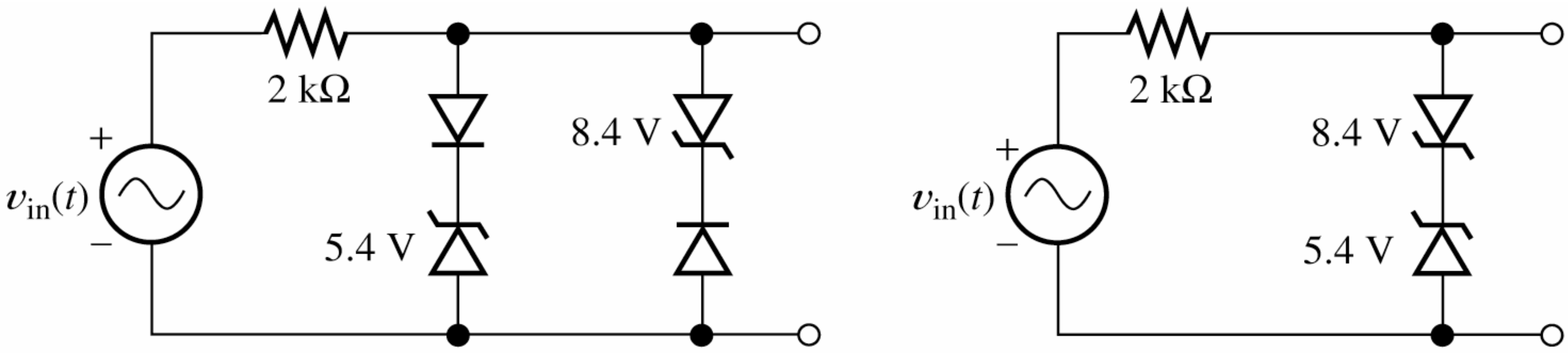


Figure 10.29 Clipper circuit.



(a) Circuit of Figure 10.29 with batteries replaced by Zener diodes and allowance made for a 0.6-V forward diode drop

(b) Simpler circuit

Figure 10.30 Circuits with nearly the same performance as the circuit of Figure 10.29.

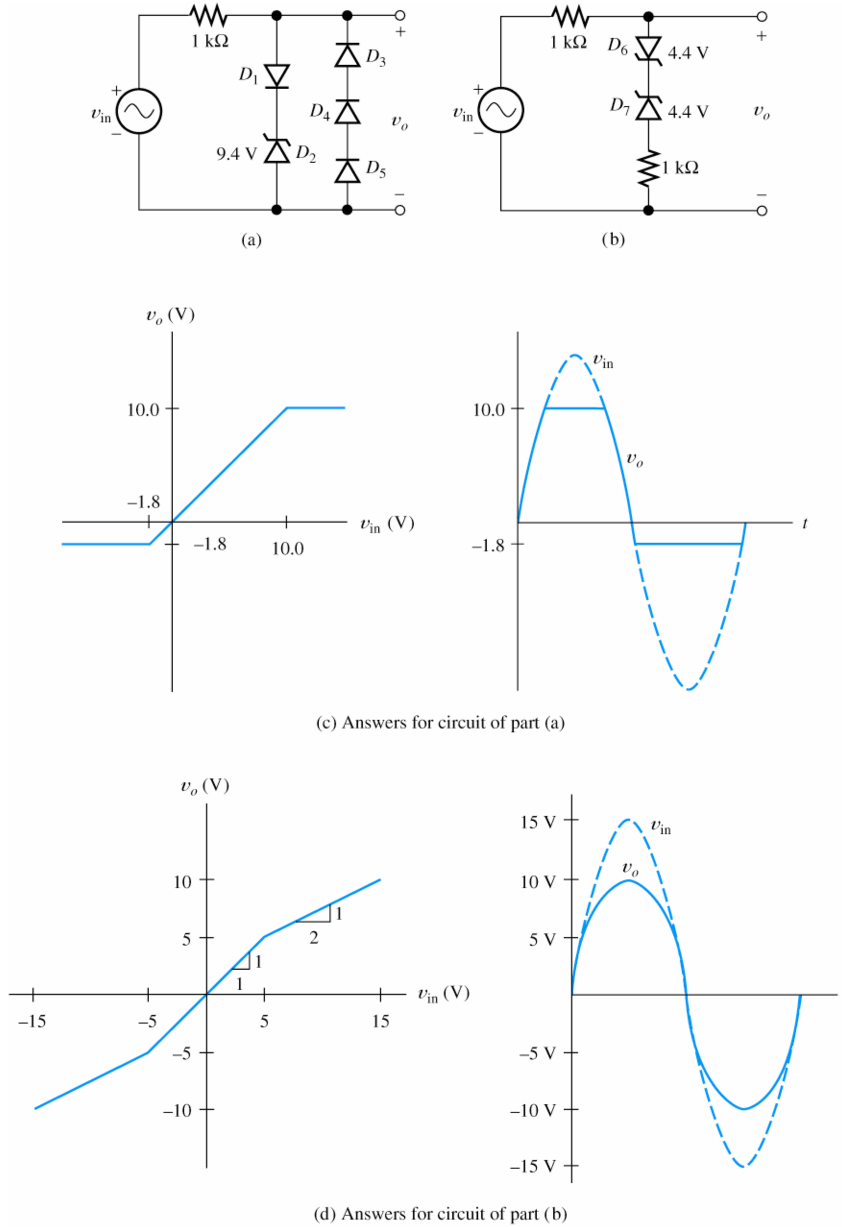


Figure 10.31 See Exercise 10.14.

