Lecture 24

PHYC 161 Fall 2016

Internal resistance

- Real sources of emf actually contain some **internal resistance** *r*.
- The **terminal voltage** of the 12-V battery shown at the right is less than 12 V when it is connected to the light bulb.

Terminal voltage, source with internal resistance

emf of source

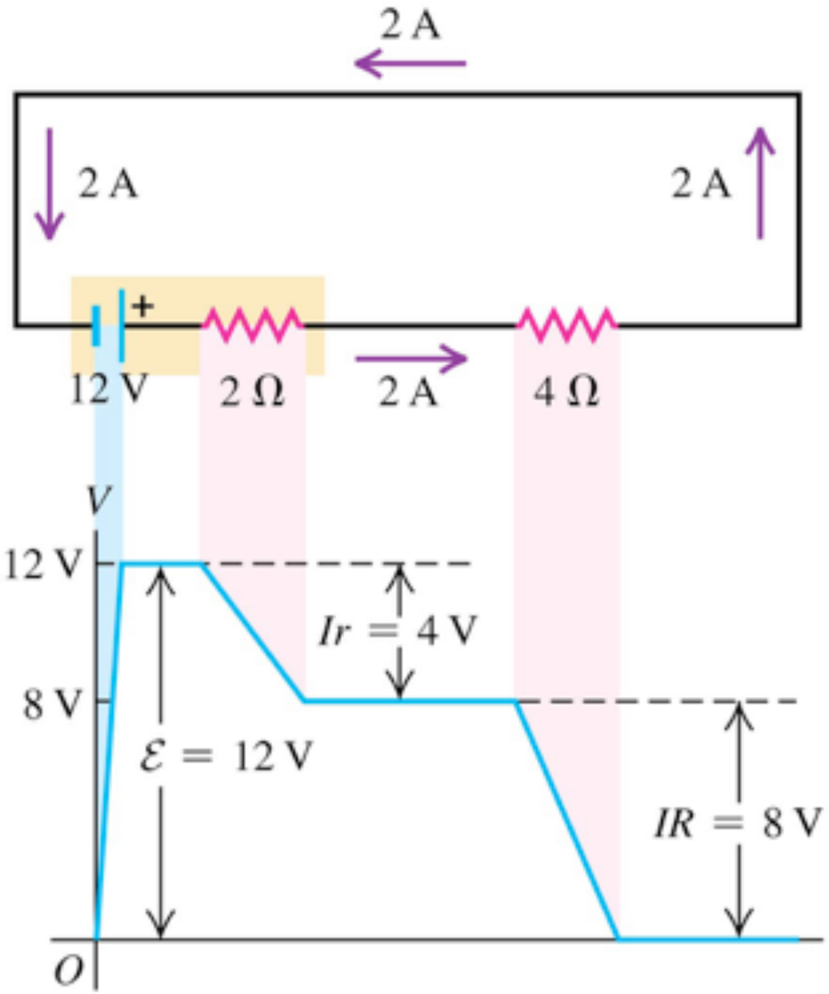
$$V_{ab} = \mathcal{E} - Ir$$

Current through source

Internal resistance of source

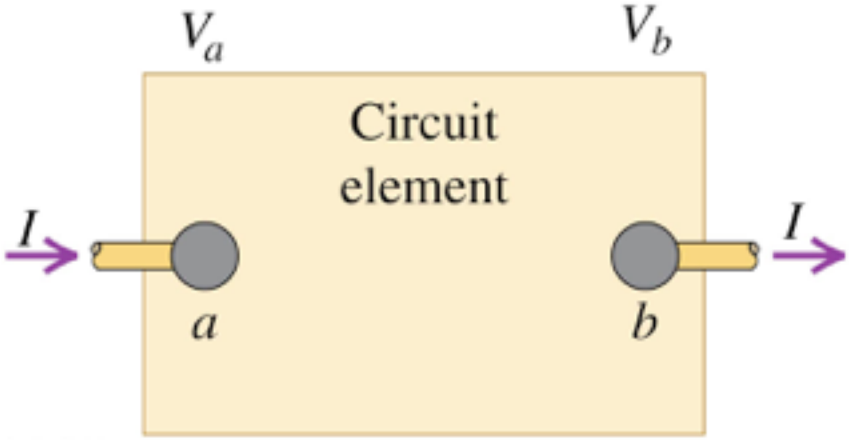
Potential changes

- The figure shows how the potential varies as we go around a complete circuit.
- The potential rises when the current goes through a battery, and drops when it goes through a resistor.
- Going all the way around the loop brings the potential back to where it started.



Energy and power in electric circuits

- The box represents a circuit element with potential difference $V_{ab} = V_a - V_b$ between its terminals and current I passing through it in the direction from a toward b.

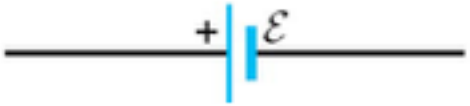
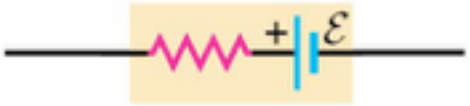
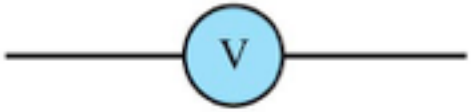


- If the potential at a is lower than at b, then there is a net transfer of energy out of the circuit element.
- The time rate of energy transfer is power, denoted by P, so we write:

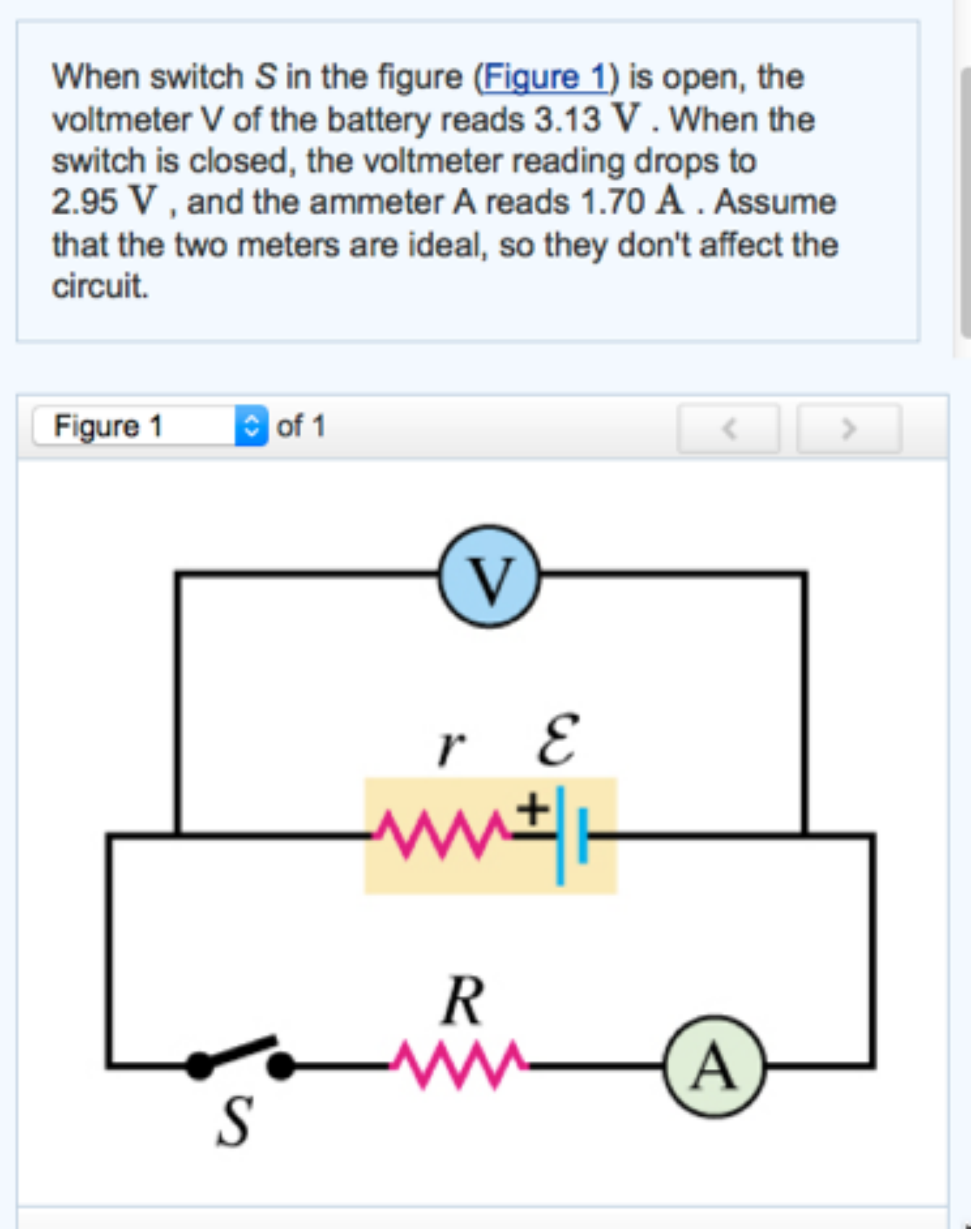
Power delivered to or extracted from a circuit element

$$\overset{\text{Power delivered to or extracted from a circuit element}}{P} = \underbrace{V_{ab}}_{\text{Voltage across circuit element}}\underbrace{I}_{\text{Current in circuit element}}$$

Table 25.4 — Symbols for circuit diagrams

	Conductor with negligible resistance
	Resistor
	Source of emf (longer vertical line always represents the positive terminal, usually the terminal with higher potential)
 or 	Source of emf with internal resistance *r* (*r* can be placed on either side)
	Voltmeter (measures potential difference between its terminals)
	Ammeter (measures current through it)

25.29

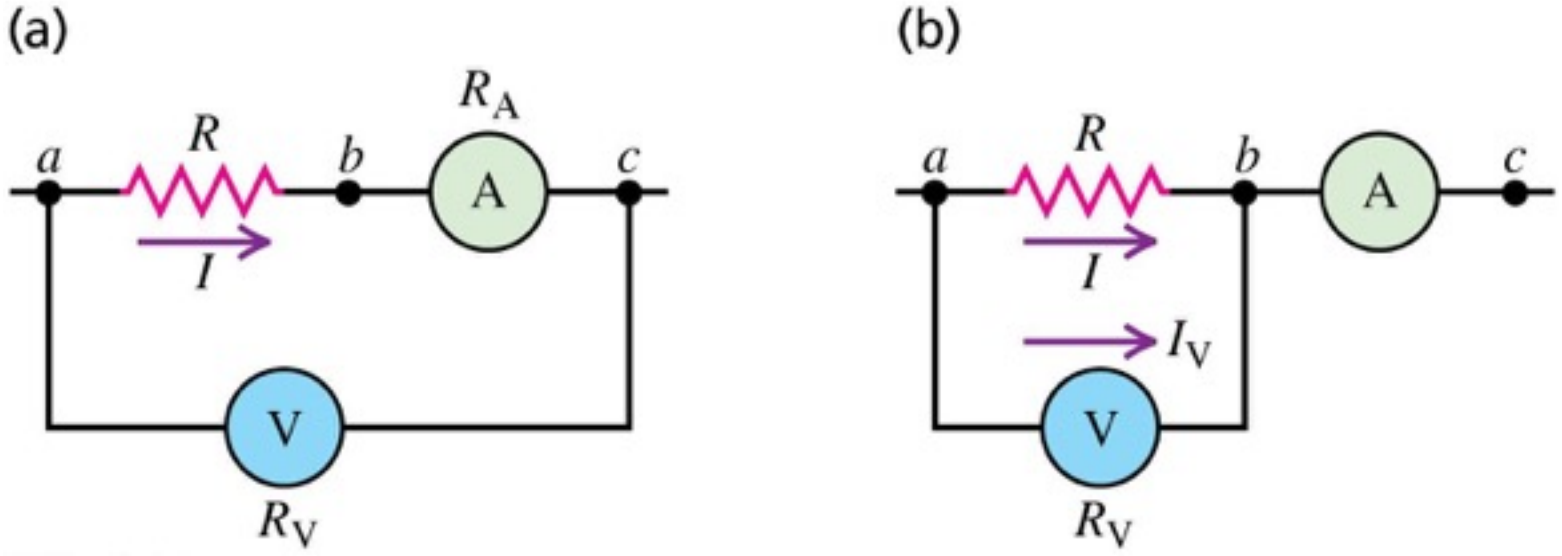


When switch *S* in the figure (Figure 1) is open, the voltmeter V of the battery reads 3.13 V . When the switch is closed, the voltmeter reading drops to 2.95 V , and the ammeter A reads 1.70 A . Assume that the two meters are ideal, so they don't affect the circuit.

