# Lecture 23
# (Electromotive Force and Power)

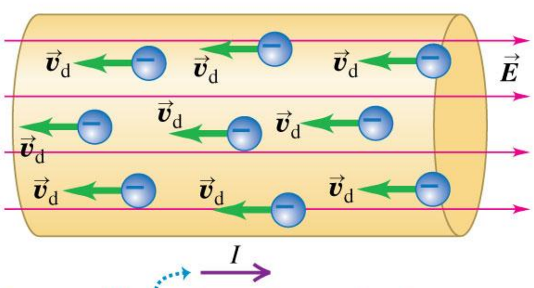
Physics 161-01 Spring 2012

Douglas Fields

# Current

- Remember that electric current in a conductor is caused by the drift of charges (usually electrons).
- The current, however, is defined to be in the direction of positive charge motion.
- This is also in the direction of the electric field which causes the drift velocity.
- But, what causes the electric field?

(b)



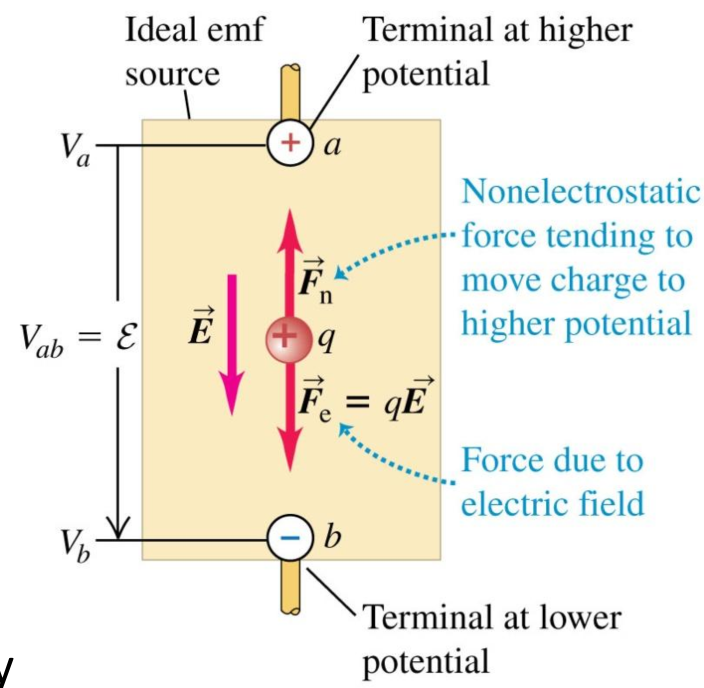

In a metallic conductor, the moving charges are electrons — but the *current* still points in the direction positive charges would flow.

# Electromotive Force

- Most of us are familiar with one driver of electric current – a battery.
- It is worthwhile to spend a few minutes talking about these.

# Electromotive Force (EMF, $\mathcal{E}$)

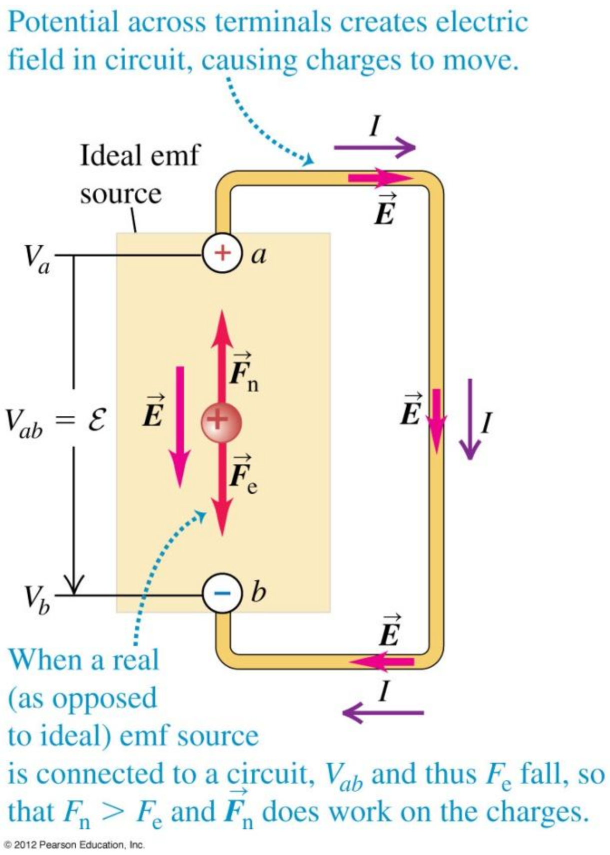
- If you look at the terminals of a battery, they are marked + and – for the high and low potential side, respectively.
- That means, internal to the battery, there is an electric field pointing from the + to the -.
- But, what causes that potential in the first place (since without anything else involved, positive charge would move to the negative terminal, etc…)
- There is some non-electrostatic force (usually chemical) that drives positive charges to the positive terminal, and negative charges to the negative terminal.
- When the battery is just sitting there, not hooked to anything, these two forces exactly cancel.
- Think of a little man sitting in there pushing positive charges to the positive terminal until there is an terminal voltage $V_{ab}$.




