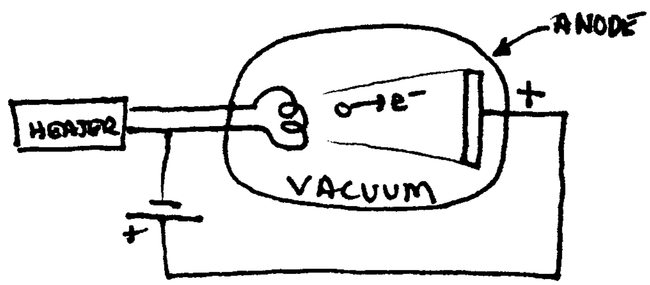
③ Consider the diagram to the right of a very secret thing known only as THE DEVICE. (a) What is the direction of the current in the vacuum? (b) electrons hit the anode at rate of 6.0×10^{12}/s. What is the current in THE DEVICE?



(a) CURRENT flows in the direction of POSITIVE CHARGE, so from ANODE TO FILAMENT.

(b) The current is the charge per unit time, defined for the direction POSITIVE CHARGES FLOW. A flow of electrons in one direction is the NEGATIVE of the current:

$$I = \text{current} = \text{RATE} * |Q_{electron}| = \underbrace{\frac{N_{electron}}{\text{TIME}}}_{\text{RATE}} \cdot |Q_{electron}|$$

so// $I = \dfrac{6.0 \times 10^{12}}{1s} \cdot 1.60 \times 10^{-19} C$

$$\boxed{I = 9.6 \times 10^{-7} \text{ Amps}}$$ (ANS)

(11) The starter motor on an AUTOBOT draws 220.0 A of current from a 12.0 V battery for 1.20 s. (a) How much charge is pumped by the battery? (b) How much electrical energy is supplied by the battery?

(a) I can get charge from the definition of current:

$$I = \frac{\Delta Q}{\Delta t} \Rightarrow \Delta Q = I\Delta t = (220.0\,A)(1.20\,s) = \boxed{264\,C}$$

LOTS OF CHARGE!

(ANS)

(b) I choose a particular form to express Power based on <u>WHAT I KNOW</u>. In this case, I know VOLTAGE and CURRENT so: $P = IV$ seems useful. To get energy I appeal to the definition of power:

$$P = \frac{\Delta E}{\Delta t} \rightarrow \Delta E = P\Delta t = IV\Delta t$$

$$= (220.0\,A)(12.0\,V)(1.20\,s)$$

$$\boxed{\Delta E = 3170\,J}$$

(ANS)

⑫ A SOLAR CELL provides an EMF of 0.45 V. (a) If the cell yields a constant 18.0 mA current for 9.0 h, how much electrical energy does it supply? (b) What is the rate it supplies energy (the power)?

(a) Since I know VOLTAGE (EMF) and current, $P = IV$ is good for computing power. I can get energy from power:

$$P = \frac{\Delta E}{\Delta t} \Rightarrow \Delta E = P\Delta t = IV\Delta t$$

$$= (18.0 \times 10^{-3} A)(0.45 V)(32400 s)$$

$$\boxed{\Delta E = 262 J}$$ (ANS)

(b) As noted above, I can get power from:

$$P = IV = (18.0 \times 10^{-3} A)(0.45 V) = \boxed{8.1 \times 10^{-3} W}$$ (ANS)

(25) A current as small as 50 mA near your heart can kill you. Suppose a nervous electrician has $R = 1\,k\Omega$ from hand to hand and touches two wires. (a) What potential difference between the two wires will generate a 50 mA current between hands? (b) When working on a live circuit, keep one hand behind your back — why?

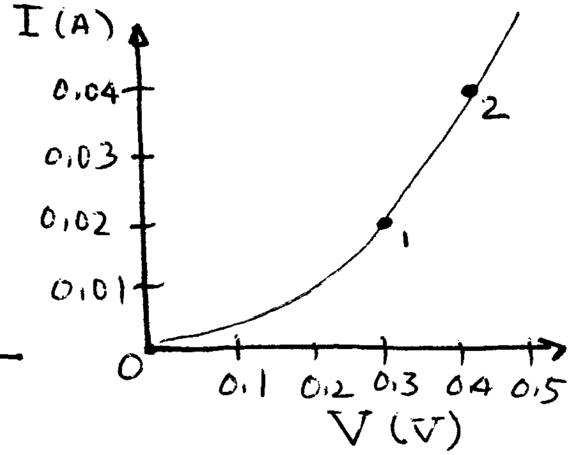
(a) Touching the two wires makes a circuit, with our heroic electrician playing the role of resistor. Applying Ohm's Law gives us the Voltage between the wires:

$$V = IR = (50 \times 10^{-3} A)(1000\,\Omega) = \boxed{50\,V} \text{ (ANS)}$$

Note in the US the most common voltage is 120 V, much higher than this.