Find $\mathcal{E}$ and r

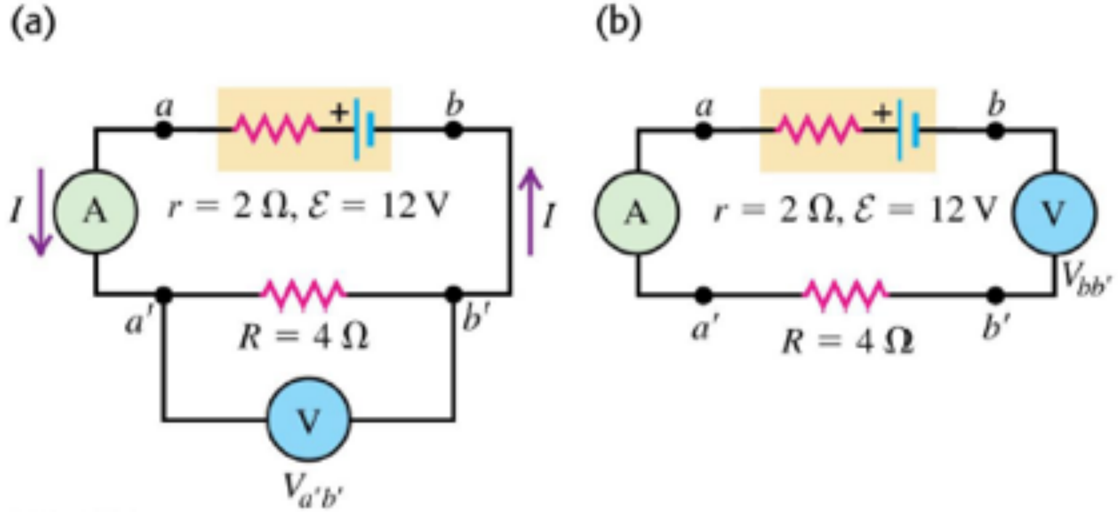
Ammeters and voltmeters in combination

- An ammeter and a voltmeter may be used together to measure resistance and power.
- Two ways to do this are shown below.
- Either way, we have to correct the reading of one instrument or the other unless the corrections are small enough to be negligible.



CPS 23-2

In diagram a, the ammeter reads 2A and the voltmeter reads 8V. What are the readings in diagram b?



A. 2A and 8V.

B. 2A and 0V.

C. 0A and 12V.

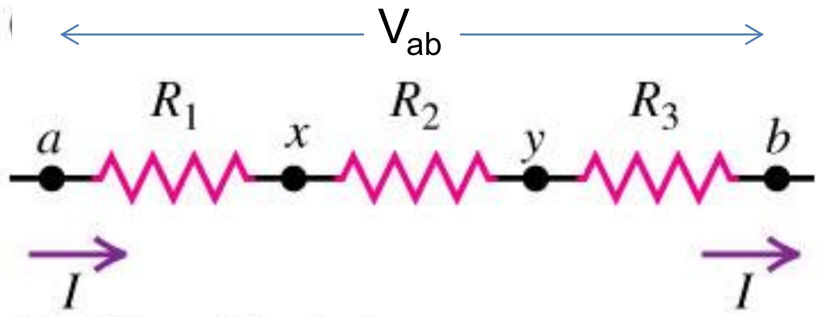
D. 0A and 0V.

E. 2A and 12V.

Series Resistors

- Since the current through each resistor is the same,

$$\begin{aligned} V_{ab} &= IR_1 + IR_2 + IR_3 \\ &= I\left(R_1 + R_2 + R_3\right) \\ &= IR_{eq} \Rightarrow \\ R_{eq} &= R_1 + R_2 + R_3 \end{aligned}$$



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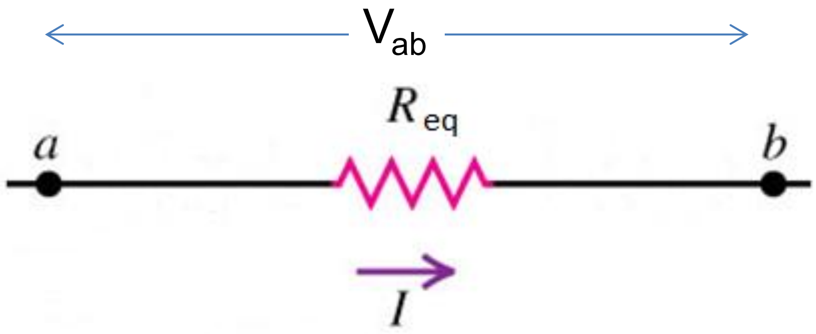


Parallel Resistors

- For resistors in parallel, the voltage across each is the same, so,

$$V_{ab} = I_1 R_1 = I_2 R_2 = I_3 R_3$$

$$and$$

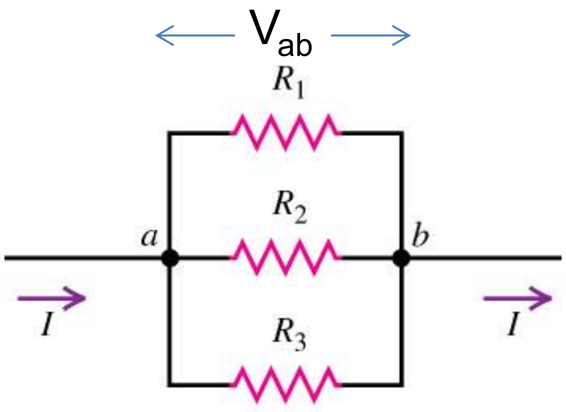
$$I = I_1 + I_2 + I_3$$

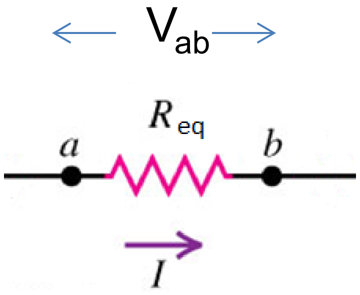
$$V_{ab} = IR_{eq} \Rightarrow$$

$$\frac{V_{ab}}{R_{eq}} = I = I_1 + I_2 + I_3$$

$$\frac{V_{ab}}{R_{eq}} = \frac{V_{ab}}{R_1} + \frac{V_{ab}}{R_2} + \frac{V_{ab}}{R_3} \Rightarrow$$

