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What is the emf of a battery that delivers 27 J as it moves 3.0 C of charge?

The units of emf are Volts, or J/C, so this problem is easily done by dimensional analysis (a fancy way of saying "looking at the units"):

$$\mathcal{E} = \frac{27\,J}{3\,C} = \boxed{9\,V}$$

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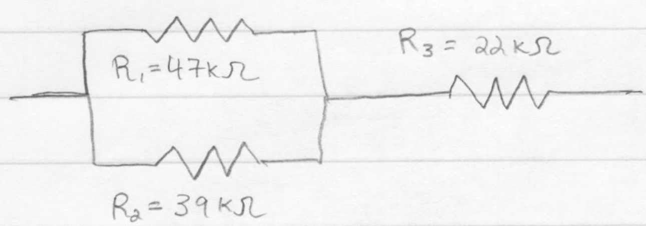

Resistors combine in the opposite manner of capacitors:

$$R_{total} = \left(\frac{1}{R_1} + \frac{1}{R_2}\right)^{-1} + R_3 = \boxed{43.3\,k\Omega}$$

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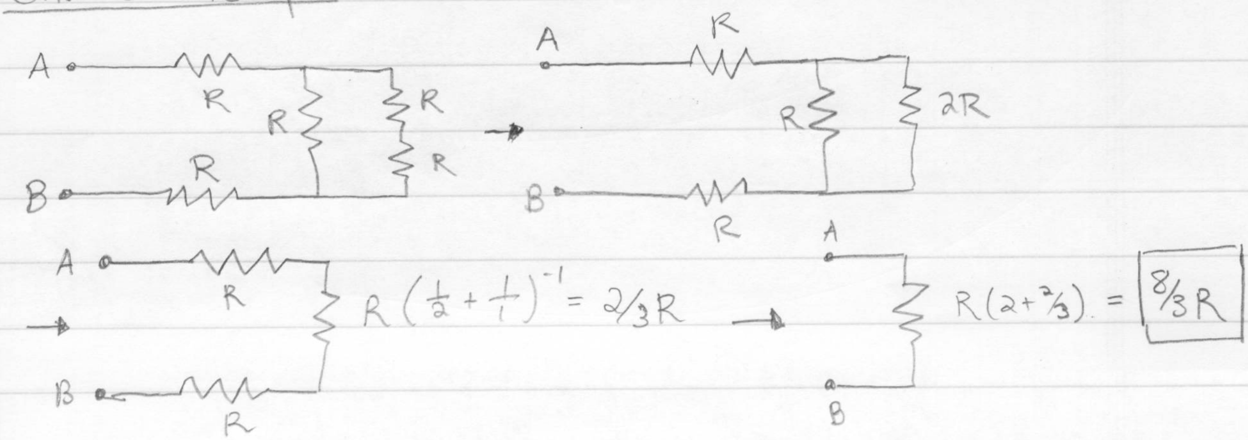
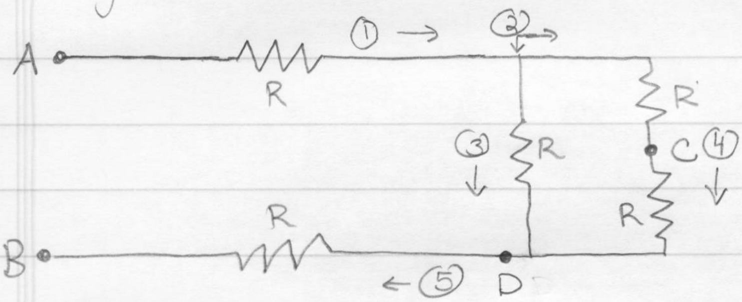
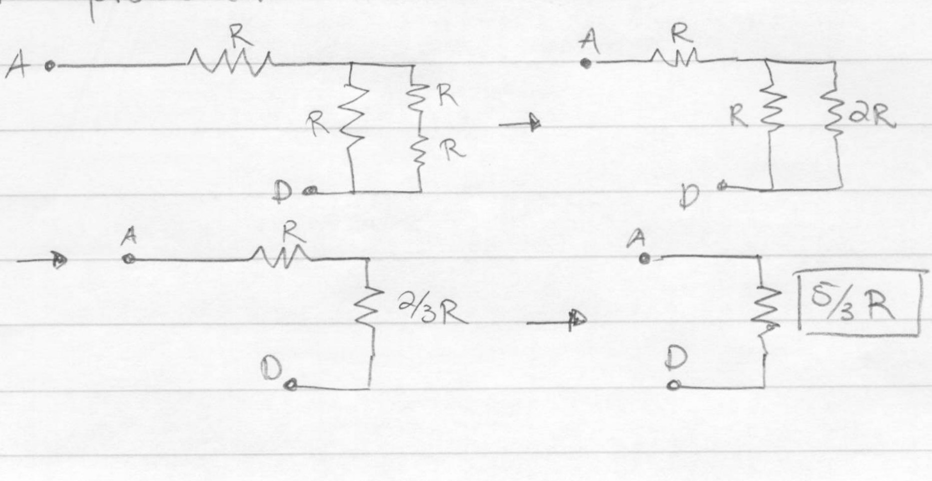


