PURDUE UNIVERSITY DEPARTMENT OF PHYSICS

Physics 21900

General Physics II

Electricity, Magnetism and Optics

Lecture 8 – Chapter 16.5-6

DC Circuits

Fall 2015 Semester

Prof. Matthew Jones

Reminder

- The first mid-term exam will be on Thursday, September 24th.
- Material to be covered is chapters 14 and 15
  - Coulomb's law
  - Electric potential energy
  - Electric field
  - Electric potential
  - Capacitors

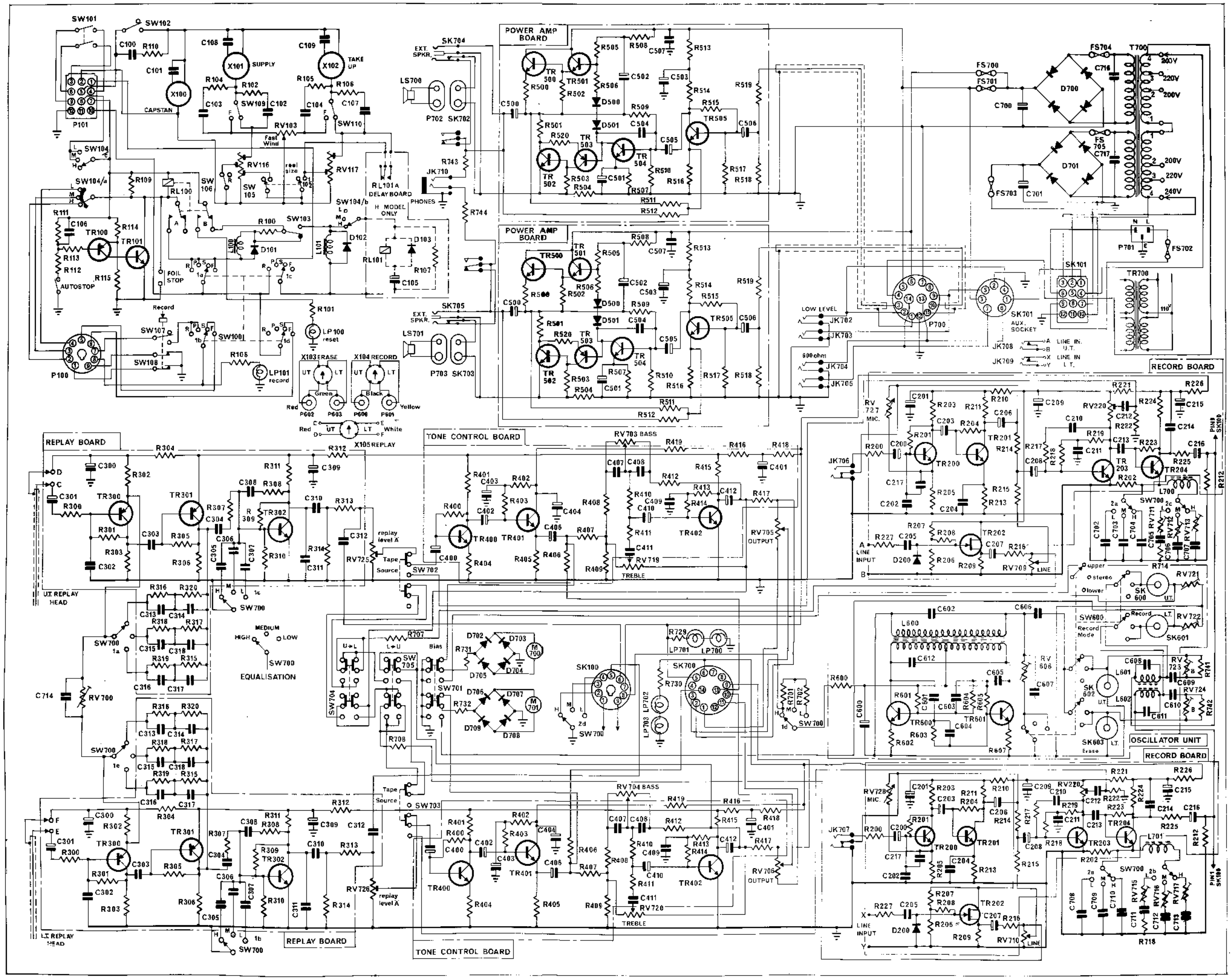


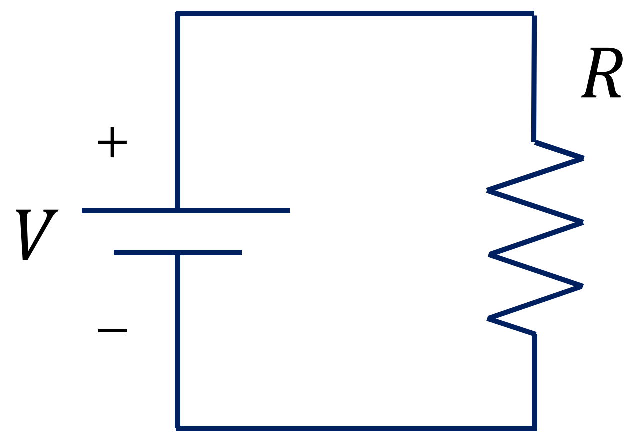
FIG 29. CIRCUIT DIAGRAM OF RECORDER

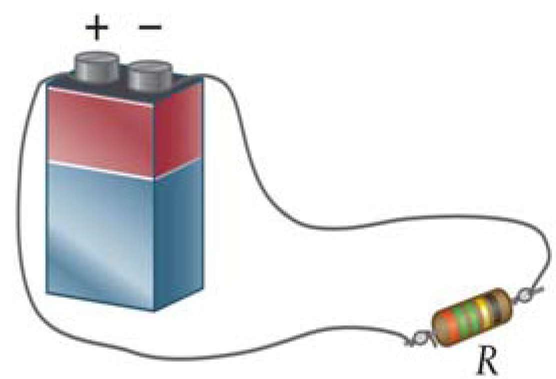
250-060 ISSUE 2


ritardando
Ped. come prima
ritardando
ritardando
(a tempo)
ritardando
Adagio
wiseGEEK