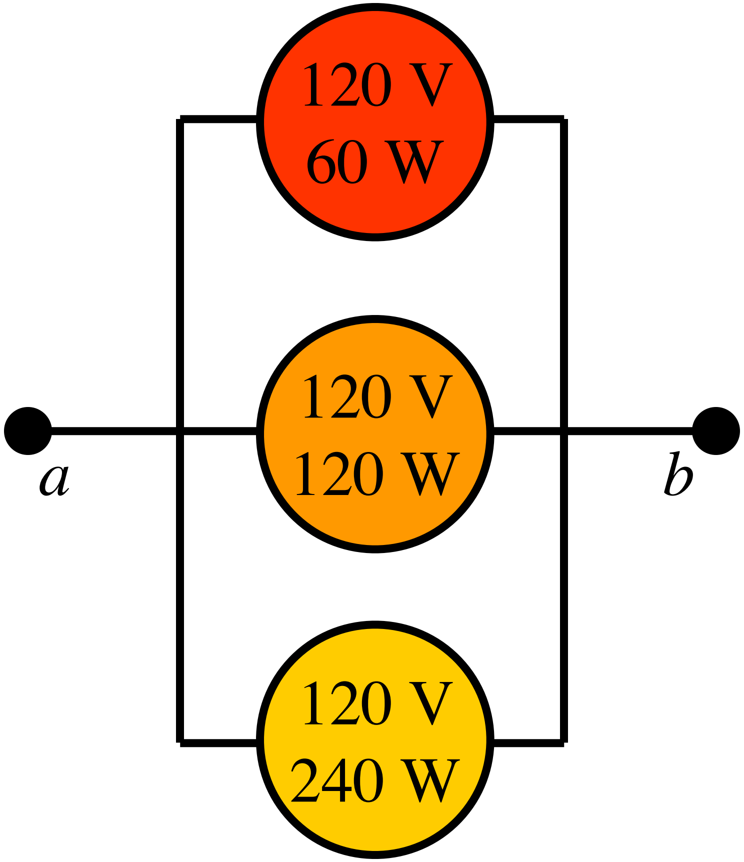
$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$





Q26.3

A 120-V, 60-W incandescent light bulb; a 120-V, 120-W incandescent light bulb; and a 120-V, 240-W incandescent light bulb are connected in parallel as shown. The voltage between points *a* and *b* is 120 V. Through which bulb is there the greatest voltage drop?



A. the 120-V, 60-W light bulb

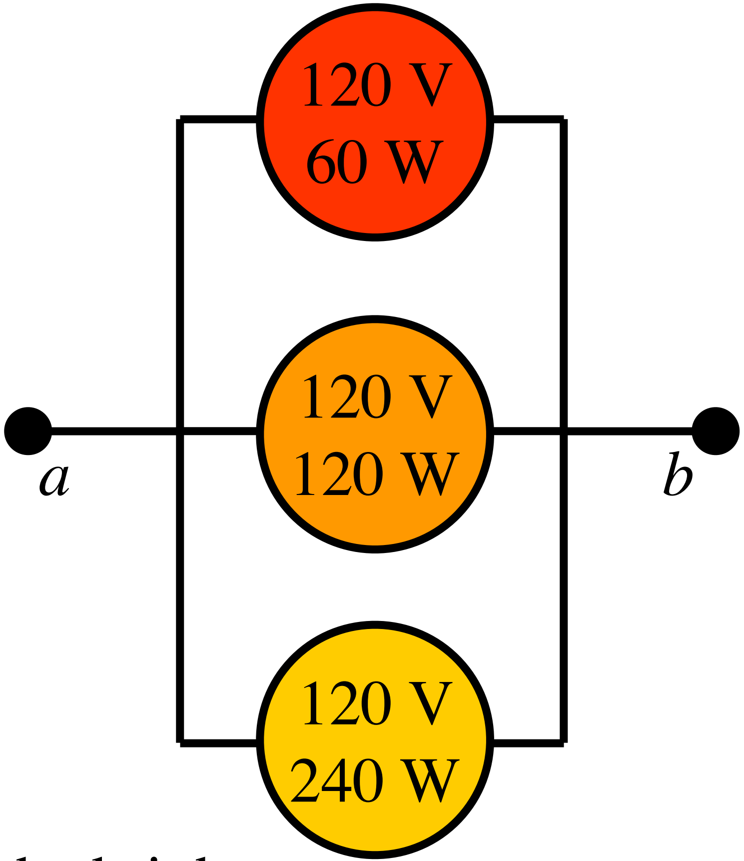
B. the 120-V, 120-W light bulb

C. the 120-V, 240-W light bulb

D. The voltage drop across all three light bulbs is the same.

Q26.4

A 120-V, 60-W incandescent light bulb; a 120-V, 120-W incandescent light bulb; and a 120-V, 240-W incandescent light bulb are connected in parallel as shown. The voltage between points *a* and *b* is 120 V. Which bulb glows the brightest?



A. The 120-V, 60-W light bulb glows the brightest.

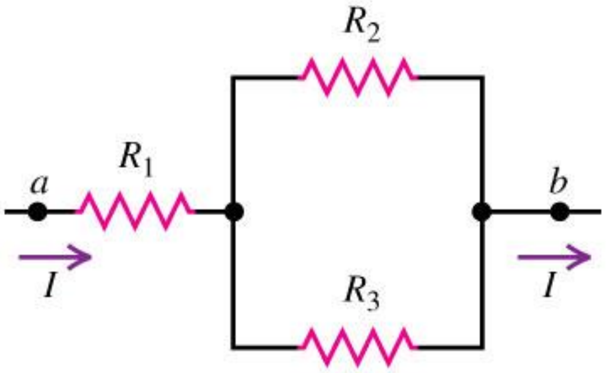
B. The 120-V, 120-W light bulb glows the brightest.