(b) By keeping one hand behind your back, you will never (at least not easily) close a circuit using the path thru your heart as a resistor.

(26) A TOP SECRET DEVICE has an I vs V graph shown at right. What is resistance at points 1 and 2?



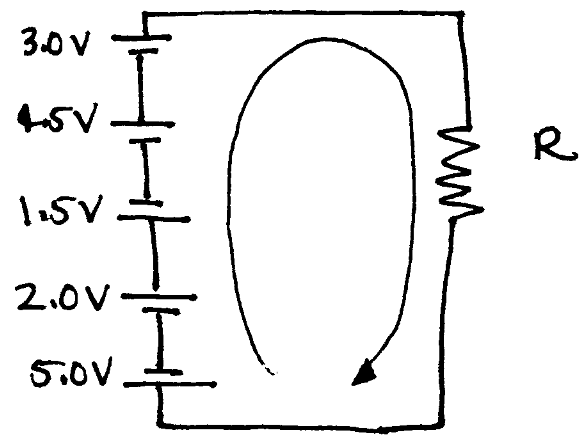
The material is not perfectly ohmic because the graph is not linear over the entire range. HOWEVER, between pts 1 and 2, it IS approximately linear (OHMIC) with slope

$$\text{SLOPE} = \frac{\Delta I}{\Delta V} = \frac{0.02\ A}{0.1\ V} = 0.2\ \frac{A}{V}$$

The inverse of this slope is the resistance in this linear regime by Ohm's Law. Since 1 and 2 are in the same regin of the graph (connected by a STRAIGHT LINE) they have the same R:

$$V = IR \Rightarrow R = \frac{V}{I} = \frac{1}{\text{SLOPE}} = \boxed{5\Omega}$$ (ANS)

(36) When I crash on a desert Island, I have a handful of mismatched batteries to power my GAMEBOY (R).
(a) Hooked up as shown, What EMF is provided?
(b) What is the current thru my Gameboy if it has $R = 3.2\Omega$?



(a) Suppose the current flows in the direction indicated by the arrow in the loop. EMF oriented with this arrow contribute positively, those oriented against contribute negatively. So:

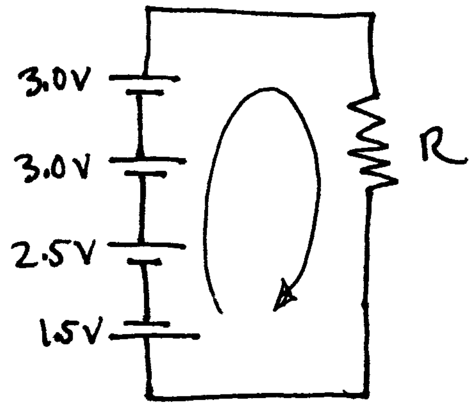
$$\mathcal{E}_{TOT} = 3.0V + 4.5V - 1.5V + 2.0V - 5.0V = \boxed{3.0V} \text{ (ANS)}$$

EXACTLY THE VOLTAGE REQUIRED BY MY GAMEBOY!

(b) I can get the current using Ohm's Law with the TOTAL EMF:

$$V = IR \Longrightarrow I = \frac{V}{R} = \frac{\mathcal{E}_{TOT}}{R} = \frac{3.0V}{3.2\Omega} = \boxed{0.94 \text{ Amps}} \text{ (ANS)}$$

(37) I also find on my desert island a satellite phone. I grudginly give up some Gameboy batteries to see if it will work as shown here. (a) What is my total EMF? (b) If I output 0.40 A, what is the resistance R of my satellite phone?

