1.

After being on side 1 for a long time, the switch moves from side 1 to side 2 at $t = 0$.

a) Find the value of $v_C(t = 0)$.

b) Find an expression for $v_C(t > 0)$.

c) Find the value of the energy stored by the capacitor at time $t = 3\tau$ where $\tau$ = time constant for circuit after $t = 0$.

**SOL’N:**

a) $v_C(t = 0) = 36$ V. C charges to voltage of power supply.

b) $v_C(t \to \infty) = 0$ V, $R_{Thev} = 200$ kΩ for $t > 0$. $\tau = R_{Thev}C = 2$ ms.

$$v_C(t > 0) = 0 \text{ V} + [36 \text{ V} - 0 \text{ V}]e^{-t/2\text{ ms}}$$

c) $v_C(t = 3\tau) = 36$ V $e^{-3} \approx 1.8$ V, $w_C = \frac{1}{2}CV^2 = \frac{1}{2}(0.01 \mu)(1.8)^2 J = 16$ nJ

2. A function generator outputs the following signal, $v_i(t)$.

Design op-amp circuits to output each of the following waveforms when $v_i(t)$ is the input. You may use either one or two op-amps in each case.

a) **sol’n:** Non-inverting amp, $R_f = R_s > 1$ kΩ
3. The above circuit is from Lab 4, but some of the component values have been changed.

a) Find the minimum and maximum values allowed for $R_1$ in order to achieve proper operation: 1) successfully generating a triangle wave (which requires that $v_1$ switches from high to low and back), and 2) avoiding clipping that would occur if $v_2$ exceeded the rail voltage for the op-amp.
**SOL:N:** a) $R_1$ and $R_2$ form V-divider between $v_1$ and $v_2$. $v_2$ must pull $v_+$ of 1st op-amp below 0 V in order to switch $v_1$ when $v_1$ is $-v_{\text{rail}}$ and $v_2$ is $+v_{\text{rail}}$. Need $R_1 < R_2$ for that to happen. So $R_1 = 100 \, \text{k}\Omega$ is the maximum. The other condition cannot occur, since if $v_2$ hits the rail voltage, it will just stay there. $v_1$ and $v_2$ will then stay the same and switching will never occur.

b) Choose an allowed value for $R_1$ and calculate the period of $v_2(t)$.

**SOL:N:** b) Many solutions. Key equations are:

$$0 \, \text{V} = v_+ = \frac{v_1 R_1 + v_2 R_2}{R_1 + R_2} = \frac{-v_{\text{rail}} R_1 + v_2 R_2}{R_1 + R_2}$$

solve for peak $v_2$.

$$v_{2,\text{peak}} = \frac{v_{\text{rail}} R_1}{R_2} = \frac{9 \, \text{V} \cdot R_1}{100 \, \text{k}\Omega}$$

slope of $v_2 = -\frac{I}{C} = -\frac{v_1}{R_3 C} = -\frac{v_{\text{rail}}}{R_3 C} = \frac{-9 \, \text{V}}{5 \, \text{ms}} = -1.8 \, \text{kV/s}$

Half of period = time for $v_2$ to go from -pk to +pk = $2v_{2,\text{pk}}$

or half period = $2v_{2,\text{pk}}$/slope of $v_2$.

c) Draw a graph of $v_2(t)$ and $v_3(t)$ for at least one period of $v_2(t)$. Label all important times and voltages on the graph.

**SOL:N:** b) $v_2(t) = \text{triangle wave with slope and max } v_2 \text{ and period from (b)}$.

$$0 \, \text{V} = v_+ = \frac{v_1 R_1 + v_2 R_2}{R_1 + R_2} = \frac{-v_{\text{rail}} R_1 + v_2 R_2}{R_1 + R_2}$$

solve for peak $v_2$.

$v_3(t)$ is rectangular waveform. High voltage = $+v_{\text{rail}} = 9 \, \text{V}$, low $V = -9 \, \text{V}$.

$v_3(t)$ is high when $v_2 > +2 \, \text{V} = v_+$ of third op-amp.