Circuit Diagrams

- There are a limited number of simple principles that underlie all circuit diagrams.
- We will use circuit diagrams to discuss the ideas rather than the details

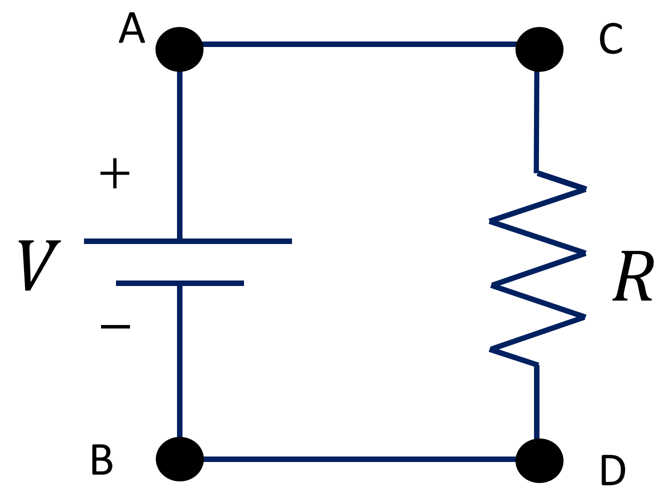




"Wires" and "Components"

- Lines in circuit diagrams represent "wires"
  - But they are wires with no resistance
- All parts of a conductor have the same electrical potential
- All parts of a circuit connected by lines, without passing through any "components" have the same electric potential.

$$V_A = V_C$$
$$V_B = V_D$$
$$\Delta \boldsymbol{V_{AB}} = \Delta \boldsymbol{V_{CD}}$$



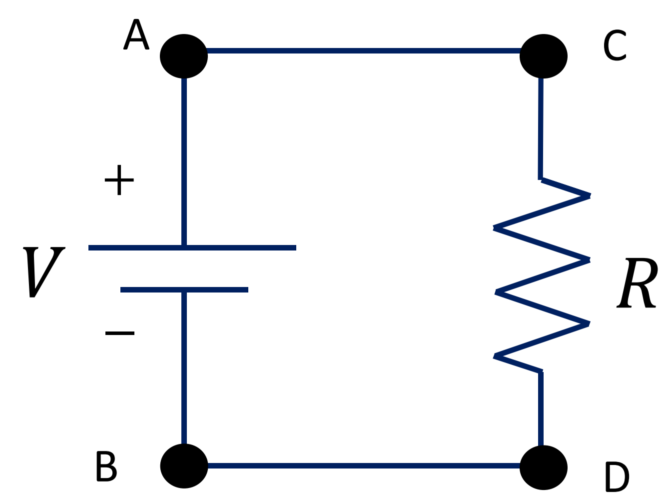
“Wires” and “Components”

- The electrical potential at all points in a circuit connected by “wires” is the same.
- The “components” in a circuit may add to or subtract from the electrical potential energy of charge carriers
  - Sources of Electromotive Force (EMF) provide energy
  - Resistors dissipate energy in the form of heat

In general,

$$\boldsymbol{V_A \neq V_B}$$

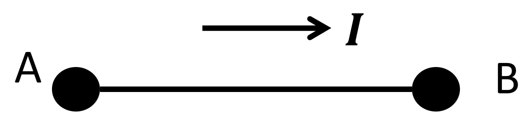
but sometimes they can be equal, like when $V = 0$ or $R = 0$.



Analyzing Circuits

- What question are we trying to answer?
  - What are the voltages at all points in the circuit?
  - What currents flow through each part of the circuit?
- These are not independent questions and if we can answer one, we can usually answer the other.
- What is the relation between potential difference across a “component” and current that flows through it?

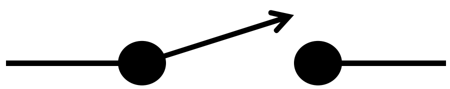
“Wires”



- Potential difference $\Delta V_{AB} = 0$
- Independent of current, I.
- This is sort of trivial, and usually we don’t even think about it this way.
- But this is exactly what we mean and one way to define the characteristics of a wire.

“Switches”

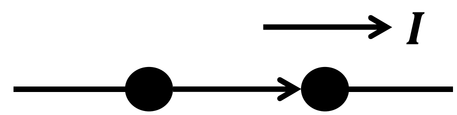
- Sometimes it is convenient to “modify” a circuit using a switch:



Open switch:

$$I = 0$$

independent of ΔV.



Closed switch:

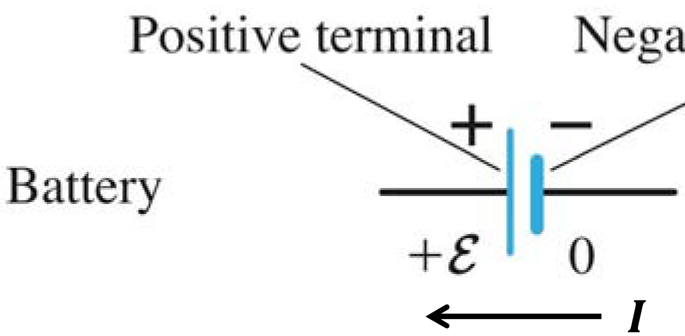
$$\Delta V = 0$$

independent of I.

- *A closed switch is exactly the same as a wire.*

Electromotive Force

- Something that "pushes" charge carriers, *i.e.* increases their electrical potential energy.



