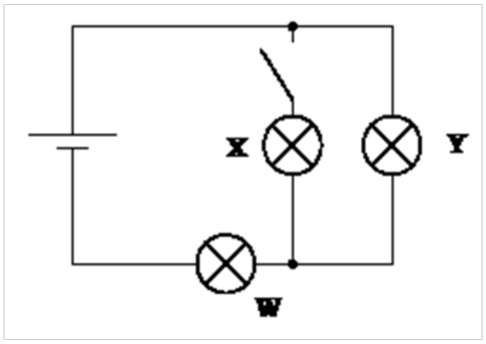
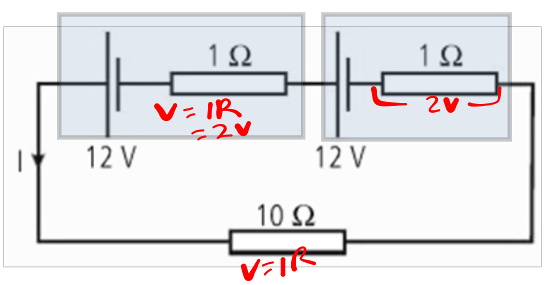
5. Three identical filament lamps (assume constant resistance) are connected to a source of emf as shown.
Predict what will happen when the switch is closed.

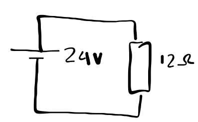


Circuits with Multiple Emfs

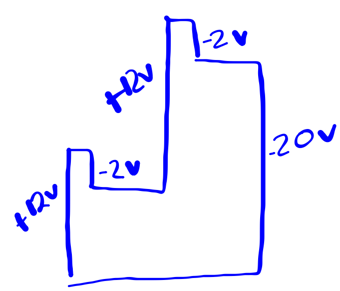
I. Emfs in series in the same direction: add the voltages

1. Determine the current in the following circuit.



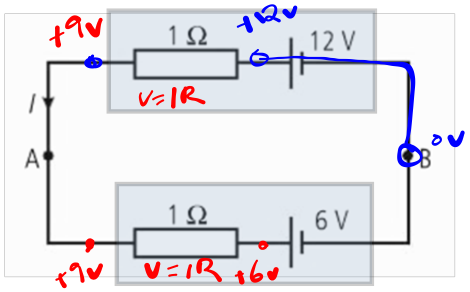


2A



II. Emfs in series in opposite directions: subtract the voltages

2. Determine the current in the following circuit.

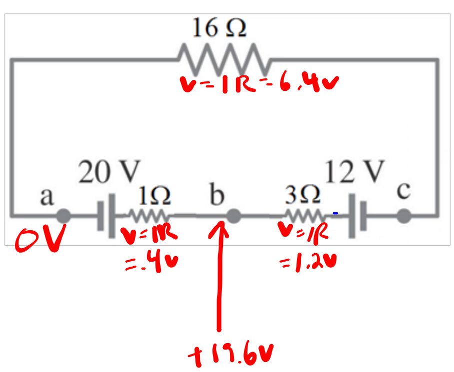


$$I = \frac{V}{R} = \frac{(+12v - 6v)}{2\,\Omega} = 3A$$

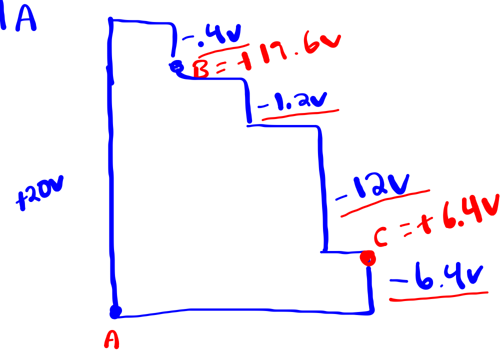
Application of series emfs in opposite directions: recharging a secondary cell

