ECE 3200
Test 1
Solutions

A) Which of the following elements are used as impurities in n-type silicon?

a: boron
b: phosphorus
c: arsenic
d: both b and c
e: None of the above

n-type Si requires impurities from group V $\Rightarrow$ P and As

(See text sec. 1.1)

B) The intrinsic carrier concentration of a group IV semiconductor is 2.0×10^9 cm^{-3} at a certain temperature. If the semiconductor is doped with boron such that the concentration of boron atoms is 10^{12} cm^{-3}, which of the following is closest to the concentration of free electrons in the material?

a: 10^{12} cm^{-3}
b: 10^{10} cm^{-3}
c: 10^{8} cm^{-3}
d: 10^{6} cm^{-3}
e: 10^{4} cm^{-3}

$$N_a = 10^{12}\,cm^{-3} >> n_i = 2.0\times10^{9}\,cm^{-3}$$

$$\Rightarrow p_o \cong N_a$$

$$n_o = \frac{n_i^2}{p_o} \cong \frac{(2.0\times10^9\,cm^{-3})^2}{10^{12}\,cm^{-3}} \cong 4.0\times10^{6}\,cm^{-3}$$

C) A sample of silicon at room temperature is doped with phosphorus such that the conductivity of the sample is 2 (Ω-cm)$^{-1}$. The mobility of free electrons is 1350 cm^2/V-s. Neglecting the effect of holes, which of the following is closest to concentration of phosphorus atoms in the sample?

a: 10^{12} cm^{-3}
b: 10^{14} cm^{-3}
c: 10^{16} cm^{-3}
d: 10^{18} cm^{-3}
e: 10^{20} cm^{-3}

$$\sigma = e\mu_n n + \underbrace{\cancel{e\mu_p p}}_{\text{Neglect}} \cong e\mu_n n$$

$$\Rightarrow n \cong \frac{\sigma}{e\mu_n} = \frac{2\,(\Omega\text{-}cm)^{-1}}{(1.6\times10^{-19}C)(1{,}350\,\frac{cm^2}{V\text{-}s})}$$

$$\cong 9.26\times10^{15}\left(\frac{\cancel{C}}{s}\right)\left(\frac{\cancel{\Omega}}{V}\right) cm^{-3} = 0.926\times10^{16}\,cm^{-3}$$

D) The reverse-bias saturation current of a pn junction diode is 10^{-16} A. The diode is reverse biased with a voltage of 700 mV, and its temperature is 300 K. Which of the following is closest to the value of the current flowing through the diode?

a: 10^{-16} A
b: 10^{-13} A
c: 10^{-10} A
d: 10^{-7} A
e: 10^{-4} A

(Note)

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

$$\cong (10^{-16}A)\left[e^{\left(\frac{-0.7V}{0.026V}\right)} - 1\right]$$

$$\cong -1.0\times10^{-16}A$$

E) A voltage of 5 V is applied across the terminals of a pn junction diode in the reverse-bias direction. If this reverse-bias voltage is then reduced to 1 V, which of the following will happen?

a: The current through the diode will increase by a factor of approximately five.
b: The current through the diode will decrease by a factor of approximately five.
c: The diode's junction capacitance will decrease.
d: The diode's junction capacitance will increase.
e: None of the above

See sec. 1.2.2

$$C_j = C_{jo}\left(1+\frac{V_R}{V_{bi}}\right)^{-\frac{1}{2}} \Rightarrow \text{As } V_R \text{ decreases, } C_j \text{ increases.}$$

a, b, and c are false.

F) The reverse-bias saturation current of a pn junction diode is 2×10^{-12} A. The diode is forward biased with a current of 1.0 mA, and its temperature is 300 K. Which of the following is closest to the value of the voltage across the diode?

a: 0.4 V
b: 0.5 V
c: 0.6 V
d: 0.7 V
e: 0.8 V

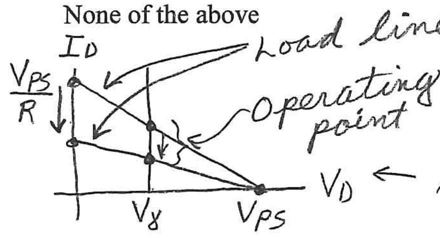
$$I_D = I_S\left[e^{(V_D/V_T)} - 1\right] \Rightarrow \frac{I_D}{I_S} = e^{(V_D/V_T)} - 1$$

