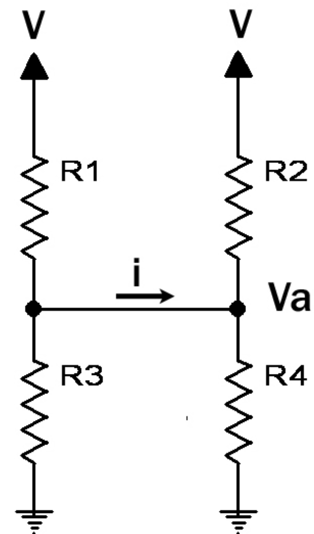
**Correct answers always include units when appropriate.**

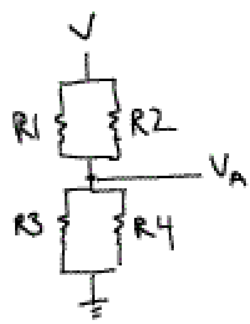
**Problem 1.** Examine the schematic to the right.




1A. What is the current "i" that flows through the middle wire?
1B. What is the voltage Va with respect to ground?

1A) Not graded – see handout from class

1B) Redraw circuit:

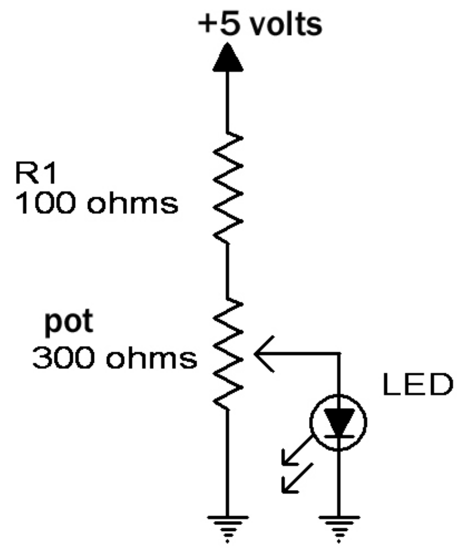



$$V_A = V\left(\frac{R3 \,\|\, R4}{R1 \,\|\, R2 + R3 \,\|\, R4}\right)$$

$$= V\left(\frac{\frac{R_3R_4}{R_3+R_4}}{\frac{R_1R_2}{R_1+R_2}+\frac{R_3R_4}{R_3+R_4}}\right) = V\left(\frac{(R_3R_4)(R_1+R_2)}{(R_1R_2)(R_3+R_4)+(R_3R_4)(R_1+R_2)}\right)$$

in units of volts

**Problem 2.** The circuit to the right includes a potentiometer.




2A. Draw an equivalent circuit replacing the pot with fixed resistance values when the wiper is at the top.

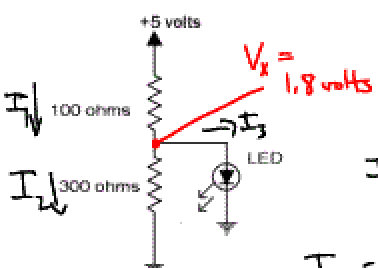
2B. Draw an equivalent circuit replacing the pot with fixed resistance values when the pot wiper is exactly in the middle of its range

2C. Draw an equivalent circuit replacing the pot with fixed resistance values when the pot wiper is at the bottom.

2D. Assume a voltage drop across the LED of 1.8 volts. For each of the cases 2A, 2B, and 2C, determine the current through the LED.

2E. In which case(s) will the LED definitely be on?

2F. In which case(s) will the LED definitely be off?




$I_1 = I_2 + I_3 \Rightarrow I_3 = I_1 - I_2$

$I_1 = \frac{5 - 1.8}{100}$

$I_2 = \frac{1.8 - 0}{300}$

$I_3 = \frac{3.2}{100} - \frac{1.8}{300} = 0.032 - .006 = 26\text{ mA}$

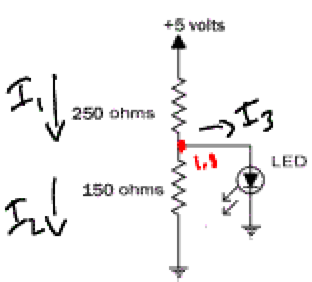
LED ON

Where

$I_1$ is the current through $R_1$

$I_2$ is the current going through the branch of the circuit that does not include the LED

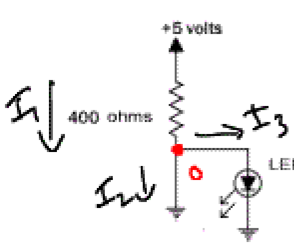
$I_3$ is the current going through the LED




