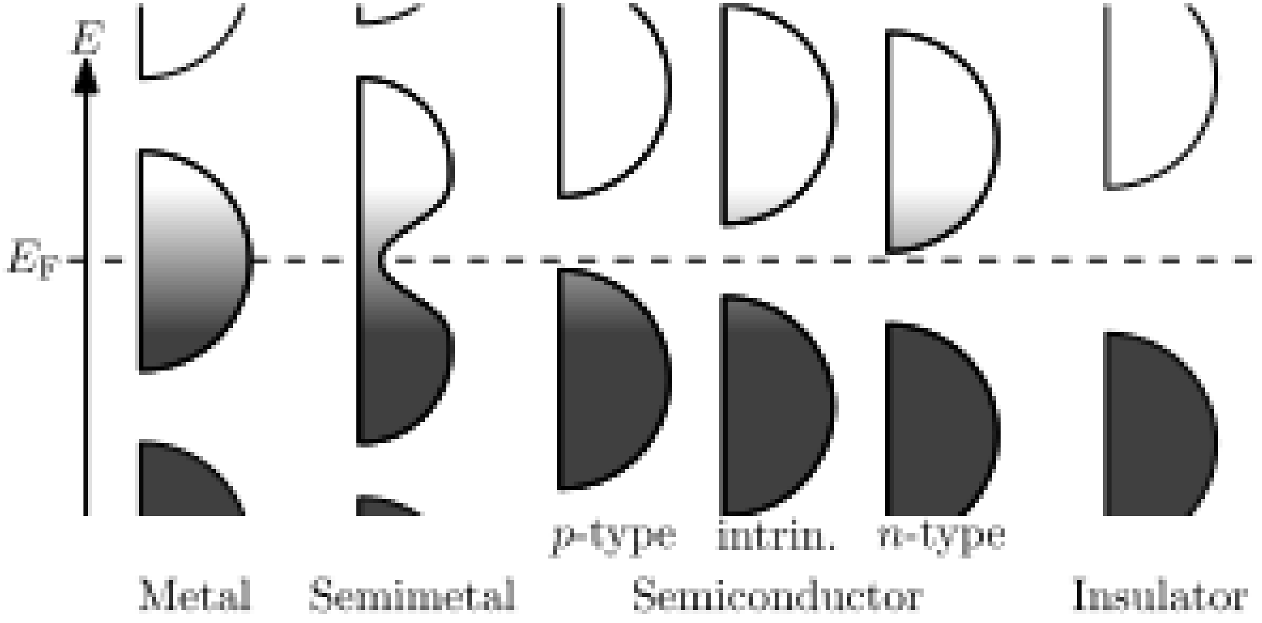
CHAPTER 4

Diodes

Lecture 9

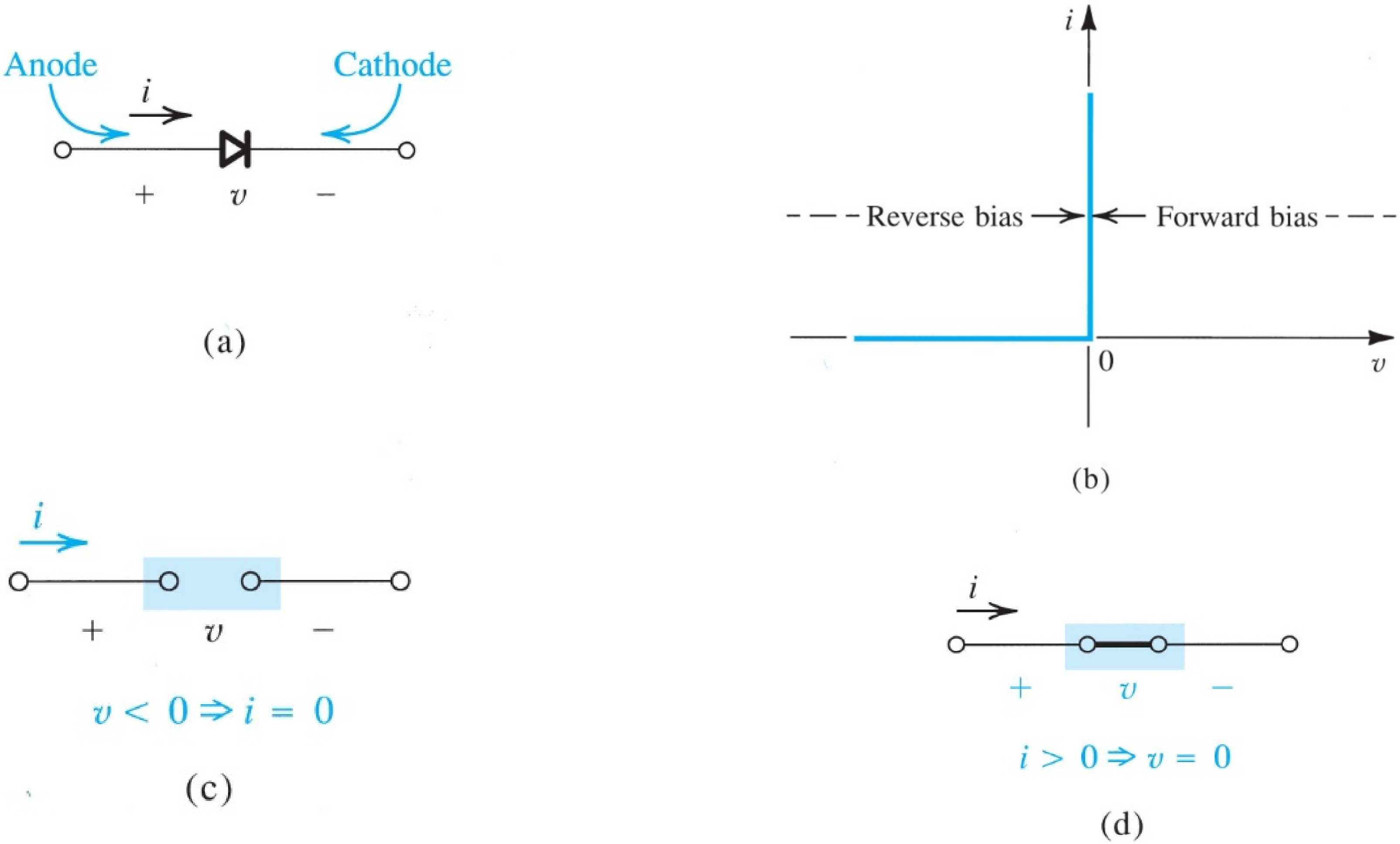


Filling of the electronic states in various types of materials at equilibrium.

Here, height is energy while width is the density of available states for a certain energy in the material listed.

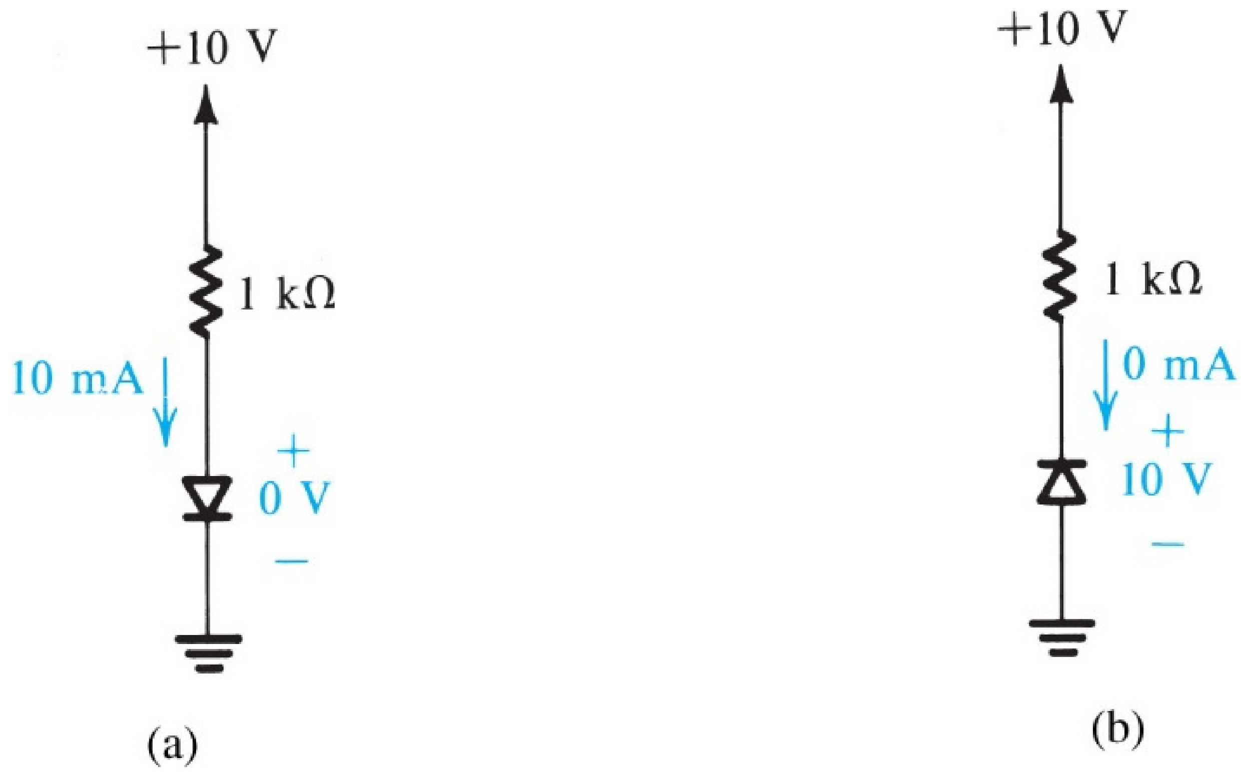
The shade follows the Fermi–Dirac distribution (**black** = all states filled, **white** = no state filled). In metals and semimetals the Fermi level E_F lies inside at least one band. In insulators and semiconductors the Fermi level is inside a band gap; however, in semiconductors the bands are near enough to the Fermi level to be thermally populated with electrons or holes

The ideal diode.

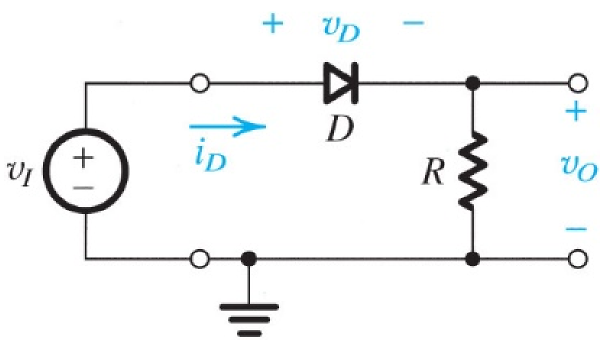


(a) diode circuit **symbol**; **(b)** ***i–v*** characteristic; **(c)** equivalent circuit in the **reverse direction**; **(d)** equivalent circuit in the **forward direction**.