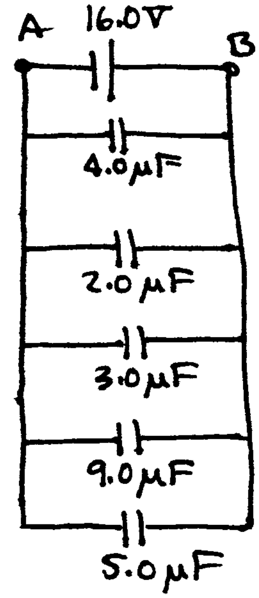


(a) As in the previous problem, I assume the current flows in the direction of the arrow, so:

$$\mathcal{E}_{TOT} = 3.0\,V + 3.0\,V + 2.5\,V - 1.5\,V = \boxed{7.0\,V} \text{ (ANS)}$$

(b) I can get R from Ohm's Law and $\mathcal{E}_{TOT}$:

$$V = IR \rightarrow R = \frac{V}{I} = \frac{\mathcal{E}_{TOT}}{I} = \frac{7.0\,V}{0.40\,A} = \boxed{17.5\,\Omega} \text{ (ANS)}$$

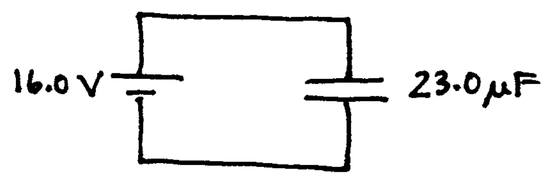


(39) Having failed to power my satellite phone in (37) I resort to building capacitor networks out of coconuts, like the one shown here. (a) What is the equivalent capacitance for this network? (b) What is the charge on a single C_{eq} that could replace this network? (c) What is the charge on the 3.0 μF capacitor?

(a) All the capacitors are in PARALLEL. In this case, the C_{eq} is:

$$C_{eq} = C_1 + C_2 + C_3 + C_4 + C_5$$
$$= 4.0\mu F + 2.0\mu F + 3.0\mu F + 9.0\mu F + 5.0\mu F$$
$$= \boxed{23.0\mu F} \text{ (ANS)}$$

(b) The equivalent circuit seen by the battery is at right. The voltage that charges the capacitor is the 16.0V battery, so the Q_{eq} is:

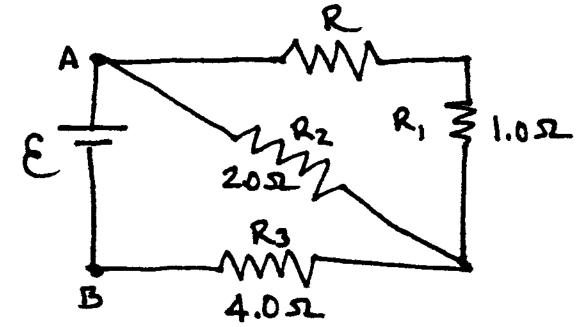


$$C_{eq} = \frac{Q_{eq}}{V} \Rightarrow Q_{eq} = V C_{eq} = \mathcal{E} C_{eq} = 16.0V \cdot 23\times10^{-6}F$$
$$= \boxed{3.7\times10^{-4} C} \text{ (ANS)}$$

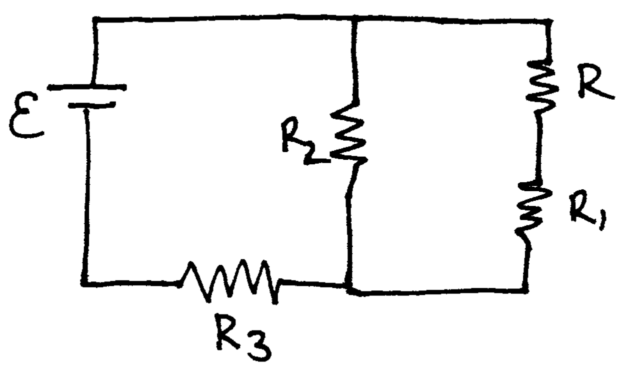
(c) Since EVERY capacitor is in parallel, they have the same $V = \mathcal{E} = 16V$ across them. So for the 3.0 μF capacitor:

$$C = \frac{Q}{V} \Rightarrow Q = CV = C\mathcal{E} = (3.0\times10^{-6}F)(16V) = \boxed{4.8\times10^{-5} C} \text{ (ANS)}$$

(42) In my quest to design a better FLUX CAPACITOR, one of my brilliant students suggests this circuit might be useful. The applied emf is $\mathcal{E} = 93.5\text{ V}$, and the current thru R_3 is 17A. How big is R?