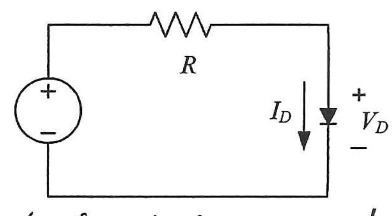
$$\Rightarrow \frac{V_D}{V_T} = \ln\left(\frac{I_D}{I_S}+1\right) \Rightarrow V_D = V_T \ln\left(\frac{I_D}{I_S}+1\right)$$

$$\Rightarrow V_D \cong (0.026V)\ln\left(\frac{10^{-3}A}{2\times10^{-12}A}+1\right) \cong 0.521\ V$$

G) The parameters of the diode in the circuit below are $V_\gamma = 0.6$ V and $r_f = 0$. The diode is forward biased. If R increases, which of the following will happen?

a: The slope of the load line will remain constant.
b: I_D will decrease.
c: V_D will decrease.
d: All of the above
e: None of the above





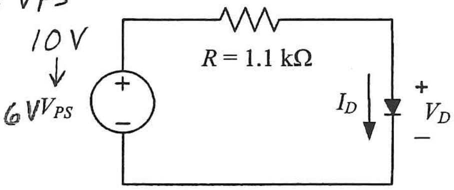
Slope of load line $= -\frac{1}{R}$ (changes)
As R increases, I_D decreases, and $V_D = V_\gamma$ (constant).

H) The parameters of the diode in the circuit below are $V_\gamma = 0.6$ V and $r_f = 0$, and $V_{PS} = 10.0$ V. Which of the following is closest to the value of I_D?

a: 2 mA
b: 4 mA
c: 6 mA
d: 8 mA
e: 10 mA

Note polarity of V_{PS}
$\Rightarrow$ Forward bias

$r_f = 0 \Rightarrow V_D = V_\gamma = 0.6V$

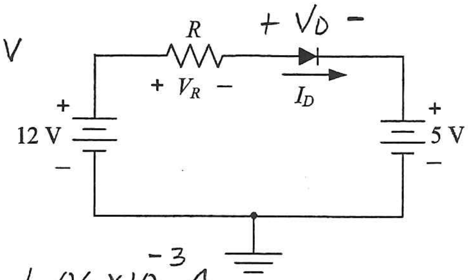


$$\Rightarrow I_D = \frac{10V - 0.6V}{1.1\,K\Omega} \cong 8.545\,mA$$

I) The reverse-bias saturation current of the diode in the circuit below is 10^{-14} A, and the diode's temperature is 300 K. The voltage drop across the resistor V_R is 6.34 V. Which of the following is closest to the value of I_D?

a: 0.4 mA
b: 0.7 mA
c: 1.0 mA
d: 1.3 mA
e: 1.6 mA

$$V_D = 12V - 5V - 6.34V$$
$$= 0.66V$$
$$I_D = I_S\left[e^{\frac{V_D}{V_T}} - 1\right]$$



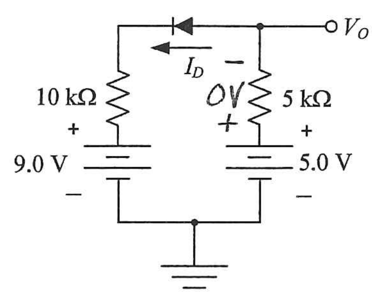
$$\Rightarrow I_D = (10^{-14}A)\left[e^{\left(\frac{0.66V}{0.026V}\right)} - 1\right] \cong 1.06 \times 10^{-3} A$$

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 V_O?