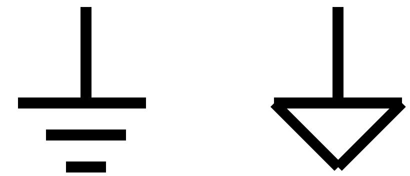
Emf ε The emf ε equals the work W done by a battery per coulomb of electric charge q that is moved through the battery from one terminal to the other in order to maintain a potential difference at the battery terminals:

$$\varepsilon = \frac{W}{q} \qquad (16.2)$$

- A battery uses its stored chemical energy to increase the electrical potential of charge carriers in the circuit.
- For an ideal EMF, $\mathcal{E}$ is independent of the current, $\boldsymbol{I}$.
- *An EMF with* $\mathcal{E} = \mathbf{0}$ *is exactly the same as a wire.*

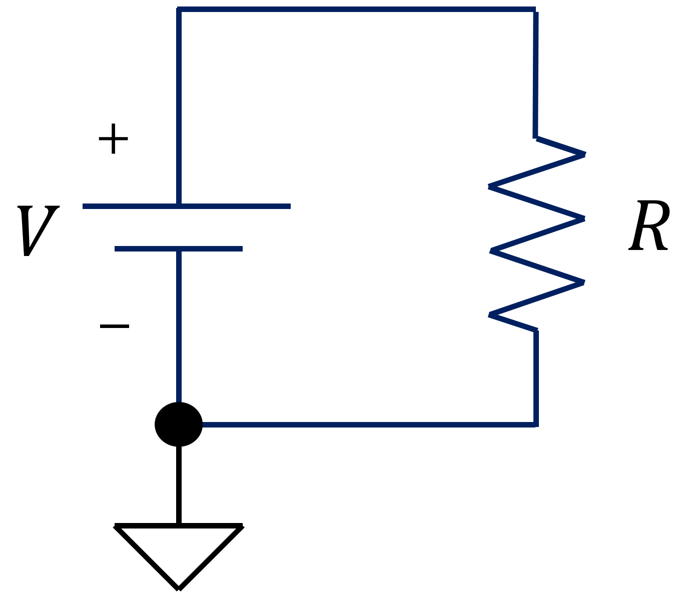
Resistors

- Ohm's law: $\Delta \boldsymbol{V_{AB}} = \boldsymbol{V_A} - \boldsymbol{V_B} = \boldsymbol{I\ R}$
- Resistors dissipate energy in the form of heat.
  - When current flows from left to right (the direction of the arrow), then $V_B < V_A$ because some of the electrical potential energy has been converted to heat.
- Algebraic signs matter!
  - If $I < 0$ then the current is really flowing in the direction opposite that shown by the arrow.
  - In this case, $V_B > V_A$.

“Ground” 

- As far as the physics is concerned, the only thing that matters is the potential difference across different parts of a circuit.
- It is convenient to define the potential at one part of the circuit to be $V = 0$.
  - We usually call this point “ground” potential.
- All “voltages” in the circuit are measured with respect to this particular choice of ground.
- Now we can talk about the specific voltages V_A, V_B rather than just ΔV_{AB}.

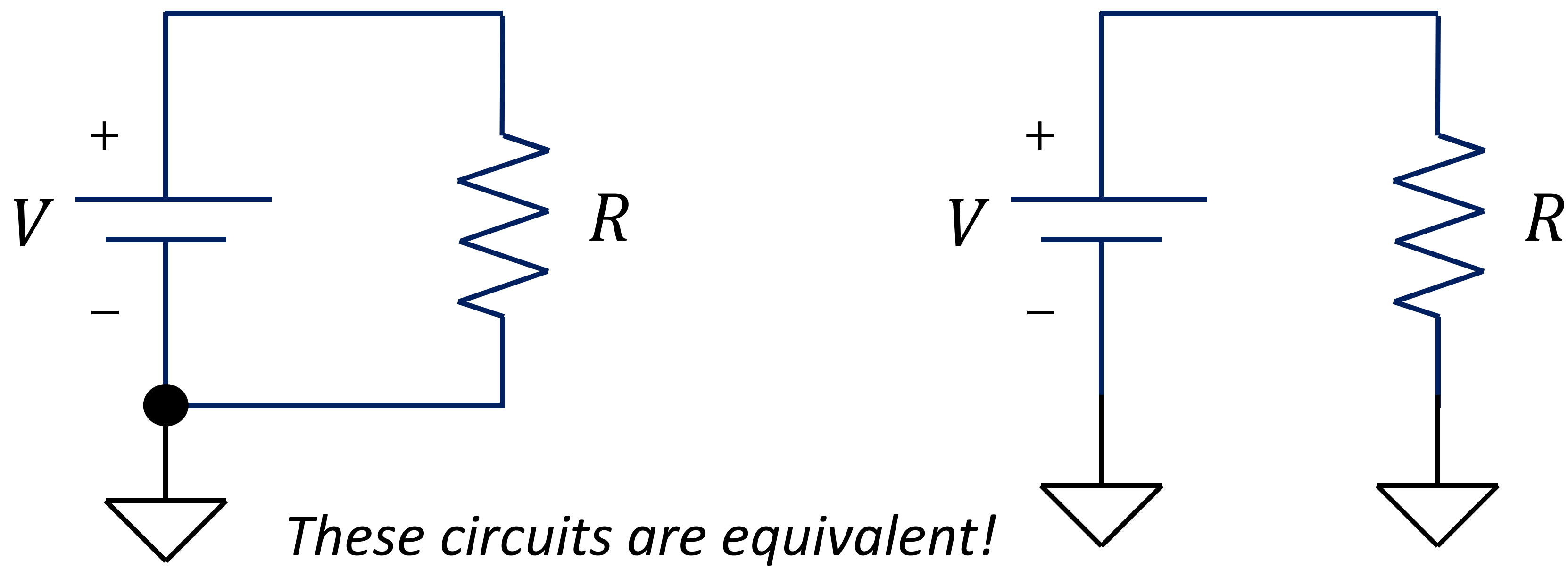
Example



Simple question:

- What is the current through the resistor?