When the emf source is not part of a closed circuit, $F_n = F_e$ and there is no net motion of charge between the terminals.

# Electromotive Force (EMF, $\mathcal{E}$)

- When there is a connection made between the terminals, current flows from positive to negative.
- Think of the little man desperately trying to keep enough positive charge on the positive terminal in order to keep the terminal voltage at $V_{ab}$.



# Circuit Symbols

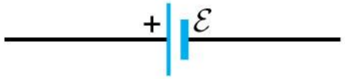
- We will need these next and for the coming chapters.

**Table 25.4 Symbols for Circuit Diagrams**

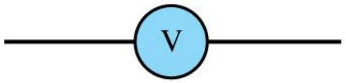


Conductor with negligible resistance

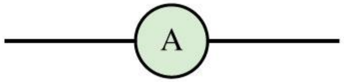

Resistor




Source of emf (longer vertical line always represents the positive terminal, usually the terminal with higher potential)



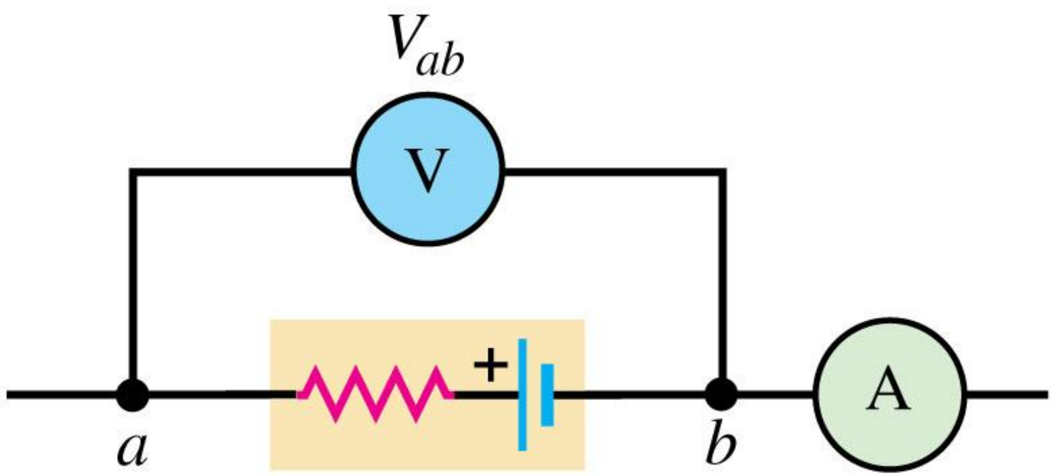

Voltmeter (measures potential difference between its terminals)
Has basically infinite resistance, and must always be connected in parallel.




Ammeter (measures current through it)
Has basically zero resistance, and must always be connected in series.