To calculate R between A and C, imagine all the possible paths along which current must flow to get from A to C and count only those resistors on those paths. (continued)



To go from A to C, current must flow along path 1 through the first resistor and then along both paths at junction 2. Current always flows down both paths at a junction unless one of them leads to an open circuit or infinite resistance. Going down both paths 3 and 4 takes us through 3 more resistors and point C. Now that we have reached point C we can stop and see that measuring R_{total} from A to C is equivalent to measuring R_{total} from A to D, and then we can apply our usual methods, as we did in the first part of the problem.



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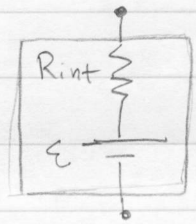
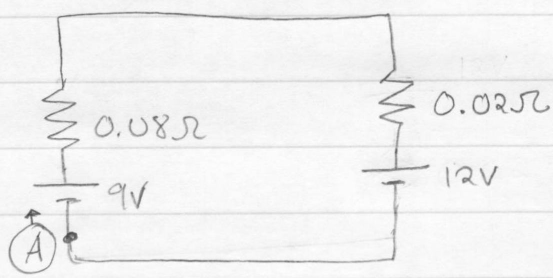
partially discharged car battery



9V, 0.08Ω

connected to a fully charged battery



Note: we choose this configuration because we are looking to charge the partially discharged battery.

Starting at point A, Kirchoff's law says:

$$9V - I(0.08\Omega) - I(0.02\Omega) - 12V = 0$$

Solving for I gives $\boxed{30A}$.

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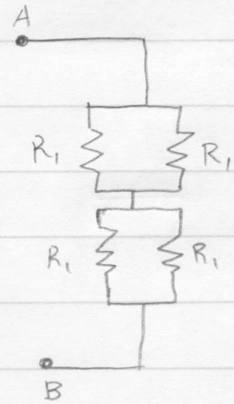
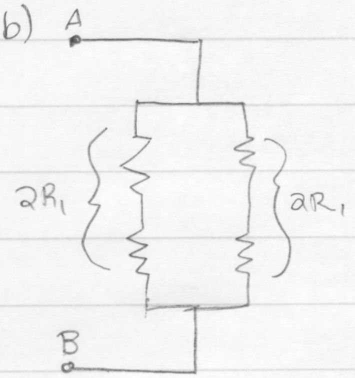
(a)



$R_{total} = R_1\left(\frac{1}{1}+\frac{1}{1}\right)^{-1} + R_1\left(\frac{1}{1}+\frac{1}{1}\right)^{-1} = \boxed{R_1}$

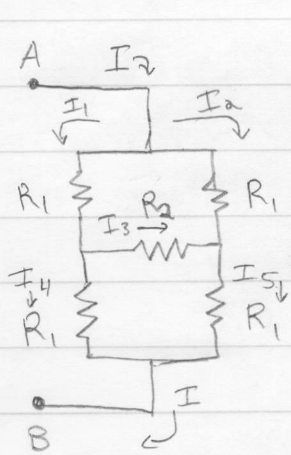
Drawing it this way makes it easier to solve. You are free to change the drawing as long as you don't change the connections.

(b)



$R_{total} = R_1\left(\frac{1}{2}+\frac{1}{2}\right)^{-1} = R_1$

(c)



Kirchoff's @ junctions

$I = I_1 + I_2$, $I_1 = I_3 + I_4$, $I_2 + I_3 = I_5$, $I = I_4 + I_5$

Kirchoff's for top loop:

$-I_2R_1 + I_3R_2 + I_1R_1 = 0 \Rightarrow (I_1 - I_2)R_1 = -I_3R_2$

Kirchoff's for bottom loop:

$-I_5R_1 + I_4R_1 - I_3R_2 = 0 \Rightarrow (I_4 - I_5)R_1 = I_3R_2$

Kirchoff's for outside loop:

$-I_2R_1 - I_5R_1 + I_4R_1 + I_1R_1 = 0$

$(I_1 + I_4 - I_2 - I_5)R_1 = 0 \Rightarrow I_1 + I_4 - I_2 - I_5 = 0$

$I_1 - I_2 = I_5 - I_4$

$I_3 = \frac{R_1}{R_2}(I_4 - I_5)$

The paths to get to the bottom resistors are identical so $I_4 = I_5$ and $I_3 = 0$. Therefore R_2 does not contribute to the resistance and $\boxed{R_{total} = R_1}$ (identical to (b)).