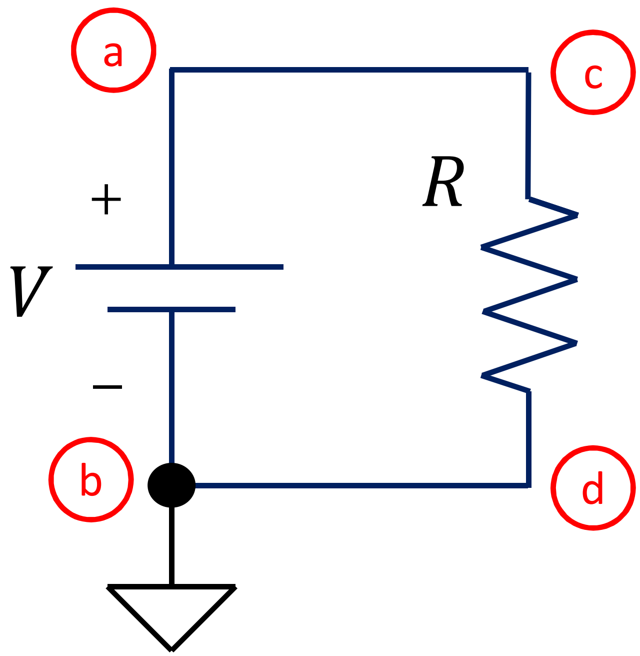
Example



These circuits are equivalent!

- The ground symbol tells us that the electrical potential of the negative terminal of the battery and the bottom end of the resistor have the electric potential $V = 0$.

Example



↓ $\boldsymbol{I}$

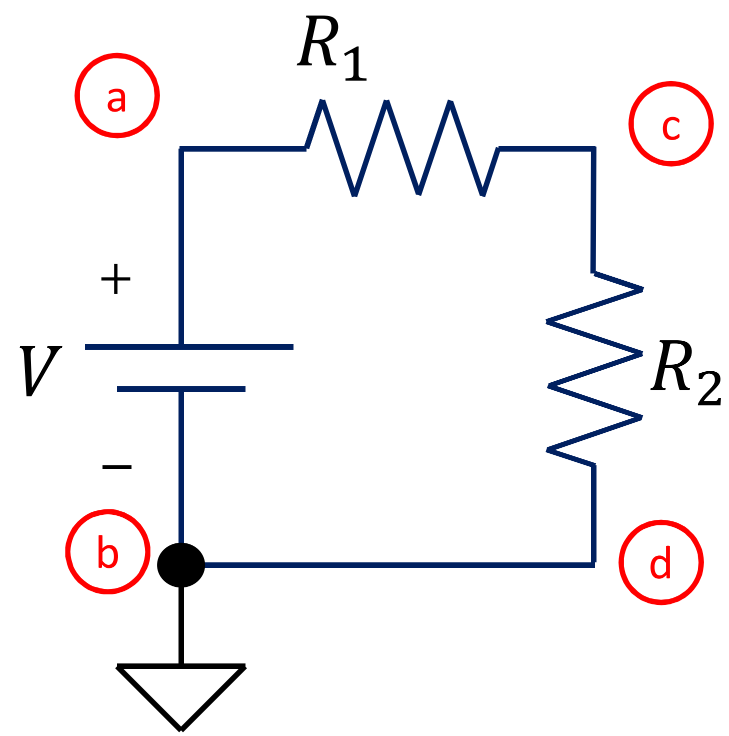
I is positive as shown because $V_c > V_d$ when we assume that $V > 0$.

- Definition of the EMF: $V_a - V_b = V$
- Definition of the wires: $V_c = V_a$ and $V_b = V_d$
- Ohm's law: $\Delta V_{cd} = I\ R$

$$I = \frac{\Delta V_{cd}}{R} = \frac{\Delta V_{ab}}{R} = \frac{V}{R}$$

- What direction?

Another Example

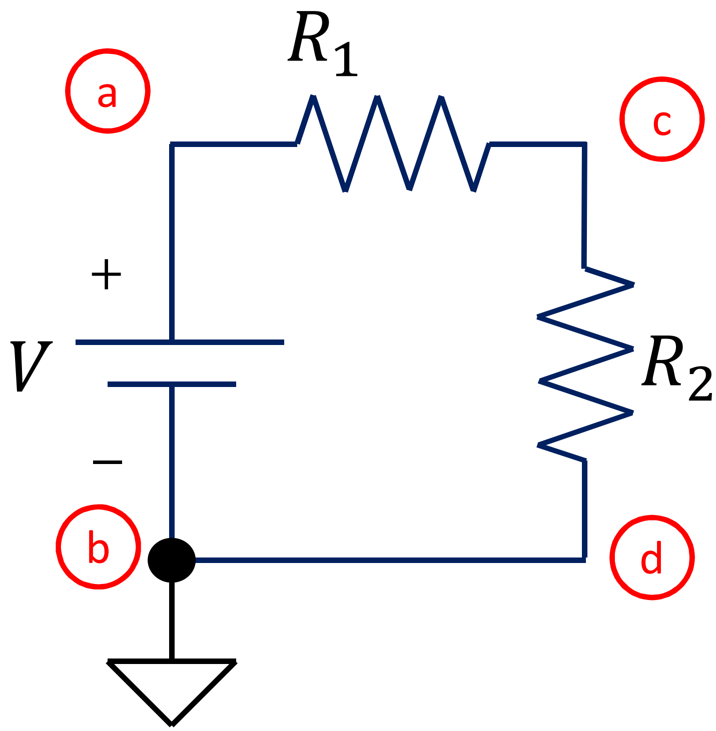


- The same current, I, flows through both resistors.
- $\Delta V_{ac} + \Delta V_{cd} = \Delta V_{ab} = V$
- Ohm's law: $\Delta V_{ac} = I\ R_1$ and $\Delta V_{cd} = I\ R_2$

