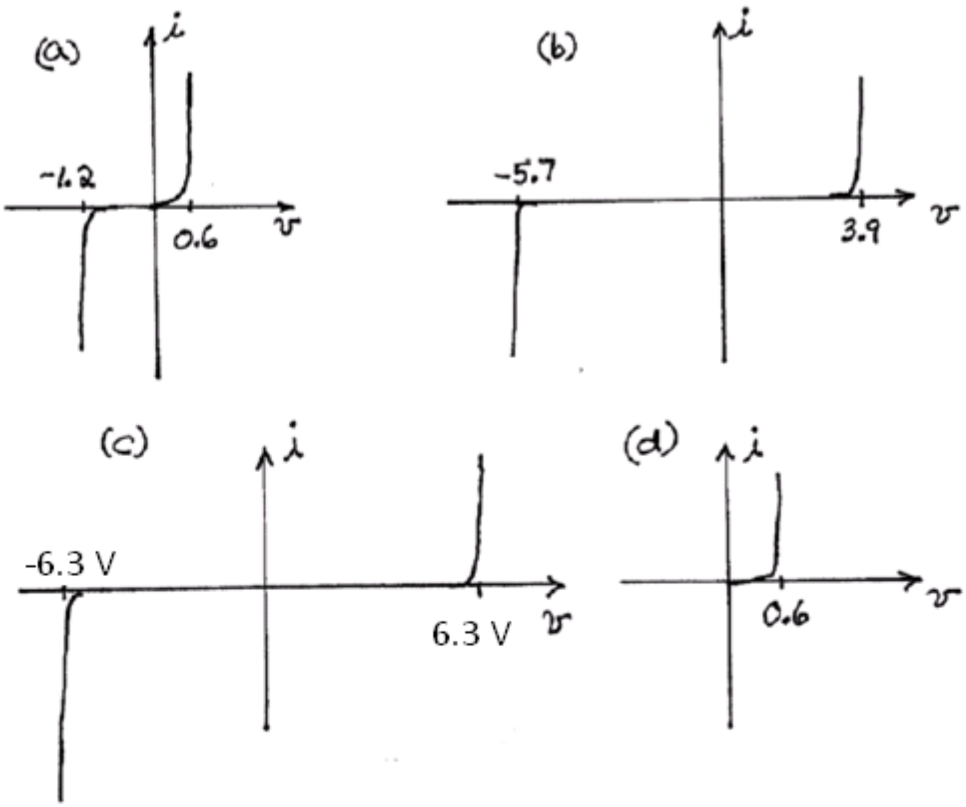
EE40 Homework #9 Solutions

GSI comment: These solutions do not keep track of units, and show them only at the very end. This practice saves little effort but increases the incidence of careless mistakes (in addition to making the derivations harder to read), and thus is not recommended.

Reading Assignments

Chapter 10 of Hambley

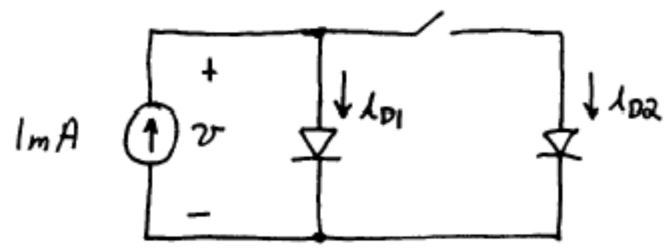
Problem 1: I-V of Diodes (Hambley P10.7)



Note that none of the Zener diodes ever operates in the forward region.

Problem 2: Ideality Factor of Diodes (Hambley P10.13)

Since the diodes are conducting forward current, we can neglect the "-1" term in the *I-V* characteristic.



With the switch open, we have:

$$i_{D1} = 10^{-3} = I_s\left[\exp(v/nV_T) - 1\right]$$
$$\cong I_s \exp(v/nV_T)$$

Thus, we determine that:

$$I_s \cong \frac{10^{-3}}{\exp(v/V_T)} = \frac{10^{-3}}{\exp(0.6/0.026)} = 9.5 \times 10^{-14} \text{ A}$$

With the switch closed, we have:

$$i_{D1} = i_{D2} = 0.5 \text{ mA}$$
$$0.5 \times 10^{-3} = I_s \exp(v/V_T)$$
$$v = nV_T \ln\frac{0.5 \times 10^{-3}}{I_s} = 582 \text{ mV}$$