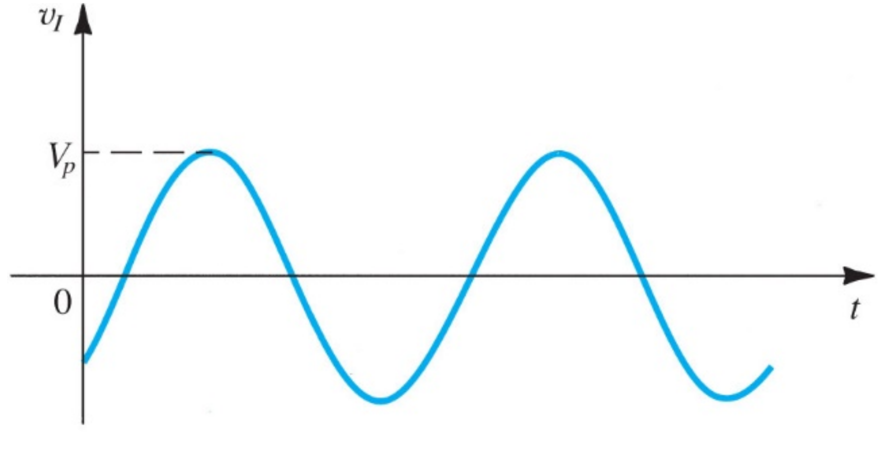
The two modes of operation of ideal diodes and the use of an external circuit to limit **(a)** the forward current and **(b)** the reverse voltage.



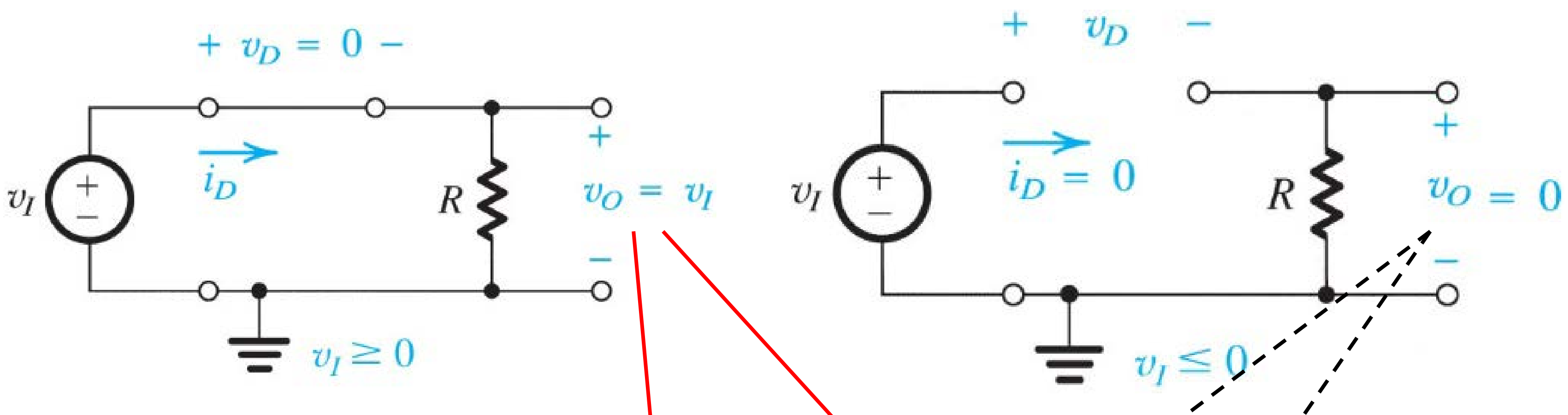
The rectifier

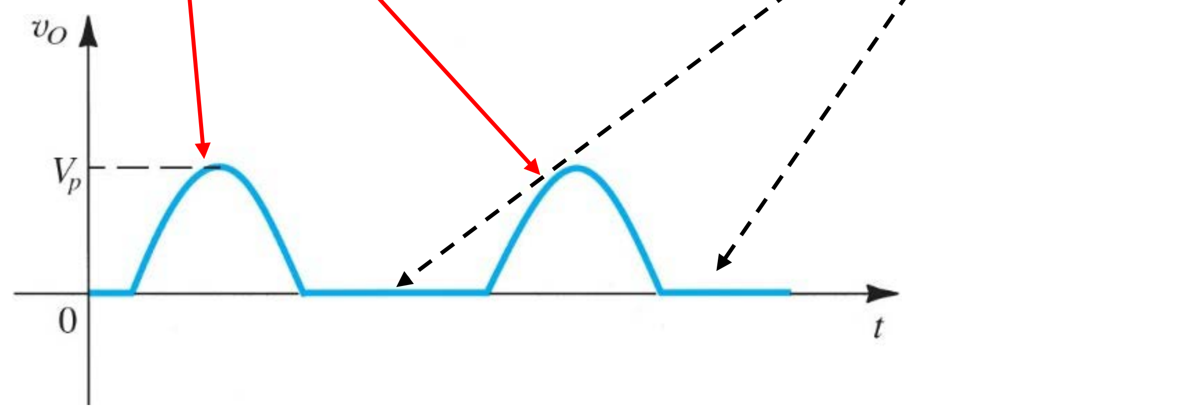


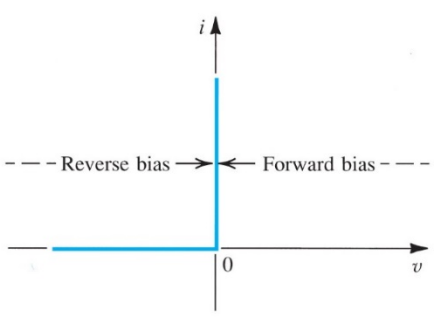
(a)



(b)

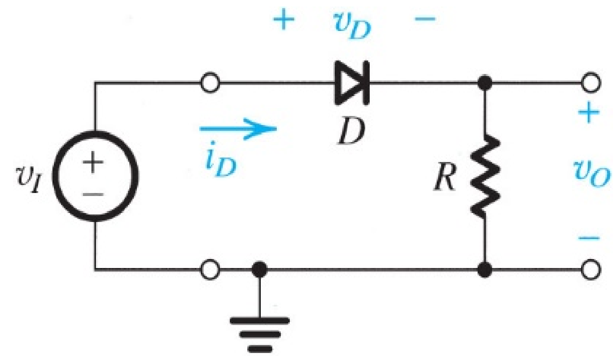






(b)

Exercise 4.1. For the circuit in Fig.(a), sketch the transfer characteristic v_O versus v_I.



(a)

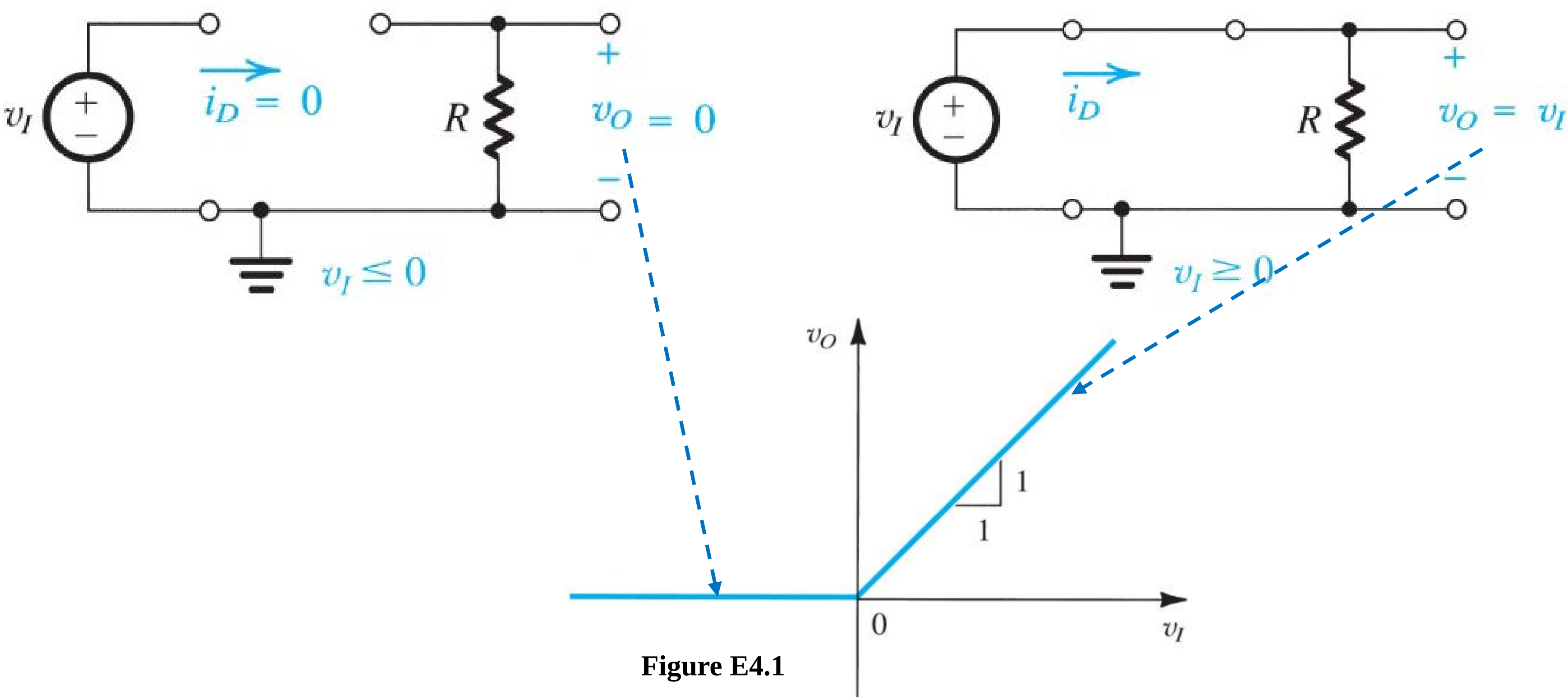
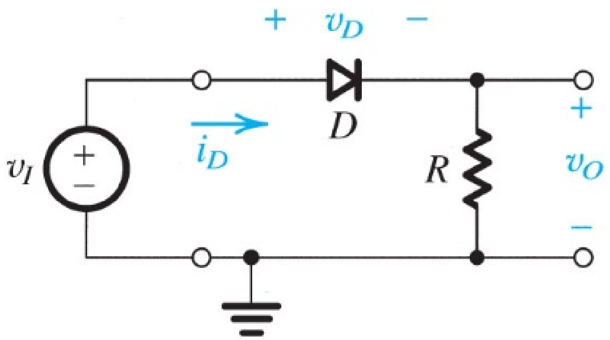


Figure E4.1

Exercise 4.3. In the circuit of Fig. (a), let v_I have a peak value of 10 V and R = 1 kΩ. Find the peak value of i_D and the dc component of v_0. (Hint: the average value of half-sine waves is V_p/π.