$$I(R_1 + R_2) = V$$

$$I = V/(R_1 + R_2)$$

Actually it was a very important example…



$$I = \frac{V}{R_1 + R_2}$$

$$\boldsymbol{V_c = V\frac{R_2}{R_1 + R_2}}$$

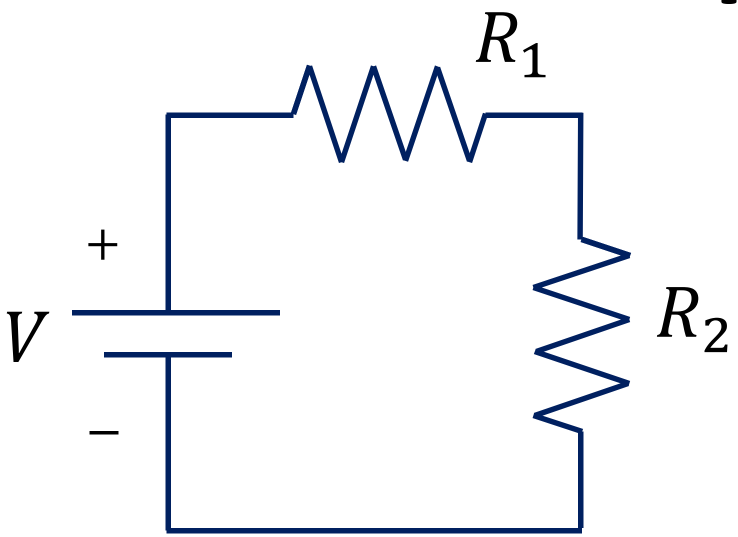
- What is V_c, the voltage at point ©?

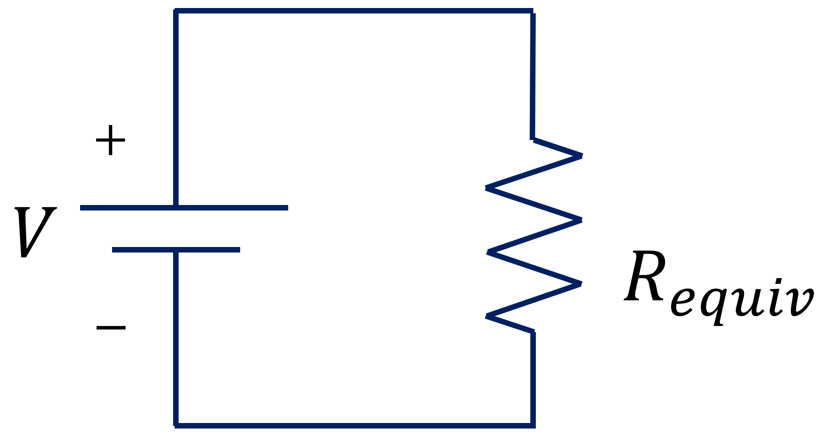
$$V_c = V_a - I\,R_1 = V - \frac{V\,R_1}{R_1 + R_2}$$

$$= \frac{V(R_1 + R_2) - V\,R_1}{R_1 + R_2} = \boldsymbol{V\frac{R_2}{R_1 + R_2}}$$

It’s called a voltage divider circuit and it is really useful.

Resistors in Series

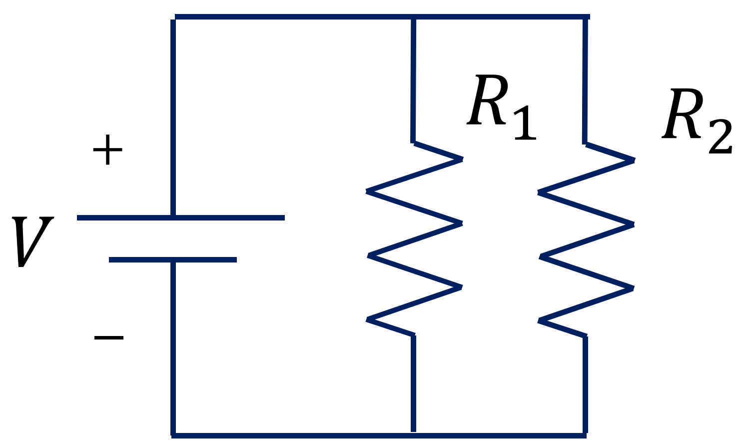


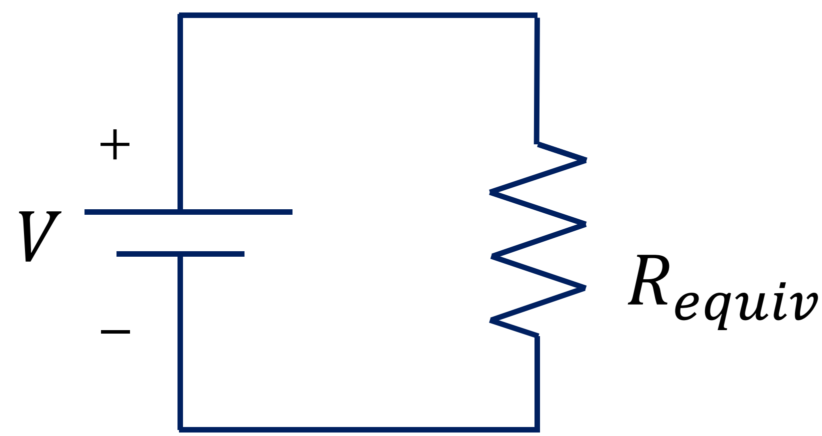


$$I = \frac{V}{R_1 + R_2} = \frac{V}{R}$$

$$R_{equiv} = R_1 + R_2$$

Resistors in Parallel





- Total current is the sum of the current through both resistors.
- Potential difference across each resistor is the same.