# Ideal vs. Real

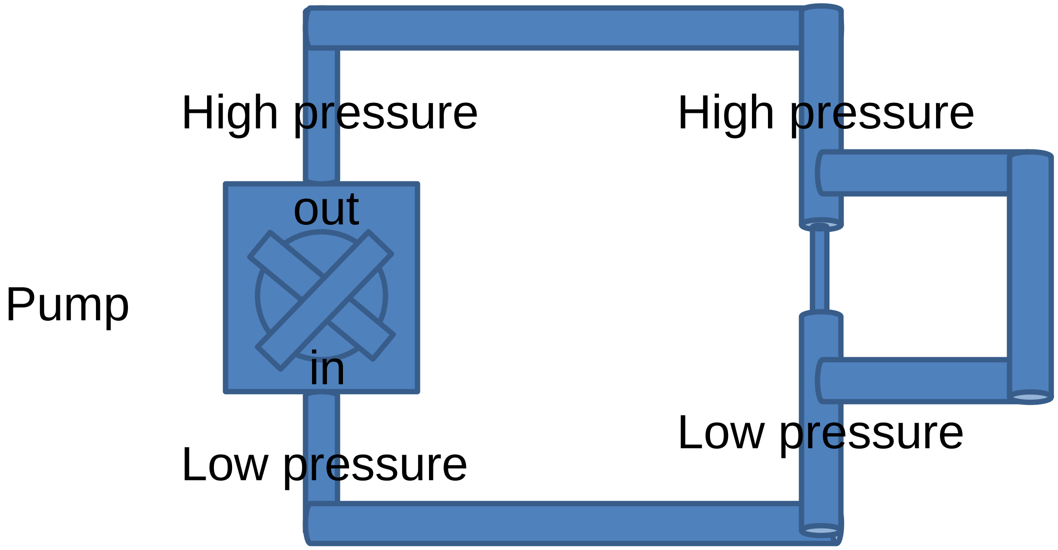
- Now, in a real source of EMF, there is usually some internal resistance.
- This can cause the terminal voltage, $V_{ab}$ to be different that the EMF voltage, $\mathcal{E}$.
- Why?




$r = 2\ \Omega,\ \mathcal{E} = 12\ \mathrm{V}$

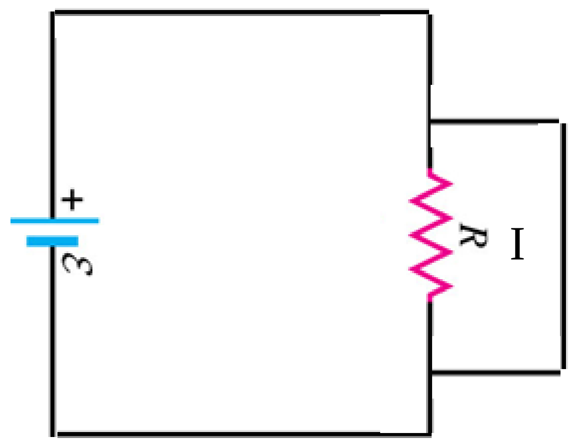
# Potential Drop Across a Resistor

- Water analogy, again.
- With no pressure drop across the restriction, no current flows through it.



