Sources, Multimeters, and Transformers

M.V. Iordache, *EEGR2051 Circuits and Measurements Lab*, Fall 2020, LeTourneau University
See https://mviordache.name/EEGR2051 for more information.

DC Power Supplies

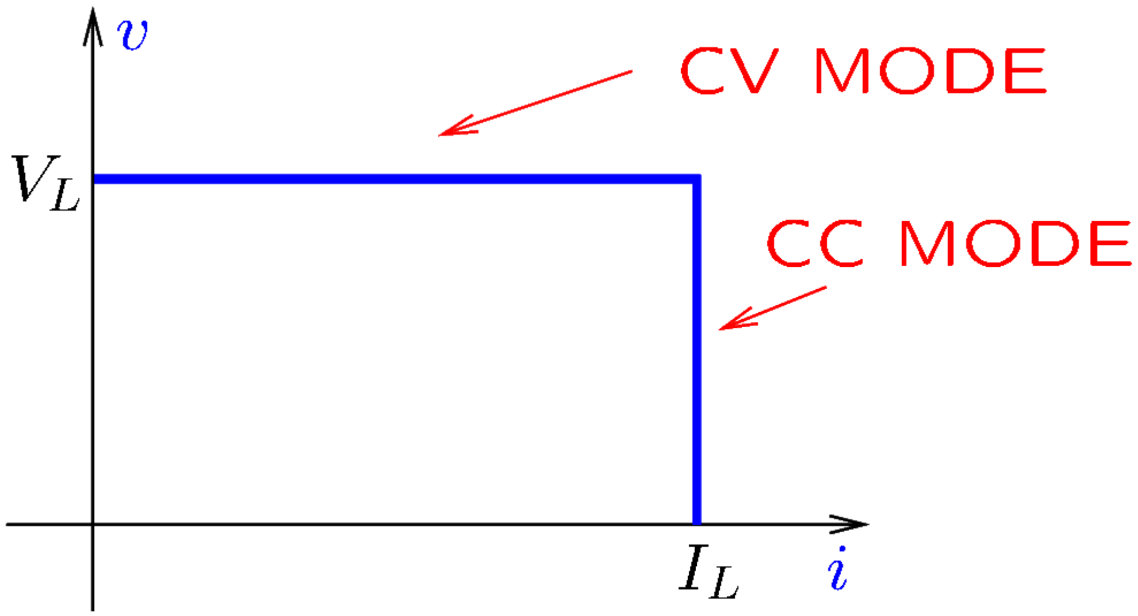
DC Power Supplies—Review

- Consist of electronic circuits that convert the AC supply of the wall outlet to DC.
- Typically, they can operate in
  - constant voltage (CV) mode.
  - constant current (CC) mode.
- The internal resistance of DC power supplies is negligible.
  - In CV mode, the source resembles an ideal source of voltage.
  - In CC mode, the source resembles an ideal source of current.

A triple DC power supply.

DC Power Supplies—Review

- When using the power supply:
  - Set the voltage limit V_L. *This will be the voltage in CV mode.*
  - Set the current limit I_L. *This will be the current in CC mode.*
- Let v be the output voltage and i the output current.
- If the source powers a circuit requiring a current $i < I_L$ at the voltage V_L, then the source operates in CV mode at $v = V_L$.
- If the circuit requires a voltage $v < V_L$ at the current $i = I_L$, then the source operates in CC mode at $i = I_L$.
- At any time, either $v = V_L$ or $i = I_L$.