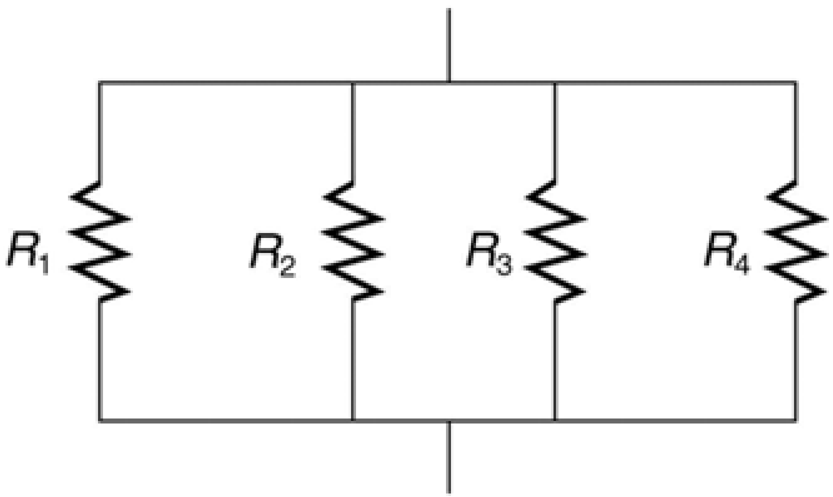
$$I_1 = \frac{V}{R_1} \qquad I_2 = \frac{V}{R_2} \qquad I = I_1 + I_2 = \frac{V}{R_{equiv}}$$

- Resistors in parallel: $\dfrac{1}{R_{equiv}} = \dfrac{1}{R_1} + \dfrac{1}{R_2}$

Generalizing

(a)

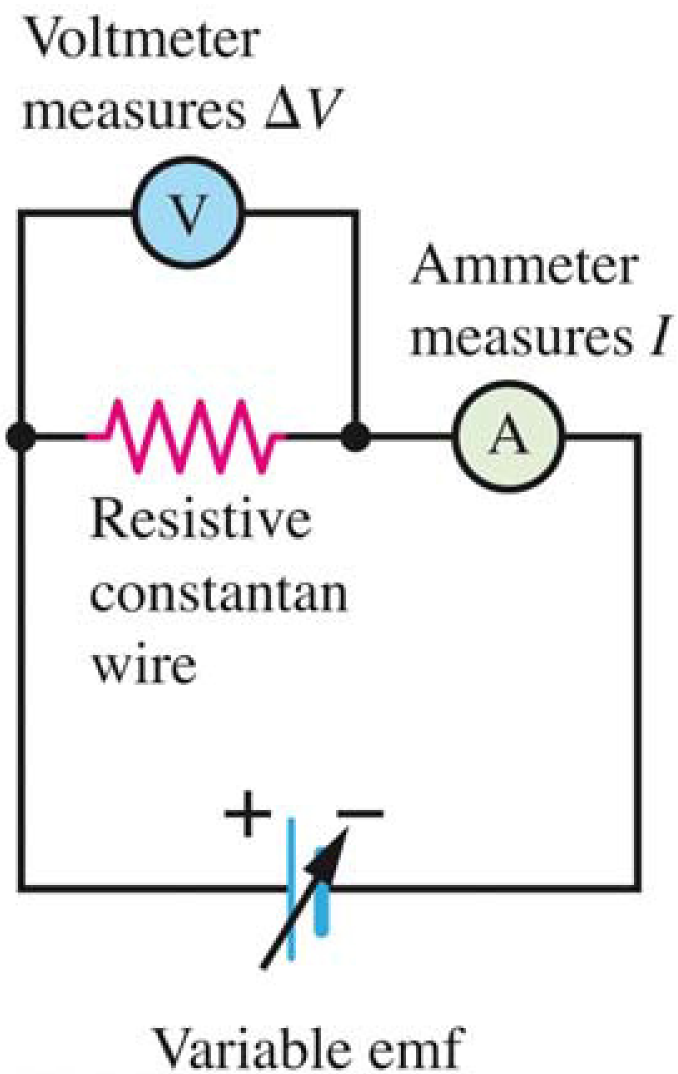
$$R_{equiv} = R_1 + R_2 + R_3 + R_4$$



(b)