Repeating the calculations with $n = 2$, we obtain:

$$I_s = 9.75 \times 10^{-9} \text{ A}$$
$$v = 564 \text{ mV}$$

Problem 3: Load-line Analysis of LED (Hambley P10.23)

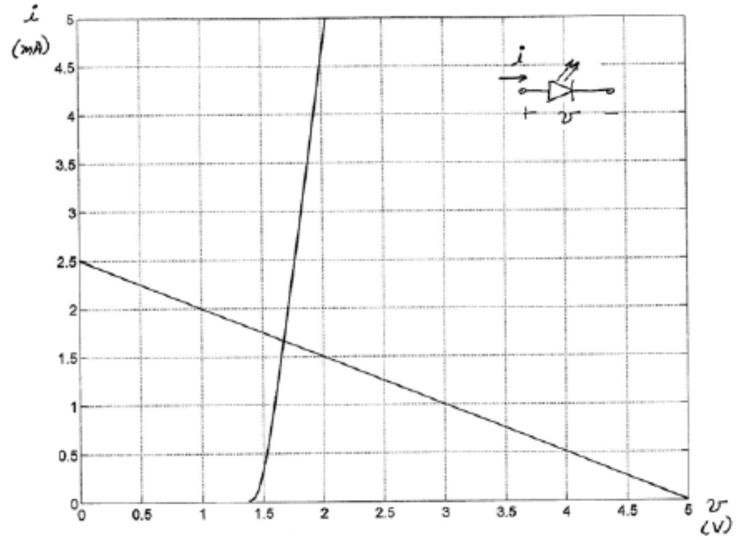
First, we derive the Thévenin equivalent of everything excluding the diode. Applying KCL at the top right node, we find:

$$i = \frac{i_x}{2}$$

Find the open-circuit voltage (replace the diode load with an open-circuit load). Noting that no current flows through the load ($i = 0$), we can apply the above equation to find that $i_x = 0$ also. Thus, the open-circuit voltage is the entire source voltage of 5 V.

Now find the short-circuit current. The short circuit causes the entire source voltage to fall across the resistor, so that 5 mA flows through it. However, according to our equation above, half of this goes into the dependent current source, bypassing the load, so the load current is 2.5 mA. Dividing this into the open-circuit voltage, we get the equivalent resistance of 2 kΩ.

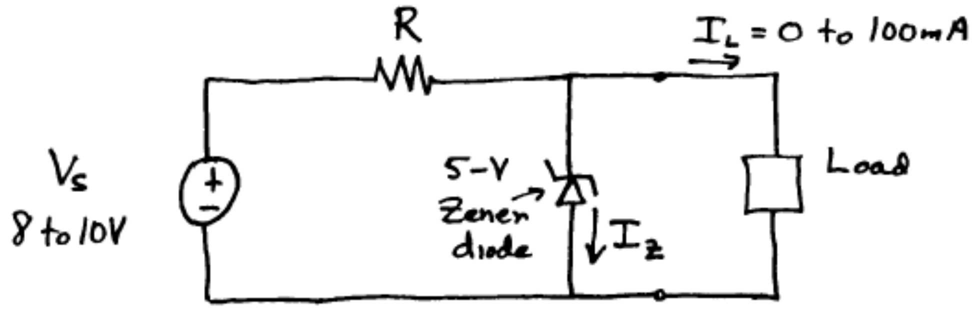
If we remove the diode, the Thévenin equivalent for the remaining circuit consists of a 5-V source in series with a 2-kΩ resistance. The load line is



At the intersection of the characteristic and the load line, we have $v \cong 1.70$ V and $i \cong 1.7$ mA.

Problem 4: Voltage Regulator Design with Zener Diode (Hambley P10.29)

The diagram of a suitable regulator circuit is



We must be careful to choose the value of R small enough so I_z remains positive for all values of source voltage and load current. (Keep in mind that the Zener diode cannot supply power.) From the circuit, we can write

$$I_z = \frac{V_s - V_L}{R} - I_L$$

Minimum I_z occurs for $I_L = 100$ mA and $V_s = 8$ V. Solving for the maximum value allowed for R, we have

$$R_{max} = \frac{V_s - V_L}{I_z + I_L} = \frac{8-5}{0+0.1} = 30\ \Omega$$

Thus, we must choose the value of R to be less than 30 Ω. We need to allow some margin for component tolerances and some design margin. However, we do not want to choose R too small because the current and power dissipation in the diode becomes larger as R becomes smaller. Thus, a value of about 24 Ω would be suitable. (This is a standard value.) With this value of R, we have

$$I_{R\max} = \frac{V_{s\max} - 5}{R} = 208 \text{ mA}$$

$$I_{Z\max} = I_{R\max} = 208 \text{ mA}$$

$$P_{R\max} = \left(I_{R\max}\right)^2 R = 1.04 \text{ W}$$

$$P_{Z\max} = 5 I_{Z\max} = 1.04 \text{ W}$$

Problem 5: Ideal Diode Model – Simple exercise (Hambley P10.36)

(a) The diode is on, $V = 0$ and $I = \frac{10}{2700} = 3.70$ mA.