Direction of current flow: backwards through the secondary cell

3. Determine the current in the following circuit. Which is the primary cell and which is the secondary cell?

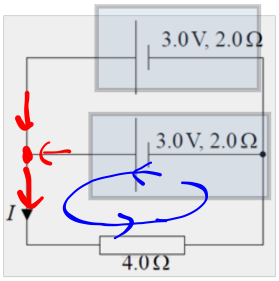


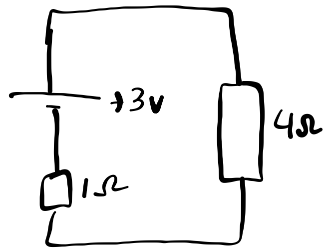
$I = .4A$



III. EMFs in parallel: same EMF but add internal resistances

4. Determine the current in the following circuit. Each identical cell has an emf of 3.0 V and an internal resistance of 2.0 ohms.





$I = \frac{V}{R} = \frac{3v}{5\Omega} = .6A$

Kirchoff's Circuit Laws

Loop Rule: Around any closed loop in a circuit, the sum of the EMFs equals the sum of the potential differences. (total voltage rises = total voltage drops)

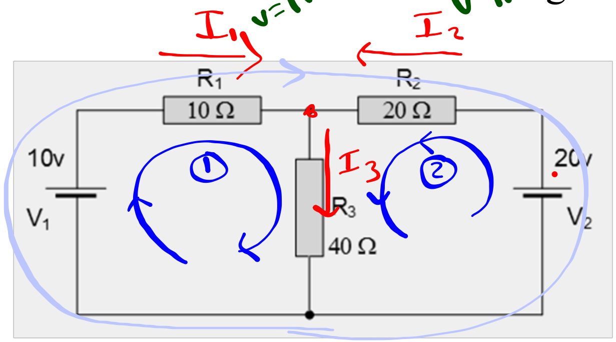
Conservation of . . .energy **Formula:** $\Sigma V = 0$

Junction Rule: At any junction in a circuit, the sum of the currents entering the junction equals the sum of the currents leaving the junction. (total current in = total current out)

Conservation of . . .electric charge **Formula:** $\Sigma I = 0$

1. Determine the current through resistor R_3.

Loop 3: $+10v - (I_1 \cdot 10\Omega) + (I_2 \cdot 20\Omega) - 20v = 0$



Loop 1

$+10v - I_1 \cdot 10\Omega - I_3 \cdot 40\Omega = 0$

Loop 2

$+20v - I_2 \cdot 20\Omega - I_3 \cdot 40\Omega = 0$

Junction

$I_1 + I_2 = I_3$

$$\begin{array}{cccc} I_1 & I_2 & I_3 & \\ \end{array}$$
$$\begin{bmatrix} 10 & 0 & 40 & 10 \\ 0 & 20 & 40 & 20 \\ 1 & 1 & -1 & 0 \end{bmatrix}$$

$1 - I_1 - 4(I_1 + I_2) = 0$

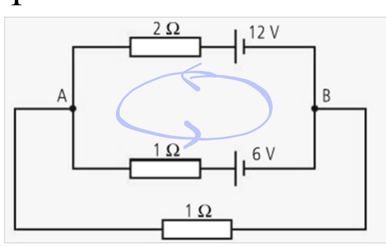
$1 - I_2 - 2(I_1 + I_2) = 0$

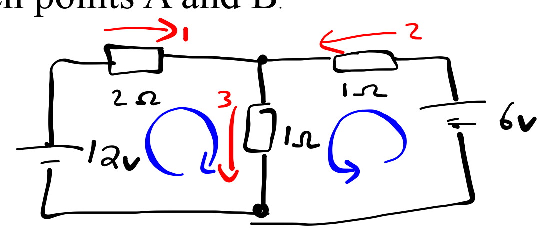
$I_1 = -.143\,A$

$I_2 = .429\,A$

$I_3 = .286\,A$

2. Determine the currents in the following circuit as well as the potential difference between points A and B.





Redraw to look like circuit in Example #1

$12 - 2I_1 - I_3 = 0$

$6 - I_2 - I_3 = 0$

$I_1 + I_2 = I_3$

$I_1 = 3.6\,A$

$I_2 = 1.2\,A$

$I_3 = 4.8\,A$

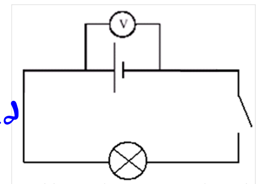
Internal Resistance of Cells

Electromotive force (emf): total energy per unit charge supplied around a circuit by the cell