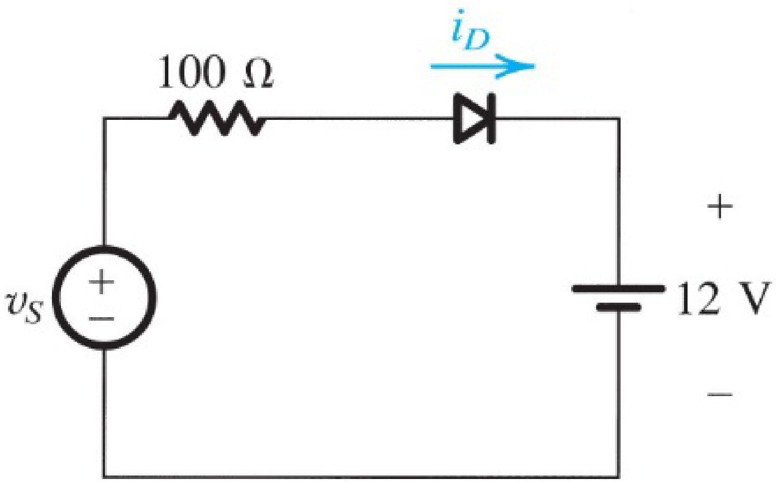


(a)

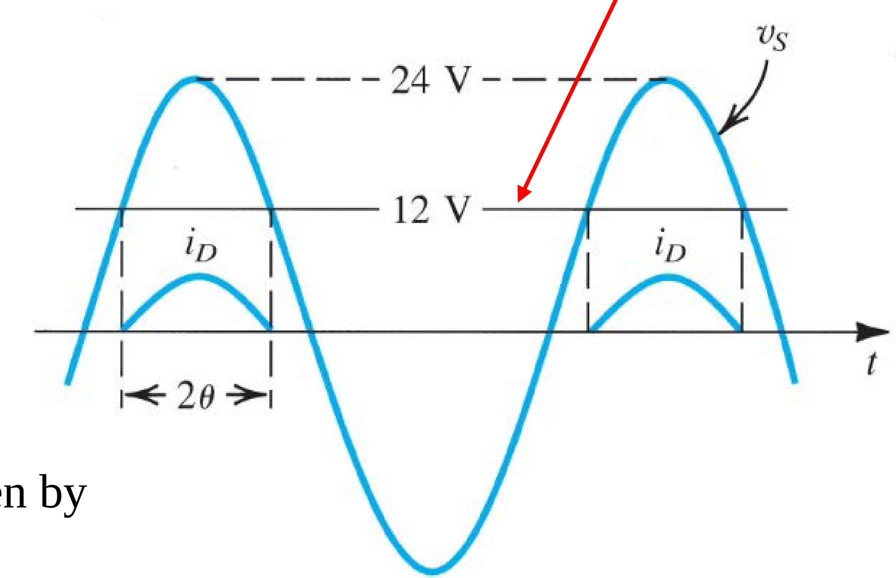
$$i_D = \frac{v_I}{R} = \frac{10}{10^3} = 10\ mA$$

$$\text{dc component of } v_0 = \frac{v_0}{\pi} = \frac{v_I}{\pi} = \frac{10}{\pi} \approx 3.18\ V$$

Example 4.1. Figure 4(a) shows a circuit for charging a 12-V battery. If v_S is a sinusoid with 24-V peak amplitude, find the fraction of each cycle during which the diode conducts. Also, find the peak value of the diode current and the maximum reverse-bias voltage that appears across the diode.



The diode conducts when v_S exceeds 12 V



The **conduction angle** is 2Θ, where Θ is given by

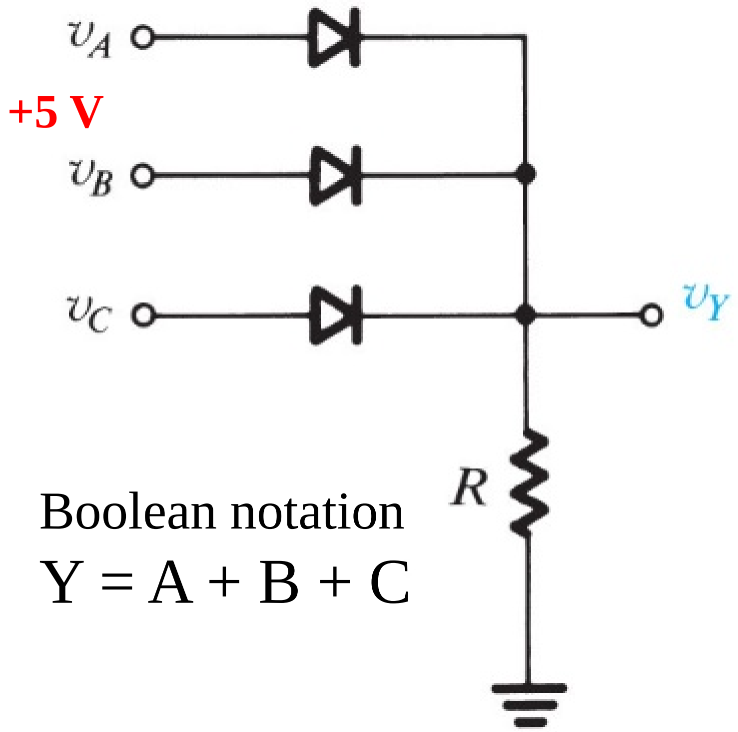
$$24\cos\Theta = 12$$

Thus $\Theta = 60^{o}$ and the conduction angle is 120^{o}, or one-third of a cycle (360^{o} or 2π).

The peak value of the diode current is given by $$I_d = \frac{24-12}{100} = 120\ mA$$

The maximum reverse voltage across the diode occurs when v_S is at its negative peak and is equal to 24 + 12 = 36 V.

Diode logic gates:
(a) OR gate; **(b)** AND gate (in a positive-logic system).



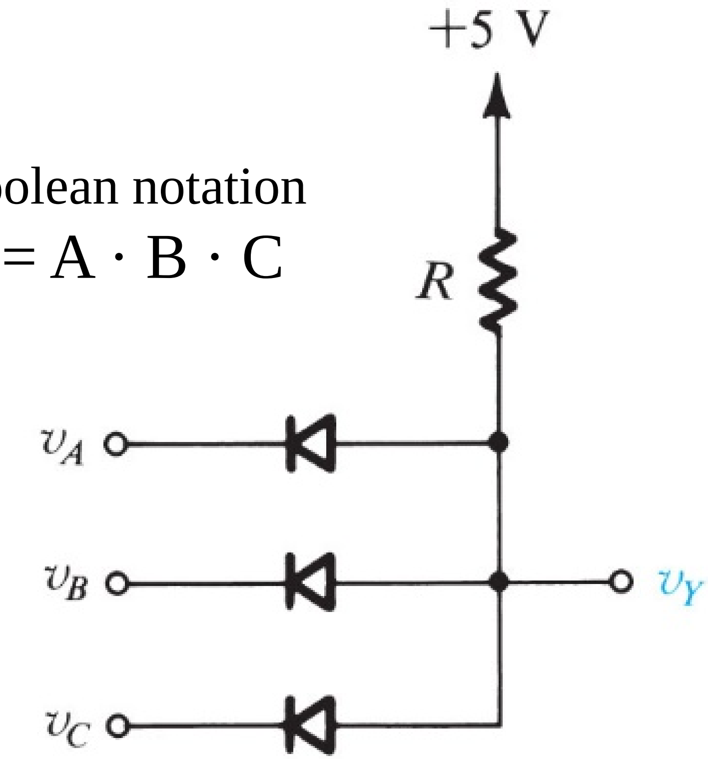
Boolean notation

$Y = A + B + C$

(a)

Boolean notation

$Y = A \cdot B \cdot C$

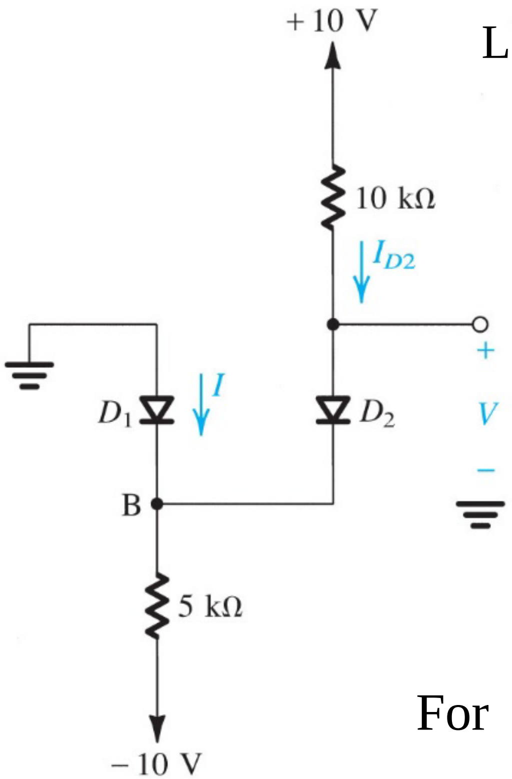


(b)

The **output** will be **high** if one or more of the **inputs are high**. This circuit implements the **logic OR function**

The **output** will be **low** if one or more of the **inputs are low**. This circuit implements the **logic AND function**

Example 4.2. Assuming the diode to be **ideal**, find the values of I and V in these circuits.



