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 

$$G = 1 + \frac{66 \, \text{k} \Omega}{24 \, \text{k} \Omega} = 3.75 > 3.$$ 

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

$$\omega = (RC)^{-1} = (37 \, \text{k} \Omega \times 32 \, \text{nF})^{-1} = 844.6 \, \text{rad/s}$$

$$f = \frac{1}{2\pi} \omega = 134.4 \, \text{Hz}$$

• Sketch $V_o$ when the oscillation amplitude has stabilized.
• The oscillation will be roughly sine shaped at $f = 134.4 \, \text{Hz}$

• 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.

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 $\frac{54 \text{k}\Omega}{54 \text{k}\Omega + 29 \text{k}\Omega} = 1.30$ V
- $V_+$ will exponentially rise between $\pm 1.30$ V.

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

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

were $\tau = RC = 32 \text{k}\Omega \times 37 \text{nF} = 1.184$ ms

For the -ve transition, $V_i = 1.30$ V, $V_f = -1.30$ V, an $V_\infty = -2$ V.

$$t = \tau \ln \left(\frac{V_f - V_\infty}{V_i - V_\infty}\right) = (1.184 \text{ ms}) \ln \left(\frac{1.30 - (-2)}{1.30 - (-2)}\right) = 1.84$ 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

$$i = (V_{CC} - \frac{2}{3}V_{CC})/56 \text{ kΩ} = (9 \text{ V} - 6 \text{ V})/56 \text{ kΩ} = 3 \text{ V}/56 \text{ kΩ} = 53.57 \mu \text{A}.$$  
Using $i$, we calculate $V_B = V_A - i(16 \text{ kΩ}) = 5.14 \text{ V}$.

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

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

$$V_R = \left(\frac{2}{3} - \frac{16 \text{ kΩ}}{56 \text{ kΩ} + 16 \text{ kΩ}}\right)\left(\frac{56 \text{ kΩ} + 16 \text{ kΩ}}{56 \text{ kΩ}}\right)9 \text{ V} = 5.14 \text{ V}$$

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

$$t = RC \ln \left(\frac{V_{\infty} - V_i}{V_{\infty} - V_f}\right) = (0.44)RC$$
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 \( V_i = V_f \), \( V_f = V_{CC}/3 \), \( V_\infty = 0 \) 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:

- \( t_{\text{high}} = 0.44 \times 43 \, \mu \text{F} \times (56 \, \text{k}\Omega + 16 \, \text{k}\Omega) = 1.36 \text{ ms} \)
- \( t_{\text{low}} = 0.44 \times 43 \, \mu \text{F} \times (16 \, \text{k}\Omega) = 0.30 \text{ ms} \)

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).