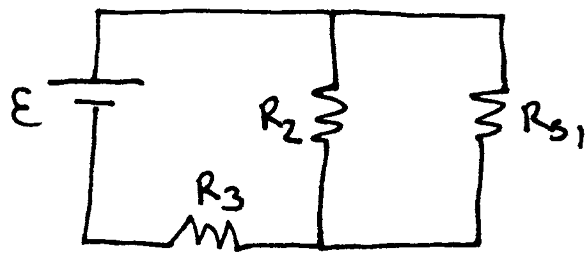
For complex looking circuits like this, I can redraw them in a more conventional form to make it easier to understand what is going on. I can move ANY WIRE so long as it does not cross another circuit element (junction, battery resistor, wire, etc). I can check my redrawn circuit by checking that along any given loop I encounter the <u>same</u> elements in both diagrams. Keeping this in mind, the crazy circuit above may be redrawn as:



There are a variety of ways to solve for R. The following is the most straightforward. I begin by working out all my reduced circuits to get the battery view.

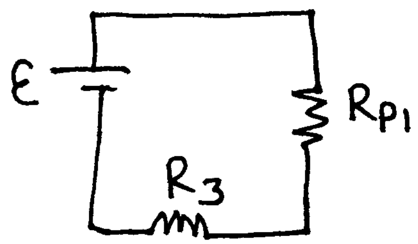
→

Reduction 1: R in series with R_1



$$R_{s1} = R + R_1$$

Reduction 2: R_2 in parallel with R_{s1}



$$\frac{1}{R_{p1}} = \frac{1}{R_{s1}} + \frac{1}{R_2} = \frac{1}{R+R_1} + \frac{1}{R_2}$$

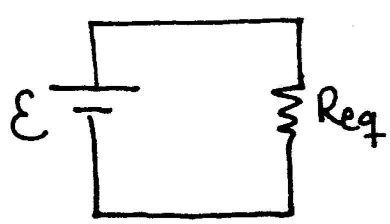
common denominator

$$\frac{1}{R_{p1}} = \frac{R_2}{R_2(R+R_1)} + \frac{R+R_1}{R_2(R+R_1)}$$

$$= \frac{R+R_1+R_2}{R_2(R+R_1)}$$

$$\Rightarrow R_{p1} = R_2(R+R_1)/(R+R_1+R_2)$$

Reduction 3: R_{p1} in series with R_3



$$R_{eq} = R_3 + R_{p1}$$

$$\boxed{R_{EQ} = R_3 + \frac{R_2(R+R_1)}{R+R_1+R_2}}$$

If I knew the numerical value of R_{eq} then I know all resistance except R, and could find R from the R_{EQ} result.

I can find Req from the given voltage and current. The 17A current thru R_3 (4Ω resistor) is the SAME current that goes thru the battery — current is not used up ever, and there are no junctions between R_3 and the battery. SO 17A must be the current that flows around the circuit in REDUCTION 3 above.

Use Ohm's law to find Req:

$$V = IR \rightarrow R = \frac{V}{I} \rightarrow R_{eq} = \frac{\mathcal{E}}{I} = \frac{93.5\,V}{17A} = 5.5\,\Omega$$

So the Resistance are: $R_{eq} = 5.5\,\Omega$ $\quad R_2 = 2.0\,\Omega$

$R_1 = 1.0\,\Omega$ $\quad R_3 = 4.0\,\Omega$

and//

$$R_{eq} = R_3 + \frac{R_2(R+R_1)}{R+R_1+R_2} \rightarrow 5.5\,\Omega = 4.0\,\Omega + \frac{2.0\,\Omega\,(R+1.0\,\Omega)}{R+1.0\,\Omega+2.0\,\Omega}$$

$$\rightarrow 5.5\,\Omega - 4.0\,\Omega = \frac{R\cdot(2.0\,\Omega) + 2.0\,\Omega^2}{R+3.0\,\Omega}$$

$$\rightarrow \quad 1.5\,\Omega = \frac{R\,(2\Omega) + 2\Omega^2}{R+3\Omega} \rightarrow 1.5\,\Omega\,(R+3\Omega) = R(2\Omega) + 2\Omega^2$$