Left Fig., assume the diodes are forward biased

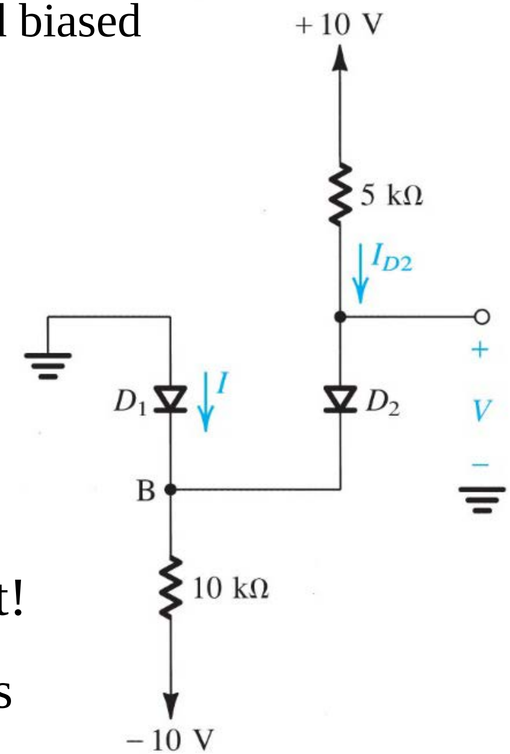
Thus, $V_B = 0$ and $V = 0$

$$I_{D2} = \frac{10-0}{10^3} = 1\ mA$$

Node equation at B

$$I + 1 = \frac{0-(-10)}{(5\,k\Omega\ \text{resistor})} = 2\ mA$$

$$\Rightarrow\ \text{I} = 1\,\text{mA and V} = 0\ \text{V, correct!}$$



For Fig.b, if we assume that both diodes are conducting, then $V_B = 0$ and $V = 0V$.

$$I_{D2} = \frac{10-0}{5} = 2\ mA;\ \text{at node B}:\ I + 2 = \frac{0-(-10)}{10} \Rightarrow I = -1\ mA,\ \text{assumption is wrong!}$$

Assume D_1 is off and D_2 is on

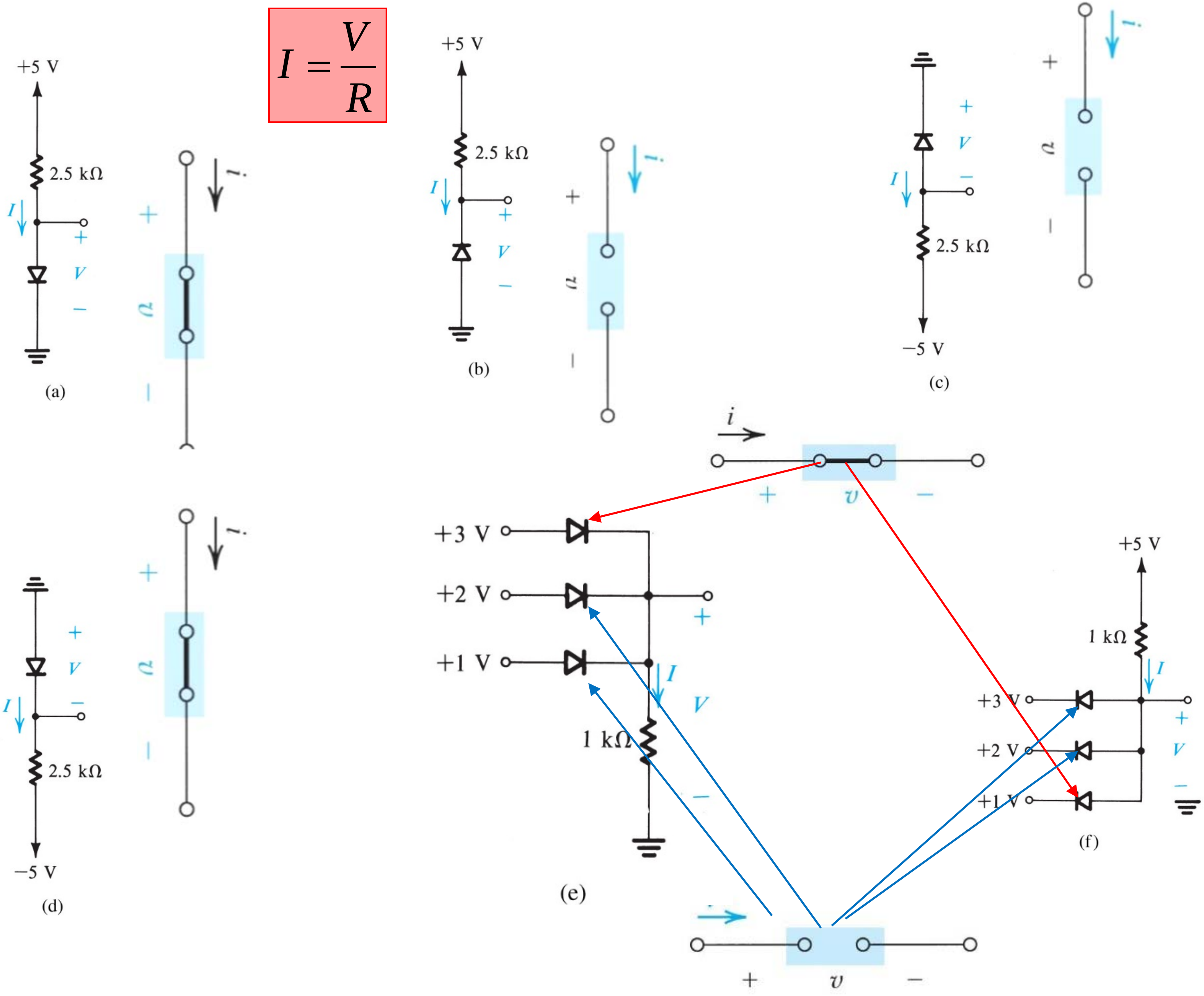
$$I_{D2} = \frac{10-(-10)}{5+10} \approx 1.33\ mA;\ \text{at node B}:$$

$$V_B = -10 + 10 \times 1.33 = +3.33\ V$$

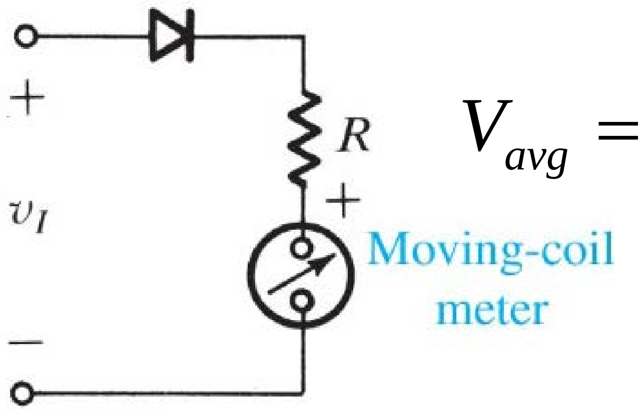
Thus D_1 is reverse biased and $I = 0$ A and $V = 3.3$ V

Exercise 4.4. Find the values of I and V in the circuits shown below **(ideal diode).**

$$\boxed{I = \frac{V}{R}}$$



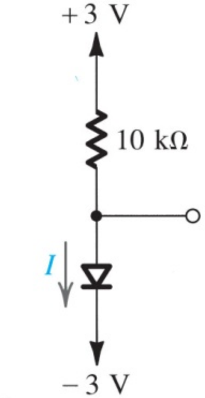
Exercise 4.5. An ac voltmeter. A moving-coil meter gives a full-scale reading when the *average* current flowing through it is 1 mA. The moving-coil meter has a 50 Ω resistance. Find the value of R that results in the meter indicating a full-scale reading when the input sine-wave voltage v_I is 20 V peak-to-peak. (Hint: the average value of half-sine waves is V_p/π)

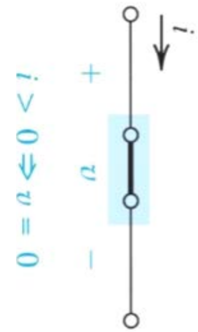


$$V_{avg} = \frac{10}{\pi}\ Volts = (50 + R)\times 10^{-3}\,A$$

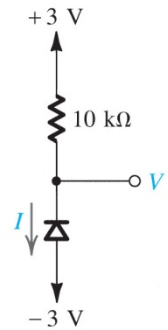
$$Thus, \quad R = \frac{10^4}{\pi} - 50 \approx 3133\ \Omega = 3.133\ k\Omega$$

Pr. 4.2. For the circuits shown in Fig. using ideal diodes, find the values of the voltages and currents indicated

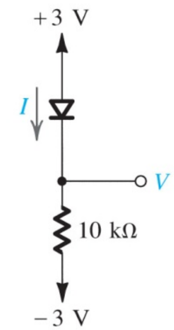




(a)



(b)



(c)

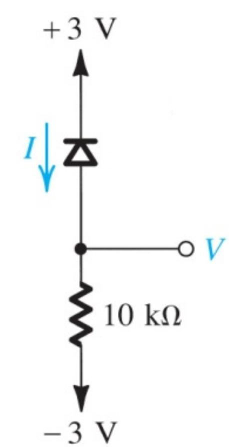
Diode is off
I = 0,
V = + 3 V

Diode is on
V = + 3 V

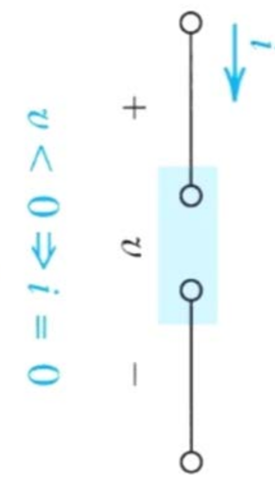
$$I = \frac{3-(-3)}{10} = 0.6 \;\; mA$$

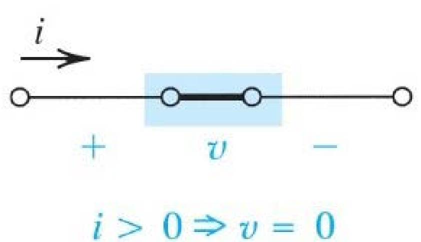
Diode is on
V = - 3 V

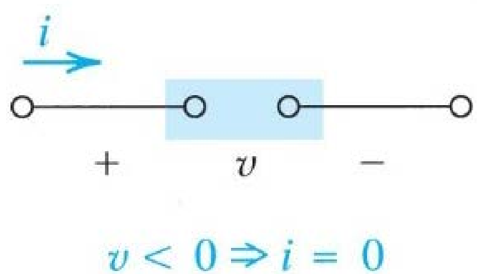
$$I = \frac{3-(-3)}{10} = 0.6 \;\; mA$$



(d)

