Section	Group	Name	Signature
Grade			
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Materials: • *PhET simulation:* PhET Circuit Construction Kit: DC

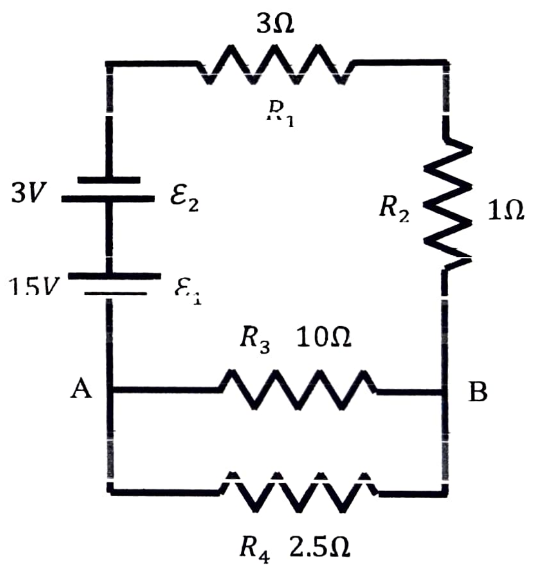
After this activity you should know: • *The definition of power provided by EMF and dissipated by resistors.* • *Understand when the power provided by an EMF is negative.* • *The equivalent resistance and relation between voltage drops and currents for resistors connected in series and in parallel.*

Open PhET Circuit Construction Kit: DC. Construct the circuit of four resistors and two EMFs (batteries) as shown. *Note that the wide side of the EMF is the high voltage side so that the polarity of the 3V EMF is opposite that of the 15V EMF.*

You can use the "non-contact" ammeter to easily measure the current simply by moving the ammeter over the wire.

1. Measure the voltage difference across each EMF in the direction of the current. That is, place the black lead where the current goes into the battery and the red lead where the current comes out of the battery. Fill appropriate entries in table below.
2. Measure the current through each EMF. Fill in appropriate entries in the table below.
3. Work is done by the EMF on the current as the charges move through the EMF. The power or rate of work is:

$$P = \frac{dU}{dt} = \frac{dq}{dt}\Delta V = \pm I\,\mathcal{E}$$



where ΔV is the voltage difference in the direction of the current. The power is positive (the current gains electrical potential energy) if the current flows through the EMF from the negative to positive terminal and the power is negative if the current flows the opposite direction.

Use your measurements to calculate the power provided by each EMF. Complete the table below. Pay attention to signs.

	$\mathcal{E}_1$	$\mathcal{E}_2$
ΔV_{bat}	-3 V	15 V
I	0.48 A	0.48 A
P_{bat}	- 1.44 W	7.2 W

4. You should have found that the power provided by the 3V battery was negative. This means that the current is providing energy to the 3V battery. Why would you want to connect a battery "backwards" in this manner? That is, why would you want the current to provide energy to a battery?

Any time you need to add energy to the battery (such as charging it) or if you need to lower the voltage of the circuit.

5. What is the net power provided by the EMFs to the current?

~~7.2 − 1.44 = 5.76W~~ 30 − 6 = 24 W

6. Measure the voltage drop across each resistor and the current through each resistor. Note: voltage drops are the absolute value of the voltage difference across the resistor. Check that Ohm's law holds for each resistor.

	R_1	R_2	R_3	R_4	R_{34}	R_{1234}
R	3Ω	1Ω	10Ω	2.5Ω	2Ω	6Ω
I	2 A	2 A	0.4 A	1.6 A	2A	2 A
$\lvert\Delta V_R\rvert$	−6 V	−2V	−4V	−4 V	−4V	−12 V
P_{diss}	−12 W	−4 W	−1.6 W	−6.4W	−8W	−24 W

7. Current always flows from high to low voltage in a resistor. Therefore current always lose power in a resistor. For this reason we usually talk about the power the current loses in a resistor, also known as the power dissipated by the resistor. The power dissipated is always positive.

   a. Determine the power dissipated P_{diss} in each resistor and complete the first four columns in the table above.

   b. This energy transferred to the resistors by the current may be used to do useful work or wasted as heat to the resistor. What is the total power dissipated by the four resistors?