(b) The diode is off, $I = 0$ and $V = 10$ V.

(c) The diode is on, $V = 0$ and $I = 0$.

(d) The diode is on, $I = 5$ mA and $V = 5$ V.

Problem 6: Ideal Diode Model – Logic Gates (Hambley P10.40)

(a) The output is high if either or both of the inputs are high. If both inputs are low the ouput is low. This is an OR gate.
(b) The output is high only if both inputs are high. This is an AND gate.

Problem 7: Battery Charging Circuit (Hambley P10.59)

(a) The current pulse starts and ends at the times for which

$$v_s(t) = V_B$$

$$20\sin(200\pi t) = 12$$

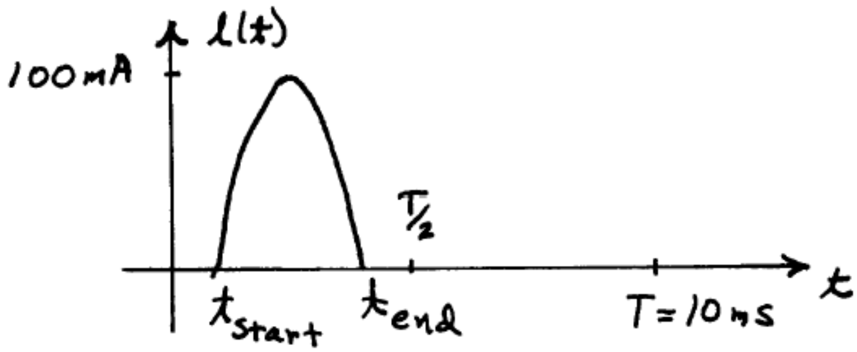
Solving we find that

$$t_{\text{start}} = \frac{\sin^{-1}(0.6)}{200\pi} = 1.024 \text{ ms} \quad \text{and} \quad t_{\text{end}} = \frac{T}{2} - t_{\text{start}} = 3.976 \text{ ms}$$

Between these two times the current is

$$i(t) = \frac{20\sin(200\pi t) - 12}{80}$$

A sketch of the current to scale versus time is



(b) The charge flowing through the battery in one period is

$$Q = \int_{t_{start}}^{t_{end}} i(t)dt = \int_{t_{start}}^{t_{end}} \frac{20\sin(200\pi t) - 12}{80} dt$$

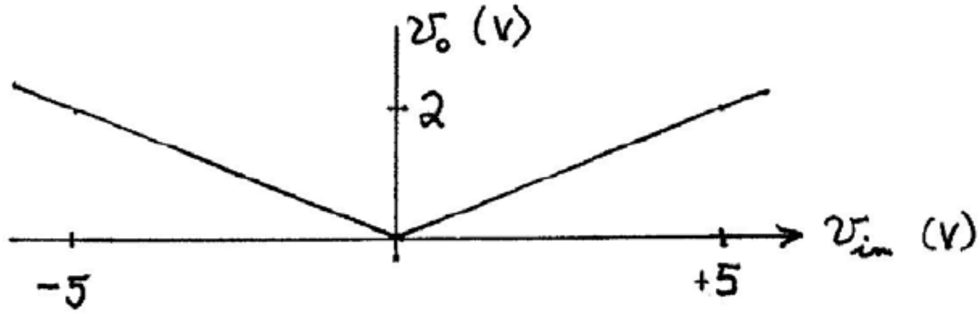
$$= \left[-\frac{1}{800\pi}\cos(200\pi t) - \frac{12t}{80} \right]_{t_{start}}^{t_{end}}$$