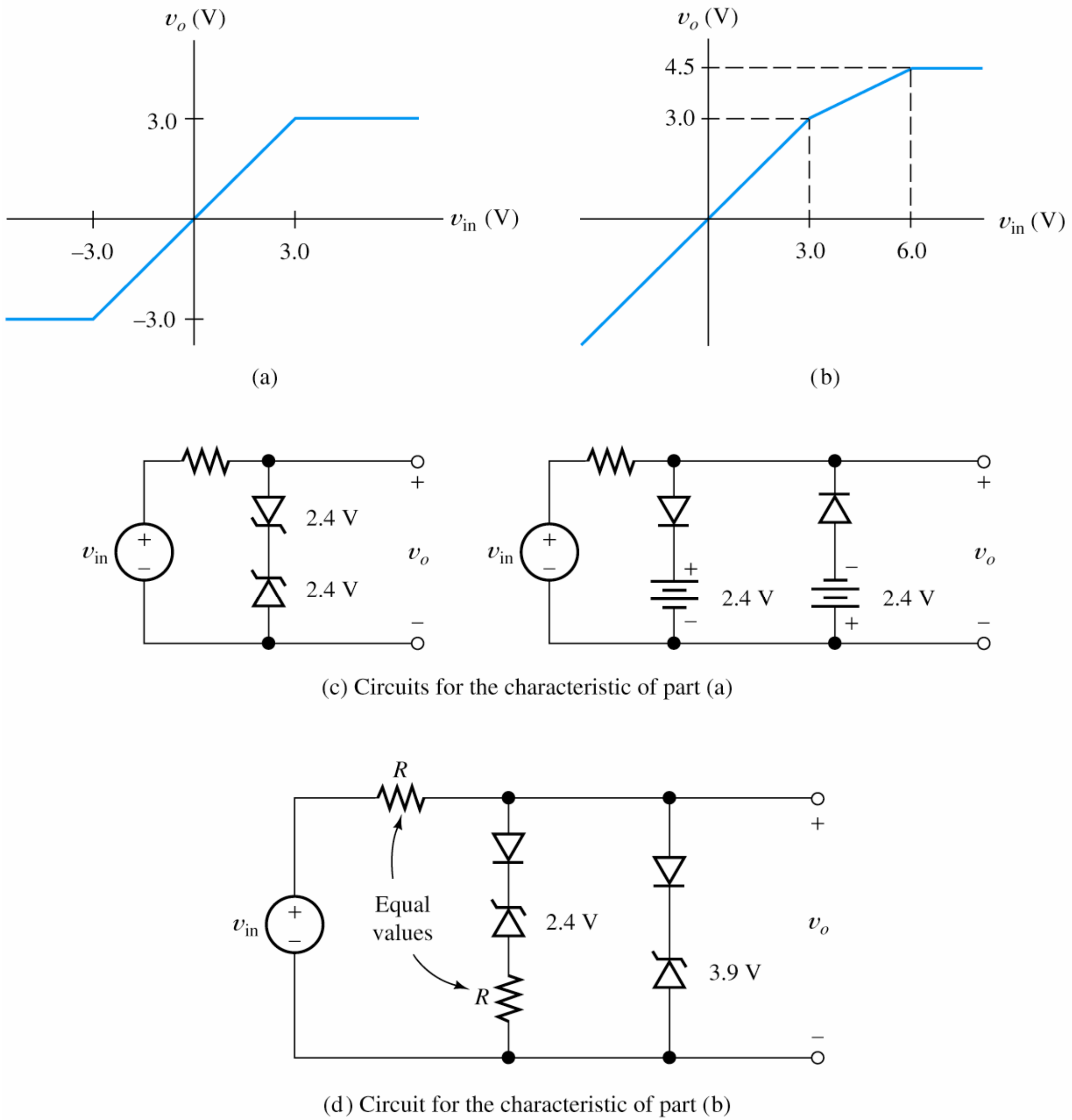
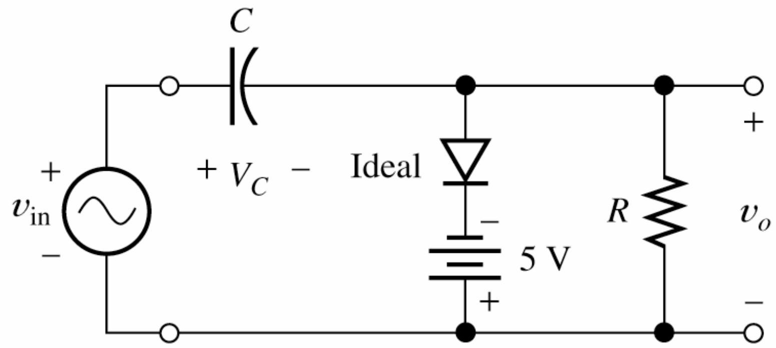
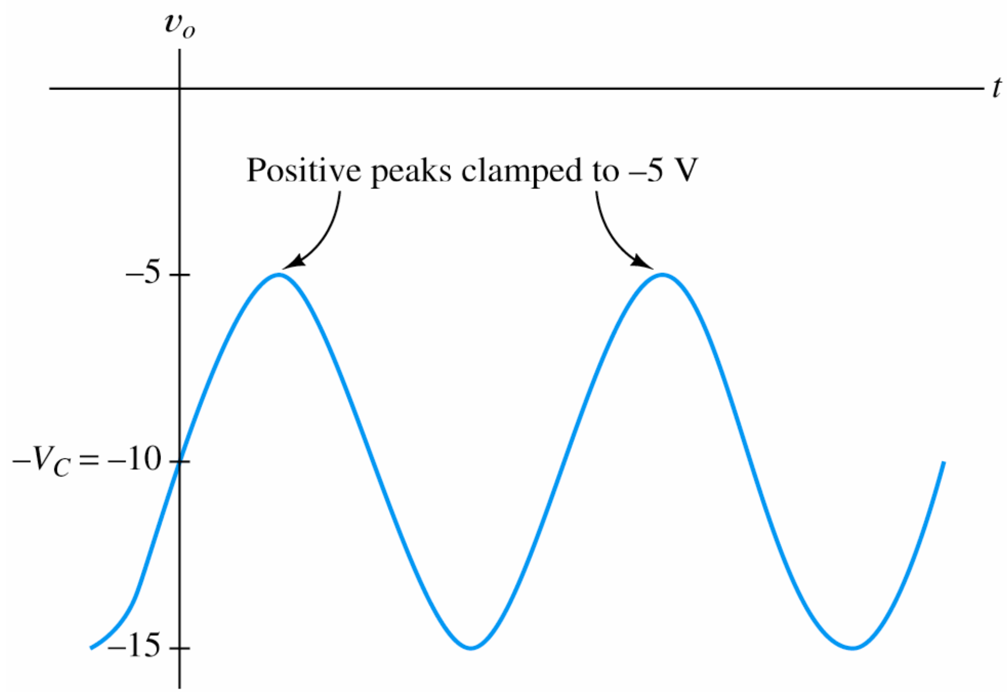