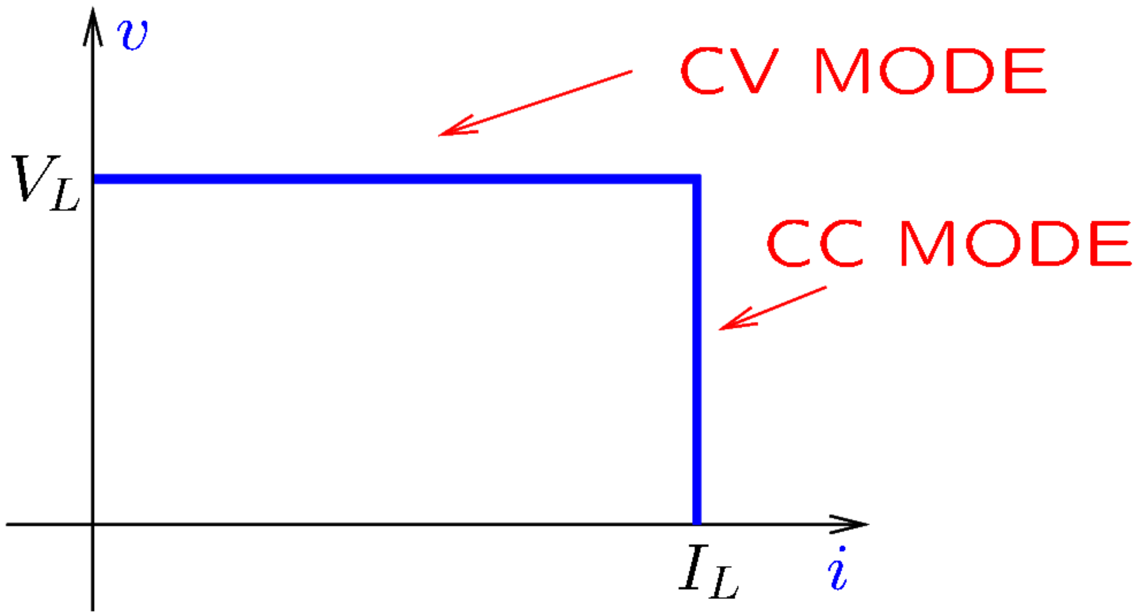
DC Power Supplies

Example: A DC power supply has $V_L = 10\ V$ *and* $I_L = 4\ A$*. Find the short-circuit current.*

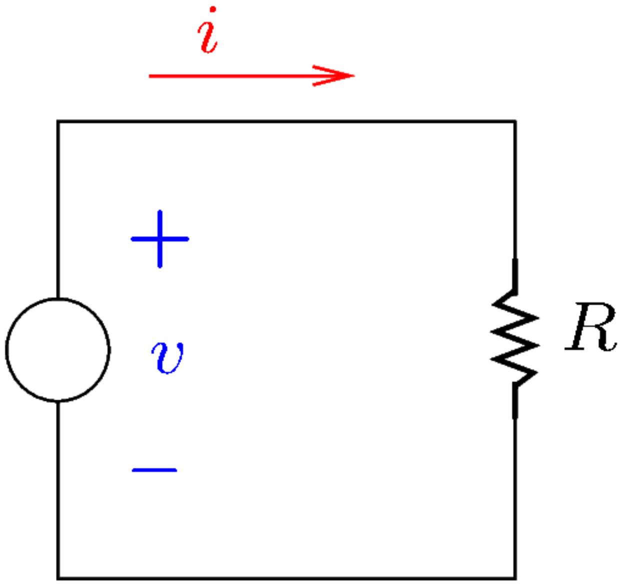
- Ideally, the resistance of a short-circuit is zero.
- Therefore, $v = 0$.
- The curve indicates that $i = I_L$ when $v = 0$. The answer is $i = 4\ A$.

Example: In the previous example, what is the open-circuit voltage?

- An open circuit implies $i = 0$.
- The curve indicates that $v = V_L$ when $i = 0$. The answer is $v = 10\ V$.