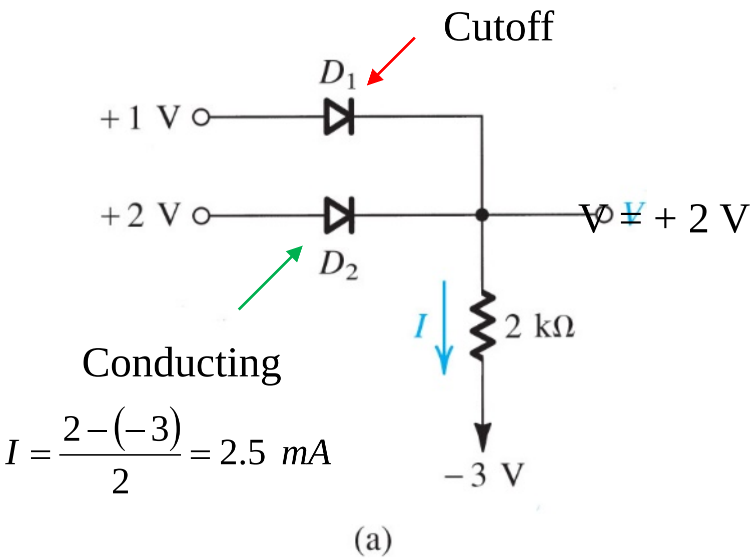






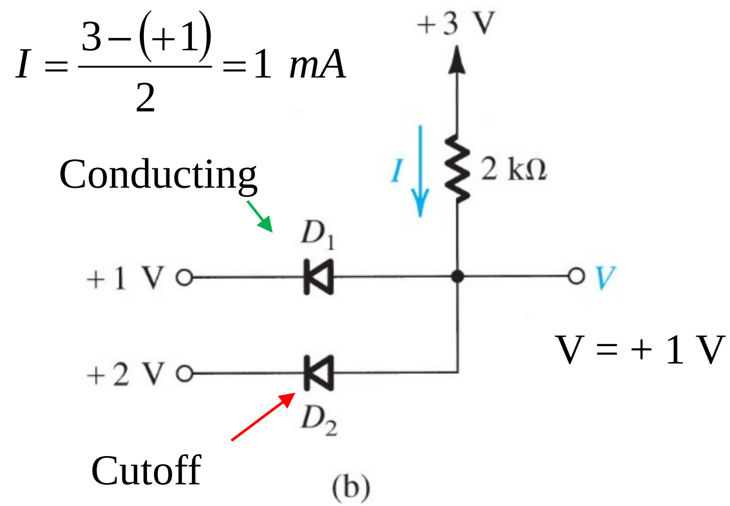
Diode is off: I = 0, V = -3 V

Pr. 4.3. For the circuits shown in Fig. using ideal diodes, find the values of the labeled voltages and currents



$$I = \frac{2-(-3)}{2} = 2.5\ mA$$

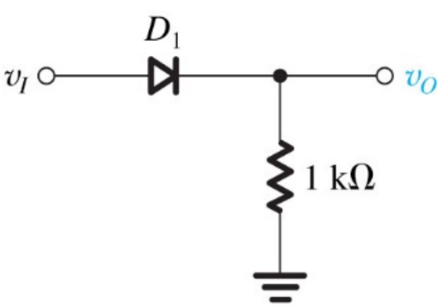
(a)



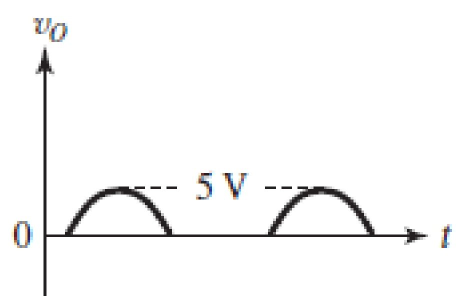
$$I = \frac{3-(+1)}{2} = 1\ mA$$

(b)

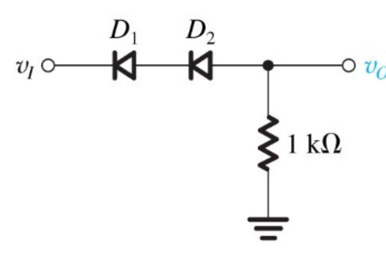
Pr. 4.4. In each of the ideal-diode circuits, V_I is a 1 kHz, 5-V peak sine wave. Sketch the waveform resulting at V_O . What are its positive and negative peak values?



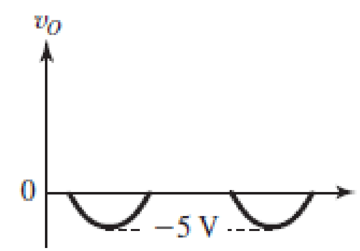
(a)



$$V_{p^+} = 5\ V; V_{p^-} = 0\ V;\ f = 1\ kHz$$

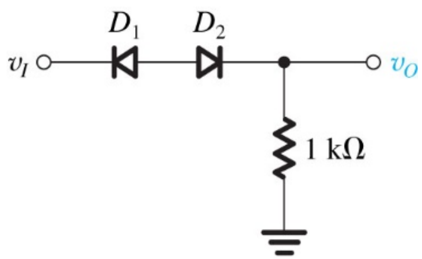


(b)

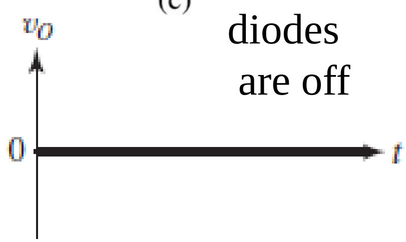


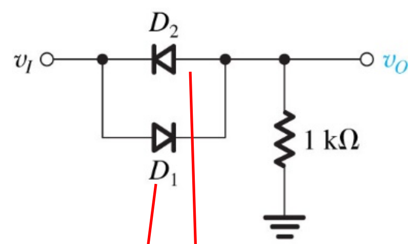
$$V_{p^+} = 0\ V; V_{p^-} = -5\ V;\ f = 1\ kHz$$

Pr. 4.4. In each of the ideal-diode circuits, V_I is a 1 kHz, 5-V peak sine wave. Sketch the waveform resulting at V_0. What are its positive and negative peak values?

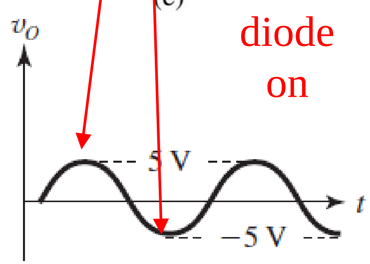


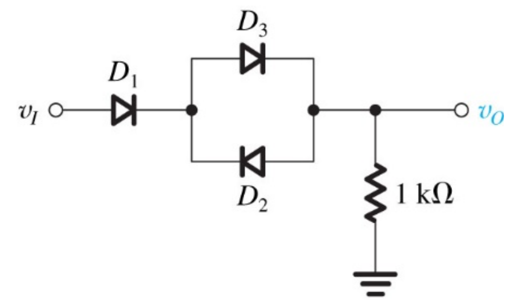
(c)



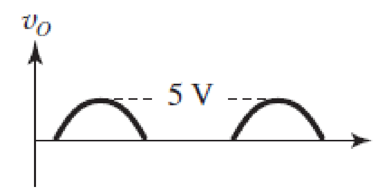


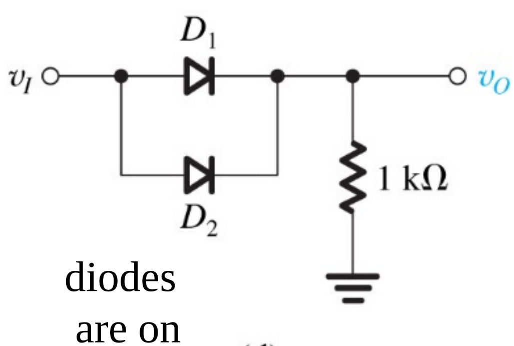
(e)



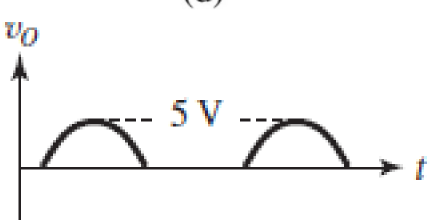


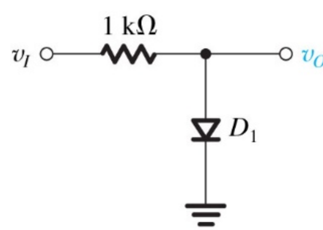
(f)



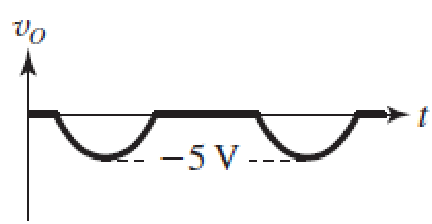


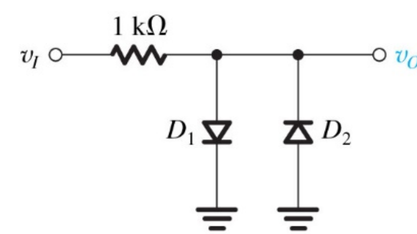
(d)



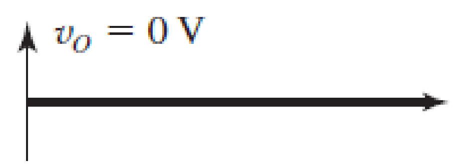


(g)

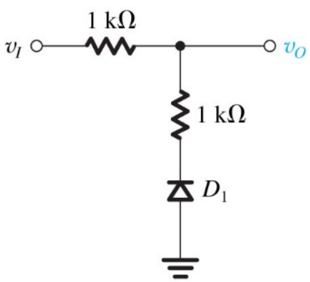




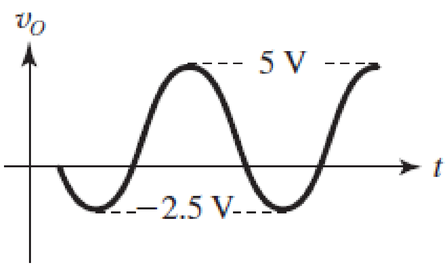
(h)



Pr. 4.4. In each of the ideal-diode circuits, v_I is a 1 kHz, 5-V peak sine wave. Sketch the waveform resulting at v_O . What are its positive and negative peak values?

