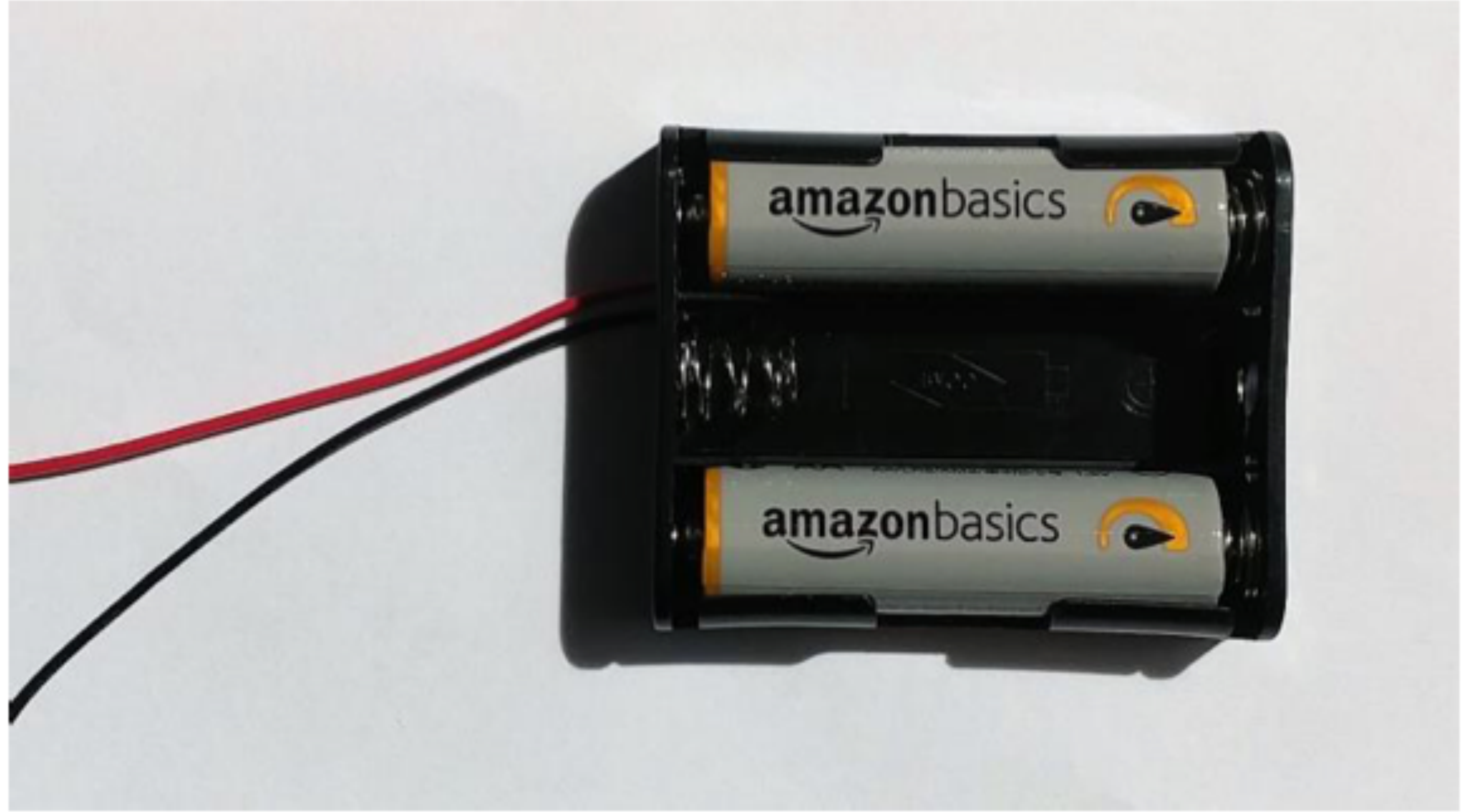
Happy Friday!
Do this now:

Take all three AA batteries out of your kit, and put (only!) **two** of them in the holder.

(Keep the third one handy.)



Take your digital multimeter out of its packaging, as well as the probes in the box

Announcements

- **Homework 1** is due now
- **Prelab 1** (which we'll do today) is due 24 hours before your lab next week
- **Lab 0** reflections due before your lab next week
- **Homework 2** is due next Friday 3pm

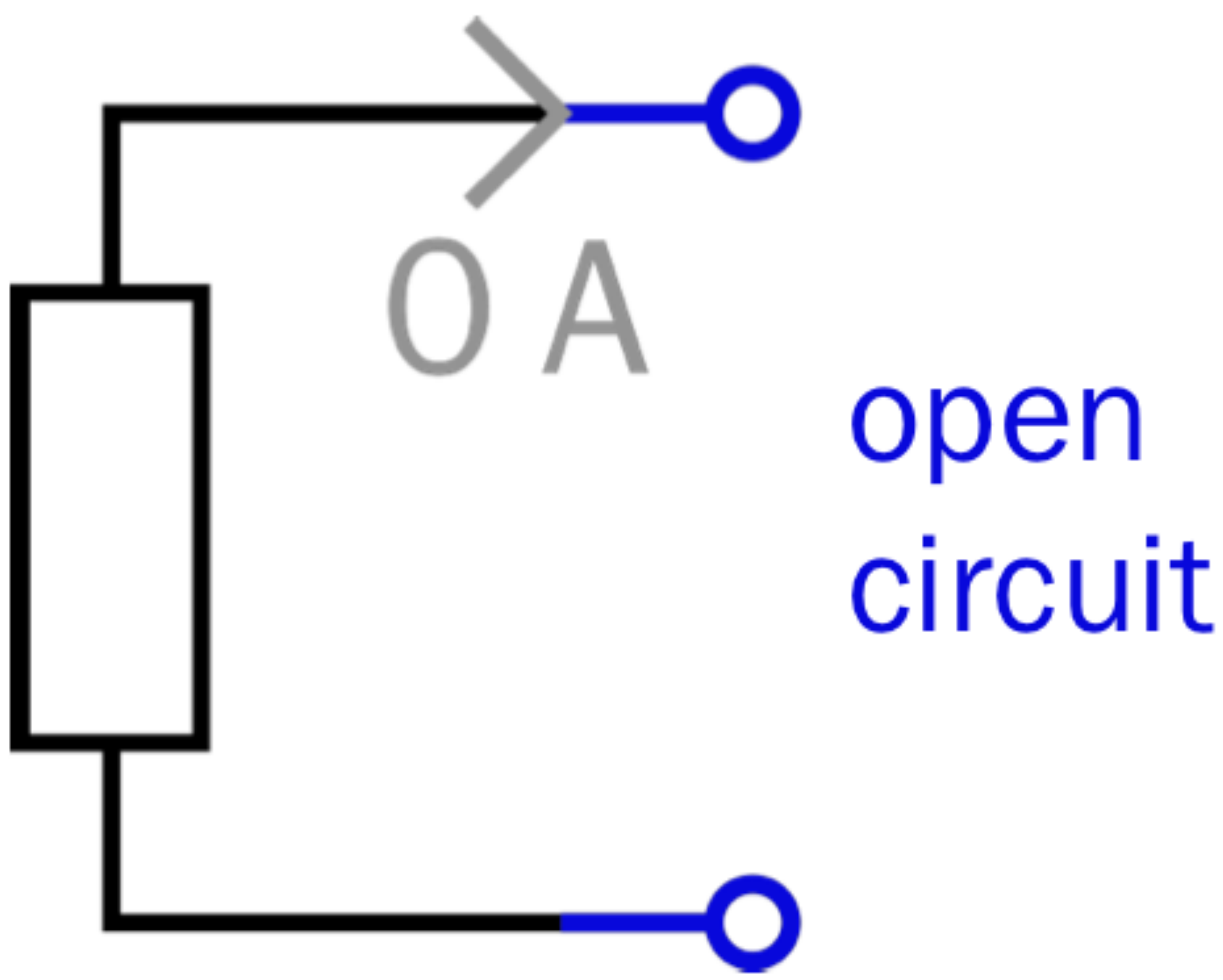
All submissions are on Gradescope, the class code is on the website (it's `973RZ9`)

Lab 1
Solar-powered USB charger
Using your multimeter

ENGR 40M
Chuan-Zheng Lee
Stanford University
14 April 2017

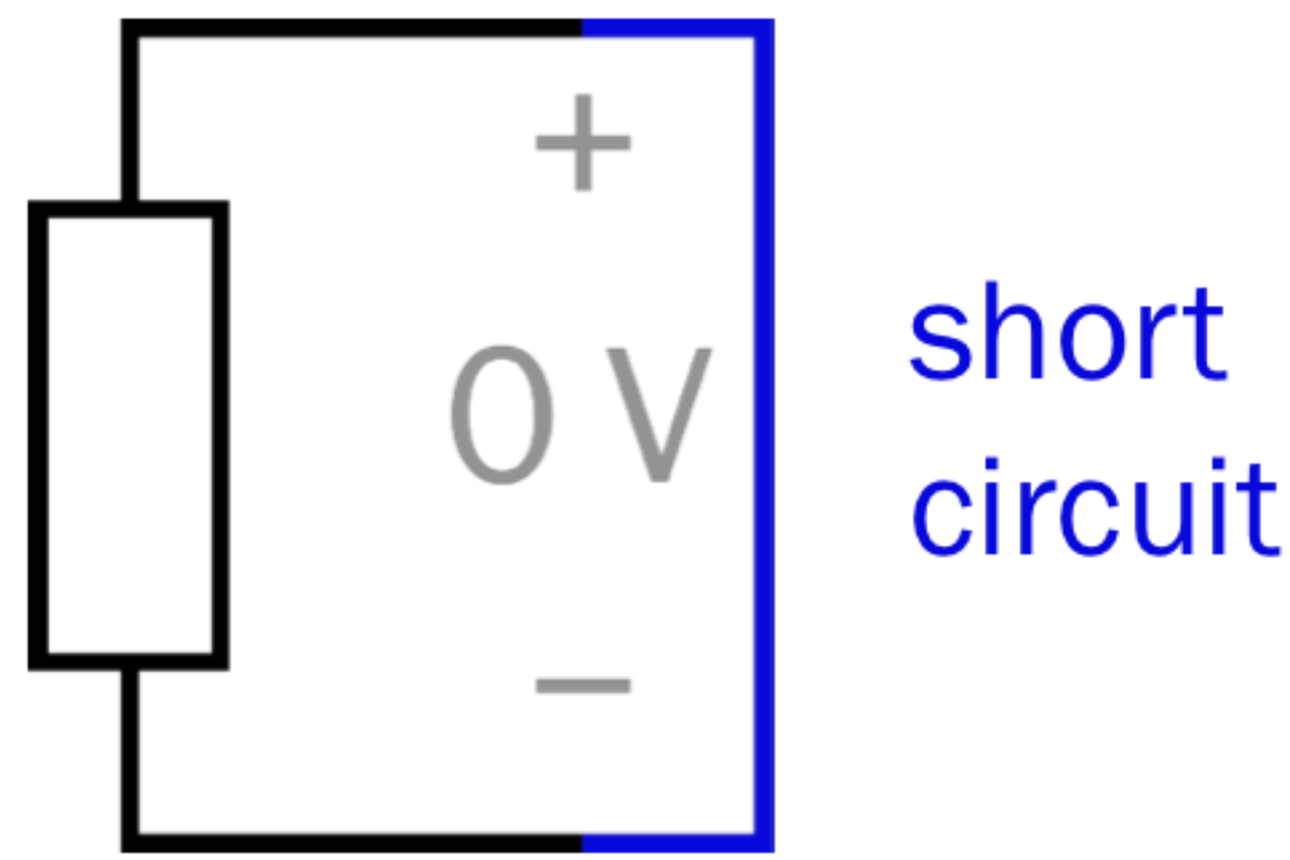
Open circuit and short circuit

Open circuit



- No connection
- Infinite resistance
- Current can't flow ($i = 0$)

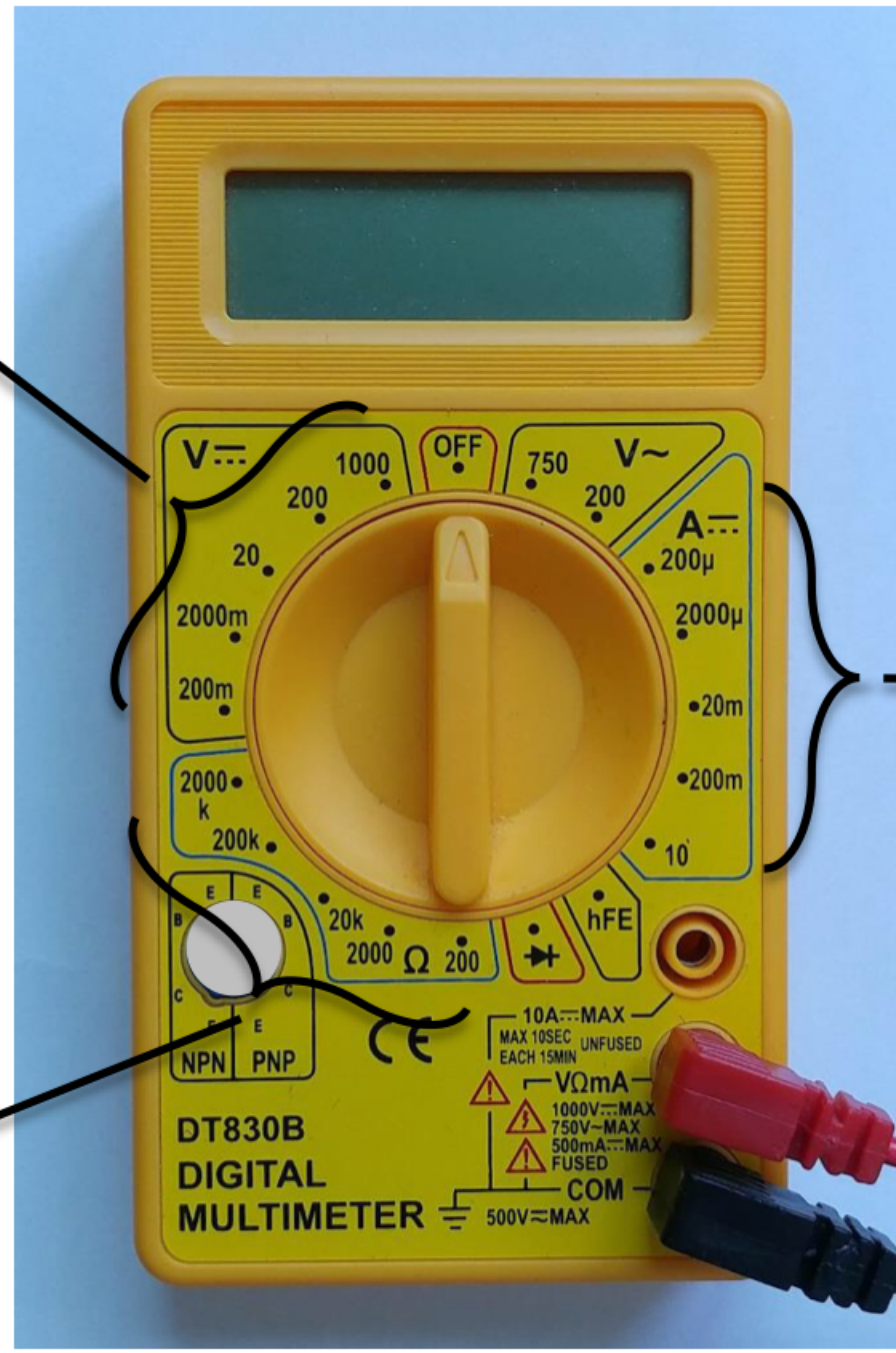
Short circuit



- Direct connection
- Zero resistance
- No potential difference ($v = 0$)

