ECE 3200
Test 1
Solutions

A) A sample of silicon at $T = 300$ K is doped with phosphorus at a concentration of 1.30×10^{16} cm^{-3}. Which of the following is closest to the minority carrier concentration?

a: 10^{16} cm^{-3}
b: 10^{10} cm^{-3}
(c:) 10^{4} cm^{-3}
d: 10^{3} cm^{-3}
e: 10^{2} cm^{-3}

Phosphorus is a donor impurity $\Rightarrow n_o \cong N_d = 1.30 \times 10^{16}\ cm^{-3}$ and holes are minority carriers

$$\Rightarrow p_o = \frac{n_i^2}{n_o} \cong \frac{(1.5 \times 10^{10}\ cm^{-3})^2}{1.30 \times 10^{16}\ cm^{-3}} \cong 1.7 \times 10^{4}\ cm^{-3}$$

B) Which of the following is true for a sample of semiconductor material if it is doped with a donor impurity?

a: The sample contains more electrons than protons.
(b:) The sample is n-type.
c: The sample has a negative electric charge.
d: All of the above
e: None of the above

See text sec. 1.1.2

Doping with donor produces free electrons $\Rightarrow$ Free electron concentration is greater than hole concentration $\Rightarrow$ n-type
(Total # electrons = # protons $\Rightarrow$ No charge)

C) Which of the following is closest to the concentration of holes in a sample of pure germanium at a temperature of 250 K?

(a:) 10^{12} cm^{-3}
b: 10^{11} cm^{-3}
c: 10^{10} cm^{-3}
d: 10^{9} cm^{-3}
e: 10^{8} cm^{-3}

$$n_i = B T^{3/2} e^{\left(\frac{-E_g}{2KT}\right)}$$

$$= (1.66 \times 10^{15}\ cm^{-3} K^{-3/2})(250K)^{3/2} e^{\left(\frac{-0.66 eV}{2(86 \times 10^{-6} \frac{eV}{K})(250K)}\right)}$$

$$\cong 1.42 \times 10^{12}\ cm^{-3}$$

D) Which of the following is closest to the thermal voltage at a temperature of 350 K?

a: 26 mV
b: 27 mV
c: 28 mV
d: 29 mV
(e:) 30 mV

$$V_T = \frac{KT}{e} = \frac{(86 \times 10^{-6} \frac{eV}{K})(350K)}{e}$$

$$\cong 0.0301\ V$$

E) I_F is the current flowing through a certain diode at room temperature when a voltage of 0.2 V is applied across the diode in the forward-bias direction. I_R is the current flowing through the same diode at room temperature when a voltage of 0.2 V is applied across the diode in the reverse-bias direction. Which of the following is closest to the magnitude of the ratio of I_F to I_R?

a: 2,400
(b:) 2,200
c: 2,000
d: 1,800
e: 1,600

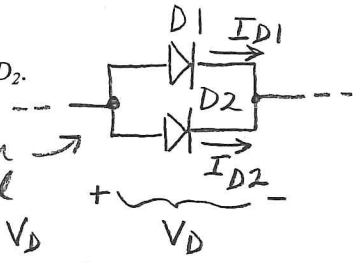
$$I_D = I_S\left[e^{(V_D/V_T)} - 1\right]$$

$$\Rightarrow \left|\frac{I_F}{I_R}\right| = \left|\frac{I_S\left[e^{(0.2V/0.026V)} - 1\right]}{I_S\left[e^{(-0.2V/0.026V)} - 1\right]}\right|$$

$$\cong \left|\frac{2,190}{-1}\right| = 2,190$$

F) Diodes D_1 and D_2 are forward-biased and connected in parallel in a circuit. The diodes have identical reverse-bias saturation currents, but D_1 has a larger emission coefficient than D_2. Which of the following statements is true?