Figure 10.32 See Exercise 10.15.

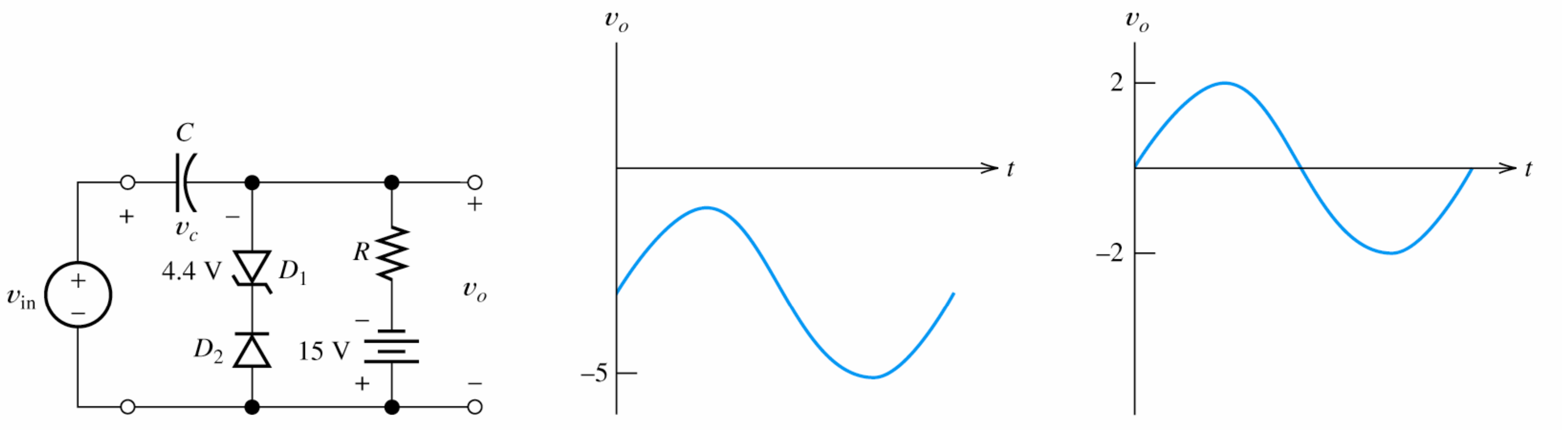


(a) Circuit diagram



(b) Output waveform for $v_{in} = 5\sin(\omega t)$

Figure 10.33 Example clamp circuit.