Modes of your digital multimeter (DMM)

Voltage meter
Voltmeter (V)



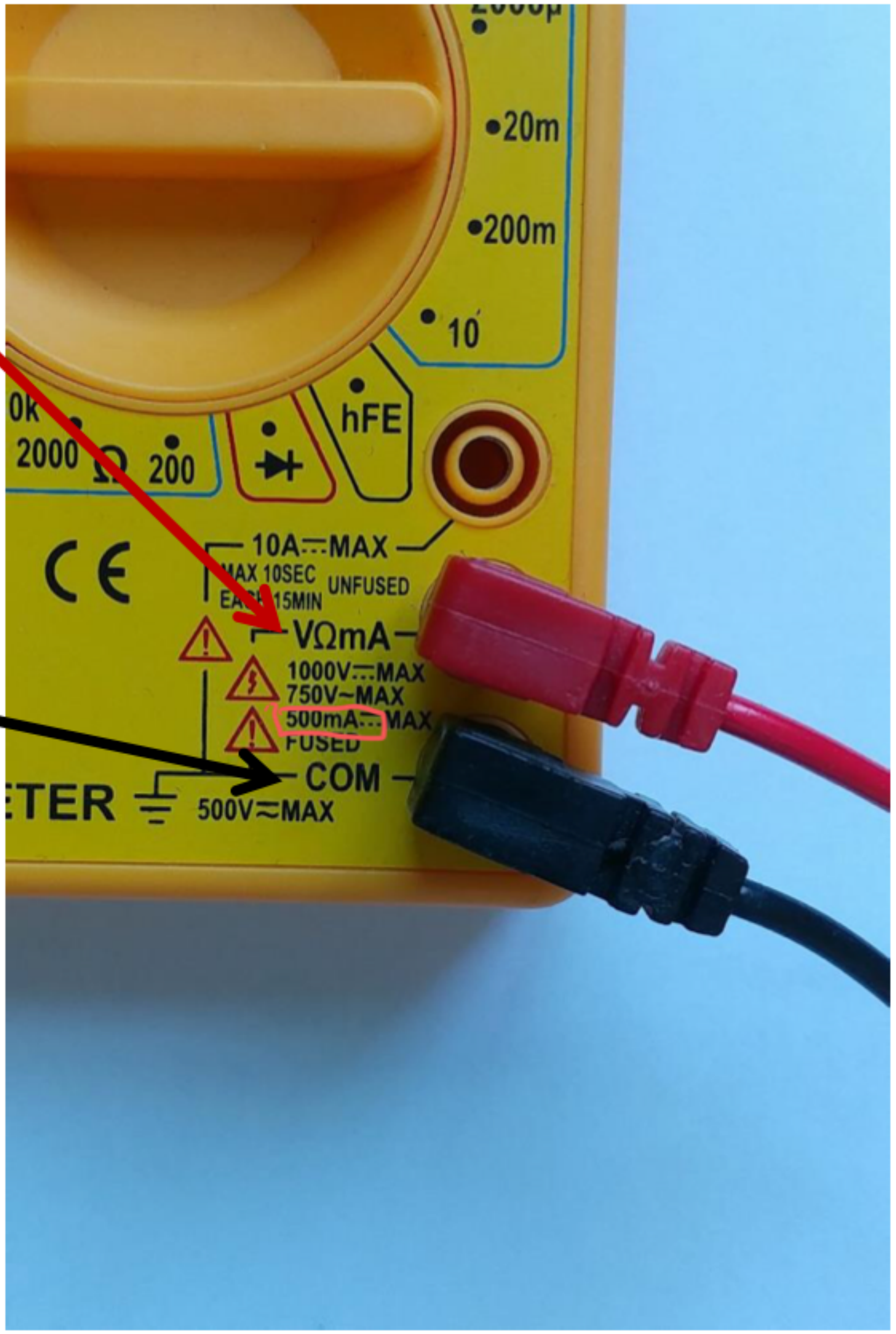
Current meter
Ammeter (A)

Resistance meter
Ohmmeter (Ω)

Other modes are beyond the scope of ENGR 40M—please ask if you're interested

Connecting your multimeter's probes

- Red probe → VΩmA, normally
  - "Volts, ohms and milliamps"
- Black probe → COM
  - "Common"
- 10A(DC) is used for higher current



Using your voltmeter (1)

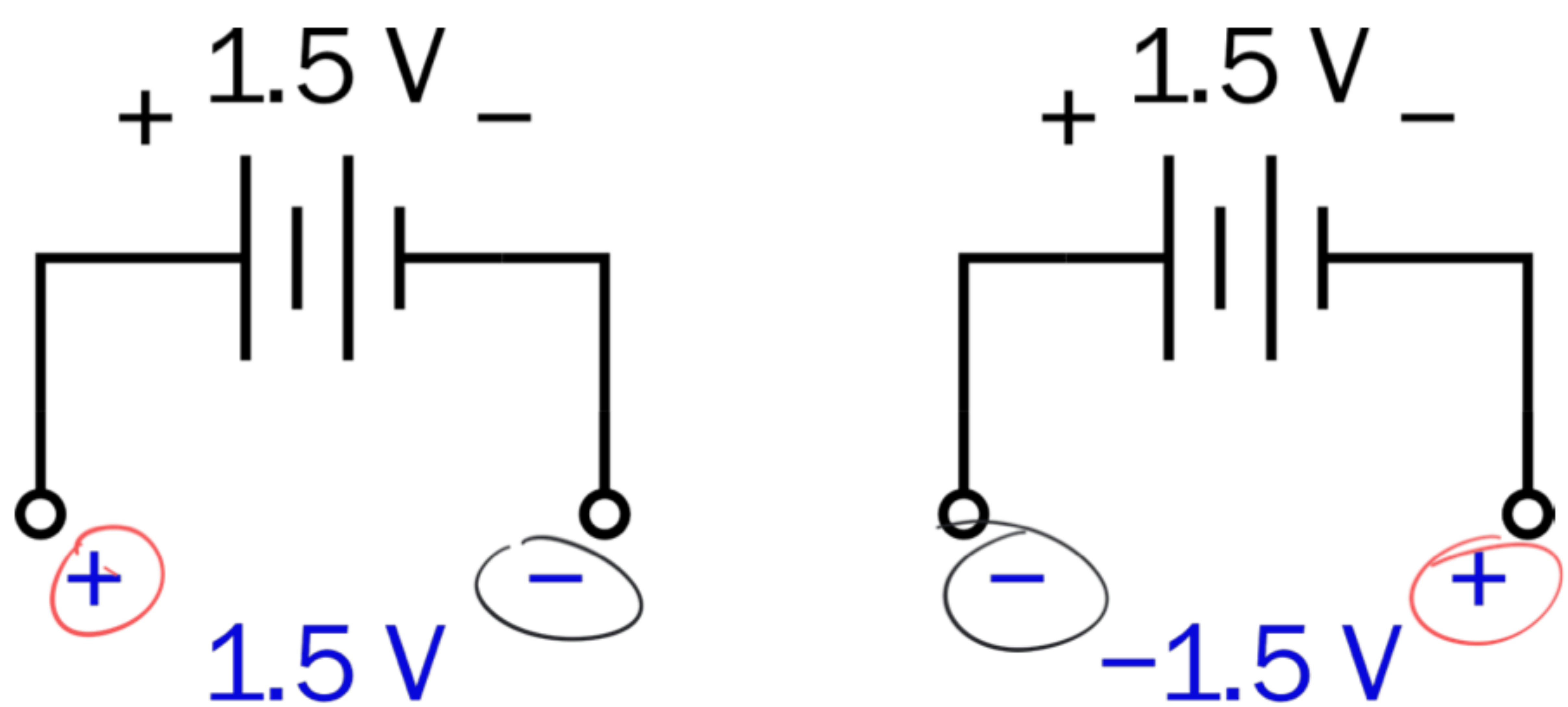
Do now:

- Use the **2000mV** scale
- Grab an AA battery
- Put one probe on each end of the battery
- Make firm contact!

- What happens if you get the probes the "wrong way round"?

Reference directions (voltage)

- When measuring voltage, the **direction** matters
- To avoid ambiguity, we label one side of a device "+", and the other side "−".
- The voltage we measure is **with respect to** this reference direction. So these are equivalent:

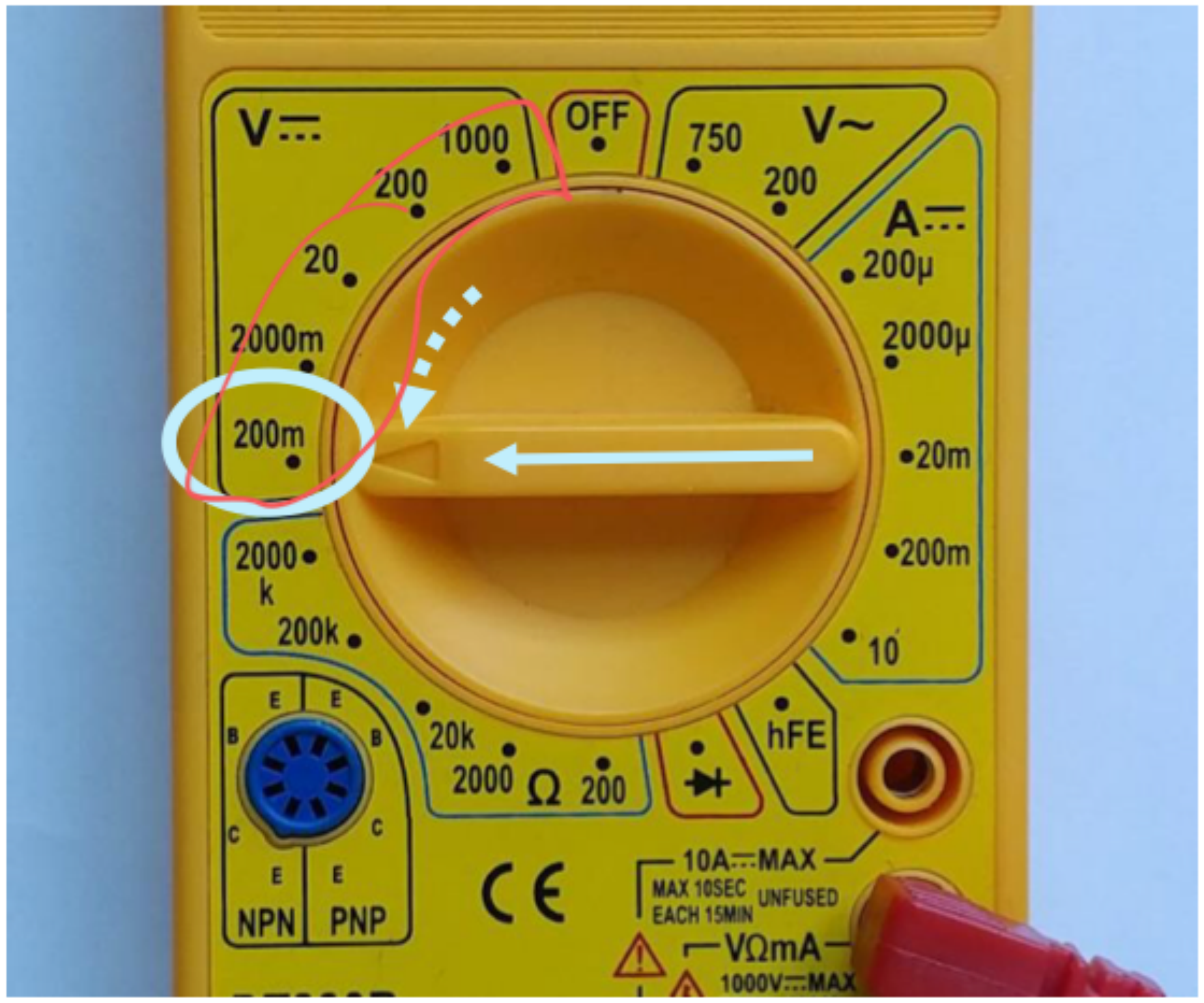


Using your voltmeter (2)

Do now:

- Change to the **200mV** scale. Measure the same battery. What does it say?
- How about on the **20V** scale?

- How should you choose the scale?