(a:) D_1 conducts less current than D_2.
b: The voltage across D_1 is smaller than the voltage across D_2.
c: Both a and b are true.
d: D_1 conducts more current than D_2.
e: None of the above



Diodes in parallel $\Rightarrow$ Same V_D

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

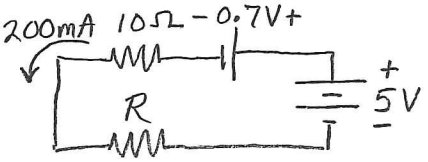
Same I_S for both diodes

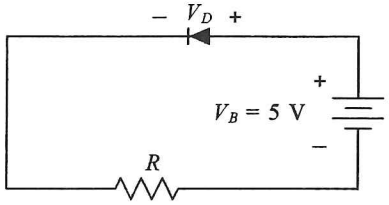
D1 has larger value of n $\Rightarrow$ D1 has smaller I_D

G) The parameters of the diode in the circuit below are $V_\gamma = 0.7$ V and $r_f = 10\ \Omega$. The current through the diode is 200 mA. Which of the following is closest to the value of R?

a: 1 Ω
b: 5 Ω
(c:) 10 Ω
d: 15 Ω
e: 20 Ω

Note $V_B \geq V_\gamma \Rightarrow$ Forward-bias





$$5V - 0.7V - 0.2A(10\Omega + R) = 0$$

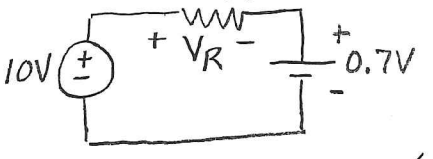
$$R + 10\Omega = \frac{4.3V}{0.2A} = 21.5\Omega \Rightarrow R = 21.5\Omega - 10\Omega = 11.5\Omega$$

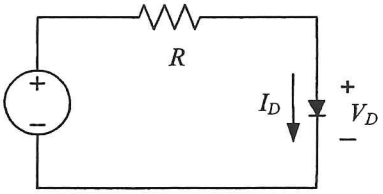
H) The parameters of the diode in the circuit below are $V_\gamma = 0.7$ V and $r_f = 0$. If $V_{PS} = 10$ V and the resistor dissipates 14 mW, which of the following is closest to the value of R?

a: 4 kΩ
(b:) 6 kΩ
c: 8 kΩ
d: 10 kΩ
e: 12 kΩ

Note $10V \geq 0.7V \Rightarrow$ Forward-bias

$V_R = 10V - 0.7V = 9.3V$



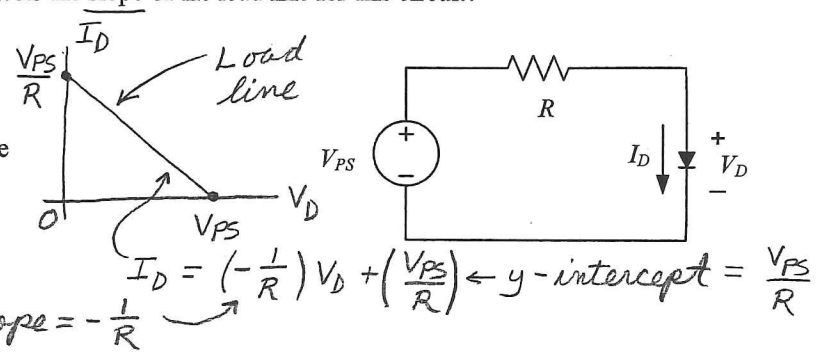


$$P_R = \frac{V_R^2}{R} \Rightarrow R = \frac{V_R^2}{P_R}$$

$$\Rightarrow R = \frac{(9.3V)^2}{14mW} \cong 6.18K\Omega$$

I) The parameters of the diode in the circuit below are $V_\gamma = 0.6$ V and $r_f = 10\ \Omega$, and $V_{PS} = 10.0$ V. Which of the following affects the slope of the load line for this circuit?