C. The 120-V, 240-W light bulb glows the brightest.

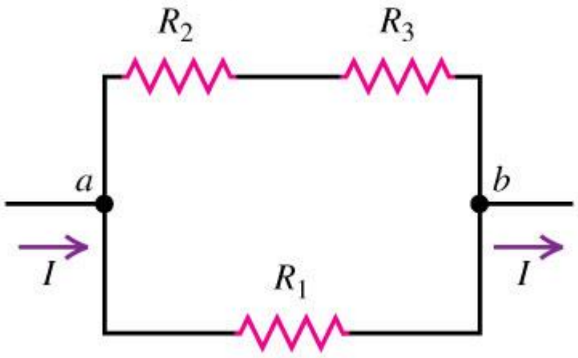
D. All three light bulbs glow with equal brightness.

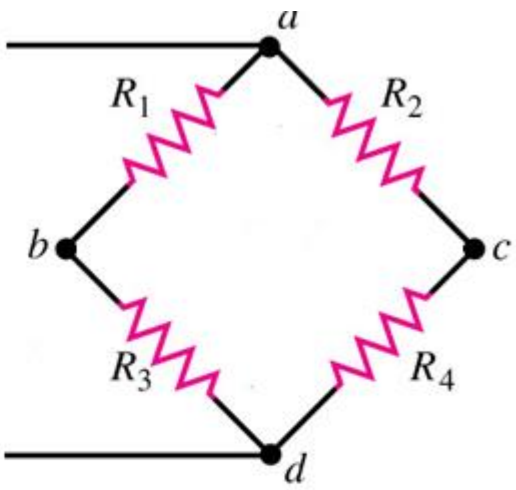
Mixed Resistors

(c) R_1 in series with parallel combination of R_2 and R_3



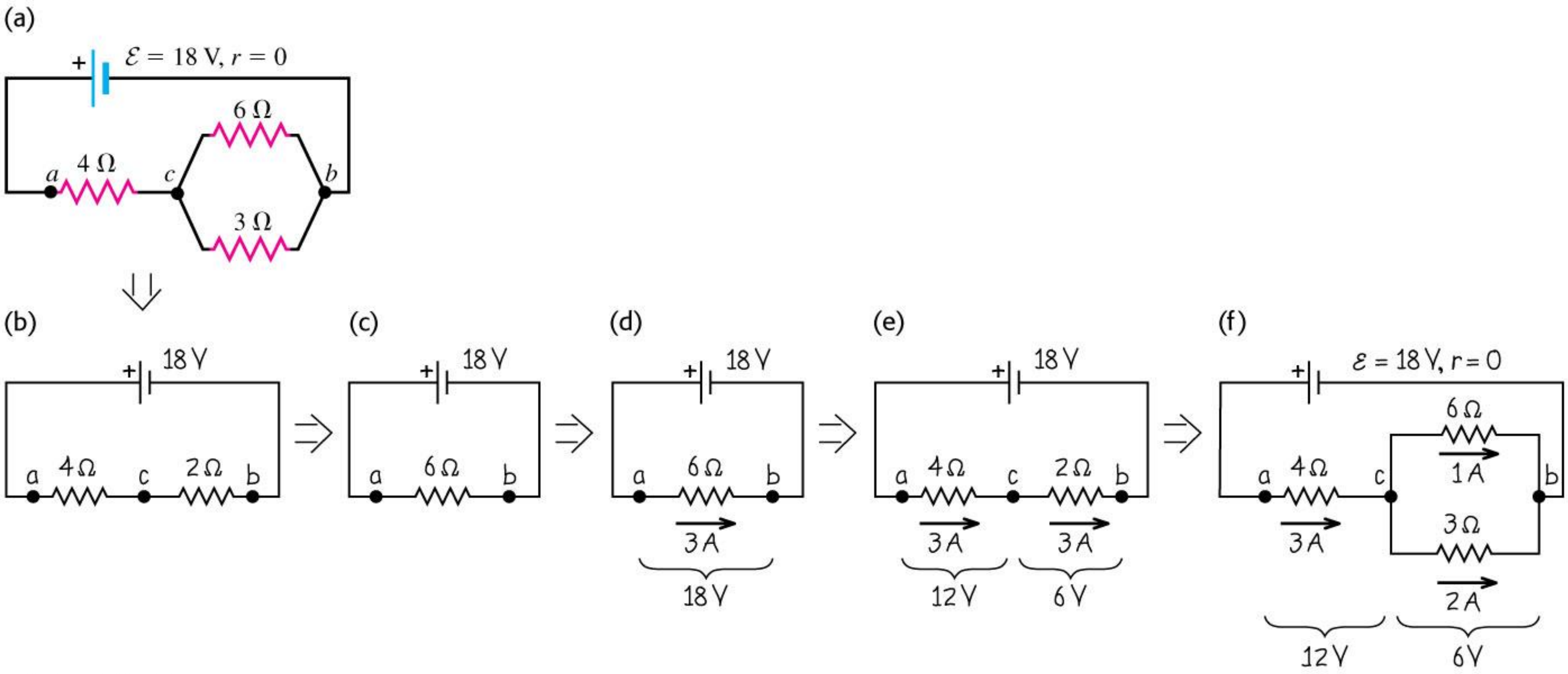
(d) R_1 in parallel with series combination of R_2 and R_3





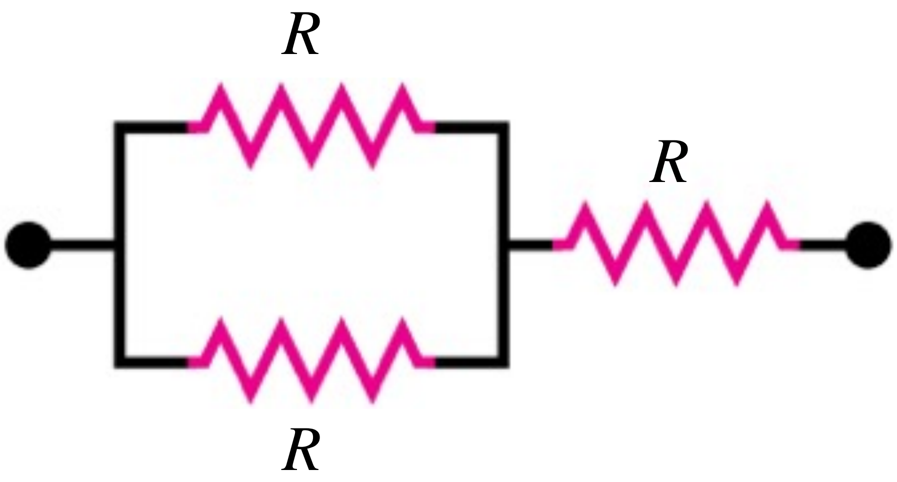
Analysis Steps

- If you are asked to determine the current through and potentials across several resistors in a circuit, follow these steps:



Q26.2

Three identical resistors, each of resistance R, are connected as shown. What is the equivalent resistance of this arrangement of three resistors?