Using your multimeter: scales

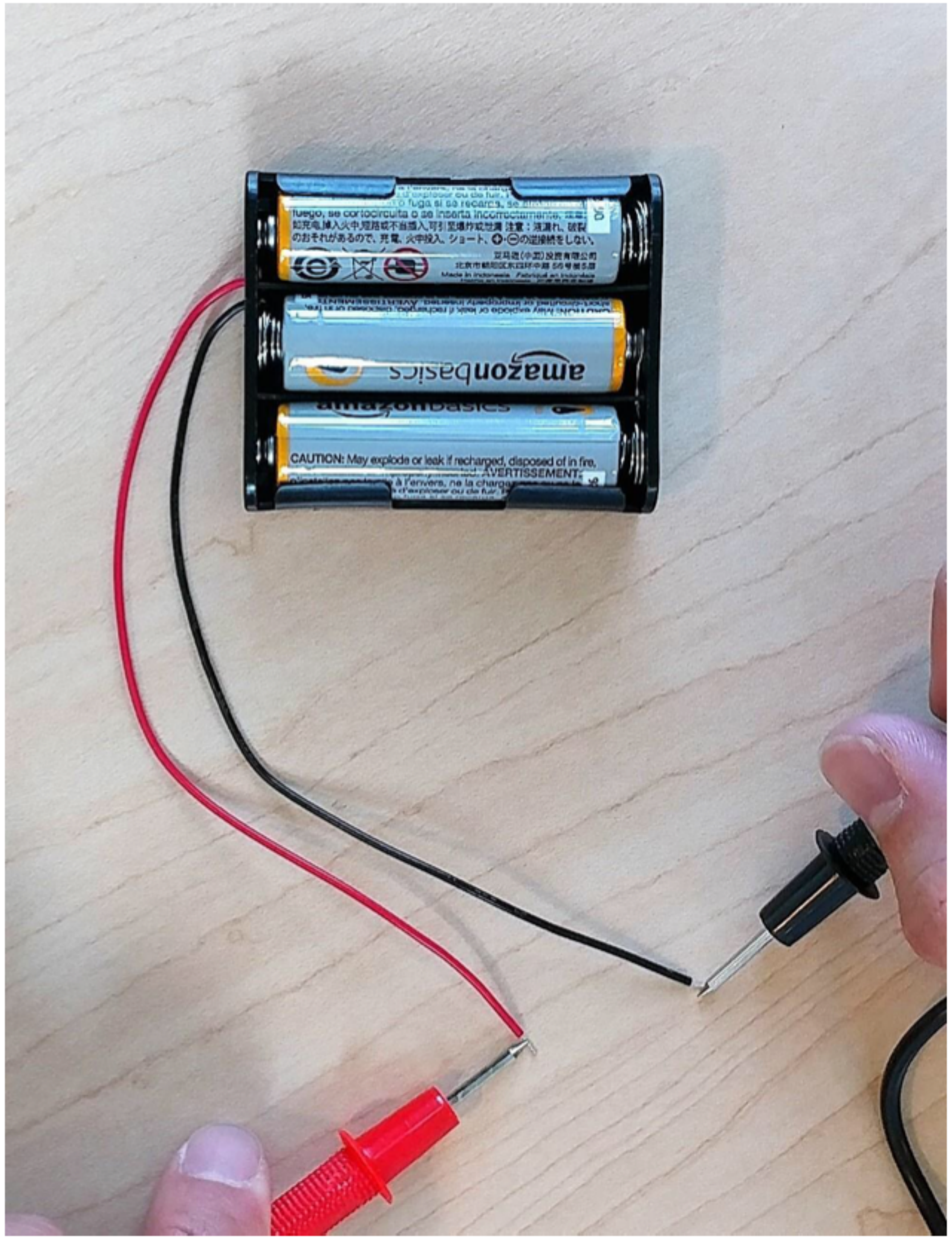
- Your multimeter has **3½ digits**: The 4th digit can only show a "1".
- Numbers indicate the **maximum** that a scale can measure.
- If you measure something exceeding the scale, the meter shows this: 

- To maximize precision, choose the smallest scale greater than what you're measuring.

Using your voltmeter (3)

Do now:

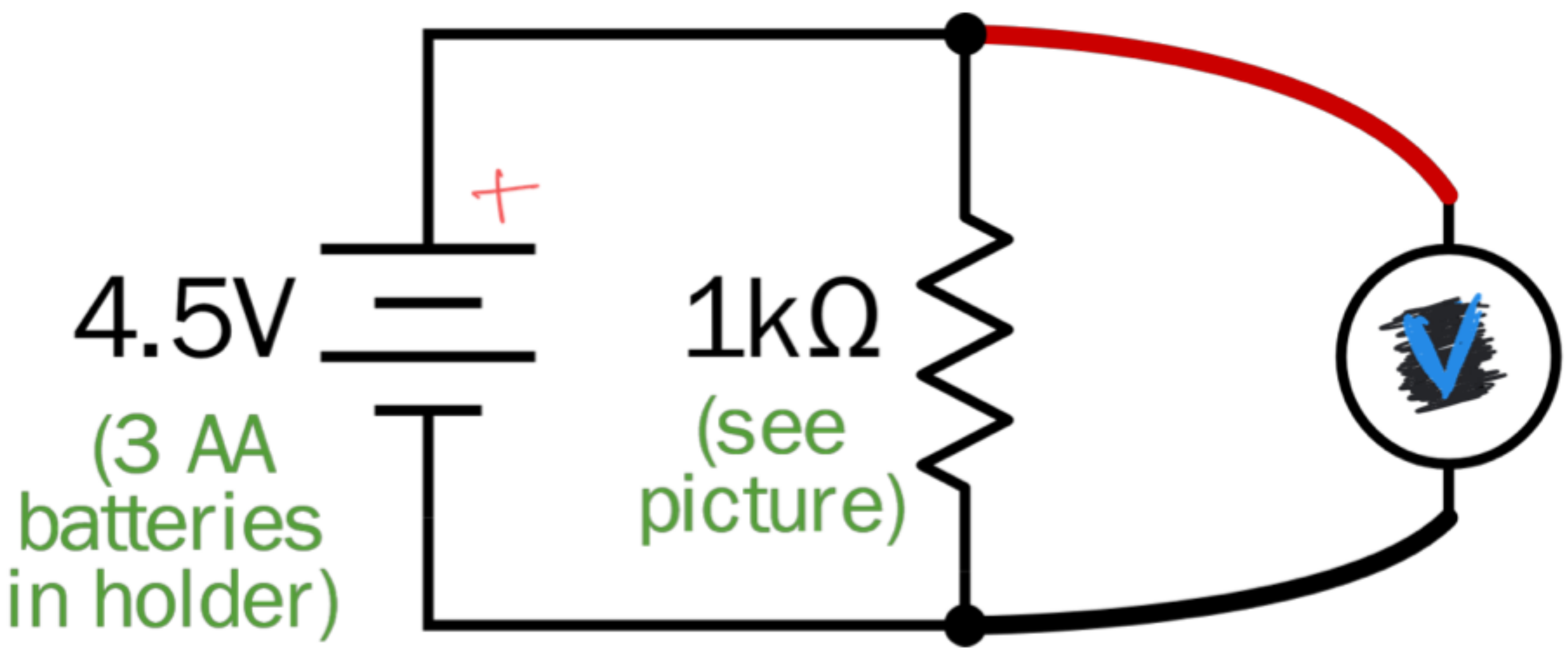
- Place all three AA batteries in the holder
- Don't let the holder wires touch each other
- Measure the voltage across the holder



- You'll need to choose the appropriate scale.
- Are the batteries in series or in parallel?

A very simple circuit

- Make this circuit using crocodile clips
- Measure the voltage across the resistor

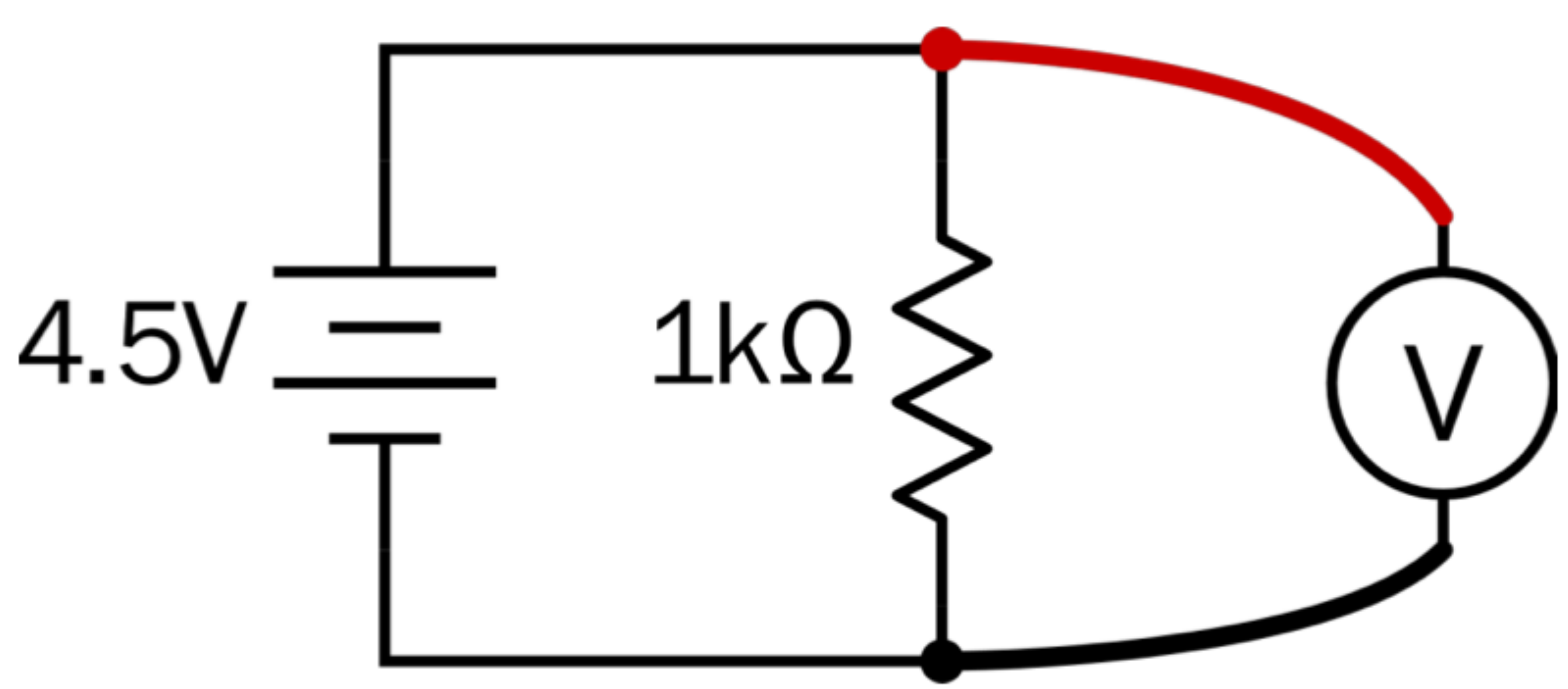


1kΩ resistor:
brown
black
red
gold

- The voltmeter is **in parallel** with the resistor.
- How does this voltage compare to the battery's?

Voltmeters connect in parallel

- To measure a voltage *across* a device, you must probe on *either side* of it.
- Therefore, voltmeters **connect in parallel.**
- In order to avoid affecting the circuit, the voltmeter takes close to *zero current*.
- We say that **the ideal voltmeter looks like an open circuit.**