a: V_γ
b: r_f
c: V_{PS}
d: All of the above
(e:) None of the above

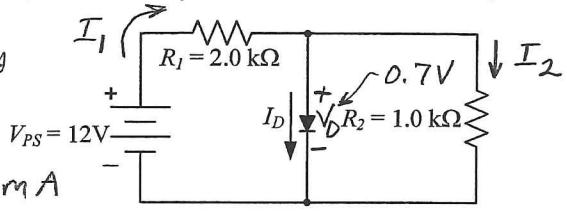


$I_D = \left(-\frac{1}{R}\right) V_D + \left(\frac{V_{PS}}{R}\right) \leftarrow y\text{-intercept} = \frac{V_{PS}}{R}$

$Slope = -\frac{1}{R}$

J) The parameters of the diode in the circuit below are $V_\gamma = 0.7$ V and $r_f = 0$. Which of the following is closest to the value of I_D?

a: 9 mA
b: 8 mA
c: 7 mA
d: 6 mA
(e:) 5 mA



Note forward bias $\Rightarrow V_D = V_\gamma = 0.7$V

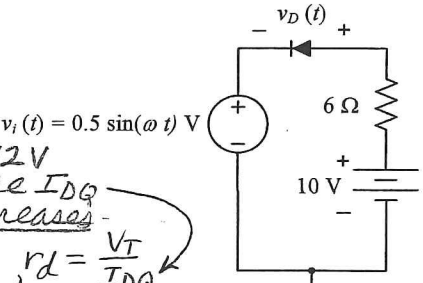
$I_1 = \frac{12V - 0.7V}{2.0K\Omega} = 5.65mA$

$I_2 = \frac{0.7V}{1.0K\Omega} = 0.7mA$

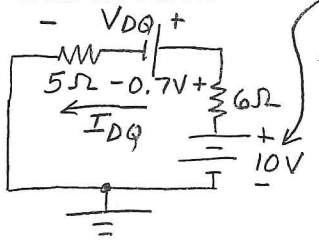
$I_D = I_1 - I_2 = 5.65mA - 0.7mA = 4.95mA$

K) The parameters of the diode in the circuit below are $V_\gamma = 0.7$ V and $r_f = 5\ \Omega$. If the battery voltage is increased to 12 V, which of the following changes will occur to the amplitudes of the AC and DC components of the diode's voltage, $v_D(t)$?

a: Both amplitudes will increase.
b: Both amplitudes will decrease.
c: DC will increase and AC will remain constant.
d: Both will remain constant
(e:) None of the above

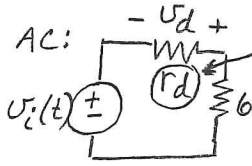


DC:



Increase to 12V will increase I_{DQ}
$\Rightarrow V_{DQ}$ (DC) increases

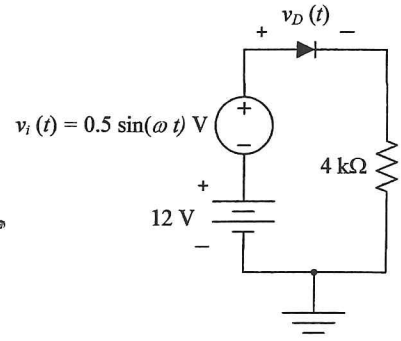
AC:



$r_d = \frac{V_T}{I_{DQ}}$
$\Rightarrow r_d$ decreases
$\Rightarrow v_d$ (AC) decreases

L) The parameters of the diode in the circuit below are $V_\gamma = 0.7$ V and $r_f = 0$. Which of the following components should be used to model the diode in the circuit's small-signal, ac representation?

a: A dc voltage source
b: A dc voltage source in series with a resistor
(c:) A resistor
d: An ac voltage source in series with a resistor
e: None of the above



AC Model:  (See text sec. 1.4)

M) Which of the following is the principal reason why current flows when a reverse-biased photodiode is exposed to light?

a: Light creates excess free electrons in the n-region.
(b:) Light creates excess free electrons and holes in the space-charge region.
c: Light creates excess holes in the p-region.
d: All of the above
e: None of the above

See text sec. 1.5

N) Which of the following devices are usually fabricated from direct bandgap materials?