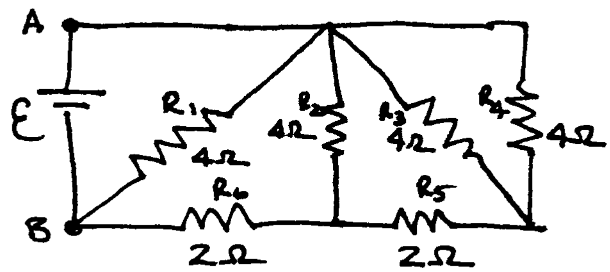
$$\rightarrow R(1.5\,\Omega) + 4.5\,\Omega^2 = R(2\Omega) + 2\Omega^2$$

$$\rightarrow \quad R(2\Omega) - R(1.5\,\Omega) = 4.5\,\Omega^2 - 2\Omega^2$$

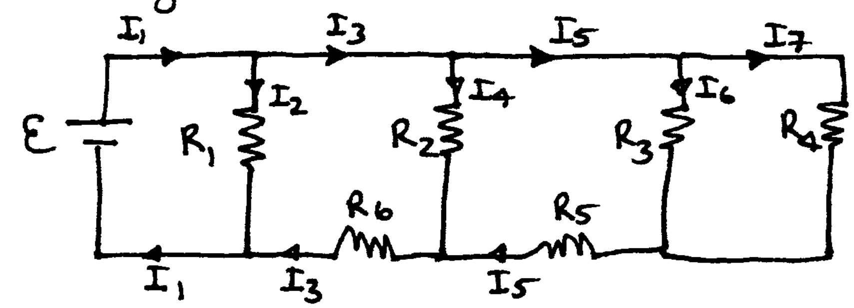
$$\rightarrow R\,(0.5\,\Omega) = 2.5\,\Omega^2 \quad \rightarrow R = \frac{2.5\,\Omega^2}{0.5\,\Omega} = \boxed{5\,\Omega = R}$$

(ANS)

(51) After the last circuit blew up we replaced it with this new improved crazy circuit.
(a) What is the equivalent resistance of this network? (b) What current flows thru the battery ($\mathcal{E} = 6.0\,V$)? (c) What current flows thru R_4 ($R_4 = 4.0\,\Omega$)?

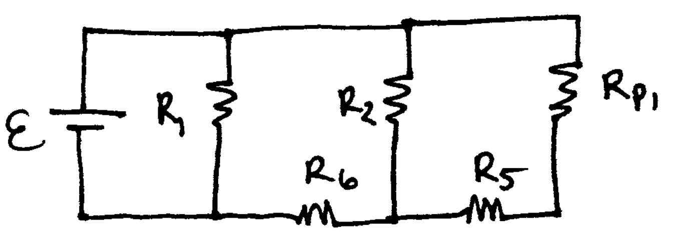


First step is to draw a standardized diagram by sliding wire contacts around. I get:



Now I reduce this (to give me part a):

REDUCTION 1 : R_3 in PARALLEL with R_4

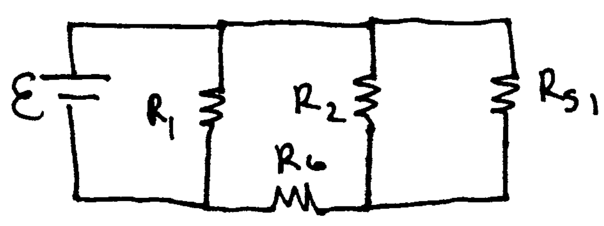


$$\frac{1}{R_{p1}} = \frac{1}{R_3} + \frac{1}{R_4}$$

$$= \frac{1}{4\Omega} + \frac{1}{4\Omega} = \frac{2}{4\Omega}$$

so// $\boxed{R_{p1} = 2\Omega}$

REDUCTION 2: R_5 in SERIES with R_{P1}

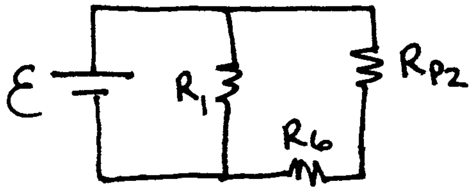


$$R_{s1} = R_5 + R_{p1}$$

$$= 2\Omega + 2\Omega$$

$$\boxed{R_{s1} = 4\Omega}$$

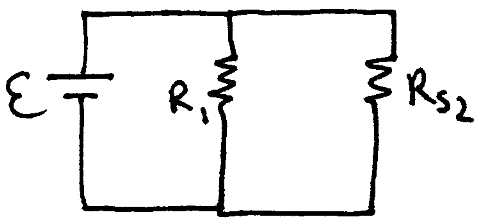
REDUCTION 3 : R_2 in PARALLEL with R_{S1}



$$\frac{1}{R_{P2}} = \frac{1}{R_2} + \frac{1}{R_{S1}} = \frac{1}{4\Omega} + \frac{1}{4\Omega} = \frac{2}{4\Omega}$$