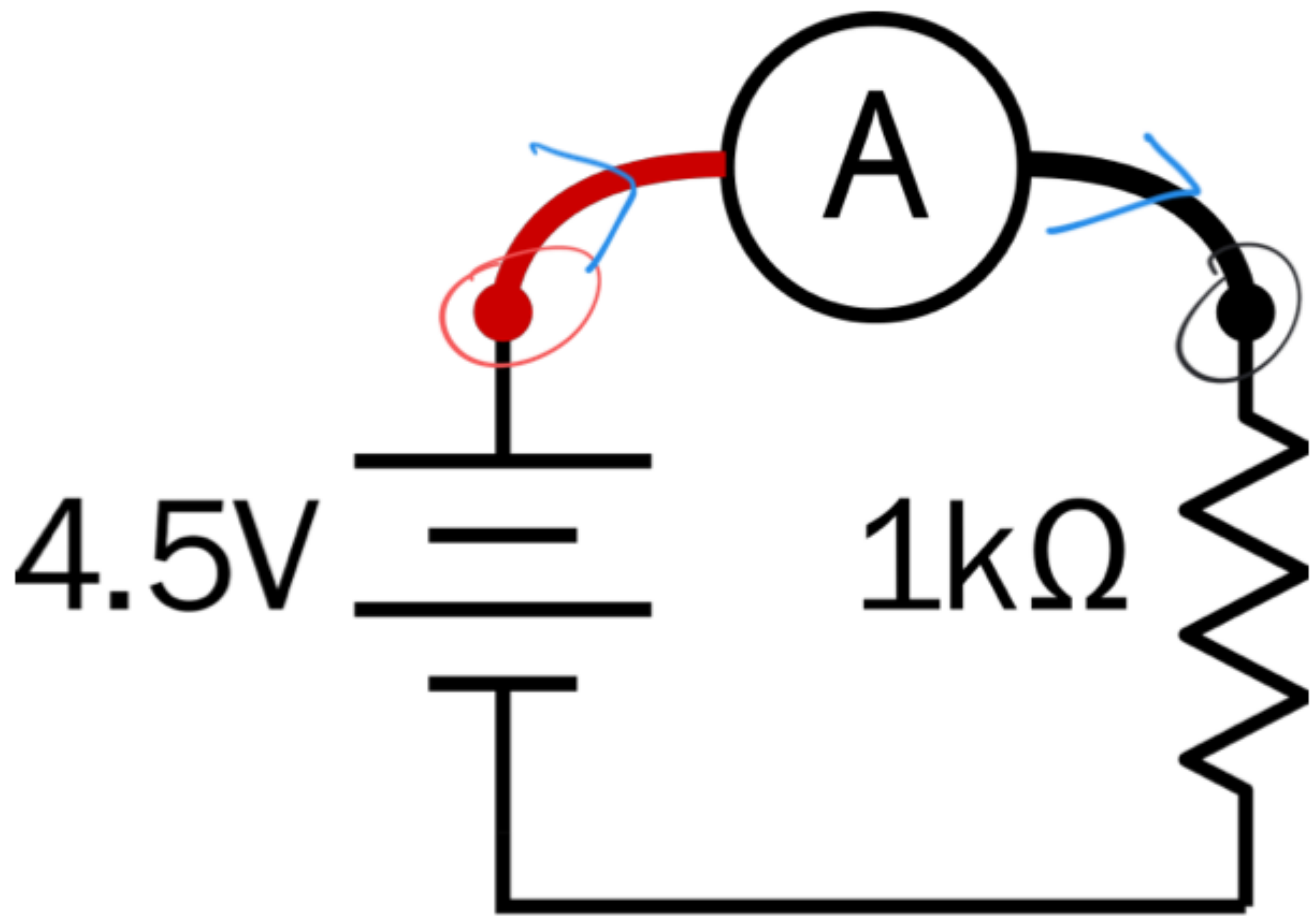


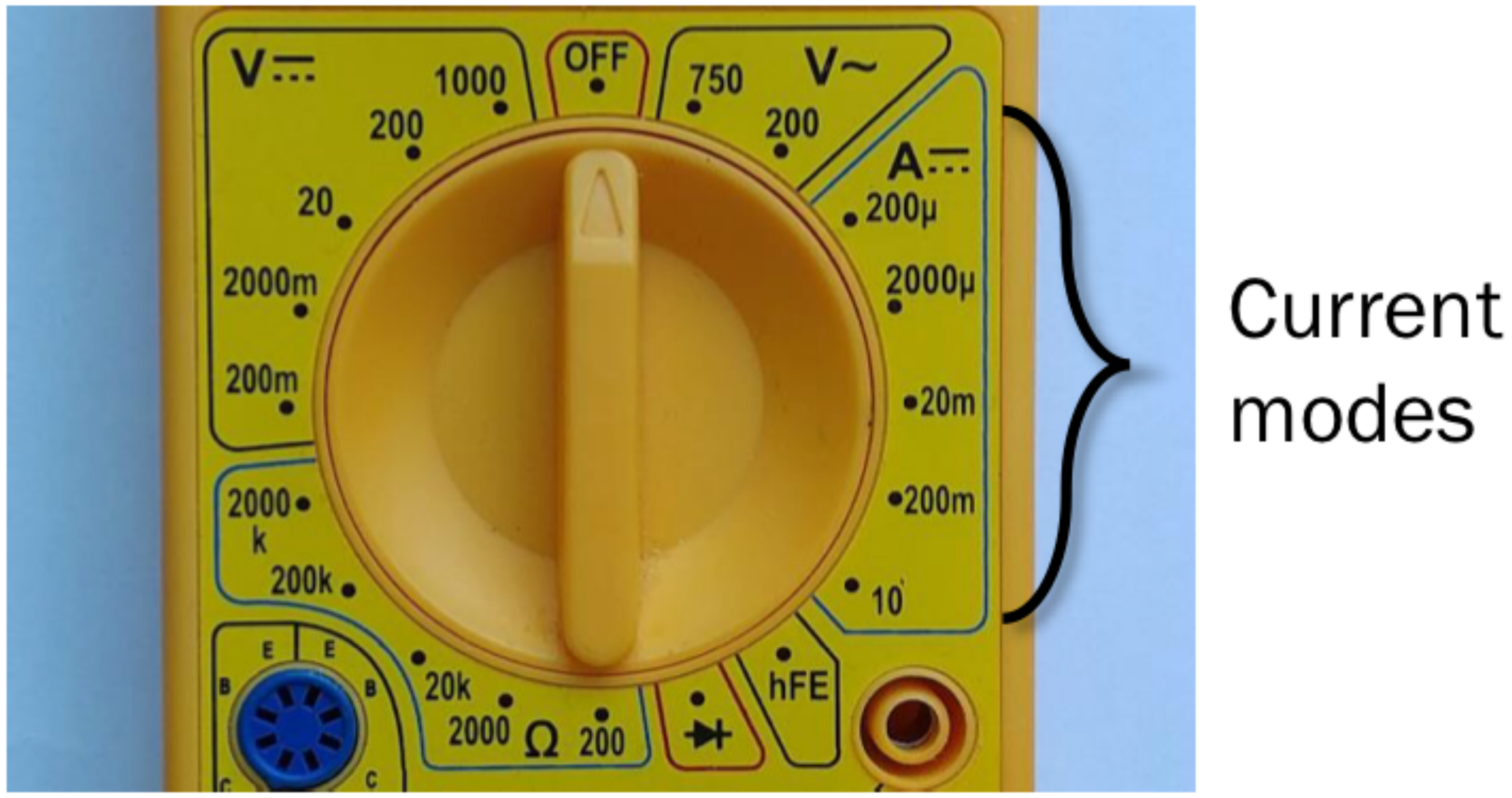
Using your ammeter

Do now:

- Measure the current through the resistor
- Important: The ammeter is **in series** with the resistor

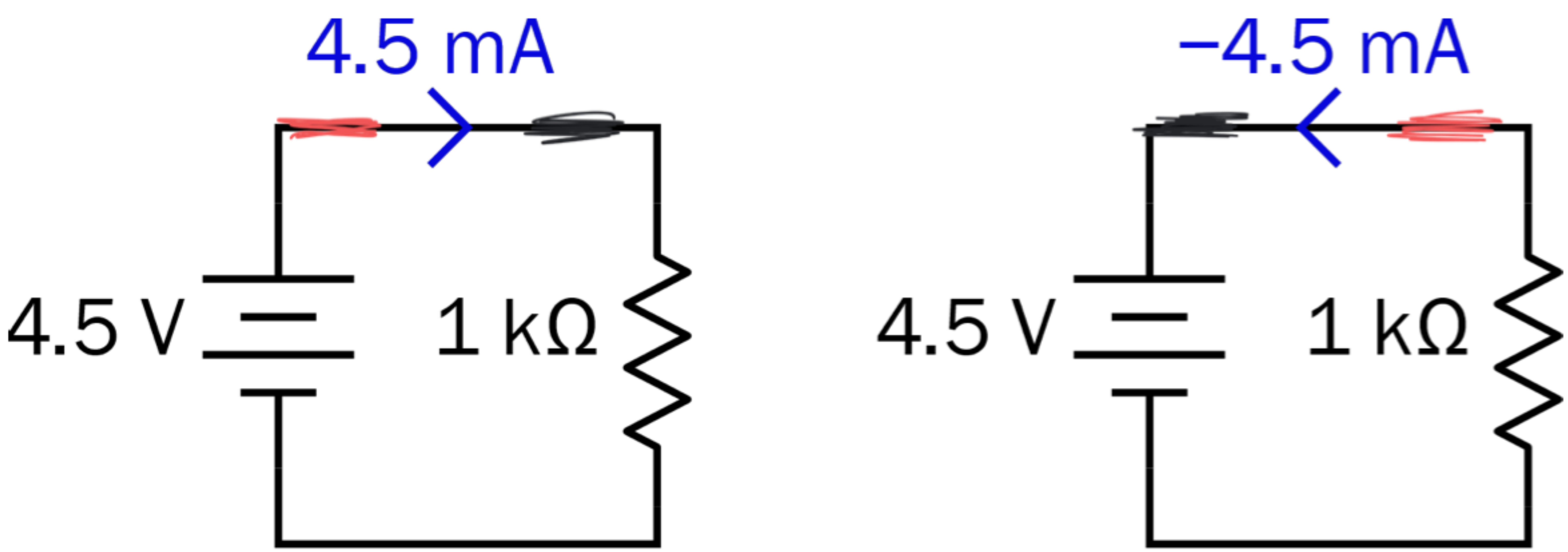
- What happens if you reverse the probes?
- What is the current through the battery?





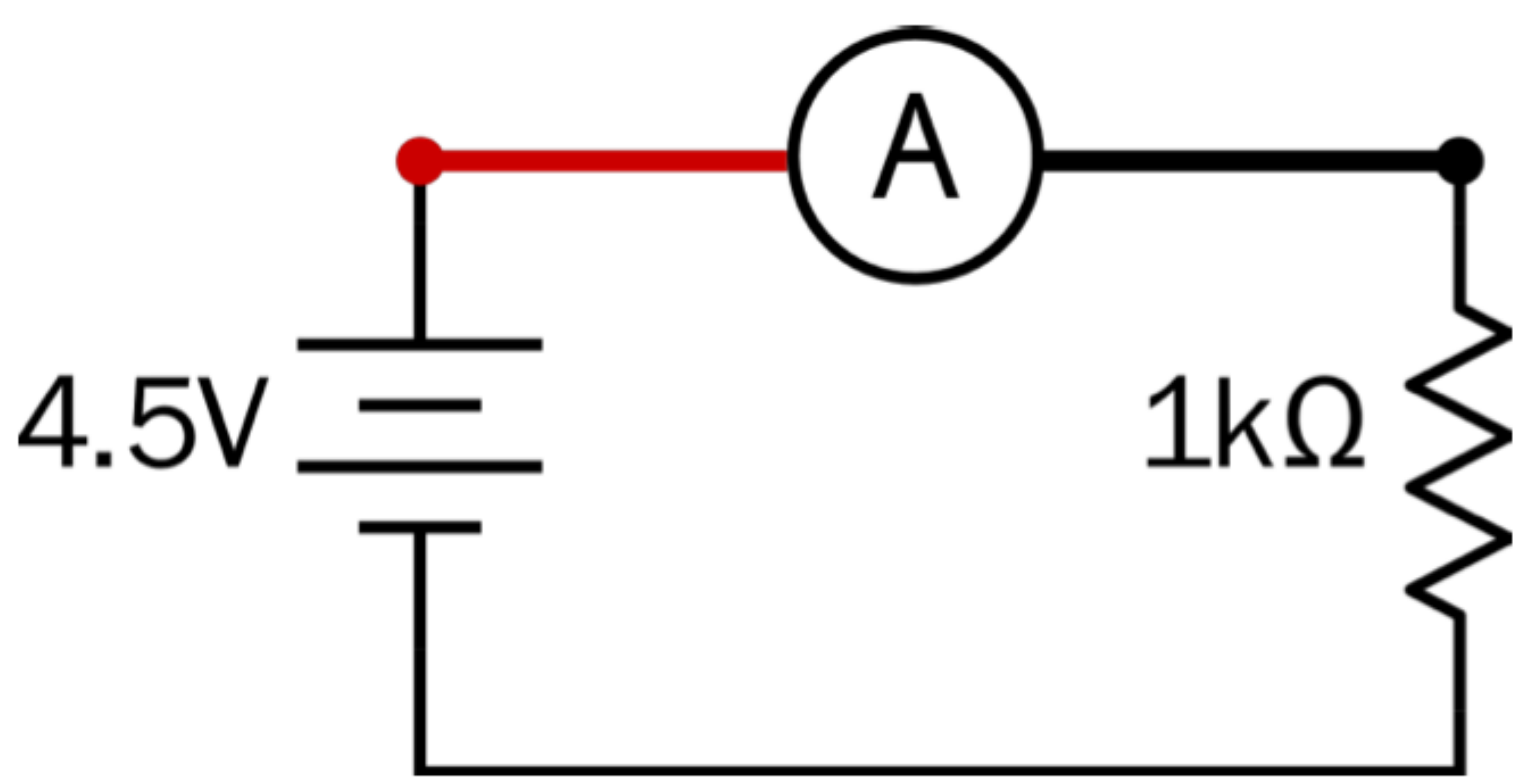
Reference directions (current)

- When measuring current, the **direction** matters
- To avoid ambiguity, we draw an arrow to indicate the direction we're assuming
- The current we measure is **with respect to** this reference direction. So these are the same thing:



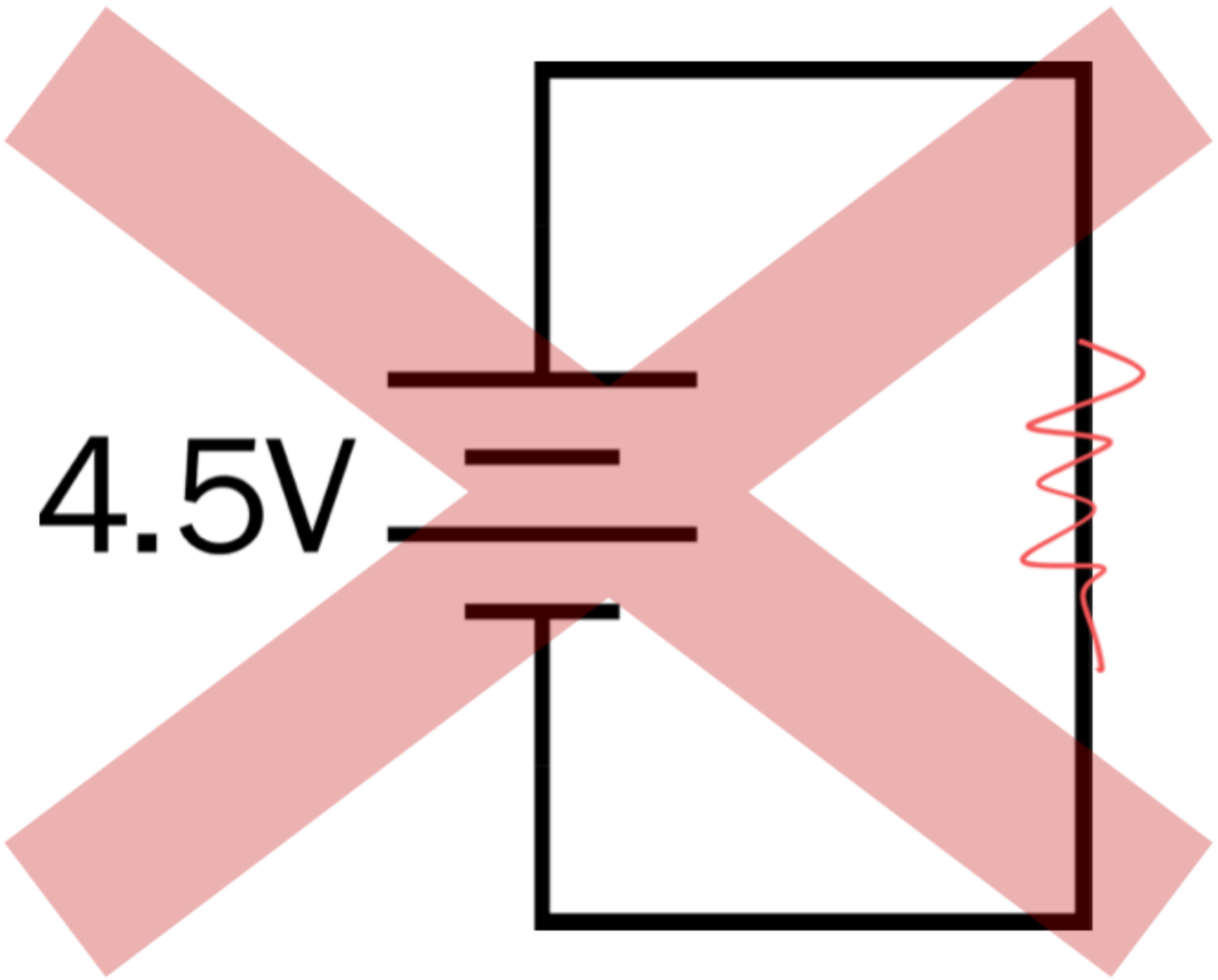
Ammeters connect in series

- To measure current *through* a device, you must place the ammeter to have *the same current* as it.
- Therefore, ammeters **connect in series.**
- In order to avoid affecting the circuit, the ammeter takes close to *zero voltage*.
- We say that **the ideal ammeter looks like a short circuit.**