a: Zener diodes
b: Schottky barrier diodes
(c:) light-emitting diodes
d: photodiodes
e: None of the above

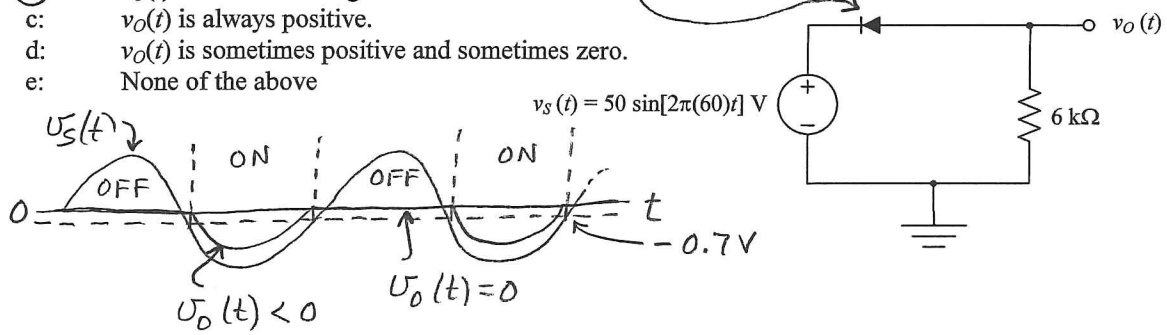
See text sec. 1.5.3

(Electron-hole recombination usually does not produce photons (light) unless the diode is made from direct bandgap material.)

O) The parameters of the diode in the circuit below are $V_\gamma = 0.7$ V and $r_f = 0$. Which of the following is true for $v_O(t)$?

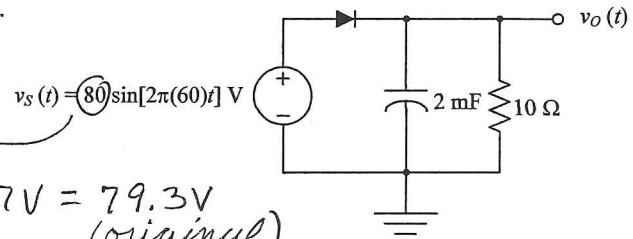
a: $v_O(t)$ is always negative.
(b:) $v_O(t)$ is sometimes negative and sometimes zero.
c: $v_O(t)$ is always positive.
d: $v_O(t)$ is sometimes positive and sometimes zero.
e: None of the above

ON when $v_S(t) \leq -0.7$V
OFF when $v_S(t) > -0.7$V



P) The cut-in voltage of the diode in the circuit shown below is 0.7 V. Which of the following will occur if the amplitude of $v_S(t)$ is reduced to 40 V?

a: The maximum value of $v_O(t)$ will decrease.
b: The ripple voltage will decrease.
(c:) Both a and b will occur.
d: The diode's peak current will increase.
e: None of the above



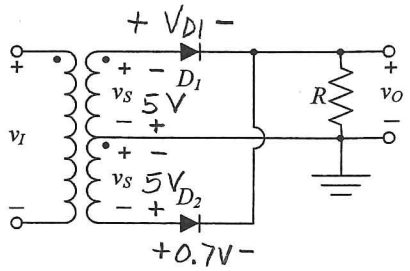
Max value of $v_O(t) = 80\text{V} - 0.7\text{V} = 79.3\text{V}$ (original)

New max value $= 40\text{V} - 0.7\text{V} = 39.3\text{V} = V_M$ (decreases)

Ripple voltage $V_r = \dfrac{V_M}{fRC} \Rightarrow V_r$ also decreases

Q) The parameters of the diodes in the circuit below are $V_\gamma = 0.7$ V and $r_f = 0$. The voltage source v_S is a sine wave whose amplitude is 5 V. Which of the following is closest to the peak inverse voltage for diode D_1?