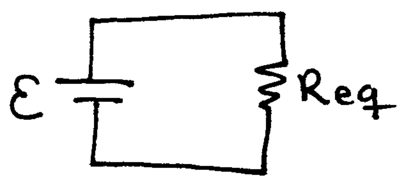
$$\boxed{R_{P2} = 2\Omega}$$

REDUCTION 4 : R_6 in SERIES with R_{P2}



$$R_{S2} = R_{P2} + R_6$$
$$= 2\Omega + 2\Omega$$
$$\boxed{R_{S2} = 4\Omega}$$

REDUCTION 5: R_1 in PARALLEL with R_{S2}



$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_{S2}} = \frac{1}{4\Omega} + \frac{1}{4\Omega} = \frac{2}{4\Omega}$$

or// $\boxed{R_{eq} = 2\Omega}$ (ANS)

(b) I can get the current that flows thru the battery from Ohm's Law and my last reduction, that shows me how the circuit looks to the battery

$$V = IR \Rightarrow I = \frac{V}{R} = \frac{\mathcal{E}}{R_{eq}} = \frac{6.0\,V}{2\Omega} = \boxed{3.0\text{ Amps}}$$ (ANS)

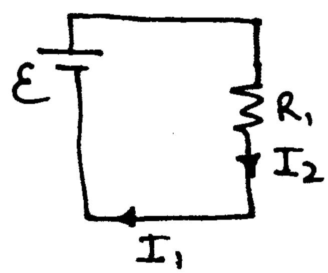
→

(c) Since I want to know the current in R_4, I need to figure out how the current divides at each junction between the battery (where I know the current) and R_4. There are 7 different currents in the circuit (as labeled in my standardized diagram).

To find the currents I use the LOOP RULE and JUNCTION RULE.

STEP 1: I_2 & I_3

LOOP RULE



$$\mathcal{E} - V_1 = 0$$

$$\mathcal{E} = V_1 = R_1 \cdot I_2$$

so// $$I_2 = \frac{\mathcal{E}}{R_1} = \frac{6.0\,V}{4\,\Omega} = 1.5\,A$$

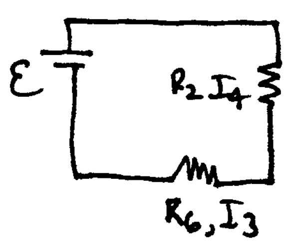
JUNCTION RULE : $I_1 = I_2 + I_3$

so// $I_3 = I_1 - I_2 = 3.0\,A - 1.5\,A = 1.5\,A$

so// $\boxed{\begin{array}{l} I_2 = 1.5\,A \\ I_3 = 1.5\,A \end{array}}$

STEP 2: I_4 and I_5

LOOP RULE



$$\mathcal{E} - V_2 - V_6 = 0$$

$$\mathcal{E} - R_2 \cdot I_4 - R_6 \cdot I_3 = 0$$

$$R_2 \cdot I_4 = \mathcal{E} - R_6 \cdot I_3$$

or// $$I_4 = \frac{\mathcal{E} - R_6 \cdot I_3}{R_2} = \frac{6V - 2\Omega \cdot 1.5A}{4\,\Omega}$$