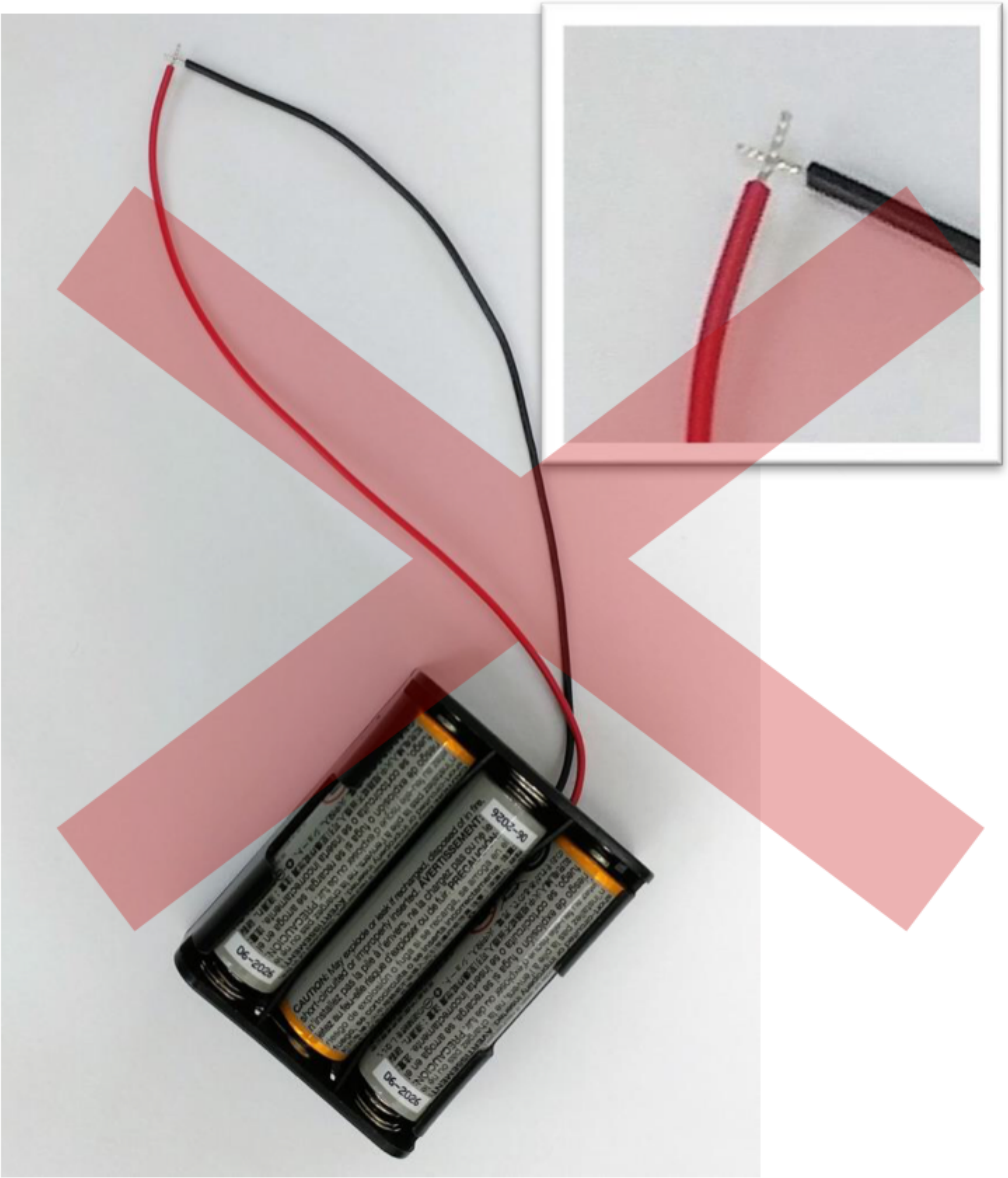
Never short-circuit a battery!

- This circuit violates **Kirchoff's voltage law**
- In practice, if you do this, the wire draws a very large current
- **This can explode a battery!** (Or, make it very hot.)
- We call this **short-circuiting a battery**



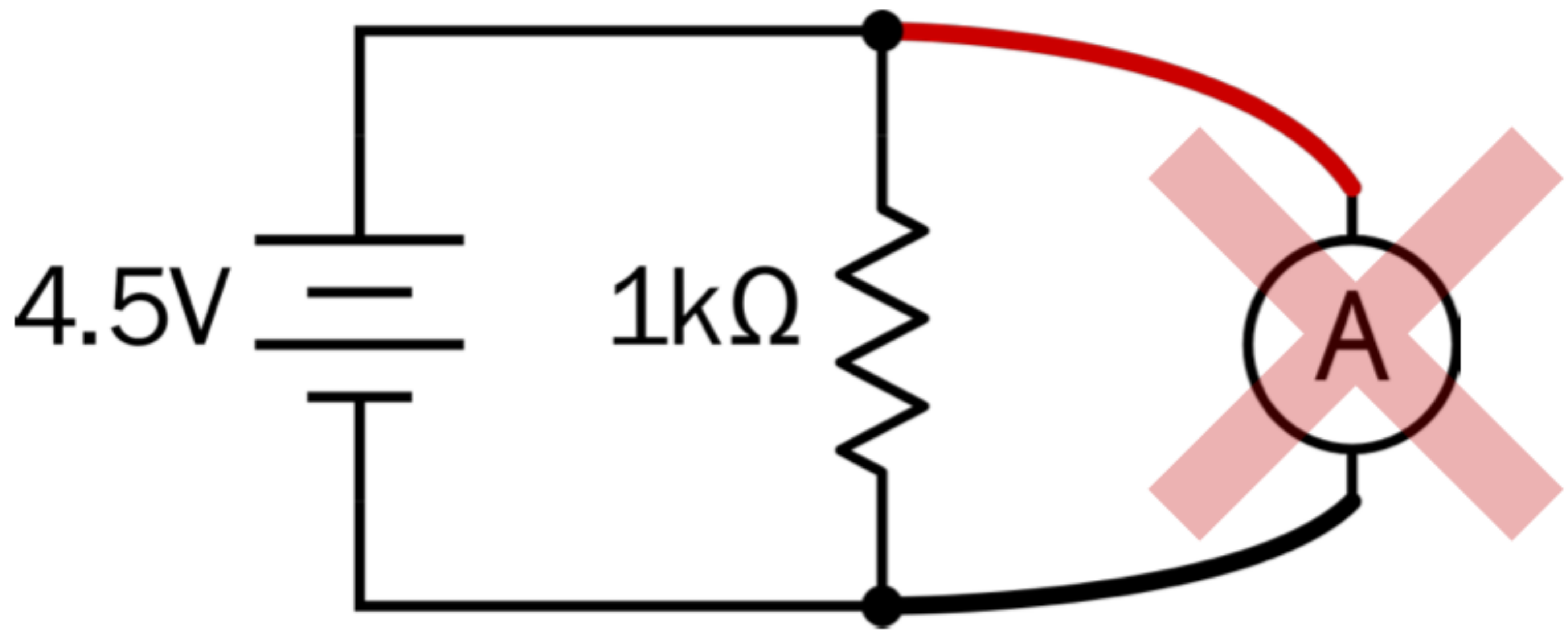
Prevent short circuits, prevent disasters

- Battery (holder) leads can touch by accident, short-circuiting the battery
- Always remove a battery from the holder before putting it away
- Always make sure the leads of the lithium ion battery can't connect



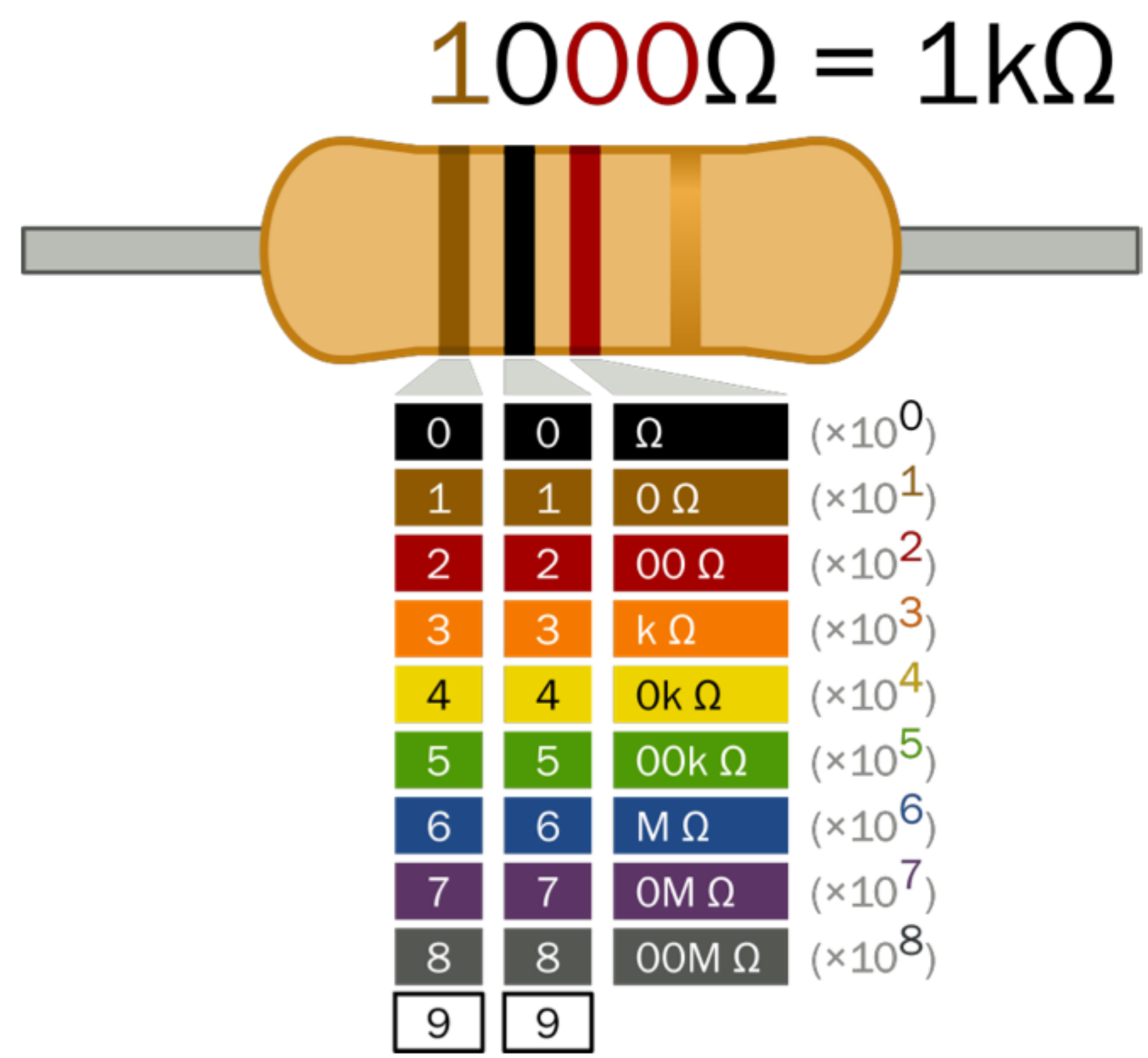
Ammeters can short-circuit batteries!

- Connecting an ammeter in parallel with a battery short-circuits the battery
- This can also damage the multimeter
- **Never connect an ammeter in parallel with a battery**
- Be careful when switching from voltage to current mode!



How to read a resistor

- Resistors are marked with colored bands

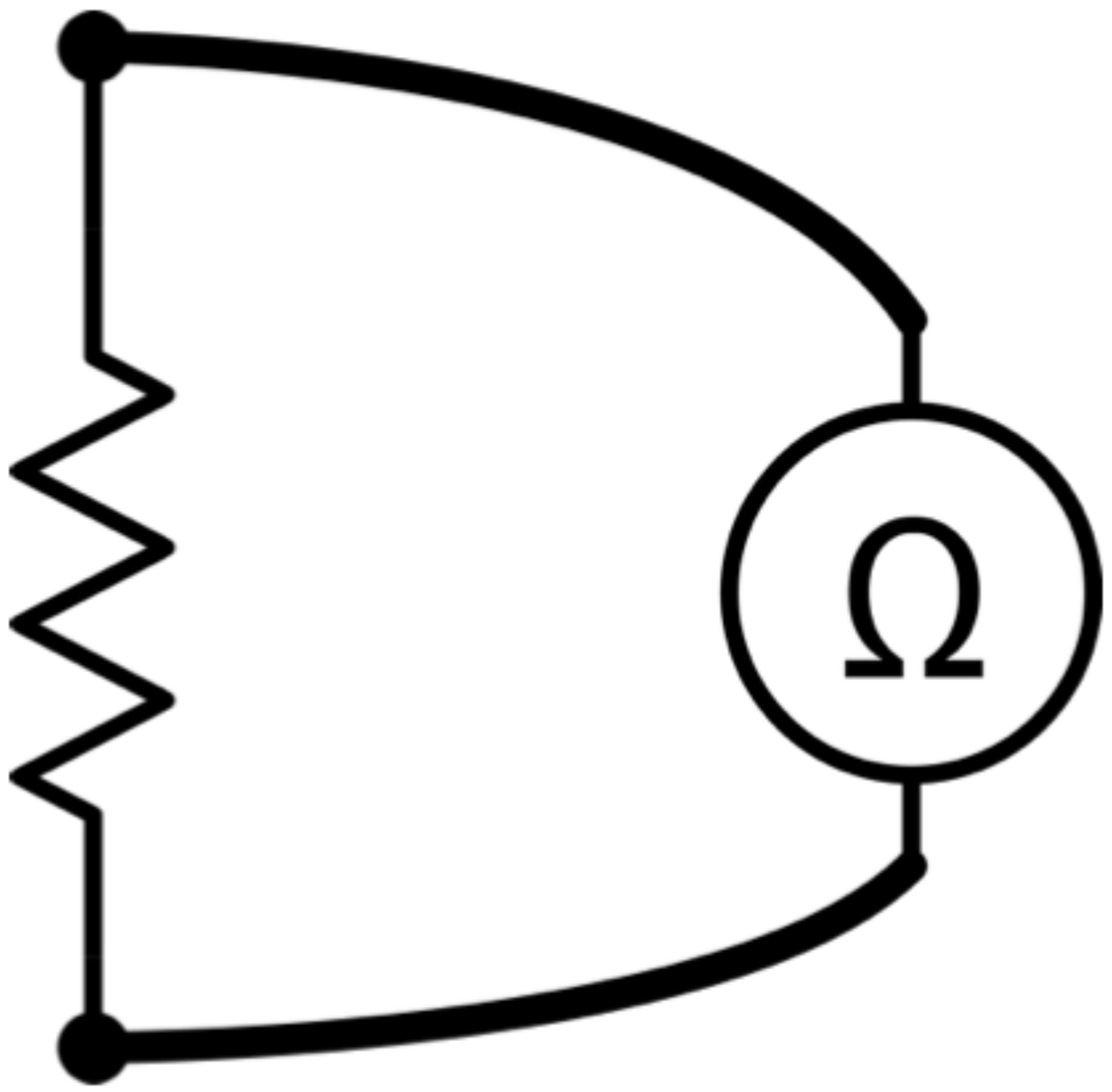


- Pick your favorite resistor, and read its value

Using your ohmmeter

Do now:

- Measure the resistance of the resistor you just read
- Note: No battery!
- Does it match?