$$\frac{1}{R_{equiv}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}$$

Measuring Voltage and Current

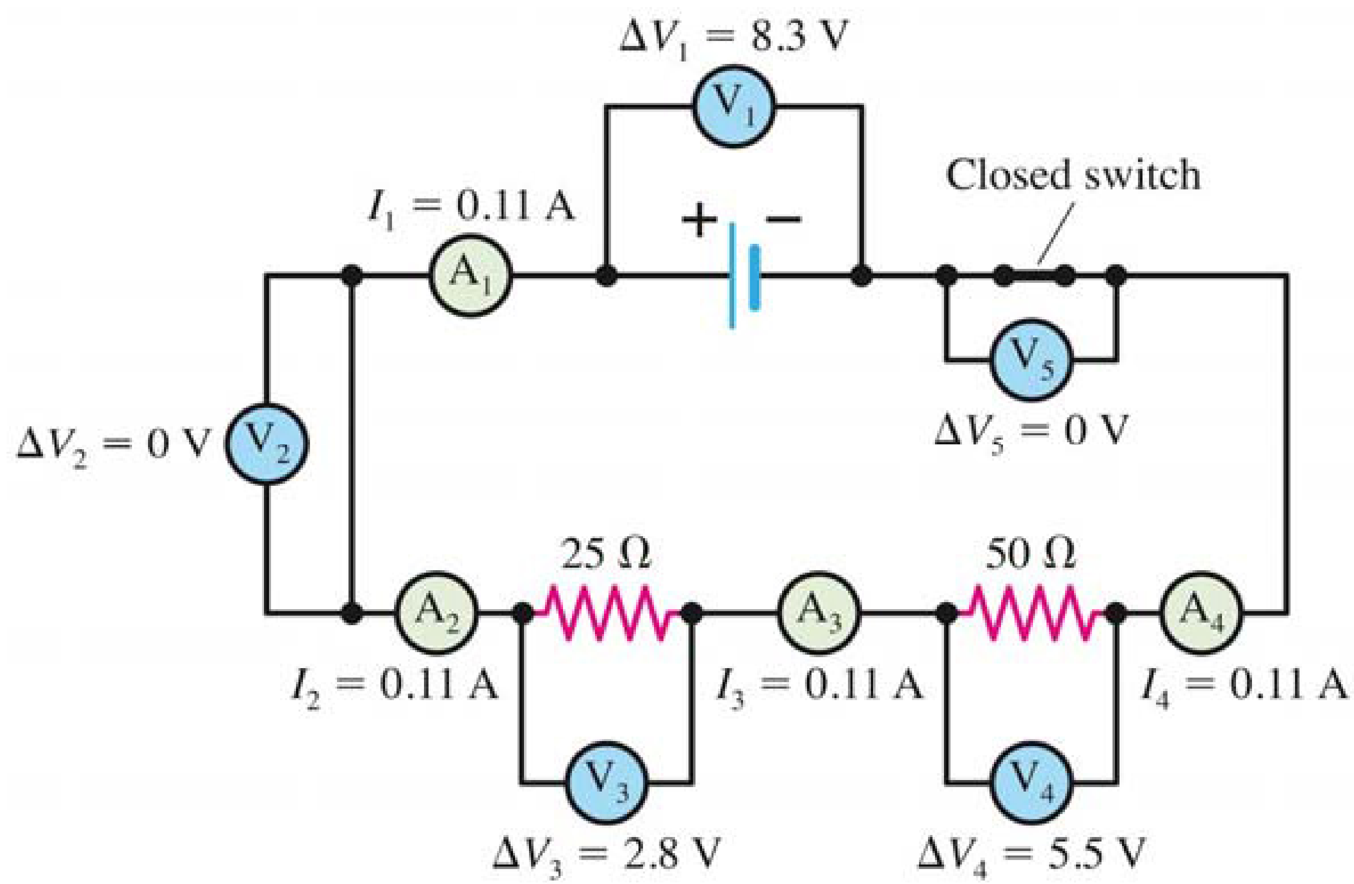


Voltmeter: measures voltage difference *across* a component… connect in parallel.

Ammeter: measures current *through* a component… connect in series.

(Usually requires breaking the circuit in order to insert the ammeter in series.)

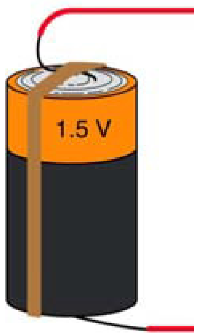
Example

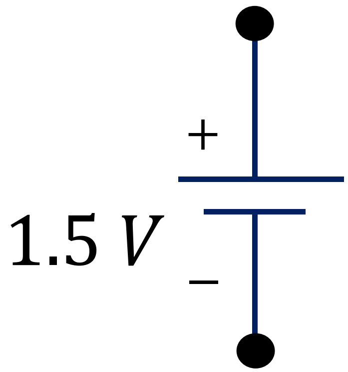


Always remember:

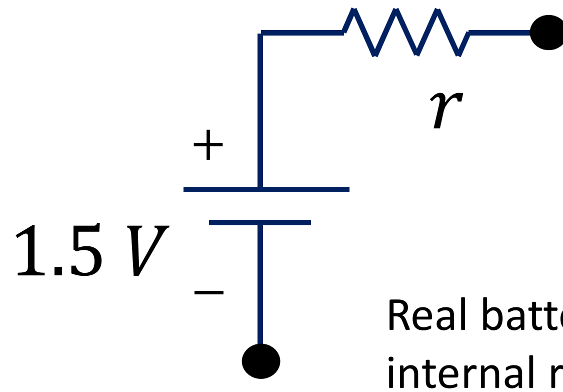
- Voltmeters connected in parallel
- Ammeters connected in series.