A. $3R$

B. $2R$

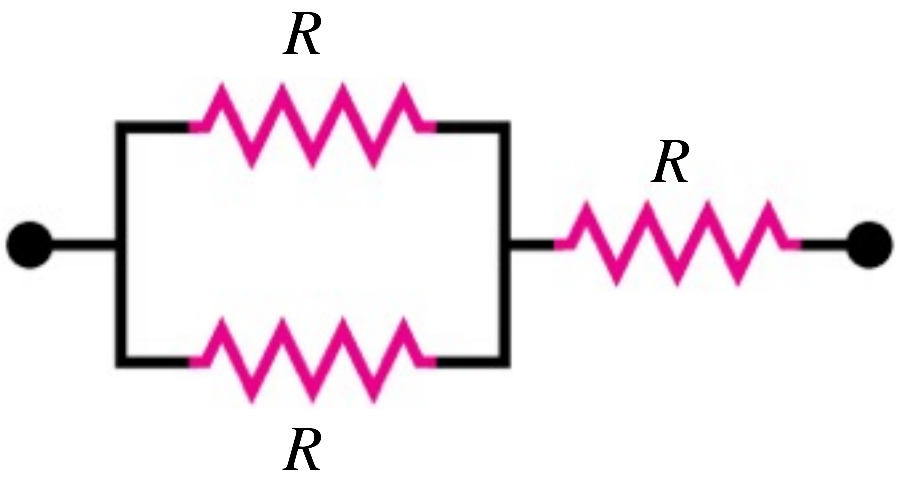
C. $3R/2$

D. $2R/3$

E. $R/3$

A26.2

Three identical resistors, each of resistance R, are connected as shown. What is the equivalent resistance of this arrangement of three resistors?



A. $3R$

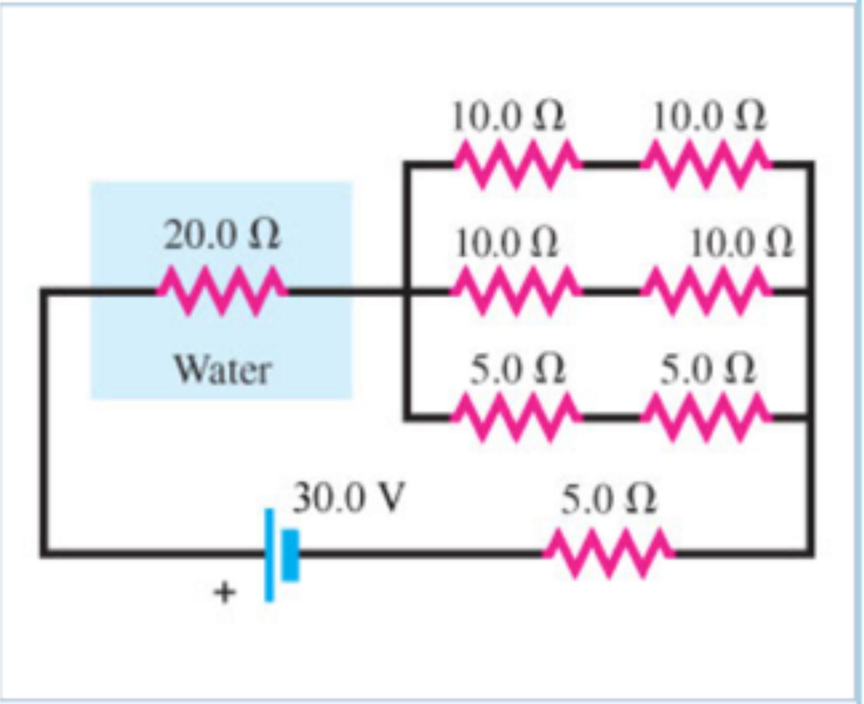
B. $2R$

[✓ C. $3R/2$]

D. $2R/3$

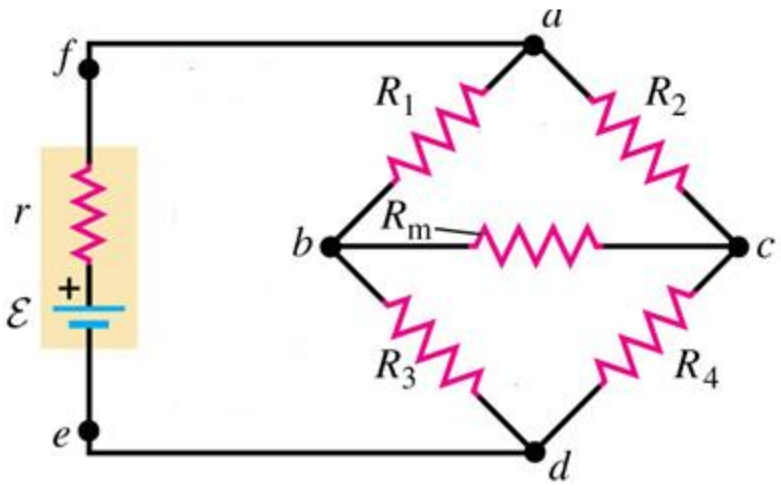
E. $R/3$

In the circuit in the figure, a 20-ohm resistor sits inside 113 g of pure water that is surrounded by insulating Styrofoam.



Caution!