(a) A circuit that clamps the negative peaks to –5 V (an allowance of 0.6-V forward drop is made)

(b) Output for $v_{in} = 2 \sin(\omega t)$

(c) Output for $v_{in} = 2 \sin(\omega t)$ and *R* returned directly to ground (diodes do not turn on)

Figure 10.34 See Exercise 10.16.

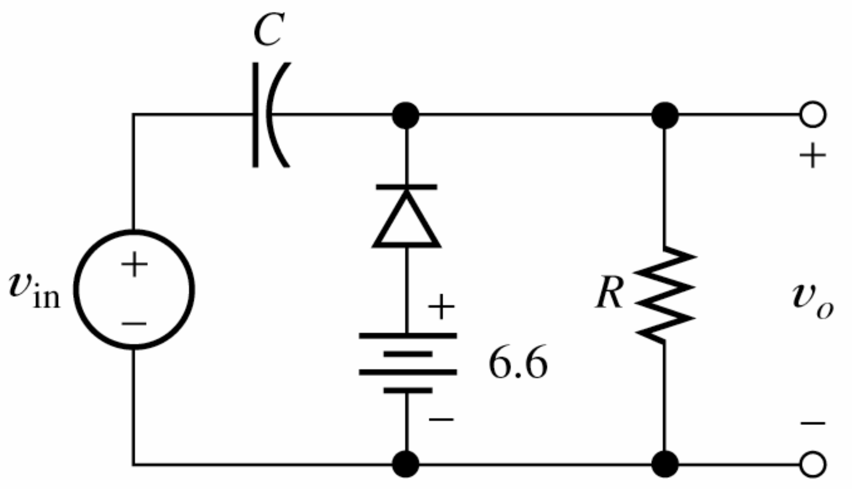


Figure 10.35 Answer for Exercise 10.17.

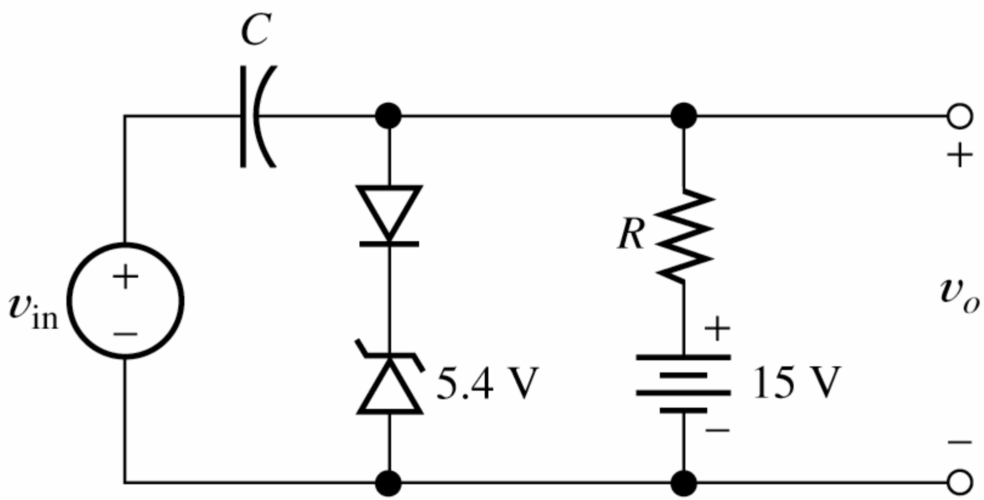


Figure 10.36 Answer for Exercise 10.18.