Real vs Ideal Batteries





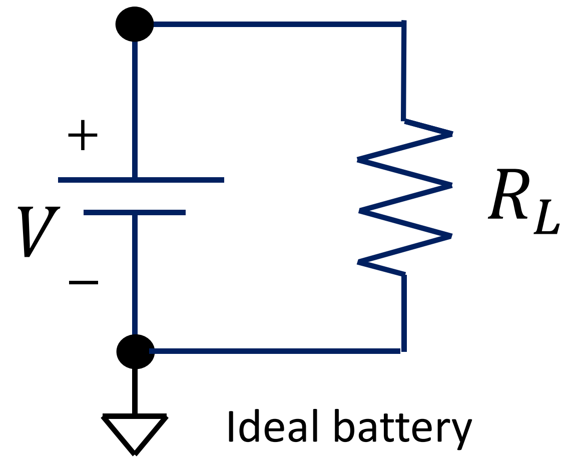
Ideal battery



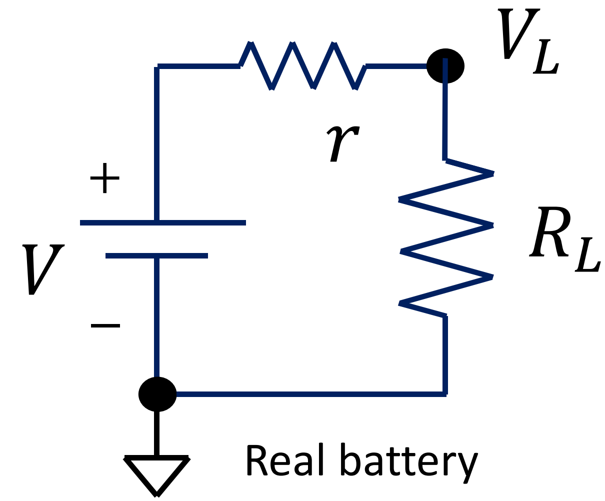
Real battery with an internal resistance, r.

- The chemical reaction will always produce a potential difference of 1.5 V (that's chemistry).
- So why does the battery die?
- The internal resistance r gradually increases with time.

Real vs Ideal Batteries



Ideal battery



Real battery

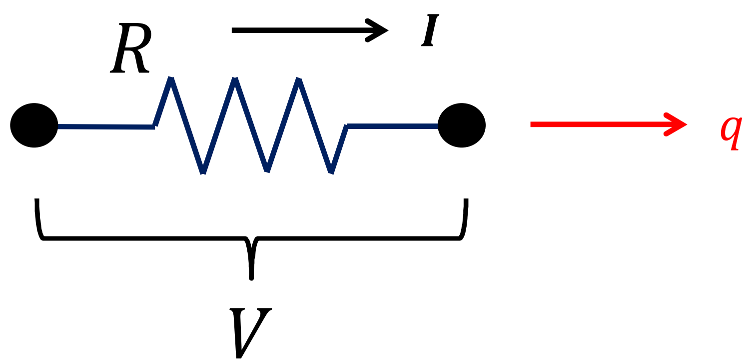
- In an ideal battery, the voltage across the load is the same as the battery voltage and $I = V/R_L$.
- In a real battery, the voltage across the load is

$$\boldsymbol{V_L = V\frac{R_L}{r + R_L}}$$

- When r is large, $V_L \ll V$.

This is not a new formula… it's just the result from analyzing the voltage divider circuit.

Power Dissipation

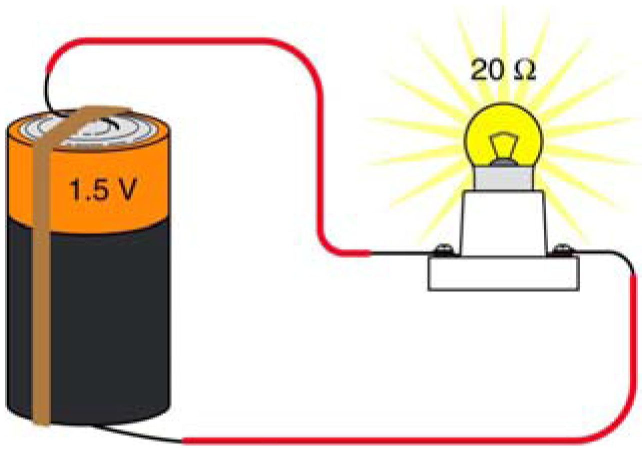


- Charge flowing in time Δt: $q = I\,\Delta t$
- Energy decrease: $q\,\Delta V = I\,V\,\Delta t$
- Energy decrease = Energy dissipated in R
- Power dissipated = Energy dissipated per unit time

$$P = \frac{\Delta E}{\Delta t} = I\,V$$

- Ohm's law: $V = I\,R$
- Power dissipated: $\boldsymbol{P = I^2 R}$ or $\boldsymbol{P = V^2/R}$

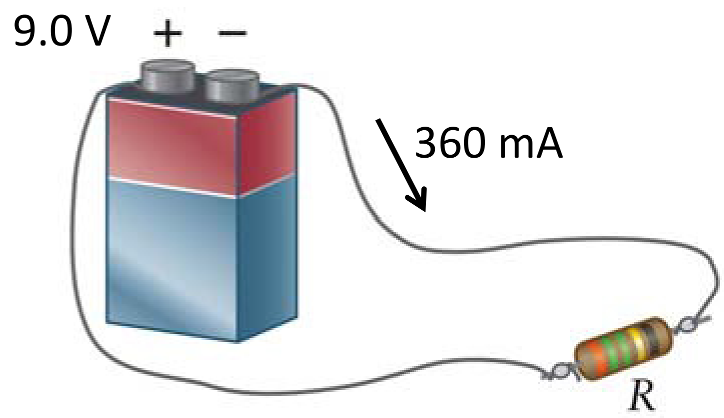
How much power is dissipated in the load?



$$P = \frac{\mathcal{E}^2}{R} = \frac{V^2}{R}$$

$$= \frac{(1.5\ V)^2}{20\ \Omega} = 0.113\ W$$

How much power is dissipated in the resistor?



$$P = I\ V$$

$$= (0.360\ A)(9.0\ V)$$

$$= 3.24\ W$$

Power Dissipation
Fuses and Circuit Breakers

- In a fuse, current passes through a metal strip.
- The strip acts as a resistor with a small resistance.

$$P = I^2 R$$

- If a fault causes the current to become large, the increased power causes the strip to melt (open circuit) and the current stops.
- A circuit breaker "opens" a switch that can be reset.

Open Circuit Breakers and Blown Fuses

- Reasons why circuits can draw too much current:
  - Too many devices plugged into one circuit
  - One device draws too much current
  - Short circuit (accidental creation of an alternate path for current to flow)
  - Ground fault (accidental creation of a path for current to ground)