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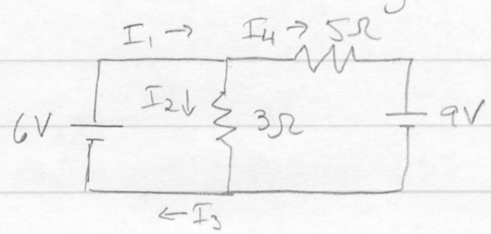
What is the current through the 3-Ω resistor?



Junctions: $I_1 = I_2 + I_4$

$I_4 = I_3 - I_2$

Left loop: $6V - I_2(3\Omega) = 0 \Rightarrow I_2 = \dfrac{6V}{3\Omega} = \boxed{2A}$

You could have seen this immediately because the potential drop across the 3-Ω resistor is fixed by the 6V battery. However, using Kirchoff also works, of course.

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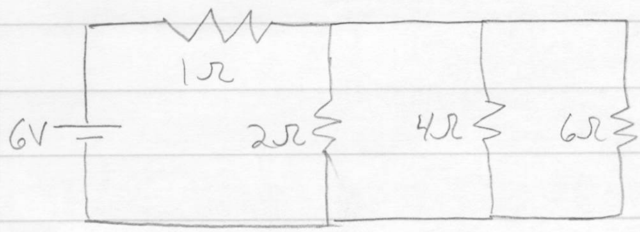
Find the current provided by the battery and the current to the 6-Ω resistor.



First we need the equivalent resistance of the entire circuit.

$$R_{total} = \left(1 + \left(\frac{1}{2} + \frac{1}{4} + \frac{1}{6}\right)^{-1}\right)\Omega = 2.1\Omega$$

$$V = IR \Rightarrow I_{total} = \frac{V}{R_{total}} = \frac{6V}{2.1\Omega} = \boxed{2.86A}$$

the voltage drop across the 1Ω resistor is $(2.86A)(1\Omega) = 2.86V$

Therefore, $6 - 2.86 = 3.14V$ drops across the parallel resistors. The current is then $\dfrac{3.14V}{6\Omega} = \boxed{0.52A}$

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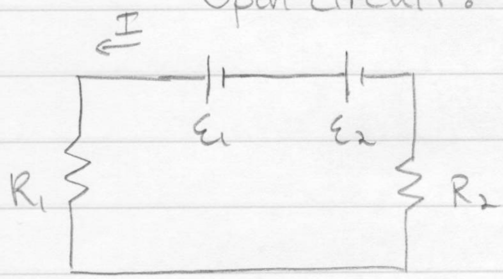
What is $\mathcal{E}_3$ in terms of $\mathcal{E}_1, \mathcal{E}_2, R_1$ and R_2 if the circuit is the same with and without the switch closed?

Open circuit:

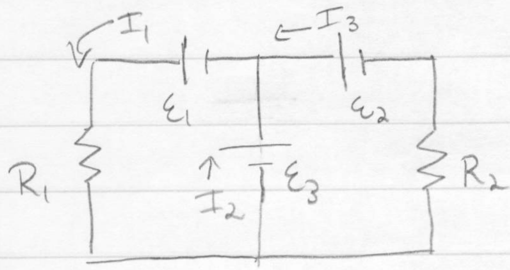


Kirchoff:

$$\mathcal{E}_2 + \mathcal{E}_1 - IR_1 - IR_2 = 0$$

$$\Rightarrow I = \frac{\mathcal{E}_1 + \mathcal{E}_2}{R_1 + R_2}$$

Closed circuit:



Kirchoff:

left loop: $\mathcal{E}_1 - I_1 R_1 + \mathcal{E}_3 = 0$

right loop: $\mathcal{E}_2 - \mathcal{E}_3 - I_3 R_2 = 0$

"makes no difference" $\Rightarrow I = I_1 = I_3$

$$\mathcal{E}_3 = I_3 R_2 - \mathcal{E}_2 = -\left(\frac{\mathcal{E}_1 + \mathcal{E}_2}{R_1 + R_2}\right) R_2 + \mathcal{E}_2 \left(\frac{R_1 + R_2}{R_1 + R_2}\right)$$

$$= \frac{-\mathcal{E}_1 R_2 - \cancel{\mathcal{E}_2 R_2} + \mathcal{E}_2 R_1 + \cancel{\mathcal{E}_2 R_2}}{R_1 + R_2}$$