a: 9 V
b: 8 V
c: 7 V
d: 6 V
e: 5 V

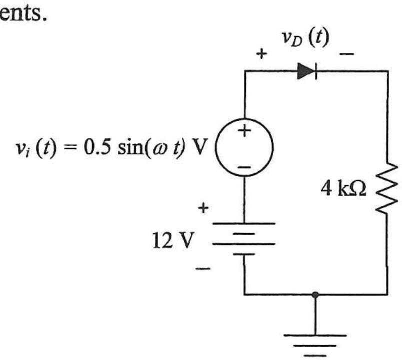
Note reverse bias

$$\Rightarrow I_D = 0$$
$$\Rightarrow V_o = 5.0V - 0V$$
$$= 5.0V$$



K) The parameters of the diode in the circuit below are $V_\gamma = 0.7$ V and $r_f = 0$. The diode's temperature is $T = 300$ K. Which of the following is a true statement?

a: The voltage $v_D(t)$ includes both DC and AC components.
b: The voltage $v_D(t)$ is constant.
c: The voltage $v_D(t)$ includes no AC component.
d: Both b and c are true.
e: None of the above



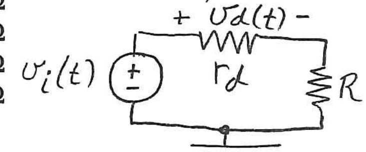
See text sec. 1.4

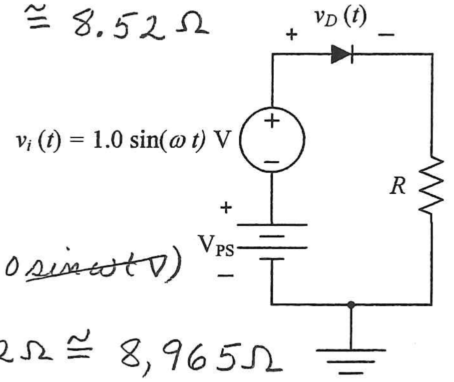
$$v_D(t) = \underbrace{V_{DQ}}_{\text{DC}} + \underbrace{v_d(t)}_{\text{AC}}$$

L) The quiescent current in the circuit below is 3.05 mA. The diode's temperature is $T = 300$ K. Which of the following is closest to the value of R such that the amplitude of the AC component of $v_D(t)$ is 0.95 mV?

a: 5.0 kΩ
b: 6.0 kΩ
c: 7.0 kΩ
d: 8.0 kΩ
e: 9.0 kΩ

$$r_d = \frac{V_T}{I_{DQ}} \cong \frac{0.026V}{0.00305A} \cong 8.52\Omega$$





$$0.00095 \sin\omega t\, V \cong \left(\frac{8.52\Omega}{8.52\Omega + R}\right)(1.0 \sin\omega t\, V)$$

$$\Rightarrow R \cong \left(\frac{1.0}{0.00095}\right)(8.52\Omega) - 8.52\Omega \cong 8{,}965\Omega$$

M) Which of the following materials is used to form the cathode in a Schottky barrier diode?

a: metal
b: moderately doped n-type semiconductor
c: moderately doped p-type semiconductor
d: heavily doped n-type semiconductor
e: None of the above

See text sec. 1.5.4

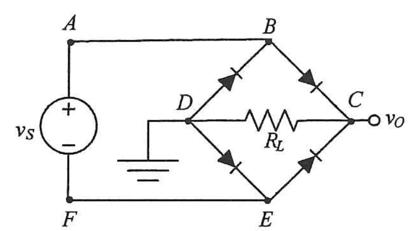
N) Which of the following best describes the typical action of a photodiode?

a: Light shining on the diode causes current to flow when the diode is reverse-biased.
b: Light shining on the diode causes current to flow when the diode is forward-biased.
c: Current flowing through the diode in the reverse-bias direction causes light to be emitted.
d: Current flowing through the diode in the forward-bias direction causes light to be emitted.
e: None of the above

See text sec. 1.5.2

O) If a filter capacitor is added to the circuit below, where should it be connected?

a: between terminals *A* and *B*
b: between terminals *A* and *D*
c: between terminals *B* and *E*
d: between terminals *C* and *D*
e: None of the above



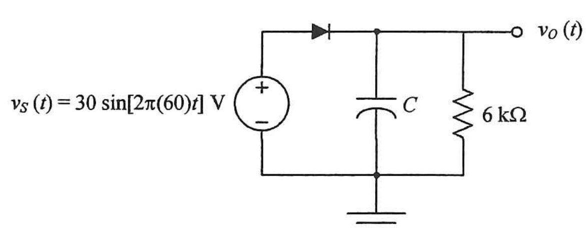
The capacitor is placed in parallel with the load to form an RC lowpass filter.