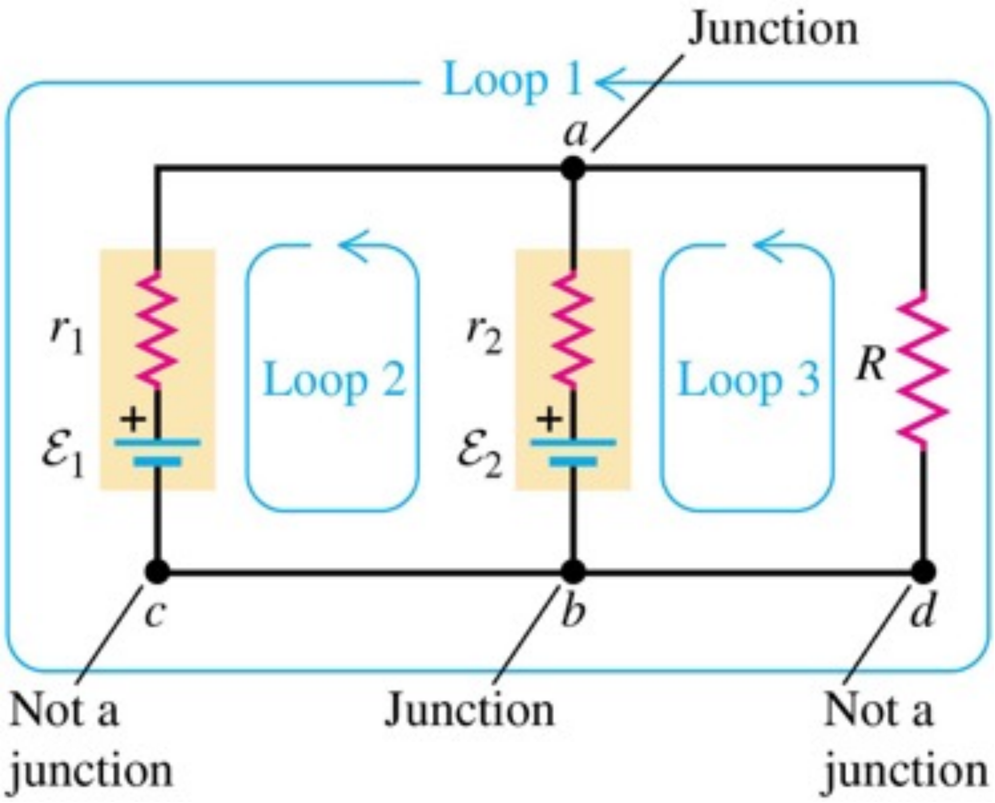
- Not all circuits can be analyzed in this way.
- In the diagram below, the resistors are neither in series or in parallel.
- We will develop another method for this analysis.



Kirchhoff's rules

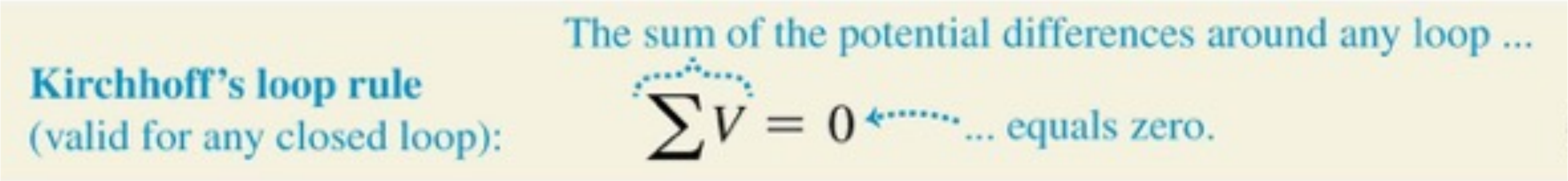
- Many practical resistor networks cannot be reduced to simple series-parallel combinations.
- To analyze these networks, we'll use the techniques developed by Kirchhoff.

Define:
Loop
Junction



Kirchhoff’s loop rule

- A **loop** is any closed conducting path.
- Kirchhoff’s loop rule (valid for any closed loop) is:



Kirchhoff’s loop rule
(valid for any closed loop):

The sum of the potential differences around any loop ...

$$\overset{\cdots}{\sum V} = 0 \leftarrow \text{... equals zero.}$$

- Conservative force —> potential at a point has a definite value

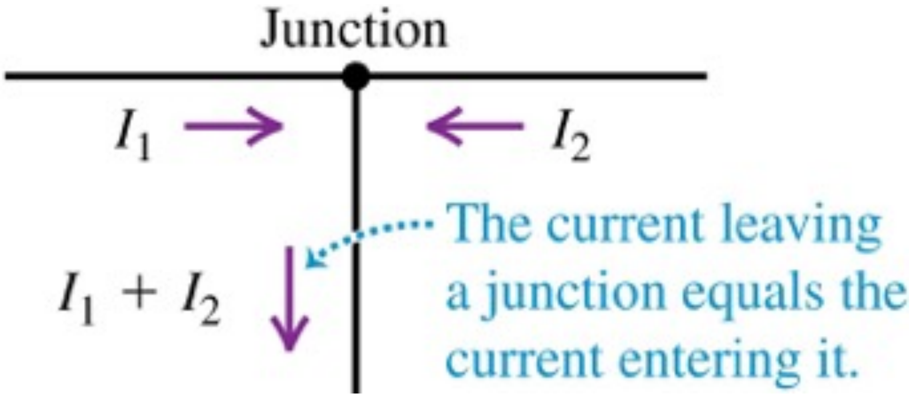
Kirchhoff's junction rule

- A **junction** is a point where three or more conductors meet.

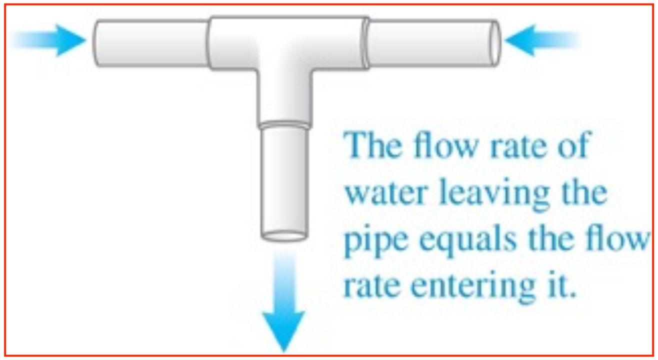
Kirchhoff's junction rule (valid at any junction):

$$\overset{\text{The sum of the currents into any junction ...}}{\sum I} = 0 \leftarrow \text{... equals zero.}$$

Conservation of charge



The current leaving a junction equals the current entering it.