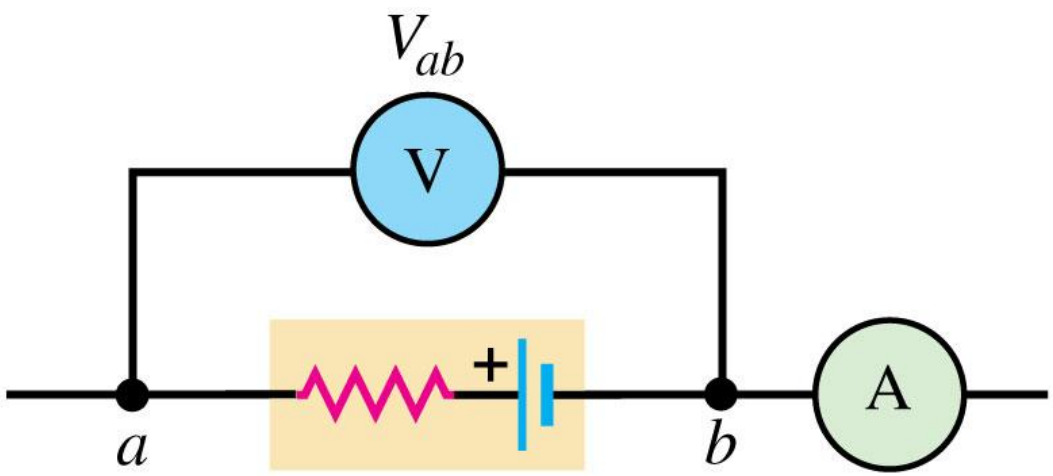
# Potential Drop Across a Resistor

- When a potential difference is applied across a resistor, a current flows, given by Ohm's Law: V=IR.
- No current, no voltage drop.
- No voltage drop, no current (through the resistor).



# Ideal vs. Real

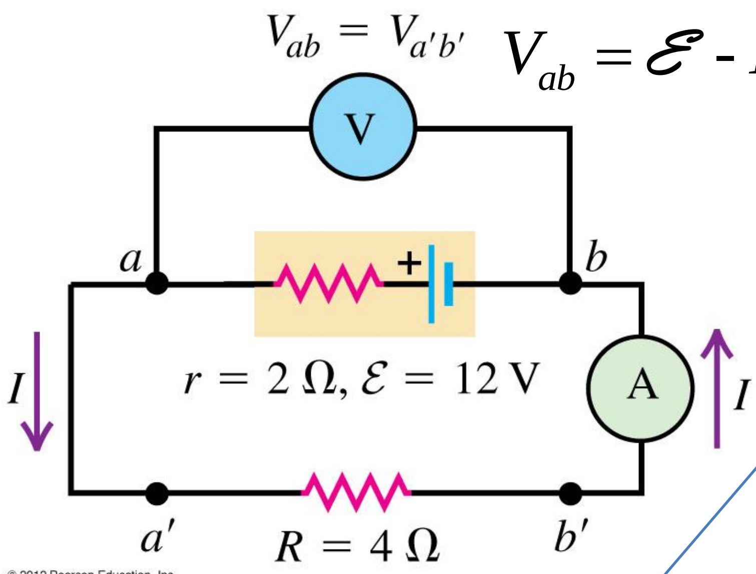
- So, here we have a (real) battery, but it is not hooked up in a circuit.
- What is the reading on the ammeter?
- What is the reading on the voltmeter?




$r = 2\ \Omega,\ \mathcal{E} = 12\ \text{V}$

# Ideal vs. Real

- Here, we have a (real) battery, that is hooked up in a circuit.
- What is the reading on the ammeter?
- What is the reading on the voltmeter?




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

$$V_{a'b'} = IR$$

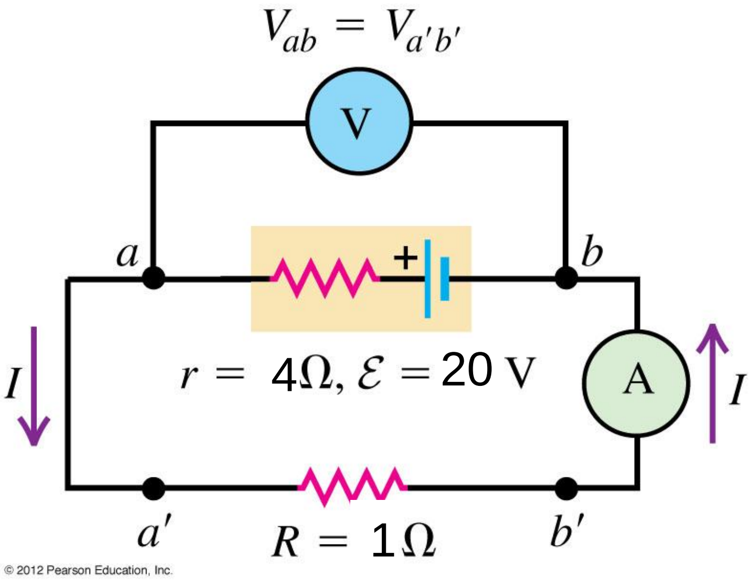
$$IR = \mathcal{E} - Ir \Rightarrow$$

$$I = \frac{\mathcal{E}}{R + r}$$

$$= \frac{12V}{4\Omega + 2\Omega} = 2A$$

# CPS 23-1

What is the current through the ammeter, and the voltage *across the battery's internal resistor*?