$$= \boxed{\frac{-\mathcal{E}_1 R_2 + \mathcal{E}_2 R_1}{R_1 + R_2}}$$

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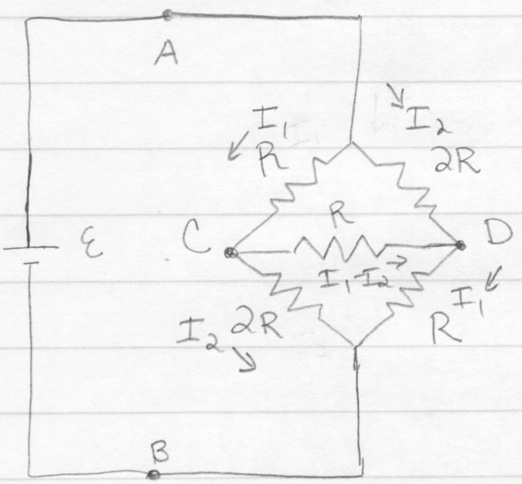
What is the equivalent resistance between A and B?



It is not easy to break this circuit into parallel/series parts. Some more advanced methods or tricks will be required.

First, connect an emf source as shown above.
The equivalent resistance will then be $R_{total} = \mathcal{E}/I_{total}$
Next, notice that a charge "sees" the same circuit when traveling from A to D as it does from B to C.
Likewise, going from A to C is the same as from B to D.
This tells you that $V_A - V_D = V_C - V_B$ and $V_A - V_C = V_D - V_B$.
Since the voltage drop and resistances are the same on these paths, the current must also be the same by Ohms law.

We have simplified the situation enough to apply Kirchoff:

ACBA: $-I_1R - I_2(2R) + \mathcal{E} = 0 \Rightarrow I_1 = \mathcal{E}/R - 2I_2$

ACDA: $-I_1R - (I_1 - I_2)R + I_2(2R) = 0$

$$-(\mathcal{E}/R - 2I_2)R - ((\mathcal{E}/R - 2I_2) - I_2)R + 2I_2R = 0$$

$$-\mathcal{E} + 2I_2R - \mathcal{E} + 2I_2R + I_2R + 2I_2R = 0$$

$$\Rightarrow 2\mathcal{E} = 7I_2R \Rightarrow I_2 = \frac{2}{7}\frac{\mathcal{E}}{R}, \quad I_1 = \mathcal{E}/R - 2\left(\tfrac{2}{7}\mathcal{E}/R\right) = 3/7\ \mathcal{E}/R$$

$$R_{total} = \frac{V}{I_{total}} = \frac{\mathcal{E}}{5/7\ \mathcal{E}/R} = \boxed{7/5\ R}$$

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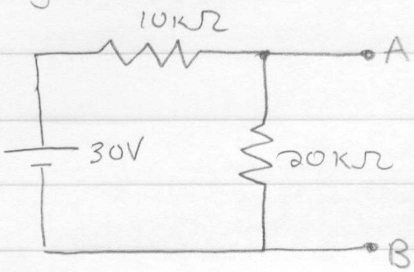

$V_{AB} = 30V - \left(\frac{30V}{30k\Omega}\right)10k\Omega = \boxed{20V}$

$I_{AB} = \frac{30V}{10k\Omega} = \boxed{3mA}$

Note: hooking up an ideal ammeter in this way circumvents the 20kΩ resistor because, by definition, it has no resistance.

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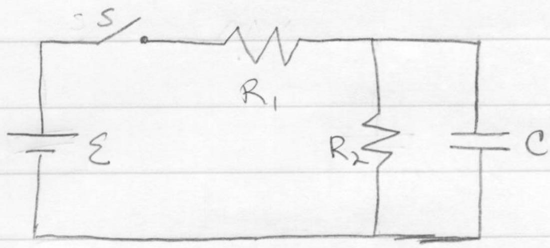

$\mathcal{E} = 100V$

$R_1 = 4k\Omega$

$R_2 = 6k\Omega$

(a) Initially, there is no voltage across C so $\boxed{V_C = 0}$ and the entire voltage drop is across $R_1 \Rightarrow I_{R_1} = \frac{100V}{4k\Omega} = \boxed{25mA}$

Of course, $\boxed{I_{R_2} = 0}$.

(b) After a long time, the current stops flowing to the capacitor so $V_C = V_{R_2} = \frac{R_2}{R_1+R_2}\mathcal{E} = \boxed{60V}$. $I_{R_1} = I_{R_2} = \frac{100V}{10k\Omega} = \boxed{10mA}$

(c) $\boxed{V_C = 60V}$ because that is what it was immediately before.

$\boxed{I_{R_1} = 0}$ because it is now a "dead end".

$I_{R_2} = \frac{60V}{6k\Omega} = \boxed{10mA}$

(d) All the charge that was on C will discharge through R_2 until $\boxed{I_{R_2} = 0}$ and $\boxed{V_C = 0}$.

Of course I_{R_1} is still zero. $\boxed{I_{R_1} = 0}$