$$Q = 194 \ \mu C$$

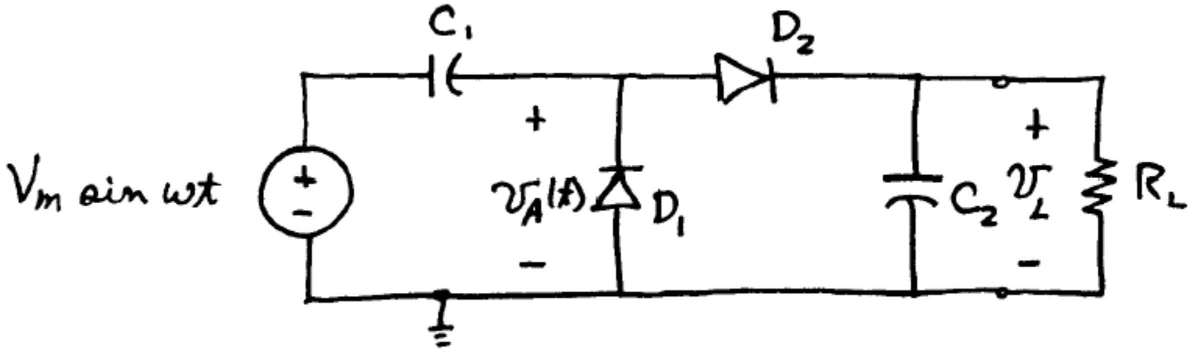
Finally, the average current is the charge divided by the period.

$$I_{avg} = \frac{Q}{T} = \frac{194 \times 10^{-6}}{10 \times 10^{-3}} = 19.4 \text{ mA}$$

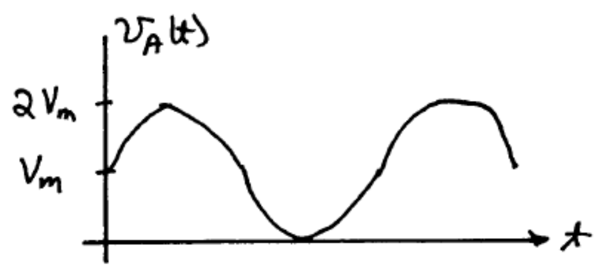
Problem 8: Wave Shaping (Hambley P10.66)



Problem 9: Voltage Doubler (Hambley P10.71)



The capacitor C_1 and diode D_1 act as a clamp circuit that clamps the negative peak of $v_A(t)$ to zero. Thus, the waveform at point A is:



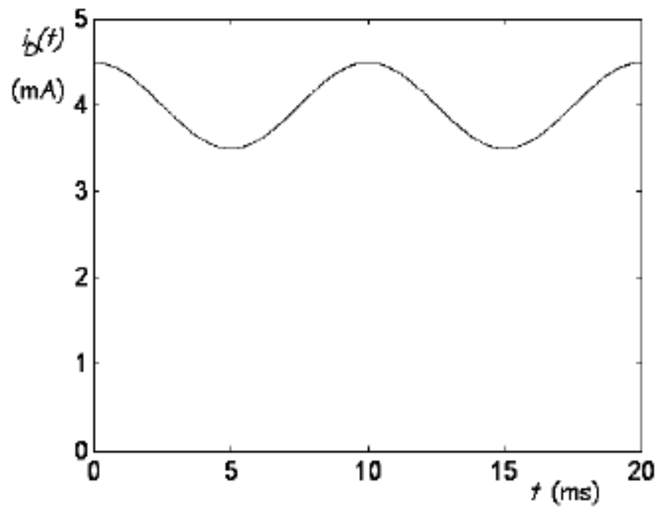
Diode D_2 and capacitor C_2 act as a half-wave peak rectifier. Thus, the voltage across R_L is the peak value of $v_A(t)$. Thus, $v_L(t) \cong 2V_m$. This is called a voltage-doubler circuit because the load voltage is twice the peak value of the ac input. The peak inverse voltage is $2V_m$ for both diodes.

Problem 10: Small-Signal Equivalent Circuit (Hambley P10.77, P10.80)

(a)

I_{DQ} represents the dc component of the diode current with no signal applied to the circuit, and $i_d(t)$ represents the changes from the Q-point current when the signal is applied. Furthermore $i_D(t)$ is the total diode current. Thus we have

$$i_D(t) = I_{DQ} + i_d(t) = 4 + 0.5\cos(200\pi t)$$



(b)

We should replace dc current sources by open circuits in a small-signal equivalent circuit. The current through a dc current source is constant. Thus, the ac current must be zero even if we apply an ac voltage. Zero current for a non-zero applied voltage implies that we have an open circuit.