A. 2A and 10V.

B. 4A and 20V.

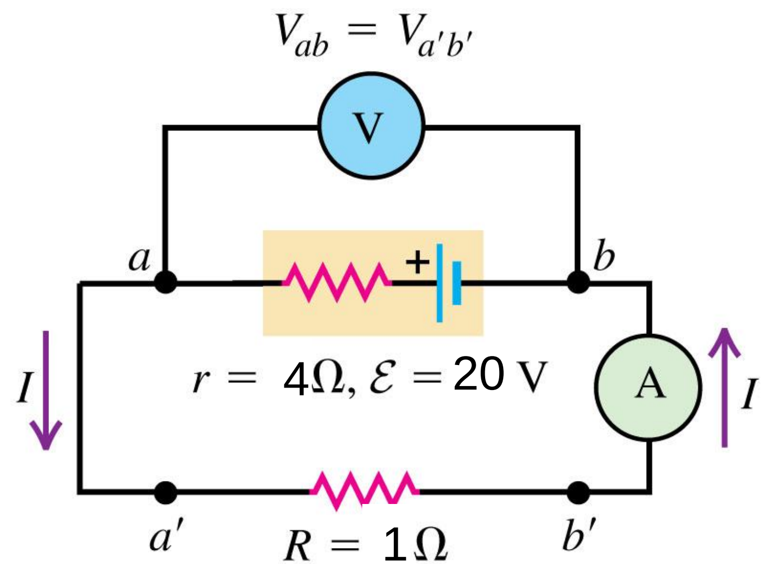
C. 5A and 20V.

D. 4A and 16V.

E. 2A and 8V.

# CPS 23-1

What is the current through the ammeter, and the voltage *across the battery's internal resistor*?




A. 2A and 10V.

B. 4A and 20V.

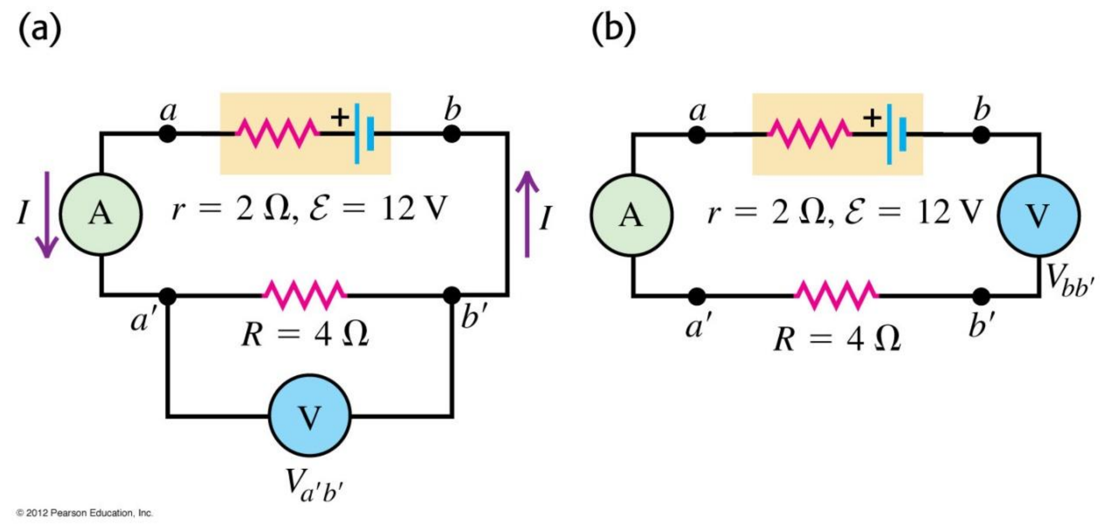
C. 5A and 20V.