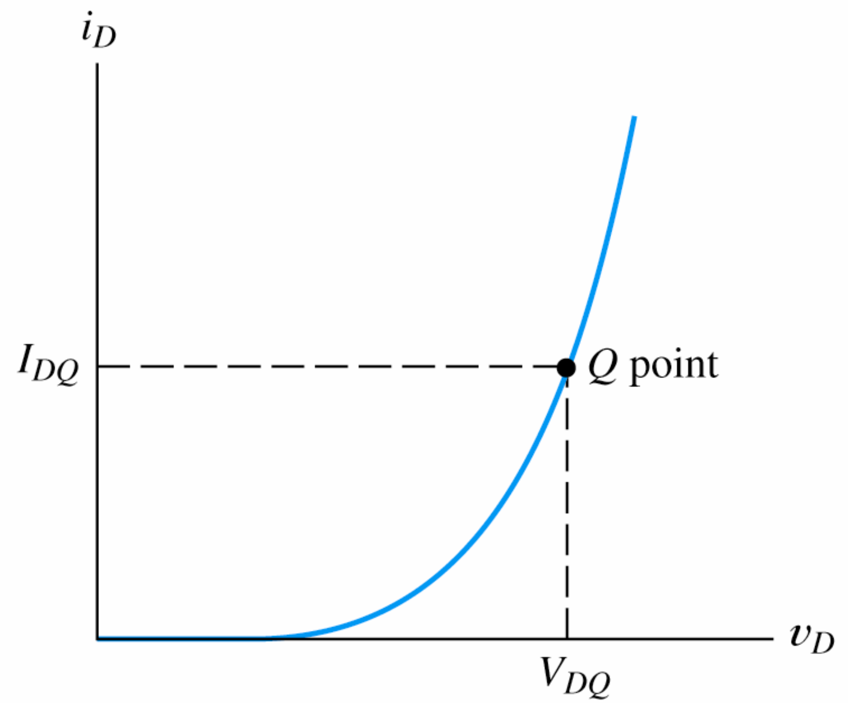
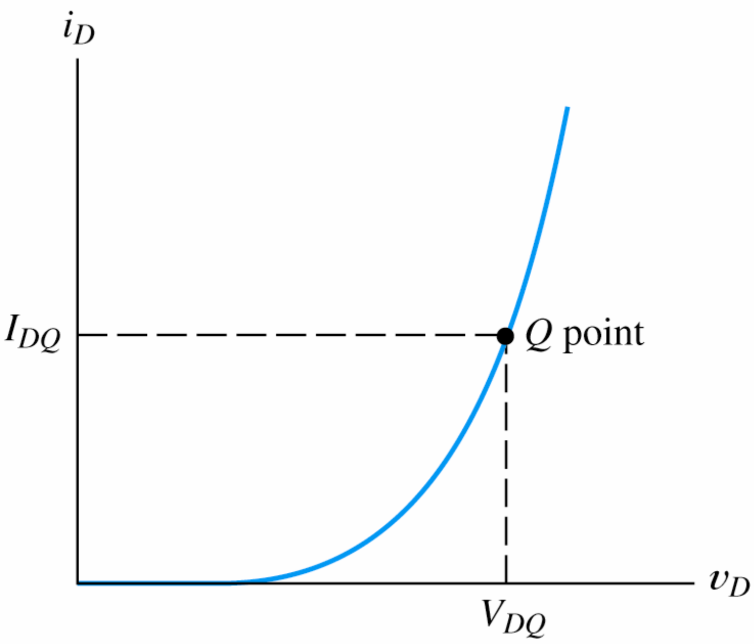


Figure 10.37 Diode characteristic, illustrating the Q point.

LINEAR SMALL-SIGNAL EQUIVALENT CIRCUITS



The small-signal equivalent
circuit for a diode is a resistance.

$$\Delta i_D \cong \left(\frac{di_D}{dv_D}\right)_Q \Delta v_D \qquad i_d = \frac{v_d}{r_d}$$

