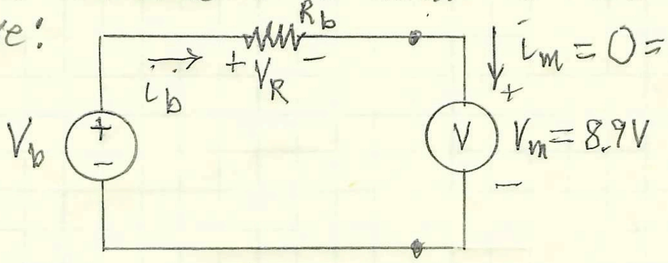
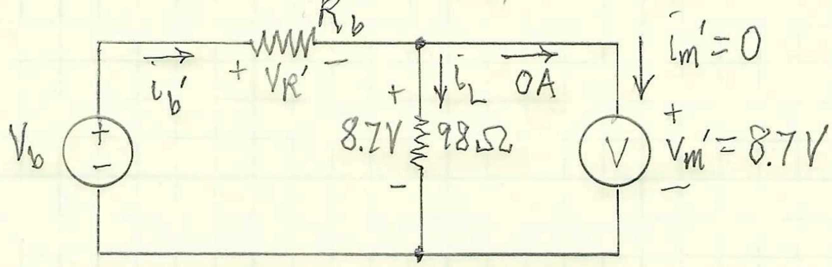
1) a) When the voltmeter is attached to the battery directly, we have:



$V_R = R_b i_b = 0$

When external resistor is attached, we have:



b) When load not present, voltmeter doesn't allow current to flow so there is no voltage drop across internal resistor.

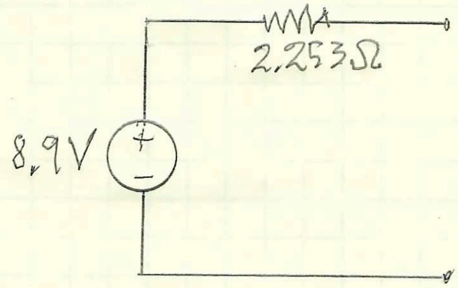
KVL: $-V_b + \cancel{V_R}^{\,0} + V_m = 0 \Rightarrow V_b = V_m = \underline{\underline{8.9V}}$, i.e., the measured voltage.

When load is present, Ohm's Law dictates current through load is $i_L = \frac{8.7V}{98\Omega} = 88.78\text{ mA}$ ← same as i_b'

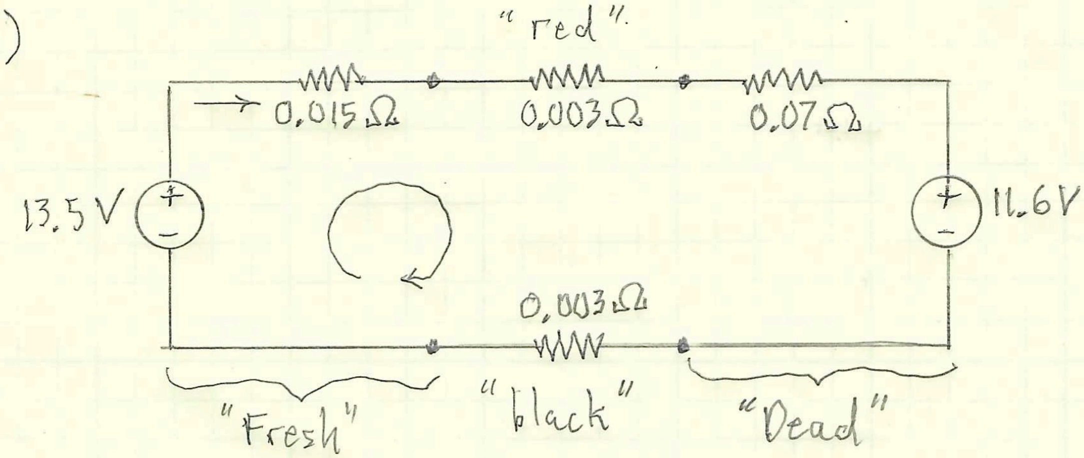
Voltage drop across R_b is $V_b - V_m' = 8.9 - 8.7 = 0.2V = V_R'$

$$R_b = \frac{V_R'}{i_b'} = \frac{0.2V}{0.08878A} = \underline{\underline{2.253\ \Omega}}$$

Thus circuit representing battery is:



2) a)



b)

All elements in series, with current i through them (which we have to solve for).