   −24W

   c. What is the relation between the total power dissipated by the four resistors and the net power provided by the EMFs?

   $$\Sigma P_{diss} = -\Sigma P_{bat}$$

8. Consider the branch point labeled *B* in the circuit.

   a. What is the current going into the branch point? *Remember that the blue dots in the simulation are electrons and the current moves in the opposite direction.*

   2 A

   b. What are the currents coming out of the branch point?

   0.4A, 1.6 A

   c. What is the relation between the total current going into a branch point and the total current going out of the branch point? *This is a general result called Kirchoff's Junction Rule.*

   $$\Sigma I_{in} = \Sigma I_{out}$$

d. Does this result work for branch point *A* also?

yes

9. Resistors 3 and 4 are connected in parallel since the high voltage ends of the resistors are connected together and the low voltage ends of the two resistors are connected together. The equivalent resistance R_{eq} obeys the relation $\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots$.

   a. Determine the equivalent resistance R_{34} of the two resistors.

   $$\frac{1}{10} + \frac{2}{5} = \left(\frac{1}{2}\right)^{-1} \approx 2\,\Omega$$

   b. Rebuild your circuit replacing R_3 and R_4 by the single equivalent resistance. Check that the currents through the other resistors and the EMFs do not change. Measure the voltage across and current through R_{34}, calculate the power dissipated by R_{34}, and fill in the fifth column in the table on page 2. Check that Ohm's law is obeyed.

   c. What is the relation between the individual currents I_3, I_4 and through the equivalent resistor I_{34} for resistors connected in parallel?

   $$I_3 + I_4 = I_{34}$$

   d. What is the relation for the voltage drops across the individual resistors, ΔV_3, ΔV_4 and the voltage drop ΔV_{34} across the equivalent resistor for resistors connected in parallel?

   $$\Delta V_3 = \Delta V_4 = \Delta V_{34}$$

10. In your new circuit, R_1, R_2 and R_{34} are connected in series since they are connected right after another without a branch point in between. The equivalent resistance for resistors in series is $R_{eq} = R_1 + R_2 + \cdots$

    a. What is the equivalent resistance R_{1234}?

    $$3\Omega + 1\Omega + 2\Omega = \boxed{6\Omega}$$

    b. Rebuild your circuit replacing R_1, R_2 and R_{34} by the single equivalent resistance. Check that the current through the EMFs do not change. Measure the voltage across and current through R_{1234} and complete the table on page 2.

c. The 15V and 3V battery hooked in opposite directions. What is the EMF of the single battery that we could have used to replace the two batteries?

12V

d. What is the relation between the power dissipated by the single equivalent resistor R_{1234} and the total power dissipated by the four individual resistors?

$$P_{diss_{1234}} = P_{diss_1} + P_{diss_2} + P_{diss_3} + P_{diss_4}$$

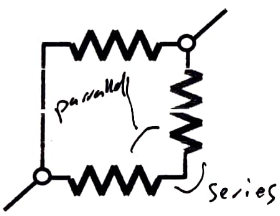
e. What is the total energy dissipated by the resistors in this circuit if we run it for 30 minutes?

$$E = P\Delta t$$

$$= 24W \cdot (30 \cdot 60)\,s$$

$$\boxed{= 43{,}200\ J}$$

11. Three resistors are connected in the different ways shown in the diagrams. The resistors are connected to the rest of the circuit at the circles. State whether all three resistors are in series, parallel or neither.



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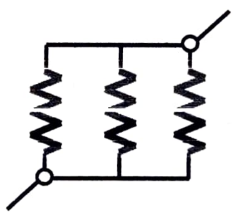
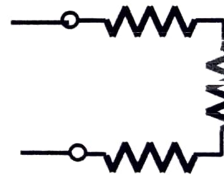
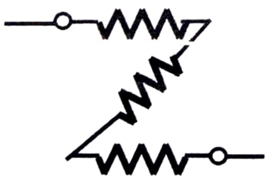


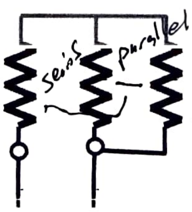
parallel



Series



Series



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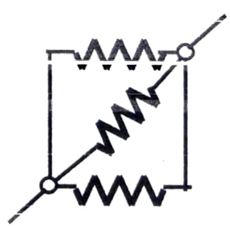

parallel