- Resistance is measured **without any power**
- For **resistors**, polarity doesn't matter

Resistance modes

Remember

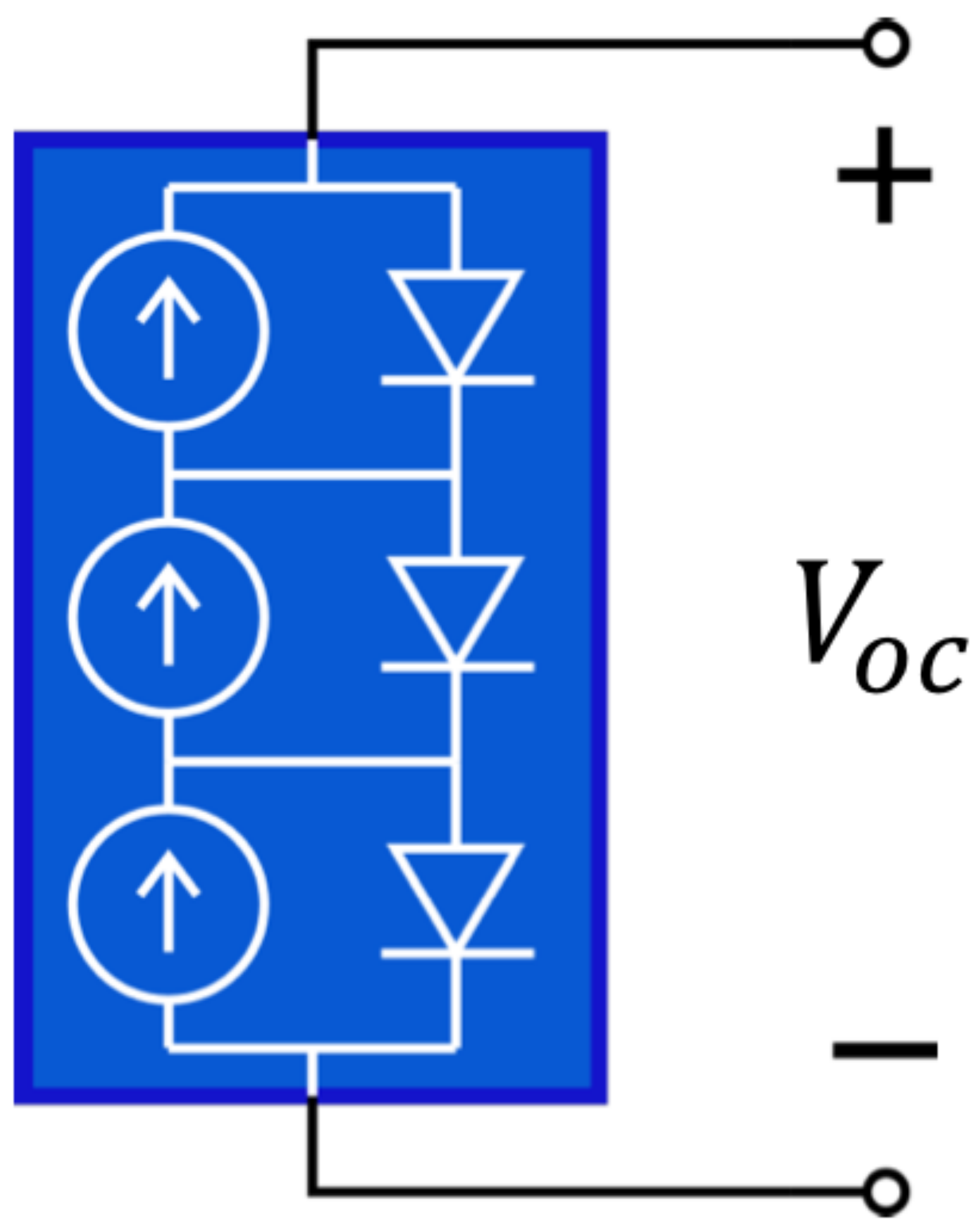
- Voltmeters connect in parallel
- Ammeters connect in series
- Ohmmeters do not connect to a live circuit

- You need to choose the right scale
- Connecting an ammeter incorrectly can destroy your circuit, your multimeter or both

Characterizing your solar cell (1)

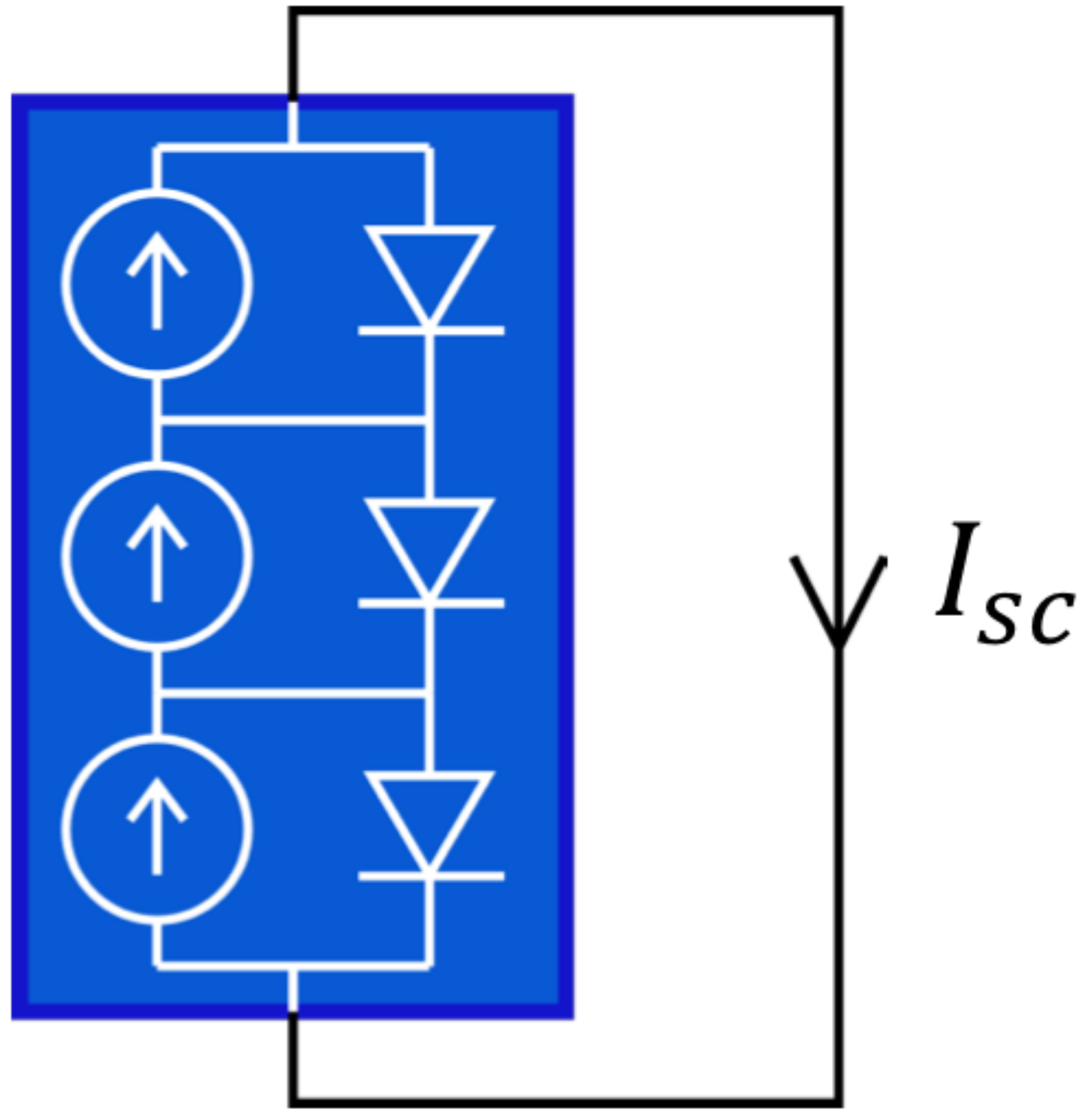
Open-circuit voltage

- Voltage across the cell when connected to an open circuit



Short-circuit current

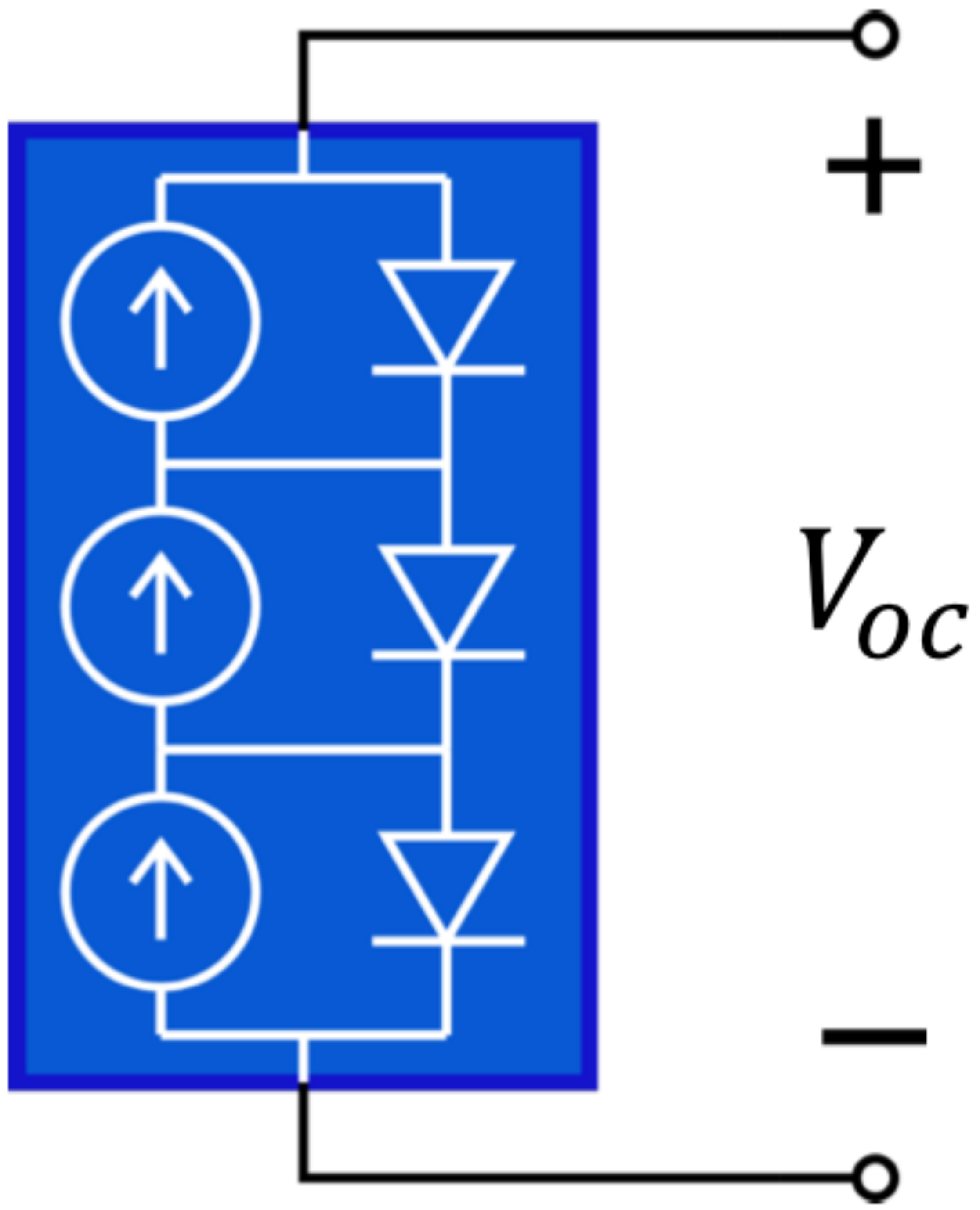
- Current through the cell when connected to a short circuit

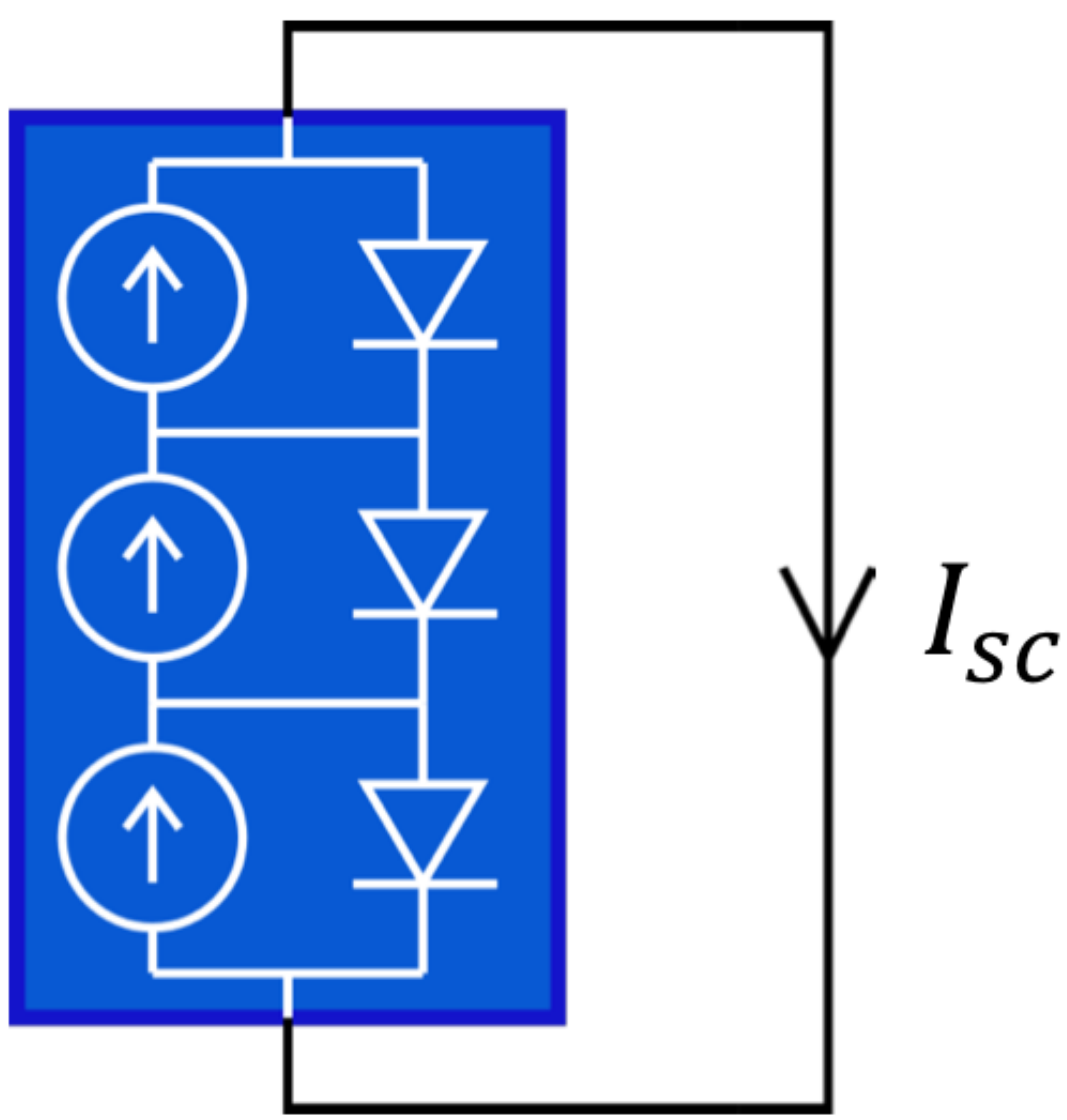


Characterizing your solar cell (2)