$$r_d \cong \left[\left(\frac{di_D}{dv_D}\right)_Q\right]^{-1}$$

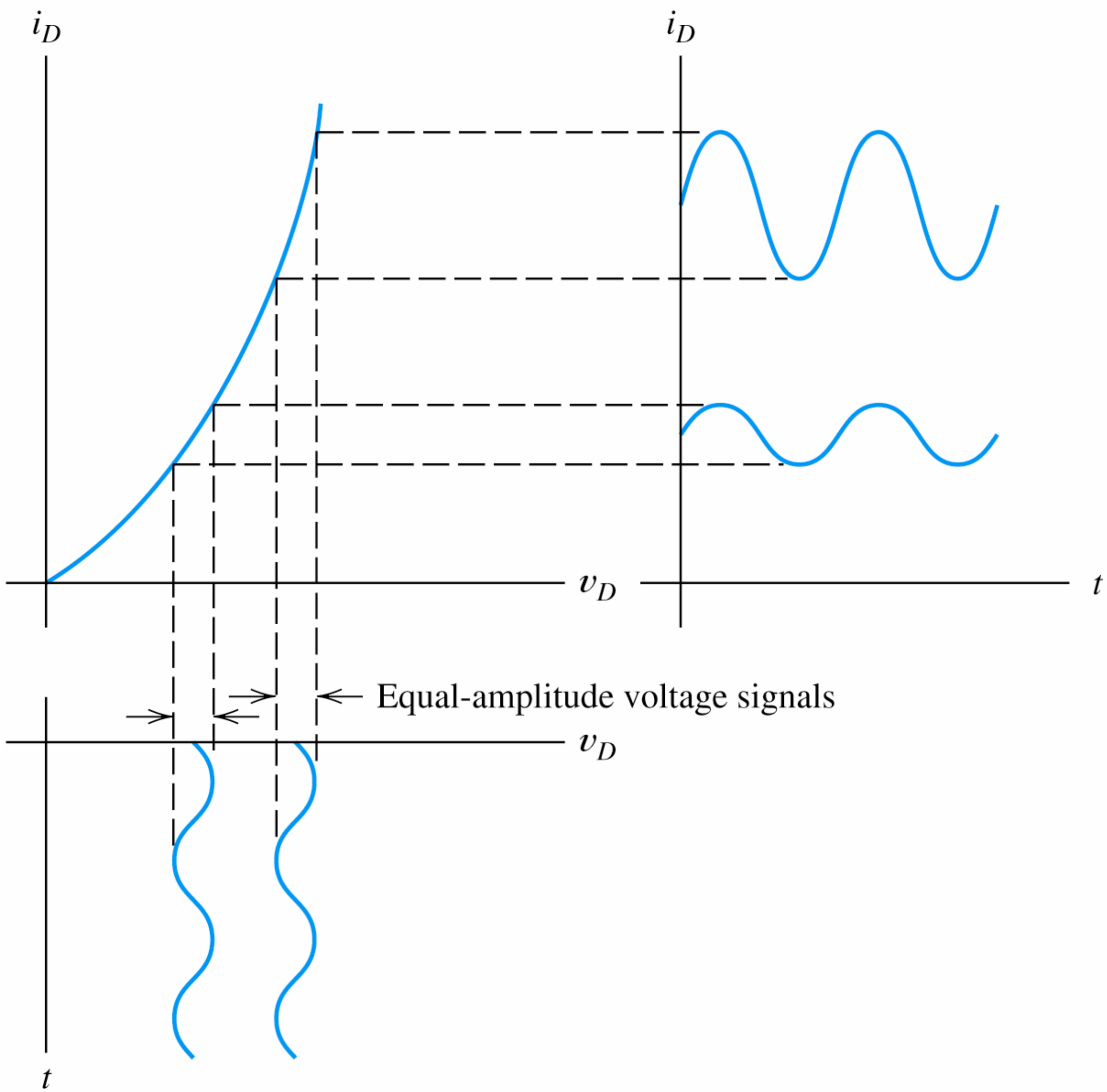


Figure 10.38 As the Q point moves higher, a fixed-amplitude ac voltage produces an ac current of larger amplitude.

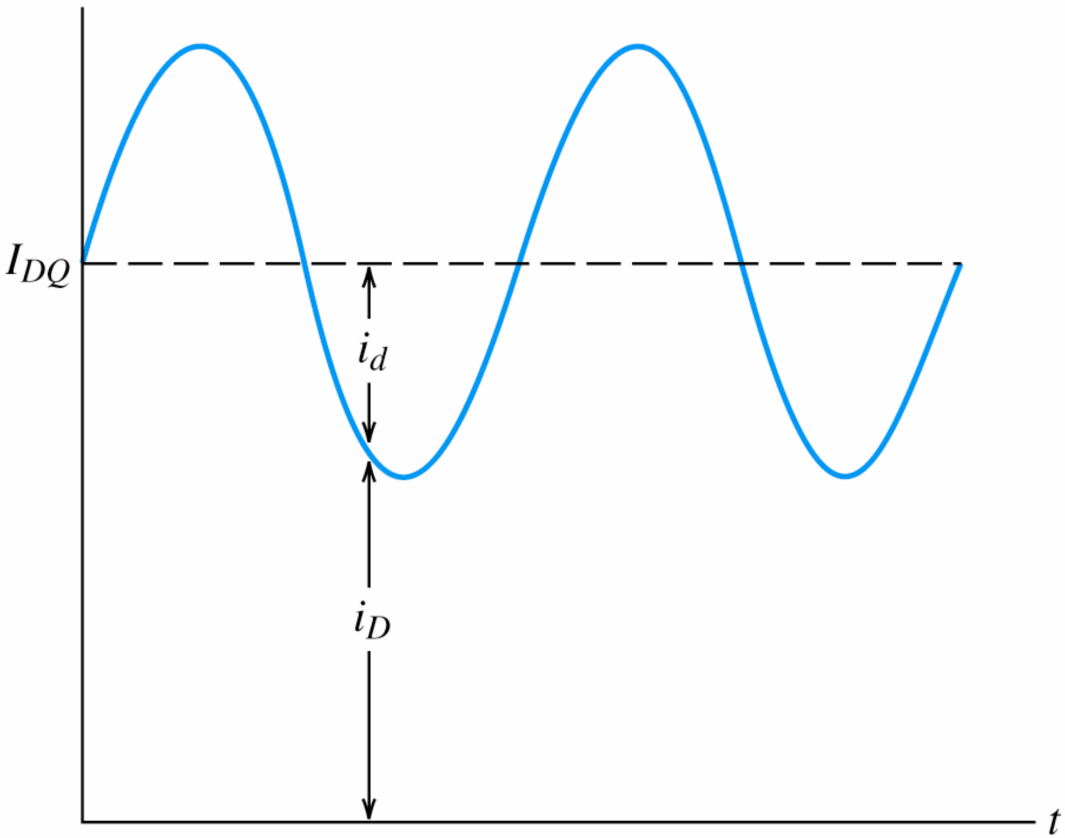


Figure 10.39 Illustration of diode currents.