D. 4A and 16V.

E. 2A and 8V.

# 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.

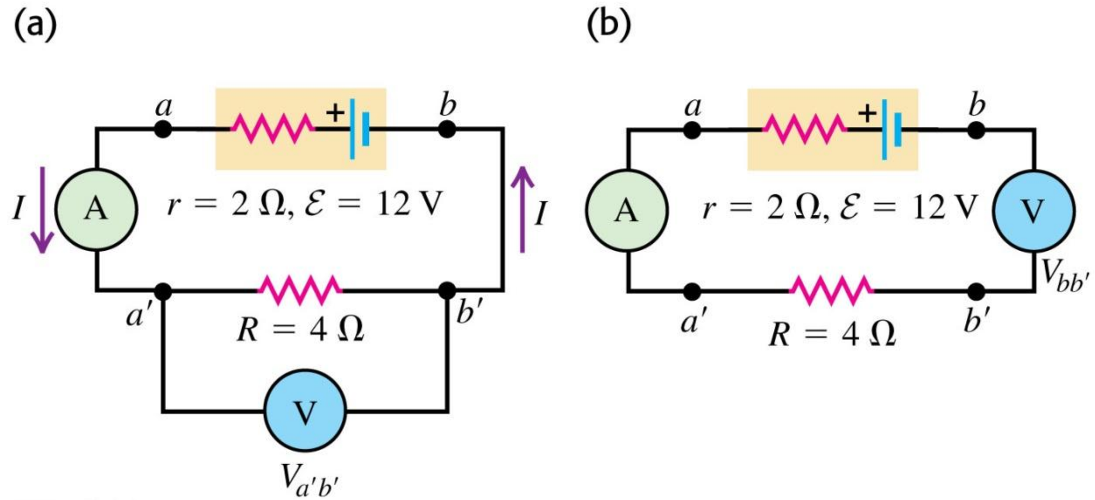
C. 0A and 12V.

D. 0A and 0V.

E. 2A and 12V.

# 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.

# Energy and Power

- What is the potential energy change of a charge going from potential zero to potential V?

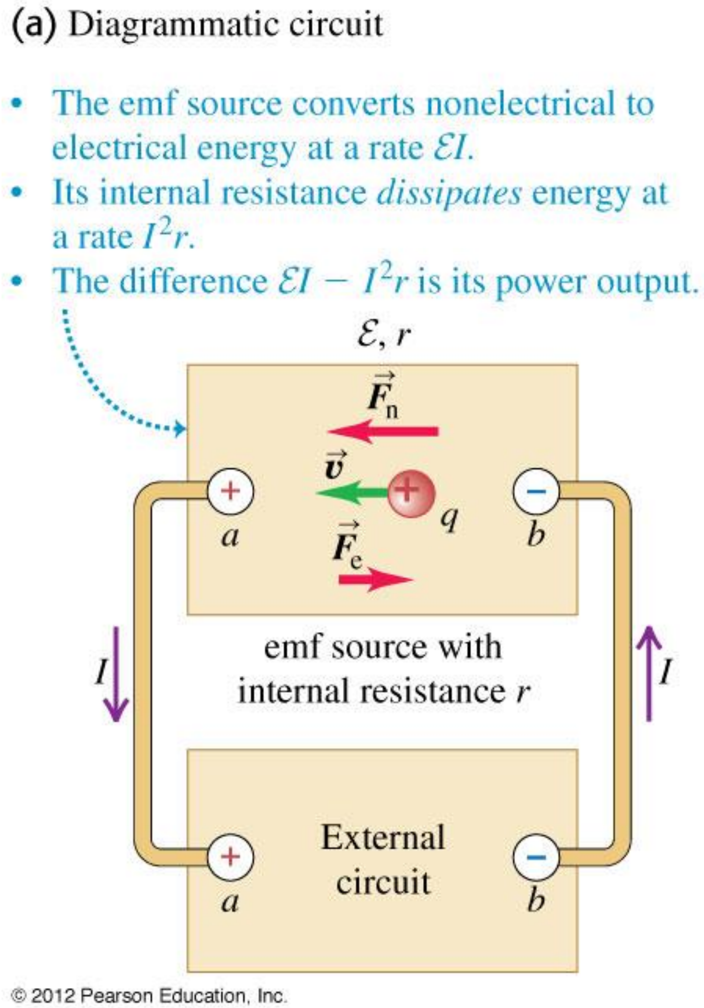
$$\Delta U = q\Delta V$$

- So, how much work does the battery do per second?