$$= 0.75\,A$$

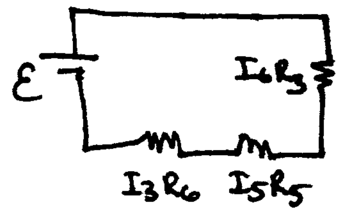
JUNCTION RULE : $I_3 = I_4 + I_5$

so// $I_5 = I_3 - I_4 = 1.5\,A - 0.75\,A = 0.75\,A$

so// $\boxed{\begin{array}{l} I_4 = 0.75\,A \\ I_5 = 0.75\,A \end{array}}$

STEP 3 : I_6 and I_7

LOOP RULE



$$\mathcal{E} - V_3 - V_5 - V_6 = 0$$

$$\mathcal{E} - I_6R_3 - I_5R_5 - I_3R_6 = 0$$

$$I_6R_3 = \mathcal{E} - I_5R_5 - I_3R_6$$

or// $$I_6 = \frac{\mathcal{E} - I_5R_5 - I_3R_6}{R_3}$$

$$= \frac{6.0\,V - 0.75A \cdot 2\Omega - 1.5A \cdot 2\Omega}{4\Omega}$$

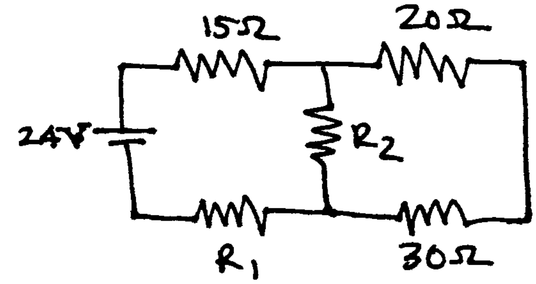
$$= \frac{1.5\,V}{4\Omega} = 0.375\,A$$

JUNCTION RULE : $I_5 = I_6 + I_7$

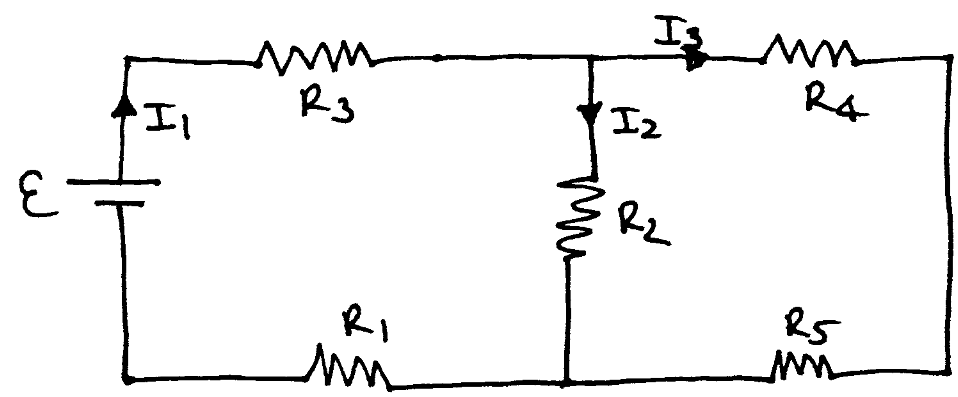
$$I_7 = I_5 - I_6 = 0.75A - 0.375A = \boxed{0.375A = I_7}$$

(ANS)

(67) For some reason that is unclear to me, I gave you this perfectly ordinary looking circuit to analyze. !! Take $R_1 = 10\Omega$ and $R_2 = 15\Omega$. (a) What is R_{eq} for the circuit? (b) What current flows thru R_1? (c) What is Voltage drop across R_2? (d) What current flows thru R_2? (e) How much power is dissipated in R_2?

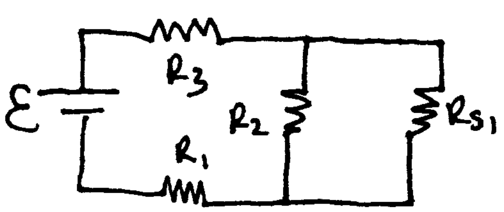


So this is extremely similar to the last 2 problems, and I'll follow a similar strategy. Let me redraw the circuit with labels instead of numbers:



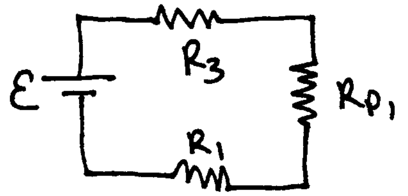
$R_1 = 10\Omega$
$R_2 = 15\Omega$
$R_3 = 15\Omega$
$R_4 = 20\Omega$
$R_5 = 30\Omega$
$\varepsilon = 24V$

REDUCTION 1: R_4 in SERIES with R_5



$$R_{s1} = R_4 + R_5 = 20\Omega + 30\Omega = 50\Omega$$

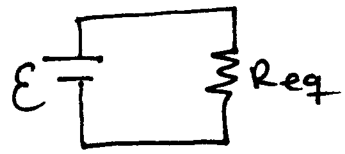
REDUCTION 2: R_2 in PARALLEL with R_{S1}



$$\frac{1}{R_{P1}} = \frac{1}{R_2} + \frac{1}{R_{S1}} = \frac{R_{S1} + R_2}{R_2 \cdot R_{S1}}$$

$$R_{P1} = \frac{R_2 \cdot R_{S1}}{R_2 + R_{S1}} = \frac{(15\Omega)(50\Omega)}{15\Omega + 50\Omega} = 11.5\Omega$$

