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 $G = 1 + \frac{92\,\text{k}\Omega}{26\,\text{k}\Omega} = 4.54 > 3$.

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

$\omega = \frac{1}{RC} = \frac{1}{35\,\text{k}\Omega \times 22\,\text{nF}} = 1298.7\,\text{rad/s}$

$f = \frac{1}{2\pi} \omega = 206.7\,\text{Hz}$

- Sketch $V_o$ when the oscillation amplitude has stabilized.
  The oscillation will be roughly sine shaped at $f = 206.7\,\text{Hz}$

- Indicate the approximate voltage of oscillation on the sketch.
  amplitude stabilized at $\pm 0.7\,\text{V}$. 
The op-amp is ideal, with $V_{CC} = 2$ V and $V_{EE} = -2$ 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 $\pm 2$ V
- $V_+$ will switch between $\pm 2 V \frac{77 k\Omega}{77 k\Omega + 33 k\Omega} = 1.40 V$
- $V_+$ will exponentially rise between $\pm 1.40 V$.

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

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

were $\tau = RC = 22 k\Omega \times 35 nF = 0.770 ms$

For the -ve transition, $V_i = 1.40 V$, $V_f = -1.40 V$, an $V_\infty = -2 V$.

\[t = \tau \ln \left(\frac{V_f - V_\infty}{V_i - V_\infty}\right) = (0.770 ms) \ln \left(\frac{1.40 - (-2)}{-1.40 - (-2)}\right) = 1.34 ms\]
Initial conditions are that the charge on the capacitor is zero. $V_{CC} = 9$ 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

$$i = (V_{CC} - \frac{2}{3}V_{CC})/52 \, \text{k}\Omega = (9 \, \text{V} - 6 \, \text{V})/52 \, \text{k}\Omega = 3 \, \text{V}/52 \, \text{k}\Omega = 57.69 \, \mu\text{A}.$$ 

Using $i$, we calculate $V_B = V_A - i(18 \, \text{k}\Omega) = 4.96 \, \text{V}$.

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

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

$$V_R = \left(\frac{2}{3} - \frac{18 \, \text{k}\Omega}{52 \, \text{k}\Omega + 18 \, \text{k}\Omega}\right) \left(\frac{52 \, \text{k}\Omega + 18 \, \text{k}\Omega}{52 \, \text{k}\Omega}\right) 9 \, \text{V} = 4.96 \, \text{V}$$

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 $V_i = \frac{V_{CC}}{3}$, $V_f = V_R$, $V_\infty = V_{CC}$ and $R = R_A + R_B$ for the charge half-cycle and $V_i = V_R$, $V_f = \frac{V_{CC}}{3}$, $V_\infty = 0$ 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:

- $t_{\text{high}} = 0.40 \times 56 \mu F \times (52 \text{k}\Omega + 18 \text{k}\Omega) = 1.57$ ms
- $t_{\text{low}} = 0.40 \times 56 \mu F \times (18 \text{k}\Omega) = 0.40$ 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).