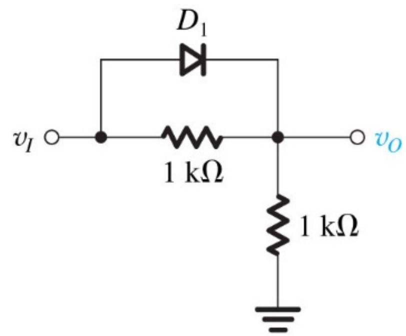


(i)

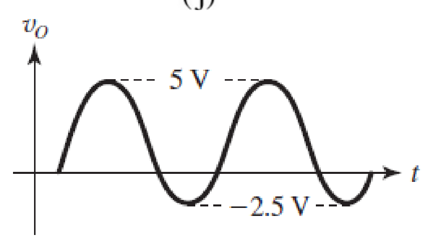


$v_I > 0$, *diode* is "*off*"
and $v_0 = v_I$
$v_I < 0$, *diode* is "*on*"
and *voltage divider*

$$v_0 = v_I \frac{1}{1+1} = 0.5 v_I$$



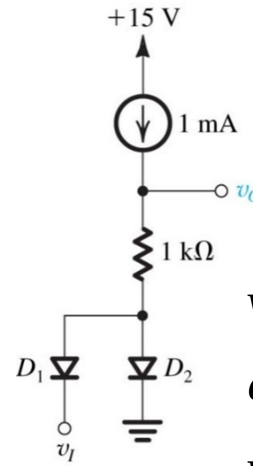
(j)



$v_I > 0$, *diode* is "*on*"
and $v_0 = v_I$
$v_I < 0$, *diode* is "*off*"
and *voltage divider*

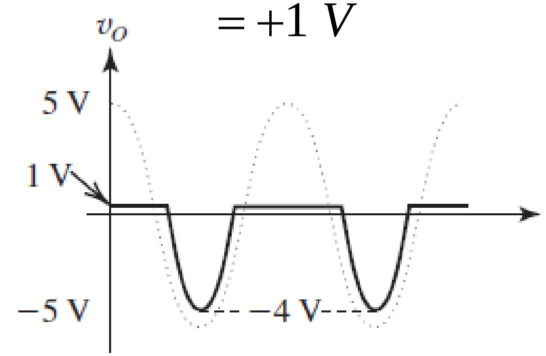
$$v_0 = v_I \frac{1}{1+1} = 0.5 v_I$$

(v_I) is negative



(k)

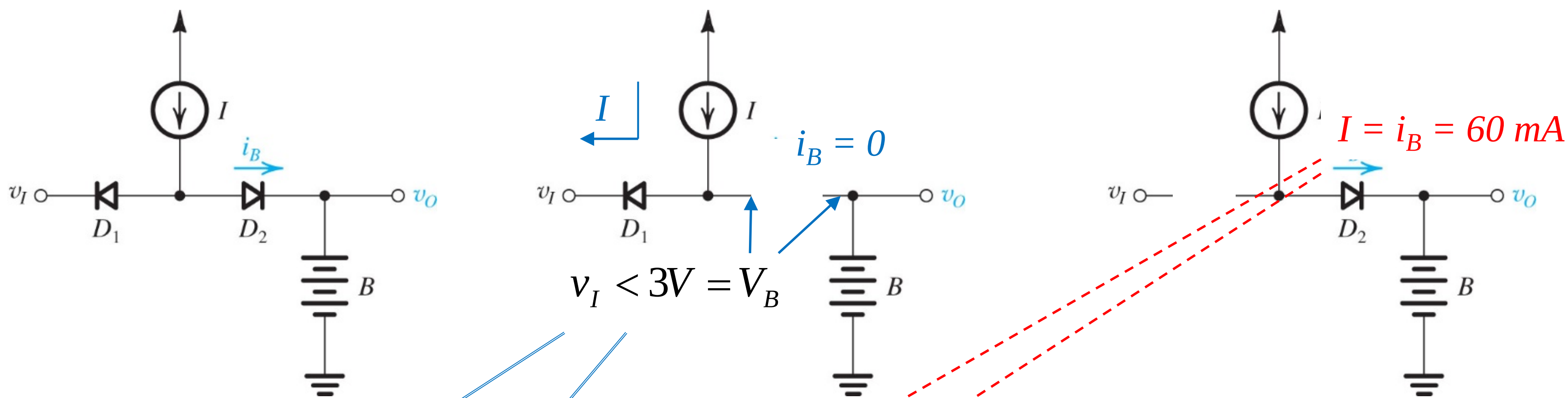
$v_I > 0$, D_1 is "*off*"
and D_2 *is* "*on*"
$v_0 = 1\ mA \times 1\ k\Omega$
$= +1\ V$

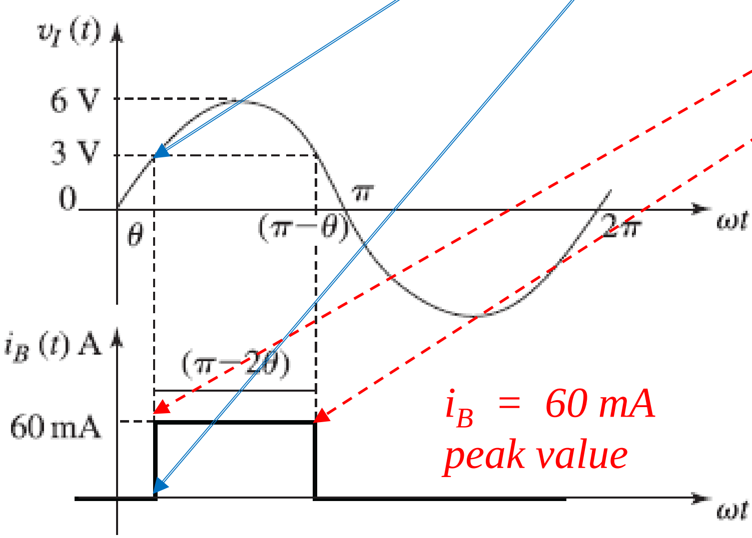


$v_I < 0$, D_1 is "*on*"
and D_2 is "*off*"
$v_0 = v_I + 1\ V = -4\ V$

f = 1 *kHz in all circuits*

Pr. 4.5. The circuits shown in Fig. is a model for a battery charge. Here V_I is a 6-V peak sine wave, D_1 and D_2 are ideal diodes, I is a 60 mA current source, and B is a 3-V battery. Sketch and label the waveform of the battery current i_B. What is its peak value? What is its average value? If the peak value of v_I is reduced by 10%, what do the peak and average values of i_B become?

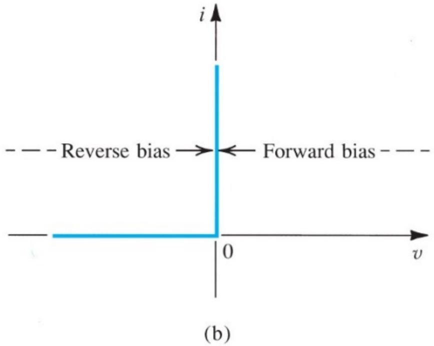




To obtain the average value of i_B, we need the conduction angle for D_2, $\pi - 2\Theta$,

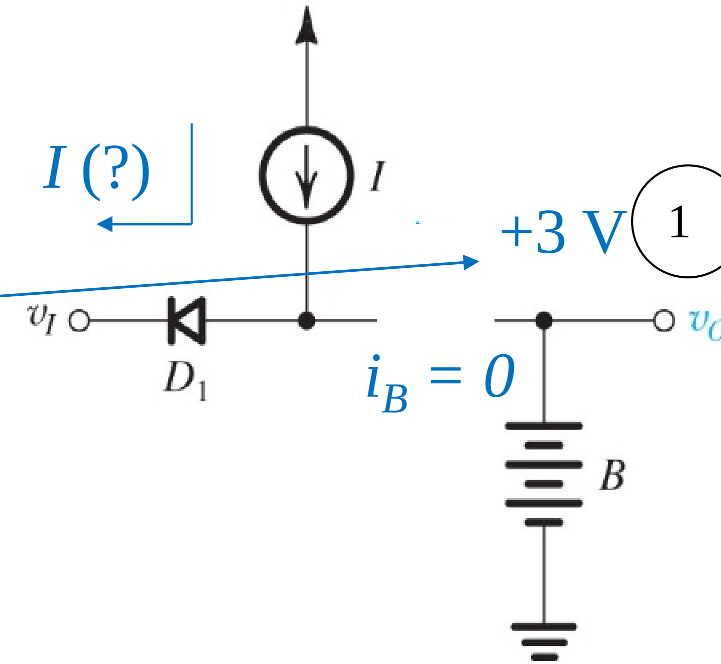
$$\theta = \sin^{-1}\left(\frac{3}{6}\right) = 30^\circ$$

$$\pi - 2\theta = 180^\circ - 60 = 120^\circ$$



2

I (?)