KVL: $-13.5 + i\,0.015 + i\,0.003 + i\,0.07 + 11.6 + i\,0.003 = 0$

$$\Rightarrow i(0.015 + 0.003 + 0.07 + 0.003) = 13.5 - 11.6$$

$$\Rightarrow i(0.091\,\Omega) = 1.9\,V$$

$$\Rightarrow i = 20.879\ A$$

The "useful power" is the power delivered to the "dead" source

$$p = iV = (20.879A)(11.6V) = \underline{\underline{242.20\ W}}$$

3) The circuit is nearly identical to the previous one with all elements in series. However, the polarity of the dead battery is reversed and some of the element values have changed.

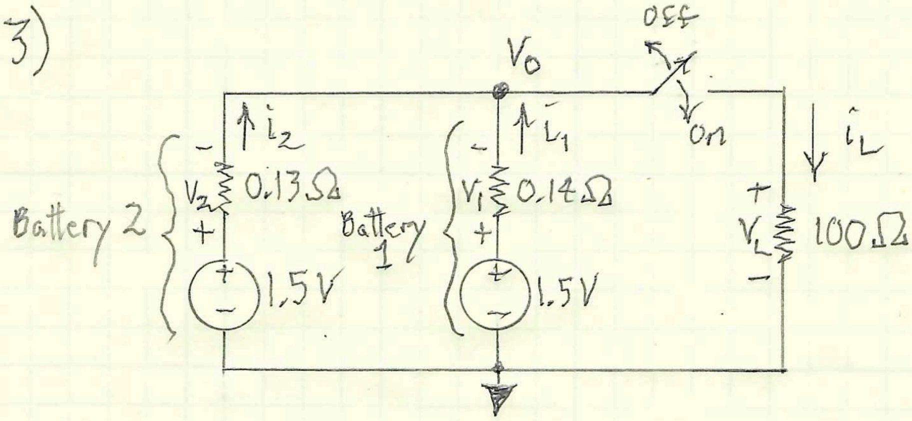
KVL: $-13.7 + i\,0.02 + i\,0.003 - 11.9 + i\,0.05 + i\,0.003 = 0$

$$\Rightarrow i(0.02 + 0.003 + 0.05 + 0.003) = 13.7 + 11.9 = 25.6V$$

$$\Rightarrow i(0.076\,\Omega) = 25.6V \quad \Rightarrow i = \frac{25.6V}{0.076\,\Omega} = \underline{\underline{336.842\ A}}$$

Car batteries are designed to deliver several hundred "cranking amp", but that is a momentary discharge. The scenario above is not momentary.

3)



$V_0 = V_L$ when switch is in the on (closed) position

a) Switch is in the on position. We want i_1.

KCL at the top node: $i_1 + i_2 = i_L$

Use Ohm's law to express the currents through the resistors in terms of the voltages across them.

$$\underbrace{\frac{1.5 - V_0}{0.14}}_{i_1} + \underbrace{\frac{1.5 - V_0}{0.13}}_{i_2} = \underbrace{\frac{V_0}{100}}_{i_3}$$ ← One equation, one unkown.

Solve for V_0. Multiply through by $(0.14)(0.13)(100)$.

$\Rightarrow 13(1.5 - V_0) + 14(1.5 - V_0) = (0.13)(0.14)V_0$

$\Rightarrow 19.5 + 21 = (13 + 14 + 0.0182)V_0 \Rightarrow V_0 = 1.4989895\text{V}$

(generally don't need this many digits, but since we're subtracting from something close to this, we'll keep them.

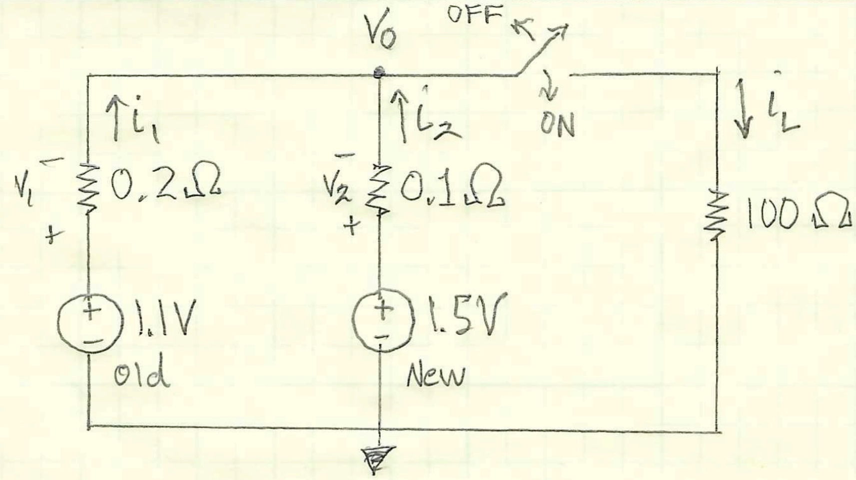
$$\underline{\underline{i_1}} = \frac{1.5 - V_0}{0.14} = \underline{\underline{7.2174 \text{ mA}}}$$