Notation for Currents and Voltages in Electronic Circuits

- v_D and i_D represent the total instantaneous diode voltage and current. At times, we may wish to emphasize the time-varying nature of these quantities, and then we use $v_D(t)$ and $i_D(t)$

- V_{DQ} and I_{DQ} represent the dc diode current and voltage at the quiescent point.

- v_d and i_d represent the (small) ac signals. If we wish to emphasize their time varying nature, we use $v_d(t)$ and $i_d(t)$.

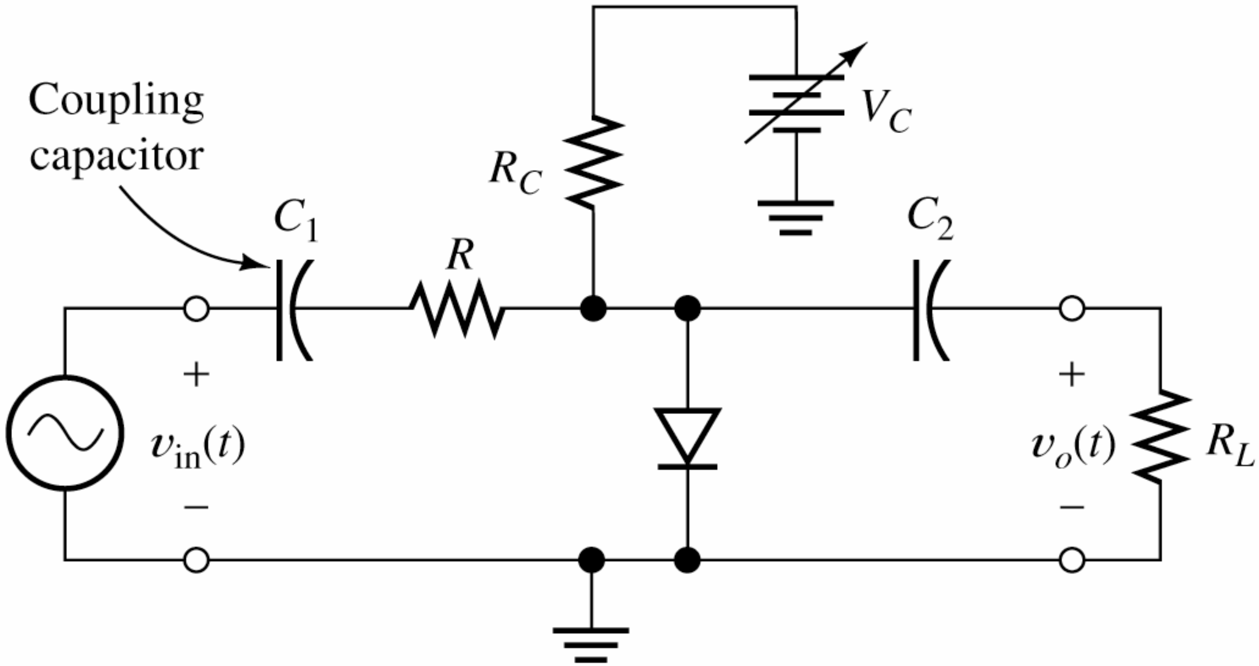


Figure 10.40 Variable attenuator using a diode as a controlled resistance.

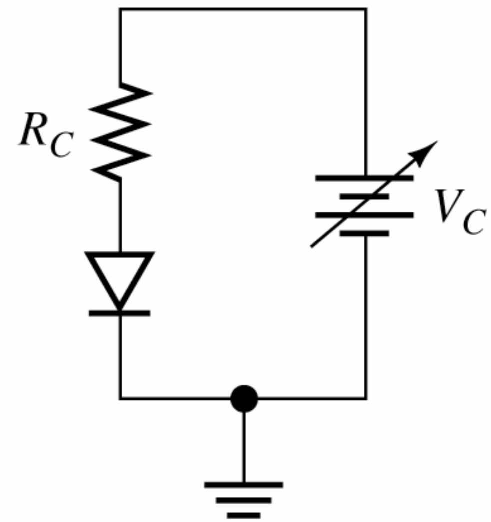


Figure 10.41 Dc circuit equivalent to Figure 10.40 for Q-point analysis.