REDUCTION 3: R_3 in SERIES with R_{P1} in SERIES with R_1



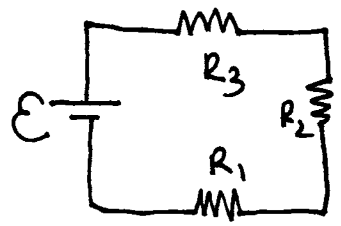
$$R_{eq} = R_3 + R_{P1} + R_1$$
$$= 15\Omega + 11.5\Omega + 10\Omega$$

$$\boxed{R_{eq} = 36.5\Omega}$$ (ANS)

(b) The current through R_1 is the same as the current thru the battery (I_1), which I can find from Ohm's Law and R_{eq}:

$$V = IR \Rightarrow I = \frac{V}{R} = \frac{\mathcal{E}}{R_{eq}} = \frac{24.0\,V}{36.5\Omega} = \boxed{0.658\,A = I_1}$$ (ANS)

(c) To get voltage V_2 across R_2 I use the LOOP RULE: the current thru R_1 and R_3 is I_1, thus:



$$\mathcal{E} - V_3 - V_2 - V_1 = 0$$
$$\mathcal{E} - I_1 R_3 - V_2 - I_1 R_1 = 0$$

or, $V_2 = -I_1(R_1 + R_3) + \mathcal{E} = -0.658A(25\Omega) + 24V$

$$\boxed{V_2 = 7.55\,V}$$ (ANS)

→

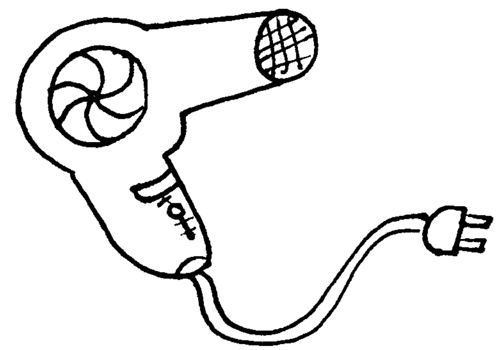
(d) If I know the voltage drop, I can find the current from Ohm's Law:

$$V = IR \rightarrow I = \frac{V_2}{R_2} = \frac{7.55\,V}{15\,\Omega} \stackrel{!}{=} \boxed{0.50\,A = I_2}$$ (ANS)

(e) Power dissipated may be computed in several ways. A convenient way is:

$$P = IV = \underbrace{(0.50\,A)}_{\leftarrow I_2} \cdot \underbrace{(7.55\,V)}_{\leftarrow V_2} \stackrel{!}{=} \boxed{3.78\,W = P_2}$$ (ANS)

(103) (a) What is the resistance of a 1500W dryer that plugs into a 120V outlet? (b) What current does the hair dryer draw when turned on? (c) How much does it cost to run the hair dryer for 5.00m at \$0.10 /kW·h? (d) In a 240V outlet in Europe, how much power is the dryer using? (e) What current does it draw from 240V?



(a) I can find resistance from the definition of power:

$$P = \frac{V^2}{R} \rightarrow R = V^2/P = (120V)^2/1500W = \boxed{9.6\Omega = R}$$

(ANS)

(b) I can find the current from another definition of power:

$$P = IV \rightarrow I = P/V = 1500W/120V = \boxed{12.5\,\text{Amp} = I}$$

(ANS)

(c) The cost is: C = PRICE * POWER * TIME

SOLN

$$C = \left(\frac{\$0.10}{kW \cdot h}\right)\left(\frac{1h}{3600s}\right)\left(\frac{1kW}{1000W}\right) \cdot 1500W \cdot 5m \left(\frac{60s}{1m}\right)$$

$$\boxed{C = \$0.0125 = 1\,\text{cent}}$$

(ANS)

→

(d) the physical properties of the hairdryer are fixed, notably the resistance R, which controls the current that flows for a given applied voltage. The power then is:

$$P = \frac{V^2}{R} = (240\,V)^2/9.6\,\Omega = \boxed{6000\,W} \text{ (ANS)}$$

! HUGE!

(e) By a similar argument as in d, the current drawn is affected by the resistance and applied voltage

so//

$$V = IR \Rightarrow I = \frac{V}{R} = \frac{240\,V}{9.6\,\Omega} = \boxed{25\text{ Amps}} \text{ (ANS)}$$