b) With the second battery removed, all the remaining elements are in series. $\Rightarrow i_1 = i_L$

KVL: $-1.5\text{V} + i_1 0.14 + i_1 100 = 0 \Rightarrow i_1 = \frac{1.5\text{V}}{100.14\Omega} = \underline{\underline{14.979 \text{ mA}}}$

So, by removing the second battery, the current supplied by the first battery slightly more than doubles.

4)



Approach this as we did the previous problem: $i_1 + i_2 = i_L$

$$\underbrace{\frac{1.1 - V_0}{0.2}}_{i_1} + \underbrace{\frac{1.5 - V_0}{0.1}}_{i_2} = \underbrace{\frac{V_0}{100}}_{i_L} \Rightarrow \left(\frac{1.1}{0.2} + \frac{1.5}{0.1}\right) = \left(\frac{1}{0.2} + \frac{1}{0.1} + \frac{1}{100}\right) V_0$$

$\Rightarrow V_0 = 1.3658\text{ V}$

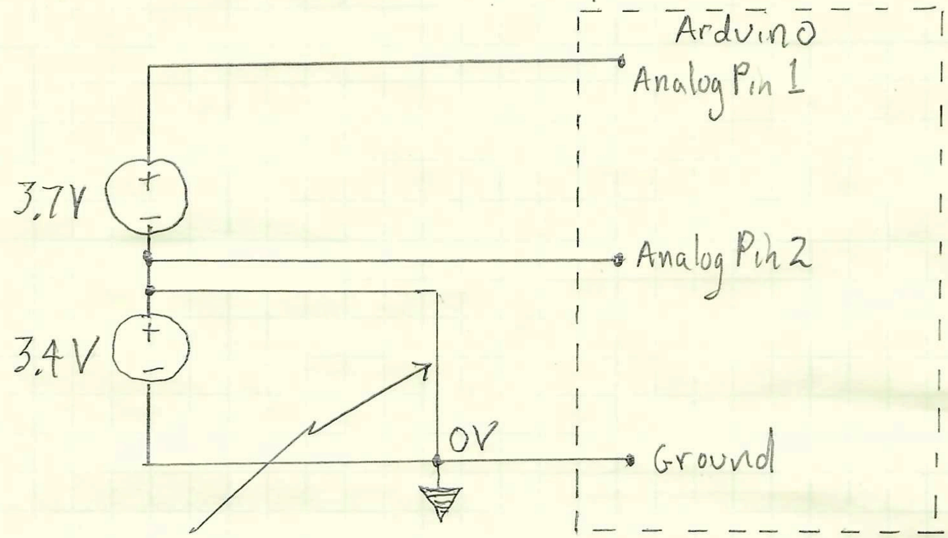
$i_1 = \frac{1.1 - V_0}{0.2} = -1.3288\text{ A}$ ⟵ current is actually flowing <u>into</u> the old battery

$i_2 = \frac{1.5 - V_0}{0.1} = 1.3424\text{ A}$ ⟵ delivering power

$i_L = \frac{V_0}{100} = 13.658\text{ mA}$ ⟵ this current is much smaller than the current flowing into the old battery, which is what we sought to show.

Side note: This is what happens when we put mismatched batteries in parallel (not good!). But there is not a similar concern for mismatched batteries in series.

5) Let's redraw the circuit but slightly rearrange things and leave the voltmeters as open circuits.



This wire, that is drawn in blue on the homework, ties the positive terminal of the 3.4V battery to ground, but the negative terminal is also connected to ground. We can't have both terminals of the battery tied to the same potential and maintain a 3.4V difference in potential across the terminals. Something is going to break.