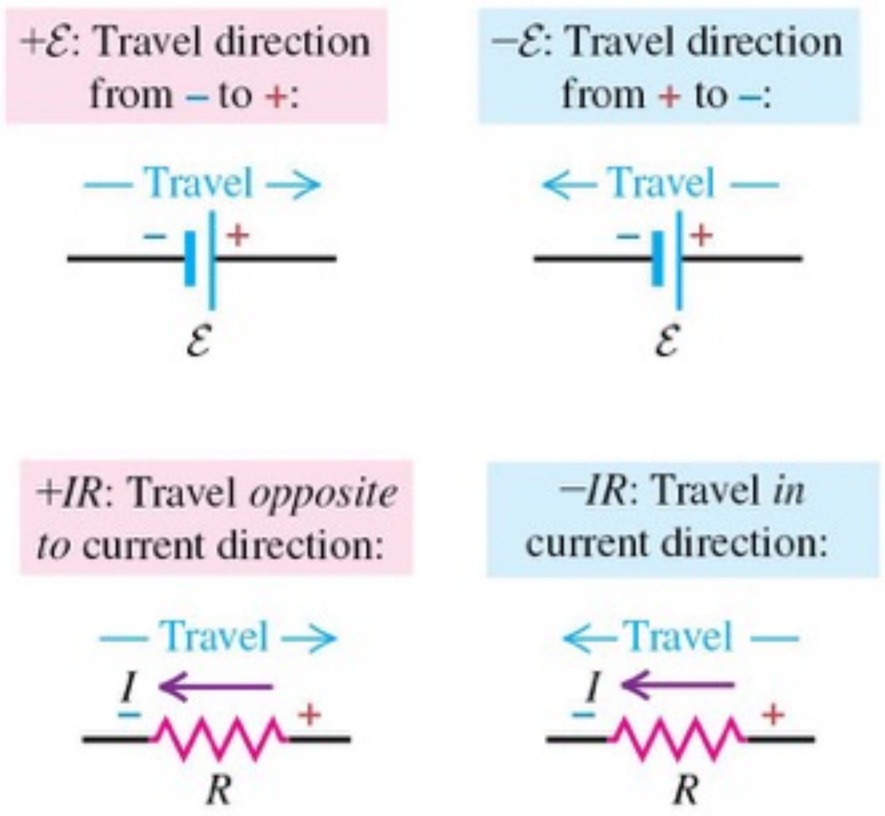


The flow rate of water leaving the pipe equals the flow rate entering it.

Sign conventions for the loop rule

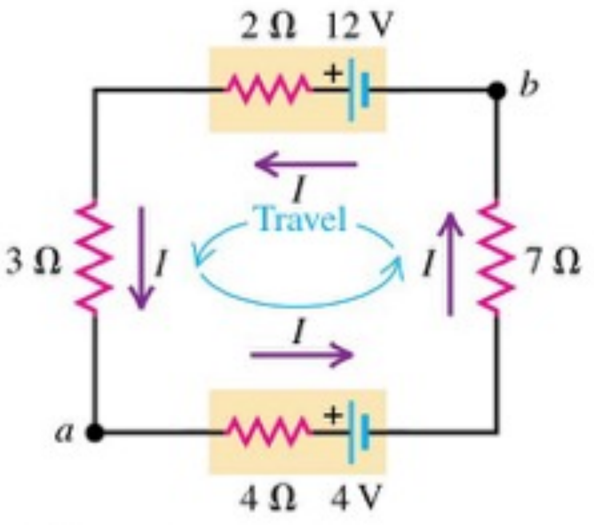
- Use these sign conventions when you apply Kirchhoff's loop rule.

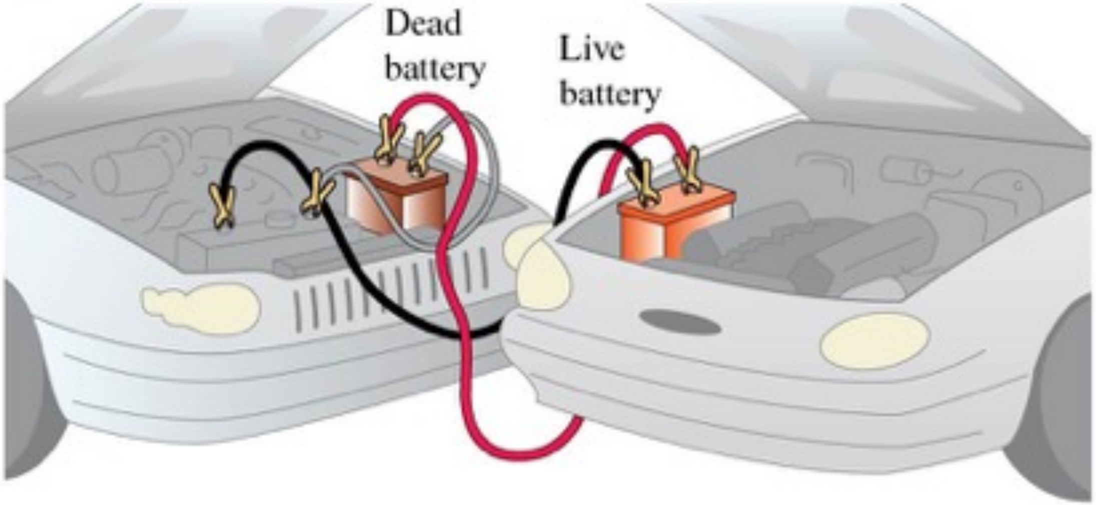
- In each part of the figure, "Travel" is the direction that we imagine going around the loop, which is not necessarily the direction of the current.



A single-loop circuit

- The circuit shown contains two batteries, each with an emf and an internal resistance, and two resistors.
- Using Kirchhoff's rules, you can find the current in the circuit, the potential difference V_{ab}, and the power output of the emf of each battery.





Back to our old “bridge” circuit: