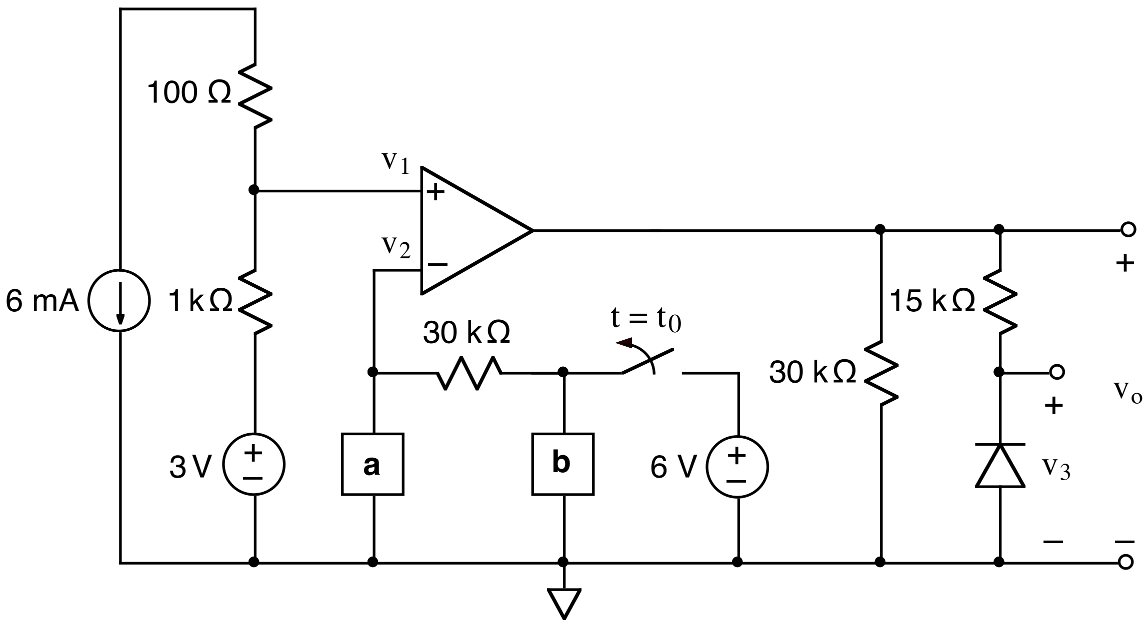
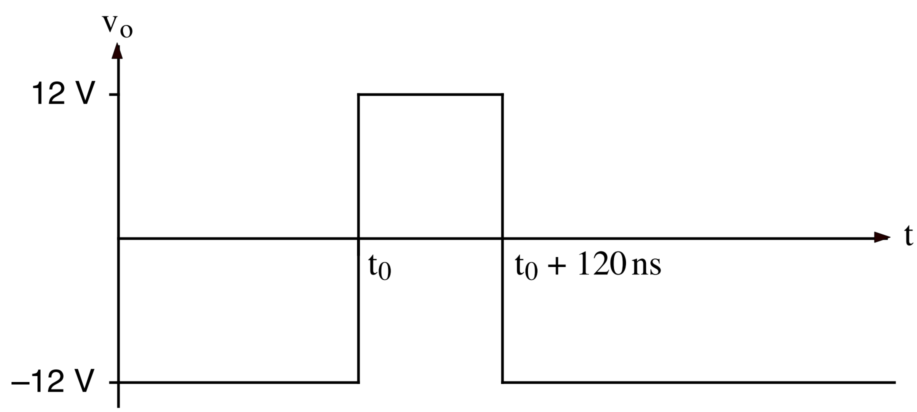
Ex:



Rail voltages = ±12 V

After being closed for a long time, the switch opens at $t = t_o$.



a) Choose either an R or L to go in box **a** and either an R or L to go in box **b** to produce the $v_o(t)$ shown above. (Note that v_o stays low forever after t_o + 120 ns.) Specify which element goes in each box and its value. Make sure $-10\text{ V} \le v_2 \le 10\text{ V}$ at all times.

b) Sketch $v_1(t)$, showing numerical values appropriately.

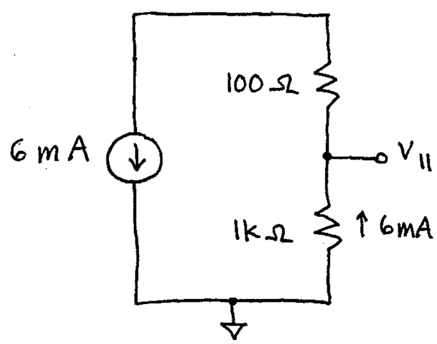
c) Sketch $v_2(t)$, showing numerical values appropriately.

d) Sketch $v_3(t)$. Show numerical values for $t < t_o$, for $t_o < t < t_o + 120$ ns, and for $t > t_o + 120$ ns. Use the ideal model of the diode: when forward biased, its resistance is zero; when reverse biased, its resistance is infinite.

Sol'n: a) First we calculate v_1. The op-amp input draws no current, implying that we may ignore the op-amp when calculating v_1.

Using superposition, we sum the values of v_1 obtained when one source at a time is turned on.

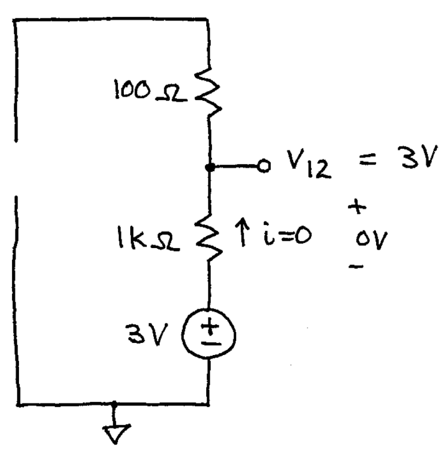
Case I: 6 mA on, 3V off



v_{11} = V drop across 1kΩ.

$$v_{11} = -6\,\text{mA} \cdot 1\,\text{k}\Omega = -6\,\text{V}$$

Case II: 6 mA off, 3V on



We sum v_{11} and v_{12} to get v_1.

$$v_1 = v_{11} + v_{12} = -6V + 3V = -3V$$

For v_o to be $-12V$ at $t = t_0^-$ we must have $v_2 > v_1$. This condition is satisfied by placing either an L or R in box **a**. If we have an L in box **a**, then it will act like a wire at $t = t_0^-$, making v_2 equal to 0V. If we an R in box **a**, however, we will have a v-divider:

$$v_2 = 6V \cdot \frac{R}{R + 30k\Omega} > 0V$$

Now we consider what might be in box **b**. If **a** is an L and **b** is an R, then $i_L(t_0^+) = i_L(t_0^-)$ will flow thru the 30kΩ and the R in **b** when the switch opens. The direction of current flow will result in $v_2 < 0V$. For sufficiently large R, we can have $v_2(t_0^+) < v_1$. Later, as the current in the L decays toward 0A, we will again have $v_2 < v_1$, causing v_o to drop to $-12V$ again. Thus, this sol'n will work.

$$\mathbf{a} = L \qquad \mathbf{b} = R$$

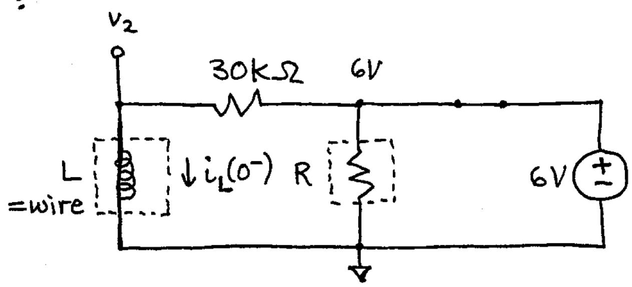
To be thorough, we consider what would happen for the case **a** = R and **b** = L. This would cause a short across the 6V source for $t < t_0$ since L = wire. This will not work!

Now we find $v_2(t)$ using the general form of solution for RL problems:

$$v_2(t>0) = v_2(t\to\infty) + \left[v_2(0^+) - v_2(t\to\infty)\right] e^{-t/\frac{L}{R_{Th}}}$$

where we take t_0 to be $t_0 = 0$ s.

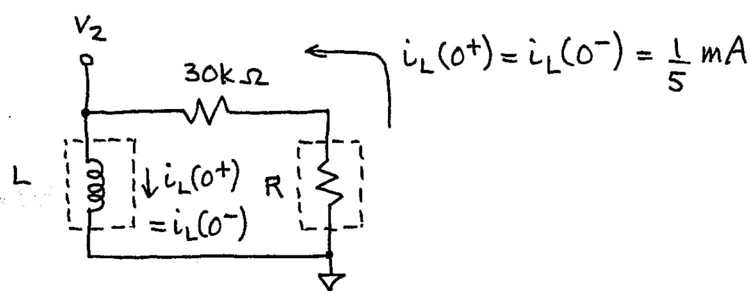
$t = 0^-$:



The R is a 2nd circuit, (in parallel with the L and 30kΩ), across the 6V source. Thus, we may ignore R.

$$i_L(0^-) = \frac{6V}{30k\Omega} = \frac{1}{5}\ mA$$

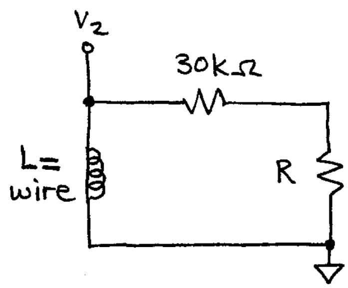
$t = 0^+$:



$$v_2(0^+) = -i_L(0^+)(30k\Omega + R)$$

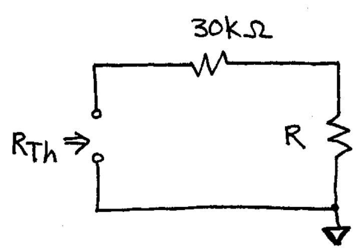
or $v_2(0^+) = -\frac{1}{5} mA(30k\Omega + R)$

$t \to \infty$:



$v_2(t \to \infty) = 0V$ since there is no power source

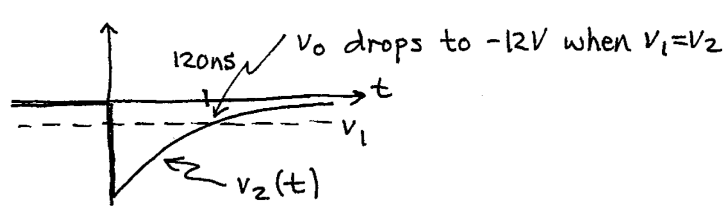
R_{Th} for $\frac{L}{R_{Th}}$ time constant = R seen looking into terminals where L is attached, (but with L removed):



$$R_{Th} = 30\,k\Omega + R$$

$$\therefore\ v_2(t > 0) = 0V + \left[-\frac{1}{5} mA\,(30k + R) - 0V \right] e^{-\frac{t}{L/(30k\Omega + R)}}$$

sketch:



We choose L and R values that yield $v_2(t) = v_1$ at $t = 120$ ns, the duration of the pulse. Recall that $v_1 = -3$V.

$$v_2(t=120\text{ns}) = -\frac{1}{5}\text{mA}(30\text{k}\Omega + R)\,e^{\frac{-t=120\text{ns}}{L/(30\text{k}\Omega+R)}} = -3\text{V}$$

We cannot solve this eq'n uniquely for R and L. Since it is difficult to solve for R, we choose a value of R and then solve for L.

We must have $v_2(0^+) < -3$V to get a pulse for v_0.

$$\therefore\ -\frac{1}{5}\text{mA}(30\text{k}\Omega + R) < -3\text{V}$$

We see that any R will work except R=0 that would short out the 6V source for $t < t_0$.

A convenient value for R is 20kΩ. This gives

$$v_2(0^+) = -\frac{1}{5}\text{mA}(30\text{k}\Omega + 20\text{k}\Omega) = -10\text{V}$$

Now we can solve for L and see if we get a reasonable value.

$$v_2(t=120\text{ns}) = -10\text{V}\,e^{\frac{-120\text{ns}}{L/50\text{k}\Omega}} = -3\text{V}$$

or $$e^{\frac{-120\text{ns}}{L/50\text{k}\Omega}} = \frac{-3\text{V}}{-10\text{V}} = \frac{3}{10}$$

or $$\frac{-120\text{ ns}}{L/50\text{k}\Omega} = \ln\left(\frac{3}{10}\right)$$

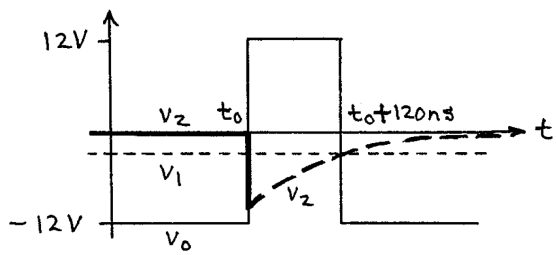
or $\dfrac{L}{50k\Omega} = \dfrac{-120\text{ ns}}{\ln\left(\frac{3}{10}\right)} = \dfrac{-120\text{ns}}{-1.204} = 99.7\text{ ns}$

or $\dfrac{L}{50k\Omega} \approx 100\text{ ns}$

or $L \approx 100n \cdot 50k\text{ H} = 5\text{ mH}$

Summary: $R = 20k\Omega$, $L = 5\text{mH}$

b) and c) We use the above results to make our plot:



d) The diode acts like a wire when current flows in the direction of the arrow in the diode symbol. Otherwise, the diode is an open circuit.

For $t < t_0$, $v_0 = -12V$ so the diode looks like a wire shorting v_3 to 0V. Applies to $t > t_0 + 120\text{ns}$, too. For $t > t_0$ & $v_0 = +12V$, the diode acts like an open, and v_3 is pulled up to $v_0 = 12V$ by the 15kΩ resistor, which has no V-drop.