The op-amp is ideal, with $V_{CC} = 10\,V$ and $V_{EE} = -10\,V$. The diode forward voltage, $V_D = 0.7\,V$.

This is a Wien bridge sine-wave oscillator. It oscillates because

$$G = 1 + \frac{46\,k\Omega}{22\,k\Omega} = 3.09 > 3.$$ 

- What is the frequency of oscillation.
- Sketch $V_o$ when the oscillation amplitude has stabilized.
- Indicate the approximate voltage of oscillation on the sketch.

\[ \omega = (RC)^{-1} = (28\,k\Omega \times 27\,nF)^{-1} = 1322.8\,\text{rad/s} \]
\[ f = \frac{1}{2\pi\omega} = 210.5\,\text{Hz} \]

- Sketch $V_o$ when the oscillation amplitude has stabilized.
  The oscillation will be roughly sine shaped at $f = 210.5\,\text{Hz}$
- Indicate the approximate voltage of oscillation on the sketch.
  amplitude stabilized at $\pm 0.7\,V$. 
The op-amp is ideal, with $V_{CC} = 2$ V and $V_{EE} = -2$ V.

![Circuit Diagram]

Initial conditions are: $V_\sim = 0$ and $V_o = +V_{CC}$.

Sketch as a function of time: 1) $V_\sim$, 2) $V_+$, 3) $V_o$

- $V_o$ will switch between $\pm 2$ V
- $V_+$ will switch between $\pm 2 V \frac{54\, \text{k}\Omega}{54\, \text{k}\Omega + 31\, \text{k}\Omega} = 1.27$ V
- $V_+$ will exponentially rise between $\pm 1.27$ V.

Timing will be symmetric between +ve and -ve pulses.

$$ (V_f - V_\infty) = (V_i - V_\infty)e^{-t/\tau}, $$

where $\tau = RC = 27\, \text{k}\Omega \times 28\, \text{nF} = 0.756$ ms

For the -ve transition, $V_i = 1.27$ V, $V_f = -1.27$ V, an $V_\infty = -2$ V.

$$ t = \tau \ln \left( \frac{V_f - V_\infty}{V_i - V_\infty} \right) = (0.756\, \text{ms}) \ln \left( \frac{1.27 - (-2)}{-1.27 - (-2)} \right) = 1.13$ ms
Initial conditions are that the charge on the capacitor is zero. $V_{CC} = 9 \text{ V}$.

- Sketch $V_o$, $V_A$ and $V_B$.
- What is the length of the $V_o = \text{high}$ and $V_o = \text{low}$ outputs?

This configuration is similar, but not the same as the configuration discussed in class. Normally $V_+$ of the upper comparator is connected to $V_B$. This means that the upper transitions will not happen at $V_B = \frac{2}{3}V_{CC}$, but instead when $V_A = \frac{2}{3}V_{CC}$. At this time, we calculate

$$i = \frac{(V_{CC} - \frac{2}{3}V_{CC})}{41 \text{ k}\Omega} = \frac{(9 \text{ V} - 6 \text{ V})}{41 \text{ k}\Omega} = 3 \text{ V}/41 \text{ k}\Omega = 73.17 \mu\text{A}.$$  

Using $i$, we calculate $V_B = V_A - i(14 \text{ k}\Omega) = 4.98 \text{ V}$.

Another way to see this is to think about Capacitor $C$ charging until $V_A = \frac{2}{3}V_{CC}$ (RESET) and discharging until $V_B = \frac{1}{3}V_{CC}$ (SET). In the usual 555 astable configuration, the trigger and threshold pins (pins 2 and 6) are both connected to the top of $C$, so $V_A = V_B$, however in the above circuit $V_A$ and $V_B$ are related by

$$V_A = V_B + (V_{CC} - V_B)\frac{R_B}{R_A + R_B}$$

(voltage divider). Setting $V_A = \frac{2}{3}V_{CC}$ and rearranging, RESET occurs when $V_B$ reaches voltage $V_R$ given by

$$V_R = \left(\frac{2}{3} - \frac{14 \text{ k}\Omega}{41 \text{ k}\Omega + 14 \text{ k}\Omega}\right)\left(\frac{41 \text{ k}\Omega + 14 \text{ k}\Omega}{41 \text{ k}\Omega}\right)9 \text{ V} = 4.98 \text{ V}$$

The durations of the charge and discharge half-cycles are then given by the usual formula

$$t = RC \ln \left(\frac{V_\infty - V_i}{V_\infty - V_f}\right) = (0.40)RC.$$
with $V_i = V_{CC}/3$, $V_f = V_R$, $V_\infty = V_{CC}$ and $R = R_A + R_B$ for the charge half-cycle and $V_i = V_R$, $V_f = V_{CC}/3$, $V_\infty = 0$ and $R = R_B$ for the discharge half-cycle. $V_o = V_{CC}$ during the charge period and $V_o = 0$ V during the discharge period. Thus:

- $t_{\text{high}} = 0.40 \times 33 \mu F \times (41 \, k\Omega + 14 \, k\Omega) = 0.73 \, ms$
- $t_{\text{low}} = 0.40 \times 33 \mu F \times (14 \, k\Omega) = 0.18 \, ms$

The shape of $V_B$ is essentially the same as that of the regular 555 astable configuration, rising and falling exponentially between the two limits - except that the upper limit is $V_R$ instead of $2/3V_{CC}$. Meanwhile $V_A$ rises exponentially from somewhat above $1/3V_{CC}$ to $2/3V_{CC}$, and then drops immediately to zero for the duration of the discharge half-cycle since it is connected directly to the discharge pin (pin 7).