a: 11 V
(b:) 9 V
c: 7 V
d: 5 V
e: 3 V



PIV for D1 occurs when $v_S = -5$ V $\Rightarrow$ D1 off and D2 on

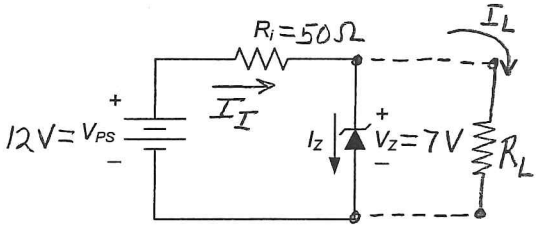
KVL: $V_{D1} = -5V - 5V - (-0.7V)$

$\Rightarrow V_{D1} = -10V + 0.7V = -9.3V$

$\Rightarrow PIV = 9.3V$

R) In the circuit shown below, $R_i = 50\ \Omega$, $V_Z = 7$ V, and $V_{PS} = 12$ V. If a resistor R_L is placed in parallel with the diode, which of the following is closest to the value of R_L that will cause I_Z to drop to half of its original value?

a: 50 Ω
b: 80 Ω
c: 110 Ω
(d:) 140 Ω
e: 170 Ω



original $I_Z = I_I = \frac{12V - 7V}{50\Omega} = 0.1A$

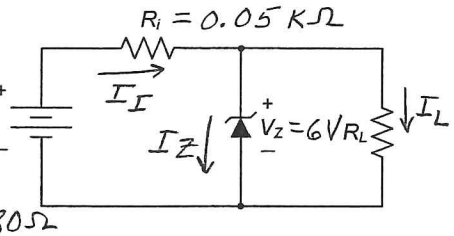
New $I_Z = \frac{1}{2}(0.1A) = 0.05A$

$\Rightarrow I_L = I_I - I_Z = 0.1A - 0.05A = 0.05A$

$\Rightarrow R_L = \frac{7V}{0.05A} = 140\Omega$

S) In the circuit shown below, $R_i = 50\ \Omega$, $V_Z = 6$ V, and R_L varies between 60 Ω and 80 Ω. The power dissipated by the diode must not exceed 290 mW. Which of the following is closest to the maximum permissible value of V_{PS}?

a: 8 V
b: 9 V
c: 10 V
d: 11 V
(e:) 12 V



$P_Z(max) = 290mW = V_Z I_Z(max)$

$\Rightarrow I_Z(max) = \frac{290mW}{6V} \cong 48.3mA$

$I_Z = I_Z(max)$ when $V_{PS} = V_{PS}(max)$ and $R_L = R_L(max) = 80\Omega$

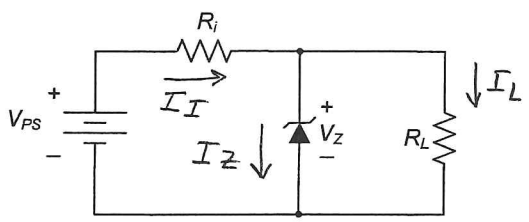
When $R_L = 80\Omega$, $I_L = \frac{6V}{80\Omega} = 0.075A = 75.0mA$

and $I_I = I_Z + I_L \cong 48.3mA + 75.0mA = 123.3mA$

$\Rightarrow V_{PS}(max) \cong (123.3mA)(0.05K\Omega) + 6V \cong 12.17V$

T) In the circuit shown below, V_{PS} varies between 18 and 20 V, $V_Z = 12$ V, and R_L varies between 50 Ω and 70 Ω. Which of the following conditions will minimize the diode's current?

a: $V_{PS} = 20$ V and $R_L = 50\ \Omega$
b: $V_{PS} = 20$ V and $R_L = 70\ \Omega$
(c:) $V_{PS} = 18$ V and $R_L = 50\ \Omega$
d: $V_{PS} = 18$ V and $R_L = 70\ \Omega$
e: None of the above



See text sec. 2.2.1

$I_Z = I_Z(min)$ when $V_{PS} = V_{PS}(min)$ and $I_L = I_L(max) \Rightarrow R_L = R_L(min)$