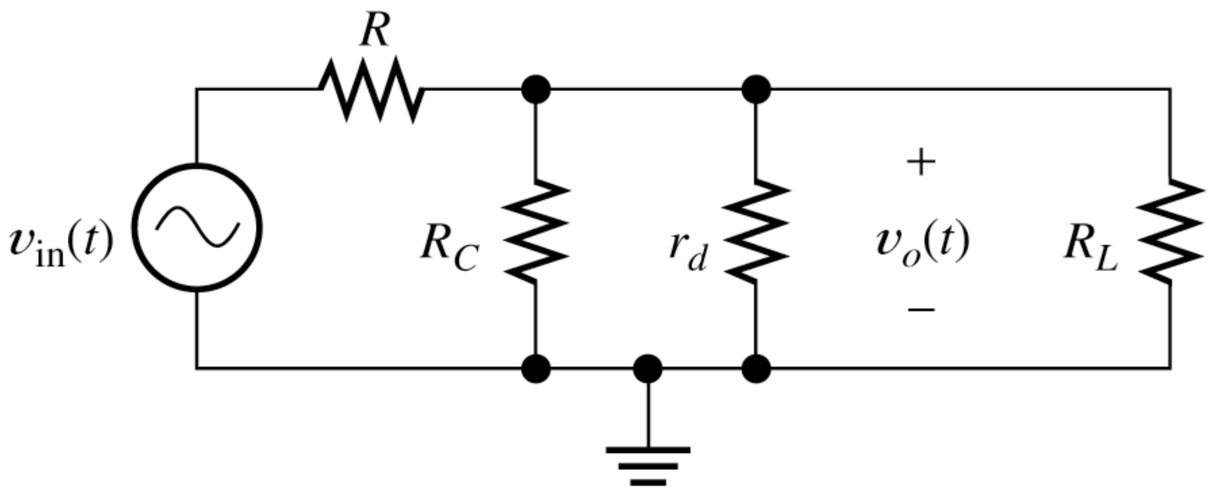


Figure 10.42 Small-signal ac equivalent circuit for Figure 10.40.

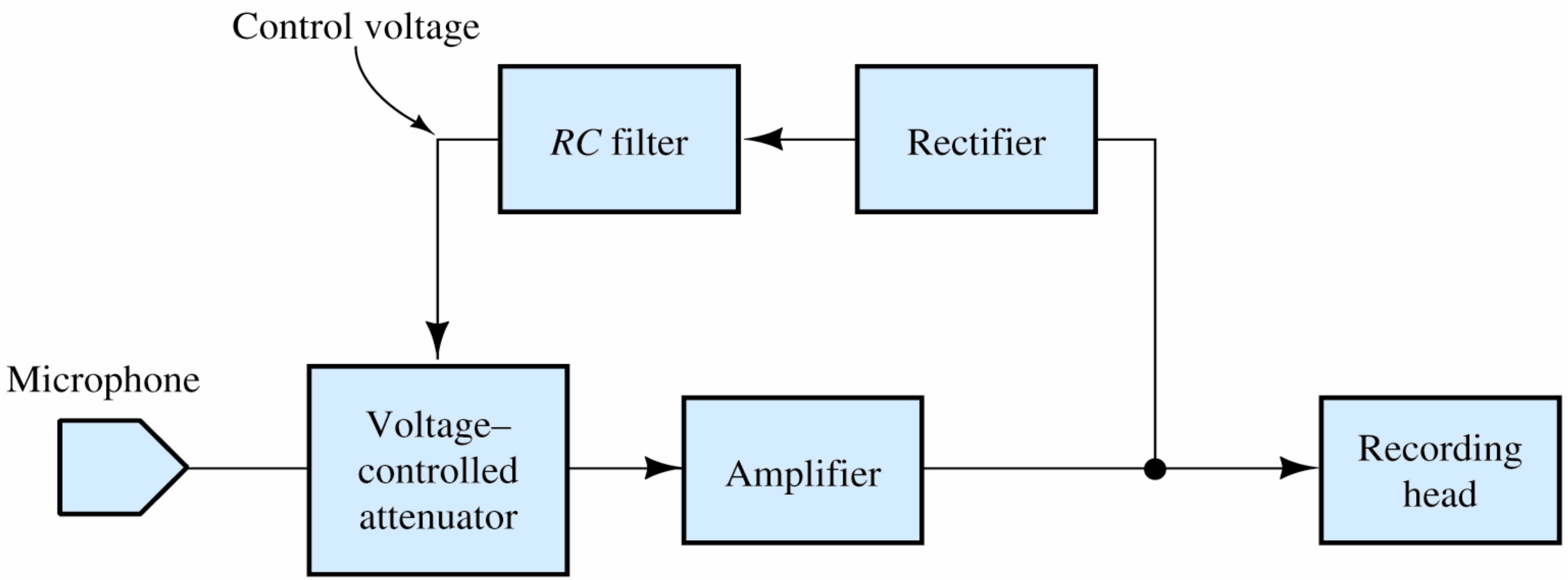


Figure 10.43 The voltage-controlled attenuator is useful in maintaining a suitable signal amplitude at the recording head.

Problem Set

- 6, 8, 15, 19, 29, 32, 34, 41, 51, 61, 62, 70, 73