+3 V

1

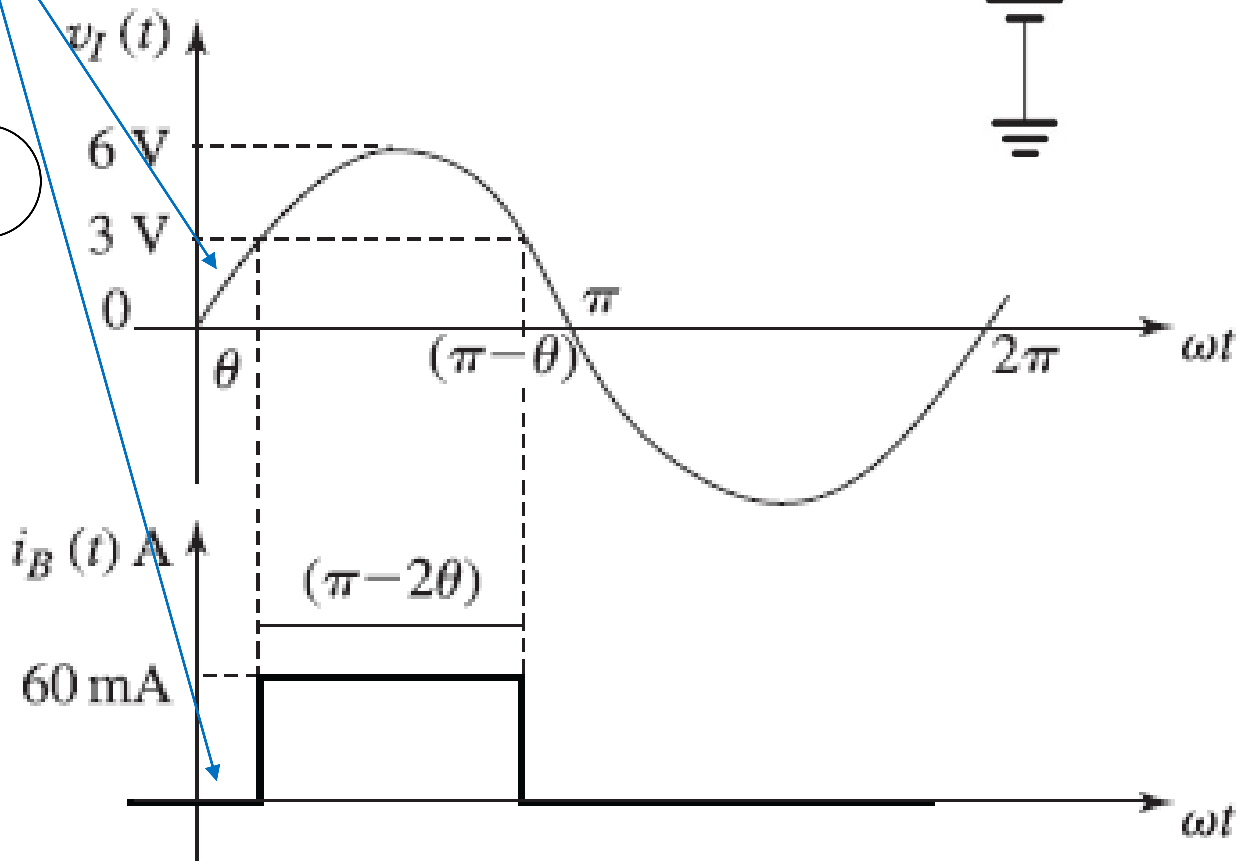
$i_B = 0$

$v_I < 3\,\text{V} = V_B$

4

Conduction angle can be found using two formulas

3

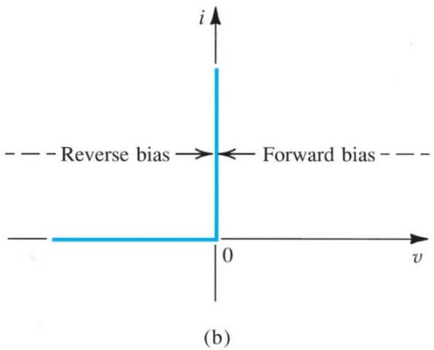


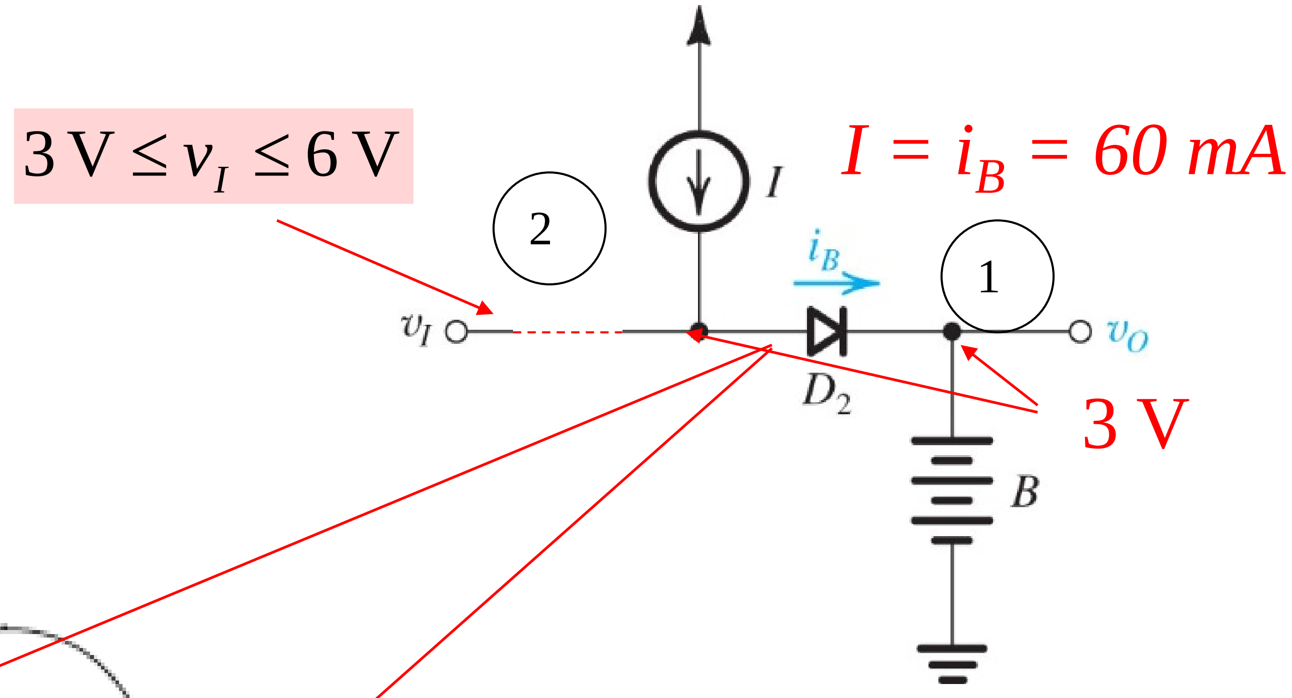
Old one

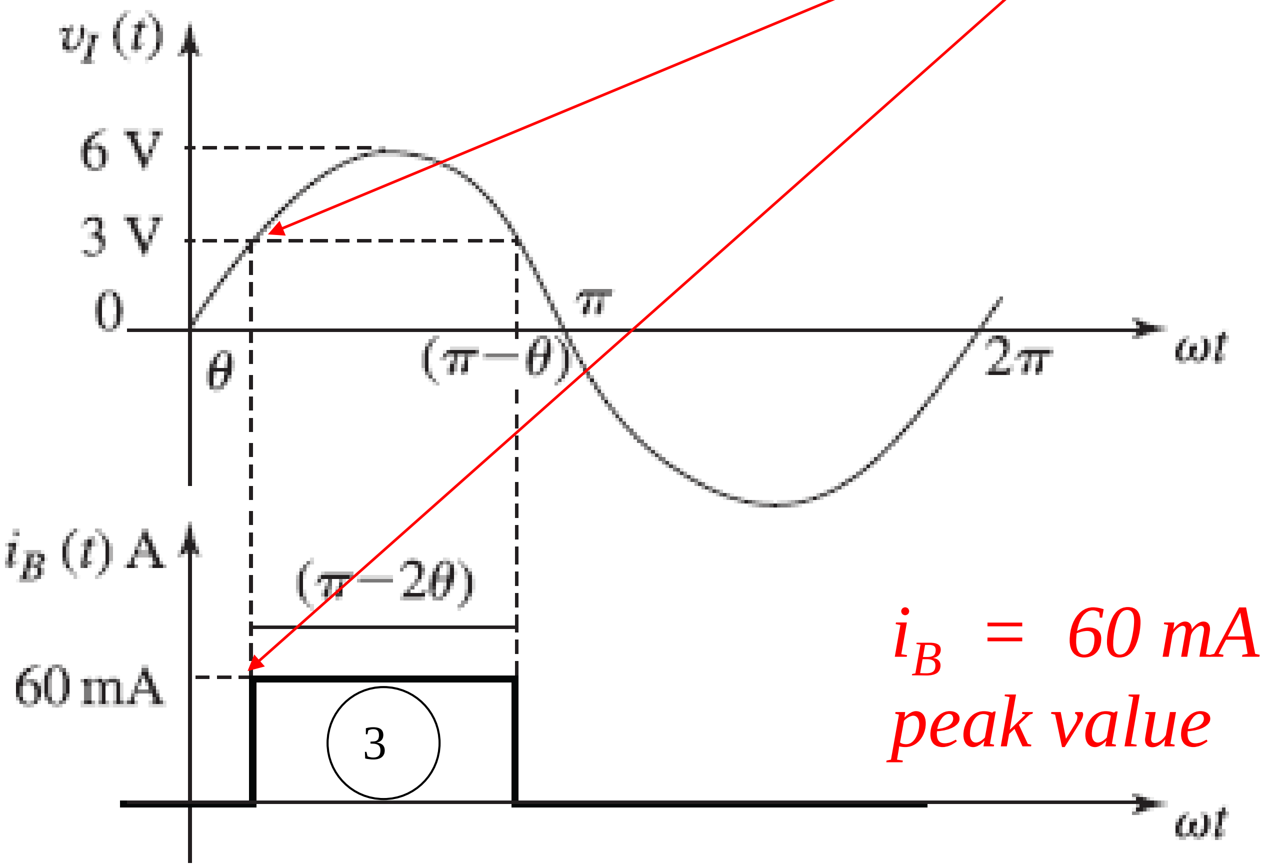
$$2\cos^{-1}\left(\frac{3}{6}\right) = 120^0$$

New one $180^0 - \theta =$

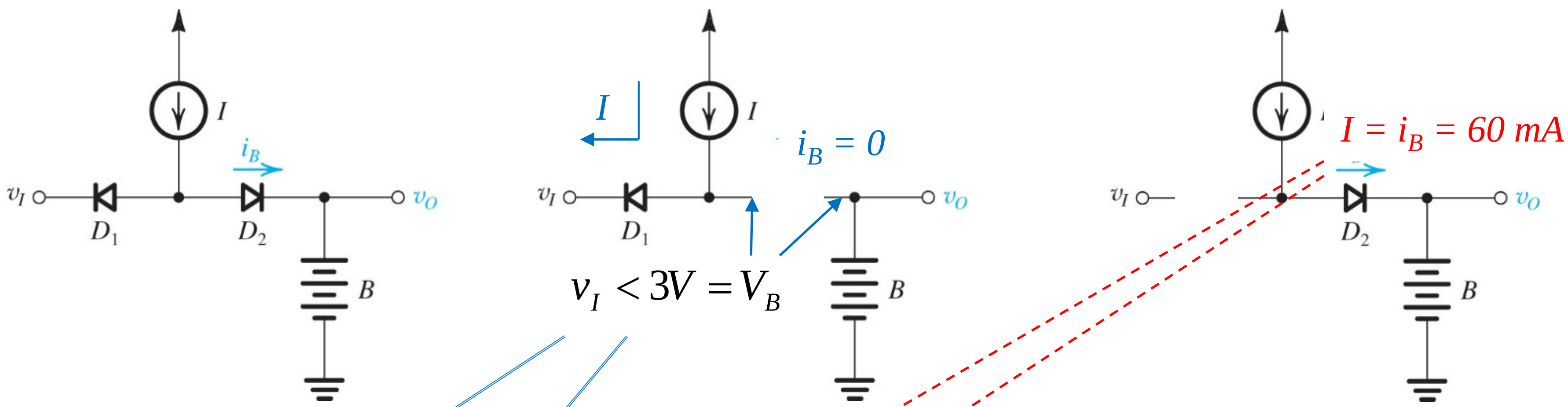
$$180^0 - \sin^{-1}\left(\frac{3}{6}\right) = 120^0$$

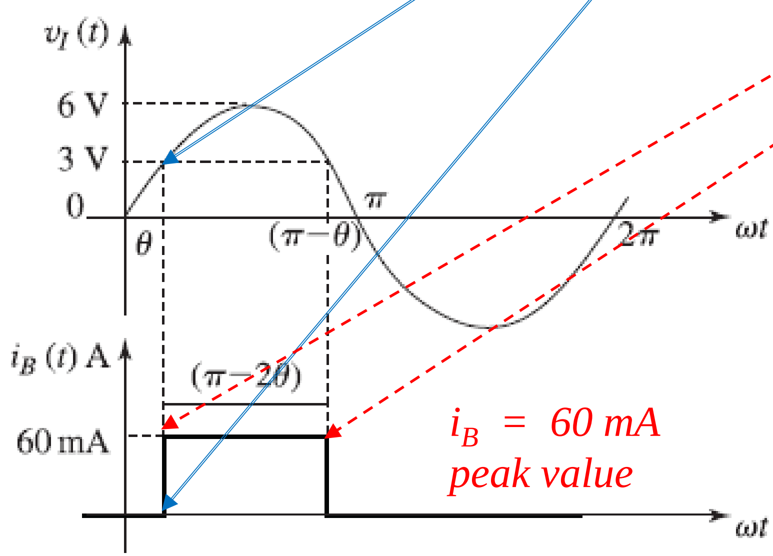

i
Reverse bias
Forward bias
0
v
(b)


$3\text{ V} \le v_I \le 6\text{ V}$
$I = i_B = 60\text{ mA}$
2
1
I
i_B
v_I
v_O
D_2
3 V
B


$v_I\,(t)$
6 V
3 V
0
π
θ
$(\pi-\theta)$
2π
ωt
$i_B\,(t)$ A
$(\pi-2\theta)$
60 mA
3
ωt
$i_B = 60\text{ mA}$
peak value

What is its average value?