$I_1 = \frac{5 - 1.8}{250} = \frac{3.2}{250}$

$I_2 = \frac{1.8 - 0}{150} = \frac{1.8}{150}$

$I_3 = \frac{3.2}{250} - \frac{1.8}{150}$ mA




$I_1 = \frac{5 - 0}{400} = 125$ mA

$I_2 = I_1$

$I_3 = 0$ diode does not conduct

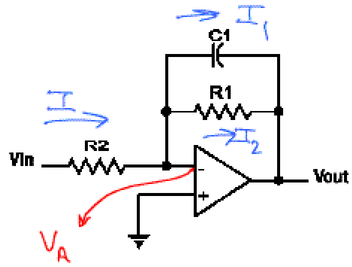
LED OFF

**Problem 3.** Examine the schematic to the right.

3A. What is Vout in terms of the other variables?

3B. **Now assume that R1 = infinity.**

What does the circuit do?




Define $V_A \equiv V_-$, because $V_-$ can be a confusing variable

Also, $V_A = 0$ (Virtual ground) if opamp is operating properly

(eq 1) $I = \frac{V_{in} - V_A}{R_2} = \frac{V_{in} - 0}{R_2} = \frac{V_{in}}{R_2}$ (eq 2) $I = I_1 + I_2$

(eq 3) $V_A - I_2 R_1 = V_{OUT} \Rightarrow -I_2 R_1 = V_{OUT} - V_A \Rightarrow I_2 = \frac{V_A - V_{OUT}}{R_1} = \frac{0 - V_{OUT}}{R_1} = -\frac{V_{OUT}}{R_1}$

(eq 4) $V_A - V_c = V_{OUT}$ but $Q_1 = C_1 V_c$

$0 - V_c = V_{OUT}$ $I_1 = C_1 \frac{dV_c}{dt}$

substitute $\rightarrow I_1 = -C_1 \frac{dV_{out}}{dt}$

Now plug equations 1, 3, + 4 into equation 2:

$$I = I_1 + I_2$$

$$\frac{V_{in}}{R_2} = -C_1 \frac{dV_{OUT}}{dt} - \frac{V_{OUT}}{R_1}$$

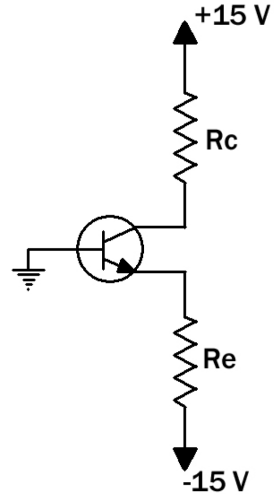
$$V_{OUT} + R_1 C_1 \frac{dV_{OUT}}{dt} = -\frac{R_1}{R_2} V_{in}$$

If $R_1 = \infty \Rightarrow$ open

Then $\frac{V_{in}}{R_2} = -C_1 \frac{dV_{OUT}}{dt} \Rightarrow V_{OUT} = -\frac{1}{C_1 R_2} \int_0^{\tau} V_{in}\, dt$

The circuit is an integrator

**Problem 4**




The transistor in the circuit to the right has a gain of 100, and exhibits a Vbe of 0.7 volts when Ic = 2 mA.

Choose Rc and Re so that Vc = 5 volts and Ic = 2mA

**Hints:**

(1) Vc is the voltage at the collector relative to ground.

(2) Remember that current can flow through a diode as long as it is forward biased. Notice that the emitter runs to -15 volts. Now, think carefully about what the relationship between the voltage at the base and the voltage at the emitter has to be, according to the original problem statement.

$$\frac{15 - V_c}{R_c} = I_c \Rightarrow R_c = \frac{15-5}{2\times10^{-3}}$$

$$= \frac{10}{2\times10^{-3}} = 5\ k\Omega$$

$$I_e = I_c + I_B = \beta I_B + I_B = I_B(\beta+1) \approx 100\, I_B \approx I_c$$

because $\beta >> 1$

$$V_{be} = 0.7 \text{ volts} = V_b - V_e$$

$$V_b = 0$$

$$0 - V_e = 0.7v \Rightarrow V_e = -0.7 \text{ volts}$$

$$V_e - I_e R_e = -15 \text{ volts}$$

$$R_e = \frac{-15 - (-0.7)}{-I_e} = \frac{-14.3 \text{ volts}}{-I_c}$$

$$R_e = \frac{-14.3 \text{ volts}}{-2mA} = 7.15\ k\Omega$$