- Measure the **open-circuit voltage** of your solar cell
- Measure the **short-circuit current** of your solar cell

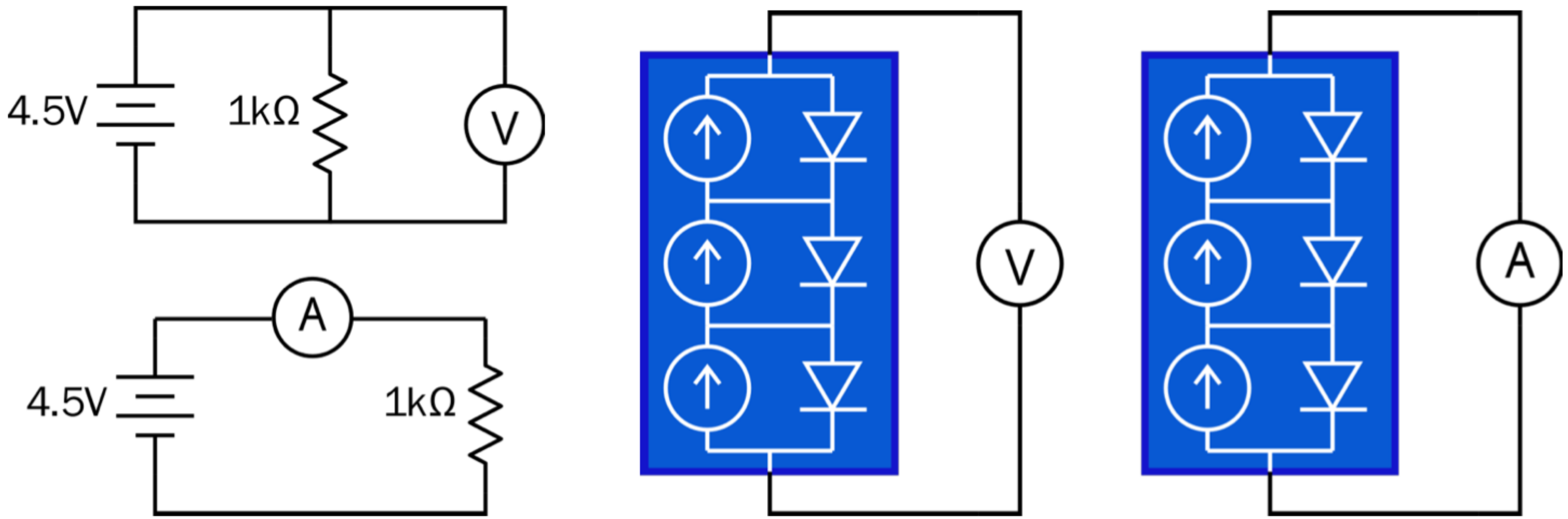
Note: Doing it here is ***not*** the answer to your prelab question P3. Why not?



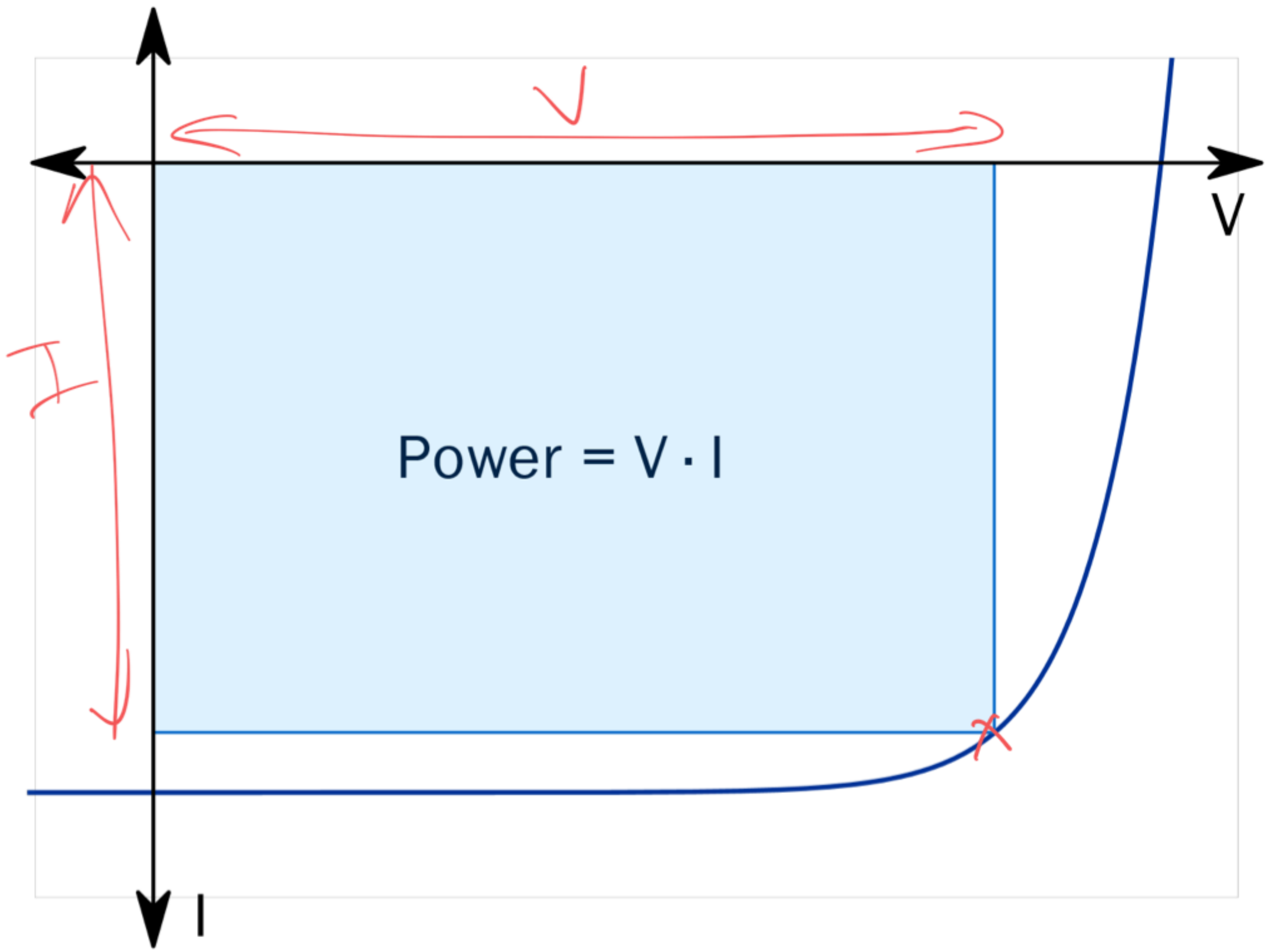


Don’t be fooled

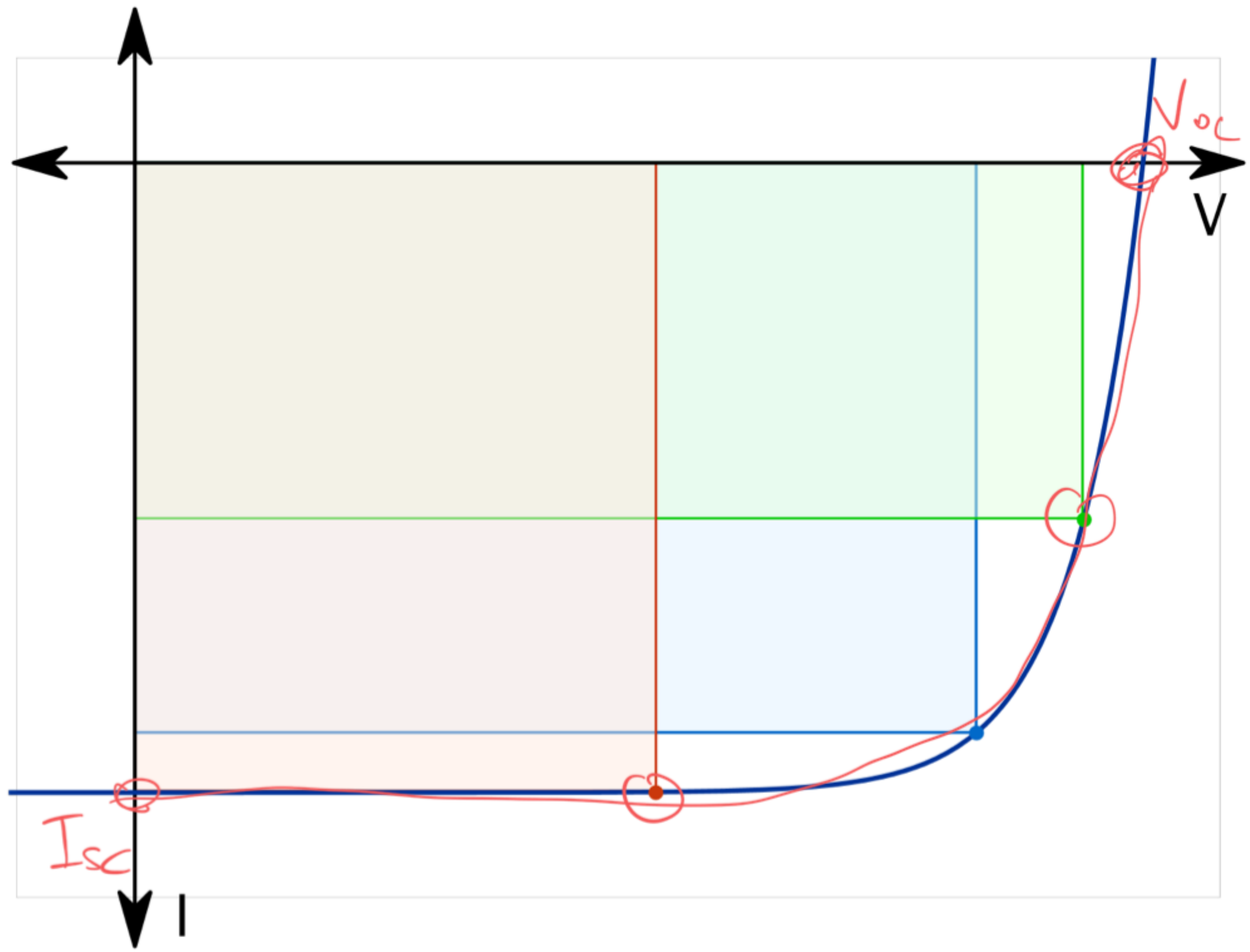
- The two meters on the left are measuring the same circuit
- The two meters on the right are measuring the solar cell in **different circuits!**



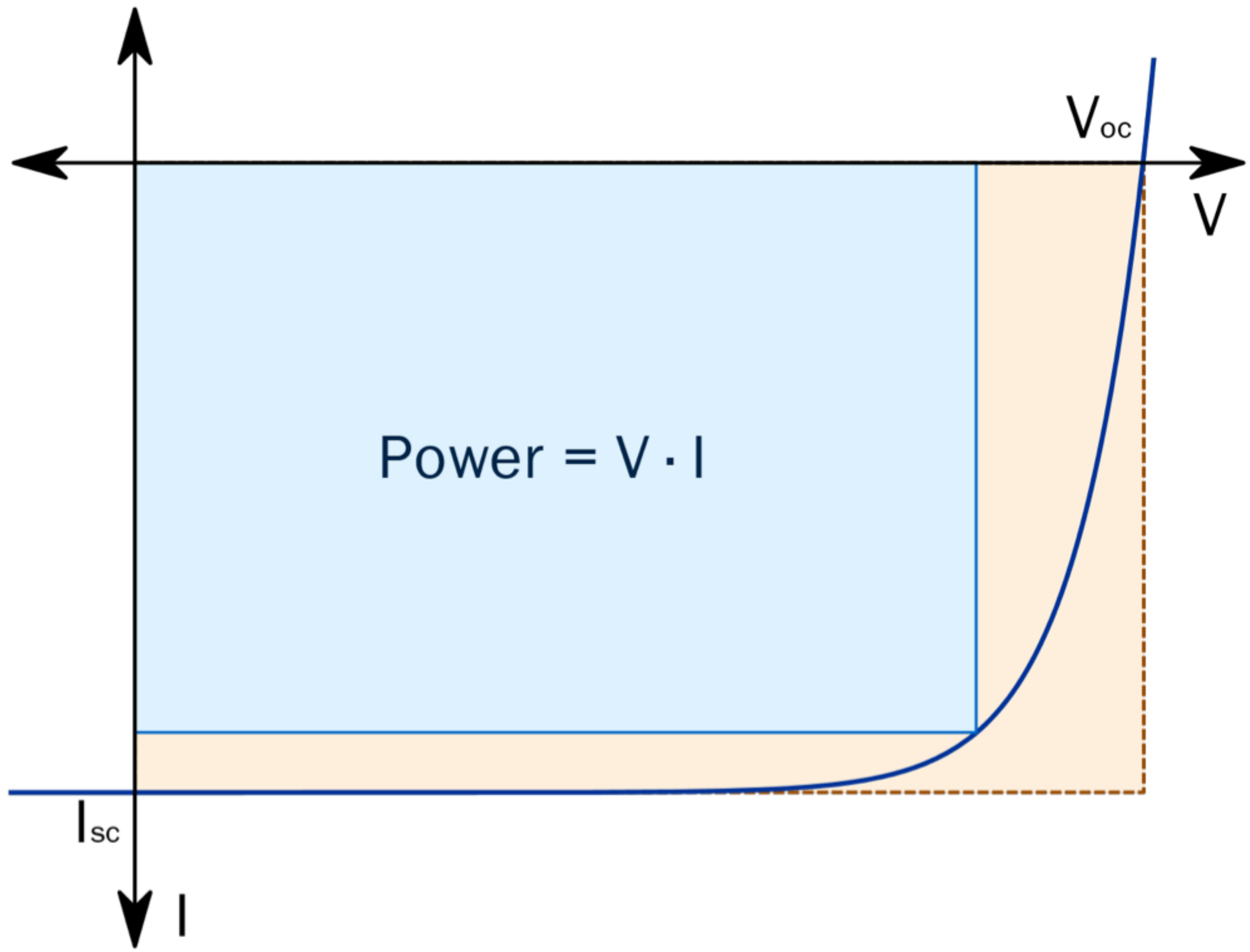
Power from I–V characteristic (1)