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

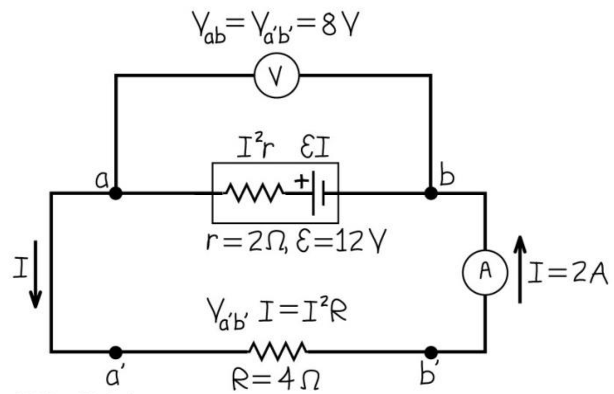
- But, energy is lost in the internal resistor.

$$P = \frac{dq}{dt}\Delta V = I\left(Ir\right) = I^2 r = \frac{V^2}{r}$$



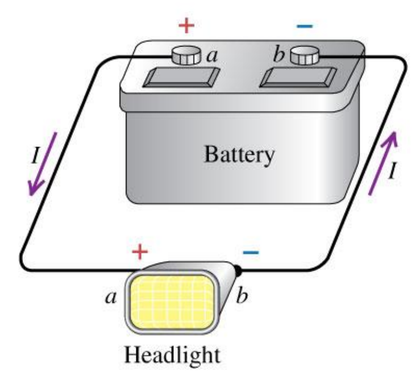
# Energy and Power

- In a real-life circuit, power is lost both in the light, and in the battery.
- Notice that when working with a cordless tool, the battery gets hot.
- The power used in the headlight heats the filament and is lost via the light and the heat lost.



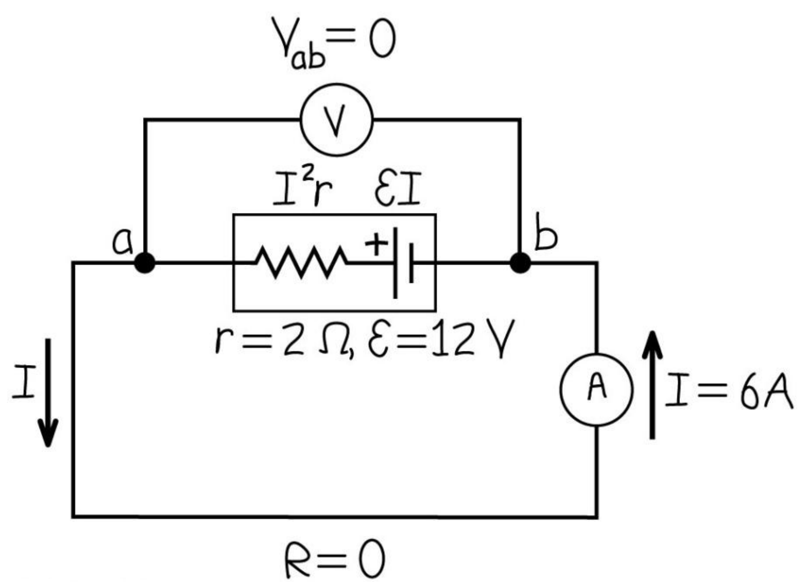


(b) A real circuit of the type shown in (a)



# Energy and Power

- Short circuiting a battery means that one directly connects the positive and negative terminals with a low-resistance wire.
- Doing so means that the current will be especially high, limited only by the internal resistance of the battery.
- Also, all of the power produced by the source, is lost in the source, hence doing this can cause a battery to heat up significantly, and perhaps explode.



# Power Input Into a Source

- One can have more than one source of EMF in a circuit, and can do this in order to recharge a battery.