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

This is a Wien bridge sine-wave oscillator. It oscillates because \( G = 1 + \frac{76 \text{ k}\Omega}{23 \text{ k}\Omega} = 4.30 > 3 \).

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

\[
\omega = (RC)^{-1} = (21 \text{ k}\Omega \times 29 \text{ nF})^{-1} = 1642.0 \text{ rad/s}
\]

\[
f = \frac{1}{2\pi \omega} = 261.3 \text{ Hz}
\]

- Sketch \( V_o \) when the oscillation amplitude has stabilized.
  The oscillation will be roughly sine shaped at \( f = 261.3 \text{ Hz} \)
- Indicate the approximate voltage of oscillation on the sketch.
  amplitude stabilized at ±0.7 V.
The op-amp is ideal, with $V_{CC} = 2\,\text{V}$ and $V_{EE} = -2\,\text{V}$.

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

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

- $V_o$ will switch between $\pm 2\,\text{V}$
- $V_+$ will switch between $\pm 2\,\text{V}$
  \[ \frac{79\,\text{k}\Omega}{79\,\text{k}\Omega + 31\,\text{k}\Omega} = 1.44 \,\text{V} \]
- $V_+$ will exponentially rise between $\pm 1.44\,\text{V}$.

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

\[
(V_f - V_\infty) = (V_i - V_\infty)e^{-t/\tau},
\]
where $\tau = RC = 29\,\text{k}\Omega \times 21\,\text{nF} = 0.609\,\text{ms}$

For the $-$ve transition, $V_i = 1.44\,\text{V}$, $V_f = -1.44\,\text{V}$, and $V_\infty = -2\,\text{V}$.

\[
t = \tau \ln \left( \frac{V_f - V_\infty}{V_i - V_\infty} \right) = (0.609\,\text{ms}) \ln \left( \frac{1.44 - (-2)}{-1.44 - (-2)} \right) = 1.11\,\text{ms}
\]
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

$$i = (V_{CC} - \frac{2}{3}V_CC)/32\, \text{kΩ} = (9\, \text{V} - 6\, \text{V})/32\, \text{kΩ} = 3\, \text{V}/32\, \text{kΩ} = 93.75\, \mu\text{A}.$$  

Using $i$, we calculate $V_B = V_A - i(15\, \text{kΩ}) = 4.59\, \text{V}$.

Another way to see this is to think about Capacitor $C$ charging until $V_A = 2/3V_CC$ (RESET) and discharging until $V_B = 1/3V_CC$ (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 $V_A = 2/3V_CC$ and rearranging, RESET occurs when $V_B$ reaches voltage $V_R$ given by

$$V_R = \left(\frac{2}{3} - \frac{R_B}{R_A + R_B}\right)\left(\frac{R_A + R_B}{R_A}\right) V_CC$$

$$V_R = \left(\frac{2}{3} - \frac{15\, \text{kΩ}}{32\, \text{kΩ} + 15\, \text{kΩ}}\right)\left(\frac{32\, \text{kΩ} + 15\, \text{kΩ}}{32\, \text{kΩ}}\right) 9\, \text{V} = 4.59\, \text{V}$$

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

$$t = RC \ln \left(\frac{V_\infty - V_i}{V_\infty - V_f}\right) = (0.31)RC$$
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:

- $t_{\text{high}} = 0.31 \times 48 \mu F \times (32 \text{k}\Omega + 15 \text{k}\Omega) = 0.70 \text{ms}$
- $t_{\text{low}} = 0.31 \times 48 \mu F \times (15 \text{k}\Omega) = 0.22 \text{ms}$

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).