Terminal Voltage (V_{term}): potential difference across the terminals of the cell

1. Compare the terminal voltage of the cell when the switch is open to the terminal voltage when it is closed.

$V_{term_{open}} > V_{closed}$



2. Compare the emf of the cell to its terminal voltage when the switch is:

a) open

$\mathcal{E} = V_{Term}$

b) closed

$\mathcal{E} > V_{Term}$

3. Explain these observations.

Internal resistance (r): the resistance supplied by the materials within the cell

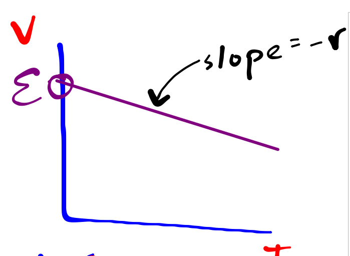
think of a cell as . . . a perfect emf and a small resistor.

Mathematical model:

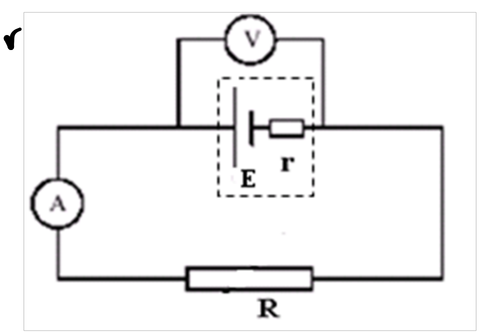
$\varepsilon = I\,\underline{R_T}$

$\varepsilon = I\,(\underline{R} + \underline{r})$

$\varepsilon = \underbrace{IR}_{V_{term}} + Ir$



$V_{term} = -rI + \mathcal{E}$



4. Use the math model to make some inferences about the behavior of a circuit containing a cell with internal resistance.

open circ. voltage

a) Emf = V_{term} . . . when no current is flowing (when R is infinite or open circuit) or if it is an ideal cell (r = 0)

b) When R>>r . . . emf = IR + Ir emf ≈ IR emf ≈ Vterm

c) When R = 0 . . . emf = Ir I = emf/r $I = I_{max}$

short circuit current

5. A resistor is connected to a 12 V source and a switch. With the switch open, a voltmeter reads the potential difference across the battery as 12 V yet with the switch closed, the voltmeter reads only 9.6 V and an ammeter reads 0.40 A for the current through the resistor. Calculate the internal resistance of the source and the maximum possible current.

$\mathcal{E} = IR_T = IR + Ir$

$\mathcal{E} = V_{term} + Ir$

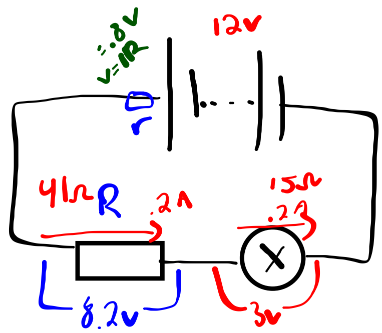
12v 9.6v .4A

$r = \frac{2.4v}{.4A} = 6\Omega$

$\underline{I_{max}}$ R = 0

$I = \frac{\mathcal{E}}{r} = \frac{12v}{6\Omega} = 2A$

6. A resistor R and a filament lamp L are connected in series with a battery. The battery has an emf of 12 V and internal resistance 4.0 Ω. The potential difference across the filament of the lamp is 3.0 V and the current in the filament is 0.20 A. Determine the resistance R.



Resistance: ratio of potential difference applied across a piece of material to the current through the material

Ohm's Law: for a conductor at constant temperature, the current flowing through it is proportional to the potential difference across it over a wide range of potential differences

Relationship:

Georg Simon Ohm
(1787 – 1854)