Power from I–V characteristic (2)

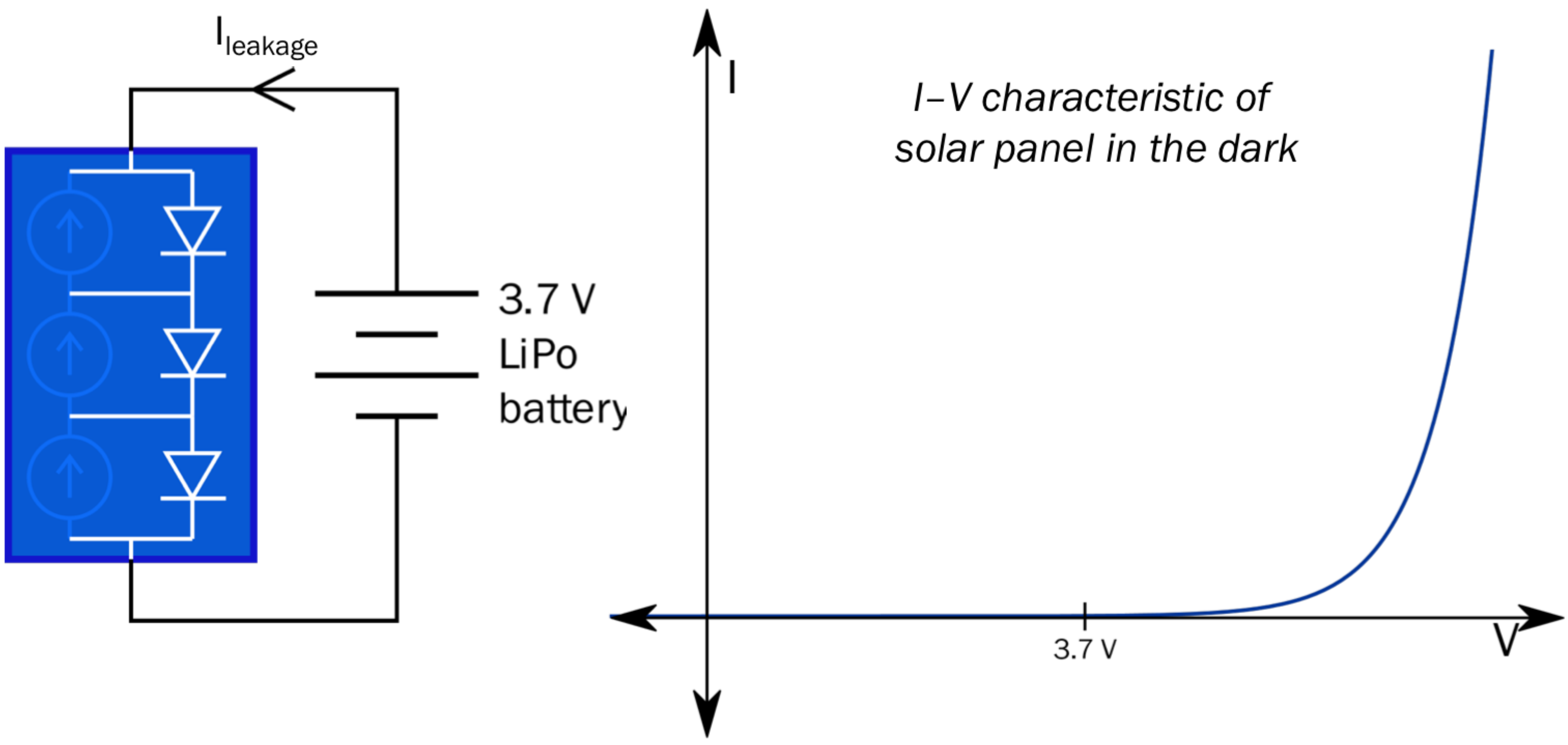


Power from I–V characteristic (3)



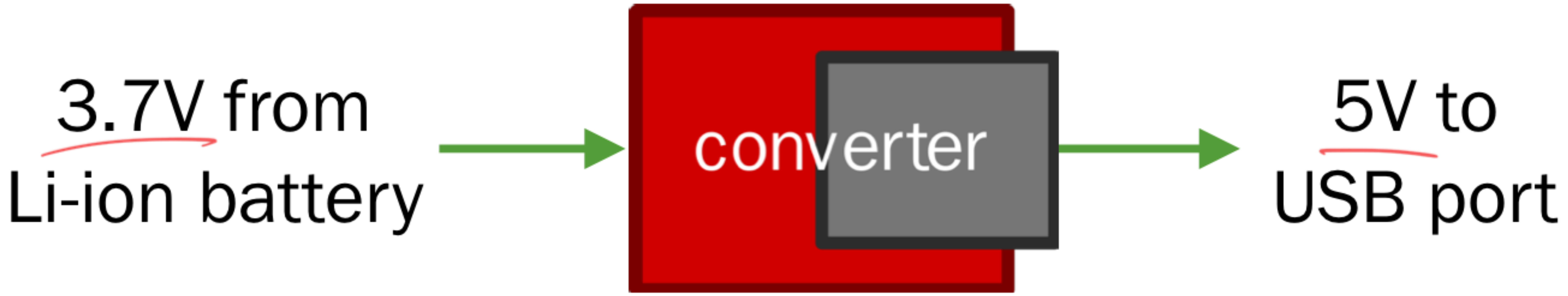
Leakage current

In the dark, the solar panel looks like a stack of diodes



Your voltage converter

- A *voltage converter* is a circuit that takes an input supply at one voltage, and uses it to provide a different voltage to another circuit
- When the output voltage is greater than the input voltage, we call it a **boost converter**
- Your converter will take any voltage less than 5V, and output 5V to its USB port



Voltage converter efficiency

- Conservation of energy implies that the output power cannot be more than the input power

$$V_{\text{in}} I_{\text{in}} = P_{\text{in}} \geq P_{\text{out}} = V_{\text{out}} I_{\text{out}}$$

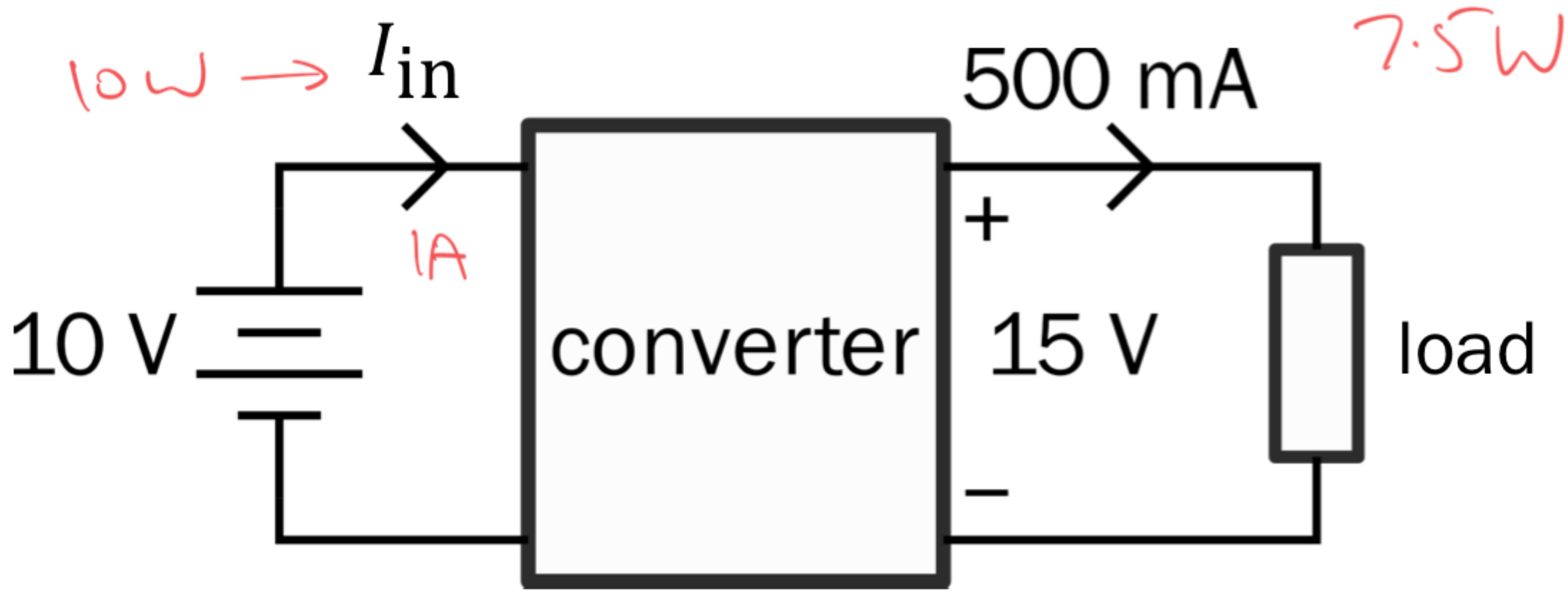
- All real converters lose energy in the conversion. We can compute their **efficiency**:

$$\text{efficiency} = \frac{P_{\text{out}}}{P_{\text{in}}} = \frac{V_{\text{out}} I_{\text{out}}}{V_{\text{in}} I_{\text{in}}}$$

- Efficiency is generally **not** a constant. It is generally quoted under particular conditions.

Converter efficiency: Example

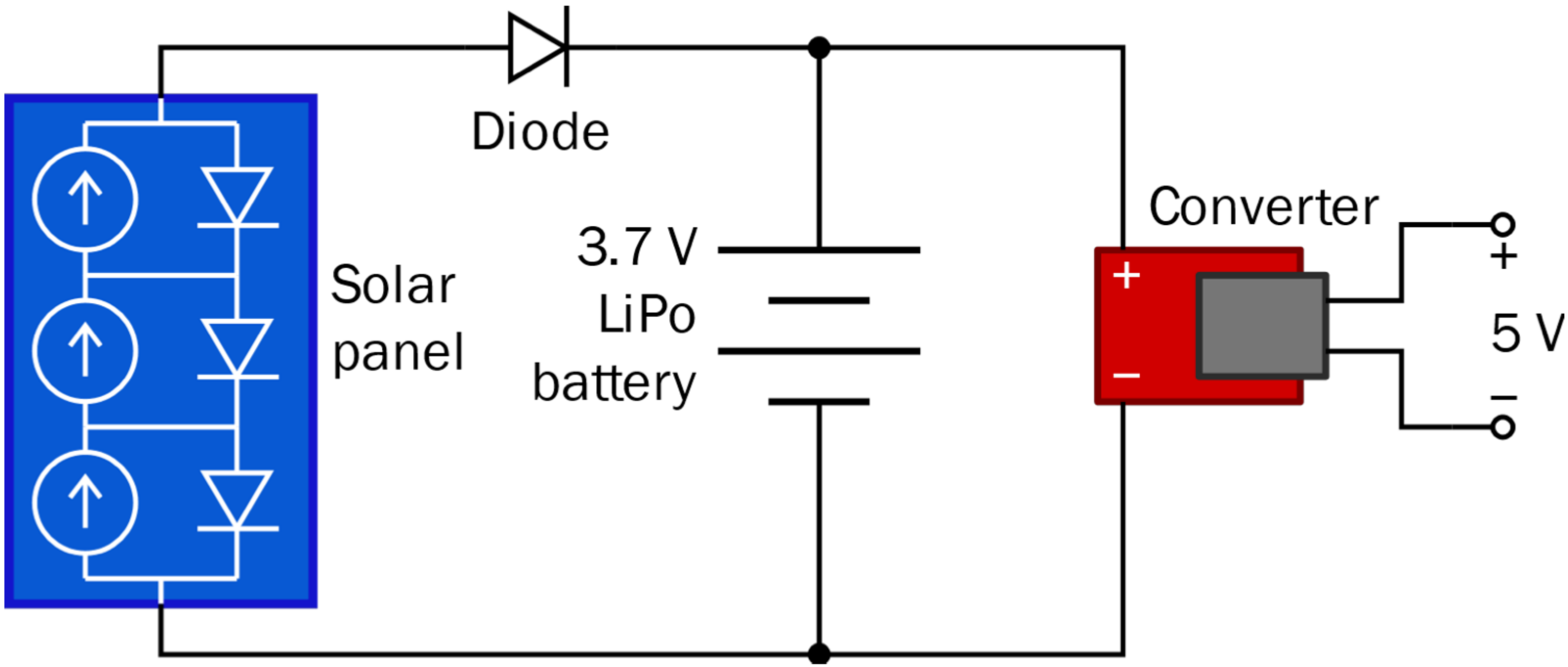
A boost converter takes an input of 10 V and provides an output of 15 V. When a load of 500 mA is placed at the output, its efficiency is 75%. What is the input current I_{in}?



Designing a solar charger circuit

- Battery should power the converter
- Solar panel should charge battery

Your solar charger's circuit



Practical matters: Wire colors

- It is convention in electronics to use
  - **black** for negative/ground, and
  - **red** for positive supply nodes.

- It is really, *really* confusing when you don't follow this convention. Please follow it.

Practical matters: Planning

- Plan your layout before you make anything permanent!
  - How long do your wires need to be?
  - Do you need to fit anything else in?
  - Soldering and tape are hard to undo

- Your LiPo battery must be well protected from the outside world, *e.g.*, sharp objects in your bag

Practical matters: Soldering

- TAs will demonstrate soldering in labs.
- Soldering is a skill that we want you to develop. We will assess your soldering, but not in lab 1.
- You’ve been learning this week, hopefully!
- Your solar panel is a large heatsink, so will be a bit harder. Patience is your friend.