P) The cut-in voltage of the diode in the circuit shown below is 0 V. Which of the following is closest to the minimum acceptable value of *C* if the output's ripple voltage must not exceed 2 mV?

a: 20 mF
b: 30 mF
c: 40 mF
d: 50 mF
e: 60 mF

$$V_r = \frac{V_M}{fRC}$$

$$\Rightarrow C = \frac{V_M}{fRV_r}$$

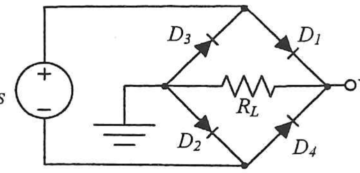


$$\Rightarrow C_{min} = \frac{30\,V}{(60\,Hz)(6\times10^3\,\Omega)(2\times10^{-3}\,V)}$$

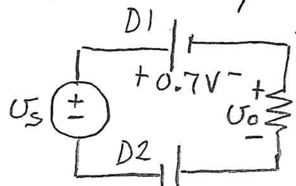
$$\cong 41.7 \times 10^{-3}\ F$$

Q) The parameters of the diodes in the circuit below are $V_\gamma = 0.7$ V and $r_f = 0$, $R_L = 125\ \Omega$, and v_S is a 60-Hz sine wave. If the peak current through R_L is 120 mA, which of the following is closest to the peak amplitude of v_S?

a: 15.0 V
b: 15.5 V
c: 16.0 V
d: 16.5 V
e: 17.0 V



Positive peak:



$v_o(peak) = (0.12A)(125\Omega) = 15V$

$\Rightarrow v_S(peak) = 15V + 2(0.7V) = 16.4V$

R) Which of the following functions is typically performed by a Zener diode in a traditional DC power supply?

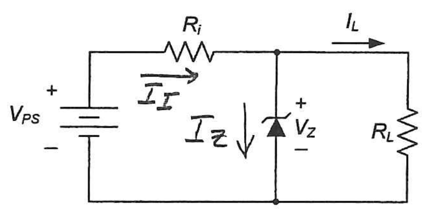
a: Half-wave rectification
b: Full-wave rectification
c: Voltage regulation
d: Filtering
e: None of the above

See text sec. 2.2

S) In the circuit shown below, $R_i = 10\ \Omega$, V_{PS} varies between 30 V and 40 V, $V_Z = 15$ V, and R_L varies between 5 Ω and 9 Ω. Which of the following is closest to the maximum diode current?

a: 0.8 A
b: 0.9 A
c: 1.0 A
d: 1.1 A
e: 1.2 A

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



$\Rightarrow I_I = \frac{40V - 15V}{10\Omega} = 2.5A, \quad I_L = \frac{15V}{9\Omega} \cong 1.67A$

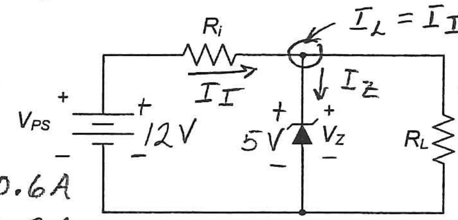
$\Rightarrow I_Z = I_I - I_L \cong 2.5A - 1.67A \cong 0.83A$

T) In the circuit shown below, $R_i = 10\ \Omega$, $V_Z = 5$ V, and $V_{PS} = 12$ V. The current through the diode must be between 100 mA and 400 mA. Which of the following is closest to the maximum permissible value of R_L?

a: 22 Ω
b: 17 Ω
c: 12 Ω
d: 7 Ω
e: 2 Ω

Note
$I_L = I_I - I_Z$

$I_I = \frac{12V - 5V}{10\Omega} = 0.7A$



$\Rightarrow I_L(max) = 0.7A - 0.1A = 0.6A$
$I_L(min) = 0.7A - 0.4A = 0.3A$

$\Rightarrow R_L(max) = \frac{5V}{0.3A} \cong 16.7\Omega$