To obtain the average value of i_B, we need the conduction angle for D_2, $\pi - 2\Theta$,

$$\theta = \sin^{-1}\left(\frac{3}{6}\right) = 30^\circ \quad \Big| \quad \pi - 2\theta = 180^\circ - 60 = 120^\circ$$

The average value of i_B will be

$$i_B|_{av} = \frac{60 \times 120^\circ}{360^\circ} = 20\ \text{mA}$$

Problem 4.5 (continue). If the peak value of v_I is reduced by 10%, what do the peak and average values of i_B become?

If the peak value of v_I is reduced by 10%, i.e. from 6 V to 5.4 V, the peak value of i_B does not change. The conduction angle of D_2, however, changes since θ now becomes

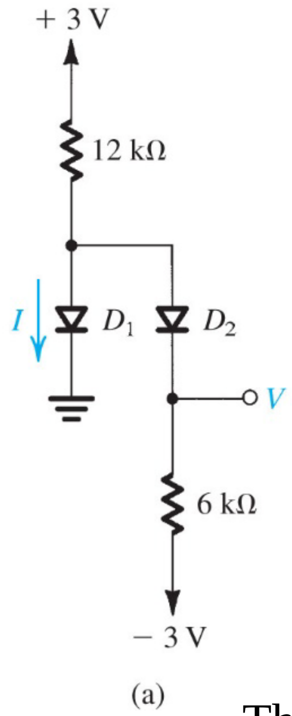
$$\theta = \sin^{-1}\left(\frac{3}{5.4}\right) = 33.75°$$

and thus

$$\pi - 2\theta = 112.5°$$

Thus the average value of i_B becomes

$$i_B|_{av} = \frac{60 \times 112.5°}{360°} = 18.75 \text{ mA}$$



(a)

Pr. 4.9. Assuming that the diodes are ideal, find the values of the labeled voltages and currents

If we assume that D_1 and D_2 are conducting, then V = 0 V and the current in D_2 will be

$$I_{D_2} = \frac{0-(-3)}{6} = 0.5 \ mA$$

The current in the 12 kΩ resistor will be

$$I_{12k\Omega} = \frac{3-0}{12} = 0.25 \ mA$$

A node equation at common anodes node (KCL) allows to find the current in D_1 as

$$I_{D_1} = I_{12k\Omega} - I_{D_2} = 0.25 - 0.5 = -0.25 \ mA$$

This current cannot be negative => assumption was wrong.

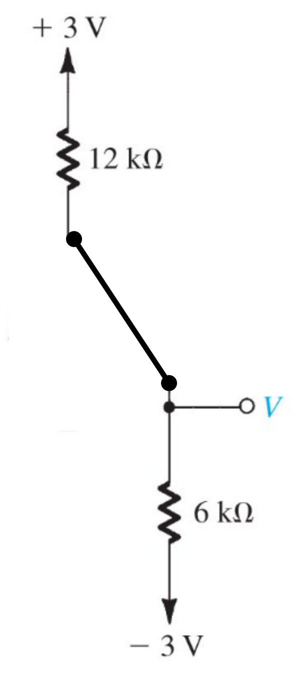
The current in D_1 is zero (diode is "off" and I = 0) and D_2 is "on".

$$The \ current \ through \ 12 \ and \ 6 \ k\Omega \ resistors \ is$$

$$I_{total} = \frac{3-V}{12} = \frac{V-(-3)}{6}$$

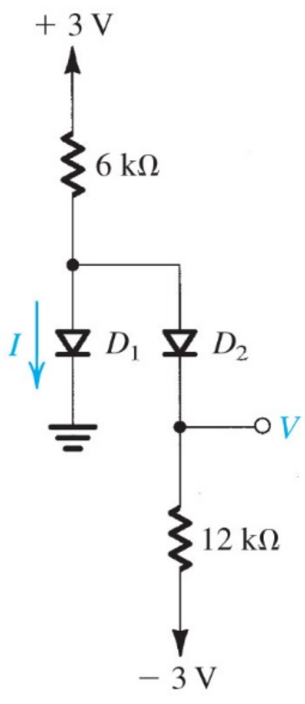
$$3 - V = 2V + 6$$

$$3V = -3 \Rightarrow V = -1 \ V$$



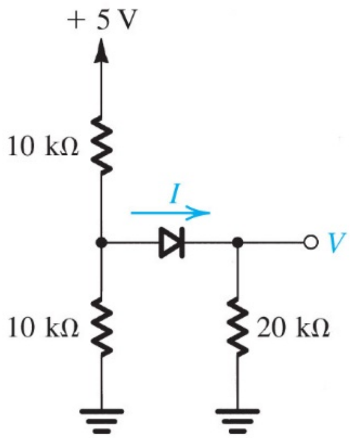
Pr. 4.9. Assuming that the diodes are ideal, find the values of the labeled voltages and currents

Solve at home and bring in class on October 1st (0.5 pt.)



(b)

Pr. 4.10. Assuming that the diodes are ideal, utilize Thevenin's theorem to simplify the circuits and thus find the values of the labeled currents and voltages.

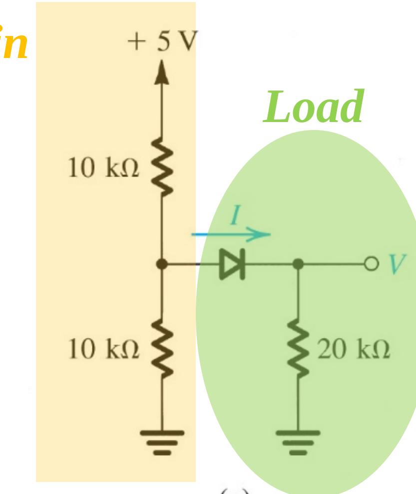


(a)

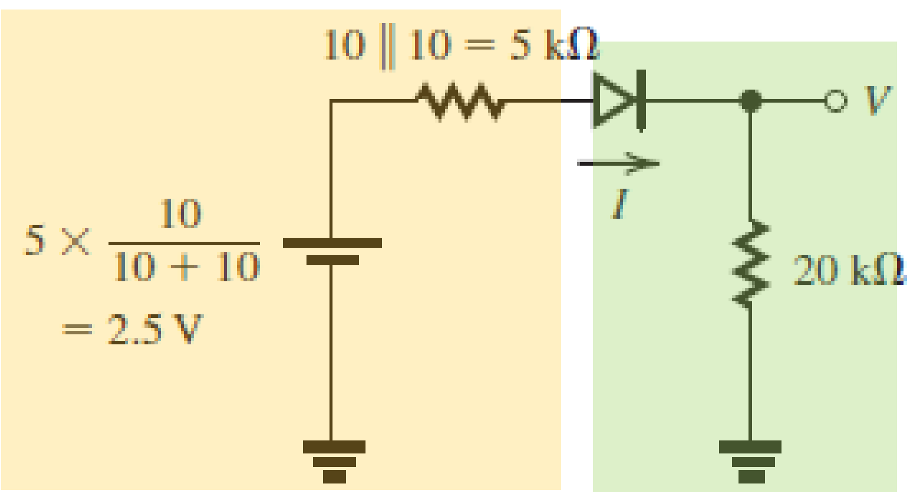
What is load?
Where is Thevenin equivalent?

$\Rightarrow$

Find Thevenin equivalent



(a)



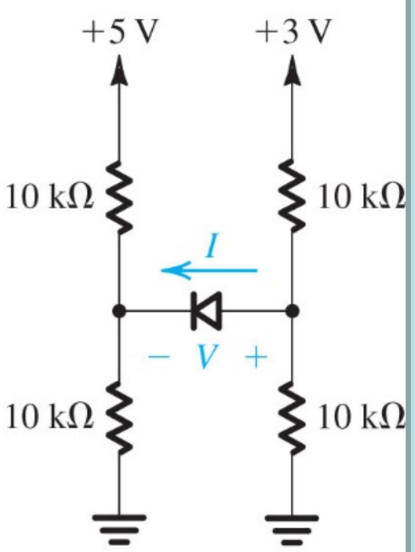
$$Diode \text{ is } "on"$$

$$Thus, \quad I = \frac{2.5\ V}{5+20} = 0.1\ mA$$

$$V = 0.1 \times 20 = 2\ V$$

Pr. 4.10. Assuming that the diodes are ideal, utilize Thevenin's theorem to simplify the circuits and thus find the values of the labeled currents and voltages. *Hint: there are two Thevenin equivalents*

Solve at home and bring in class on October 1st (0.5 pt.)



(b)

Optional HW-SIM-1: Computer Simulation Problems. Due date – October 08, 2019.
Score: up to 1.5 pts.
Use SPICE or other simulations and solve one problem: 4.53 – 7th edition or 4.51 – 6th edition

If you have any questions about simulations, please contact to student Brad Ward (our tutor) Brad.Ward@ttu.edu
You have to submit your solutions to student Shadguna Mutyala (our grader) Shadguna.Mutyala@ttu.edu

How should this HW report look? PowerPoint or PDF or Word file.

Write statement and sketch initial circuit (using SPICE). (0.2 pt.)

Sketch small-signal equivalent circuit for determining the sinusoidal V_0 (using SPICE). (0.3 pt.)

Derive formula for the phase shift between V_i and V_0. (0.3 pt.)

Find the value of I that will provide a phase shift of $\varphi = -45^0$ (0.3 pt.), and find the range of phase shift achieved as I is varied over the range of 0.1 times to 10 times this value (use SPICE and plot this dependence, $\varphi = f(I)$.) (0.4 pt.)