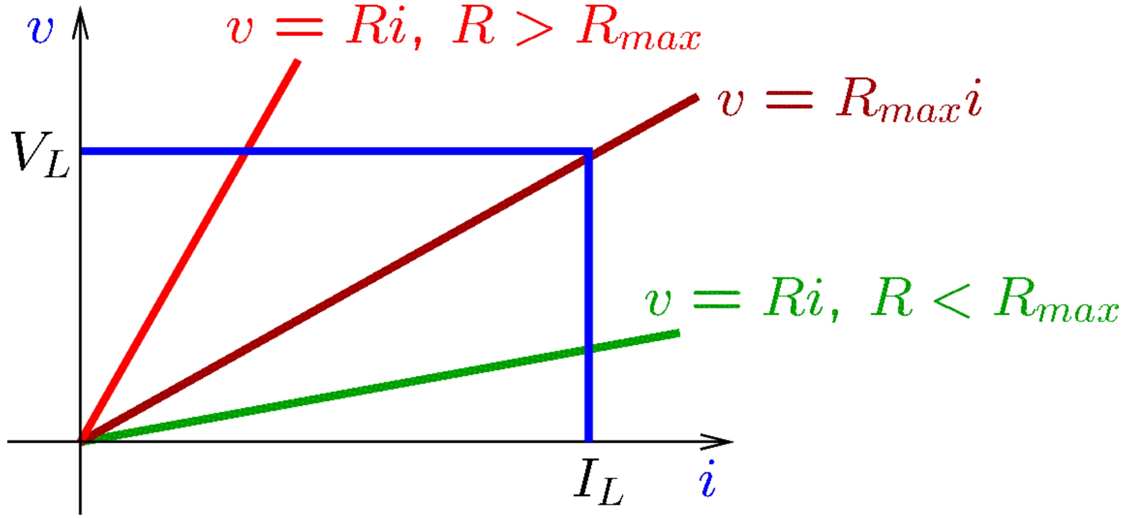
DC Power Supplies



Example: Assuming a CV/CC supply with $V_L = 15$ V and $I_L = 3$ A, find the maximum value of R for which the load operates in CC mode.

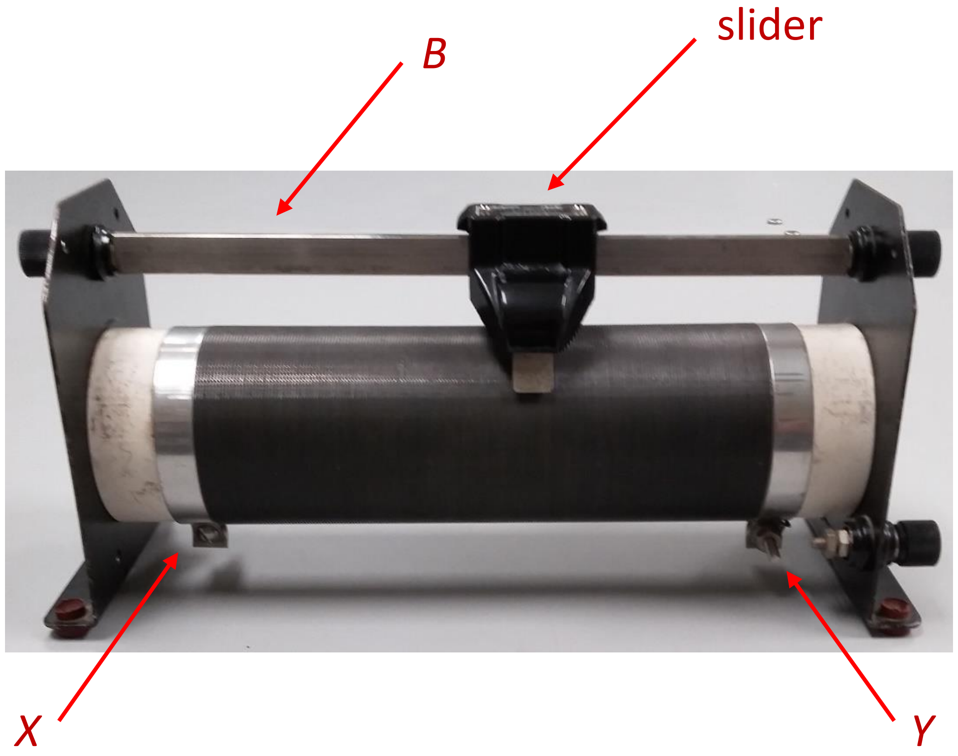
- *By Ohm's law, $v = Ri$.*
- *The equation $v = Ri$ describes a line of slope R.*
- *The maximum slope for which the line intersects the curve of the source in the CC region is*

$$R_{max} = \frac{V_L}{I_L} = 5\ \Omega$$



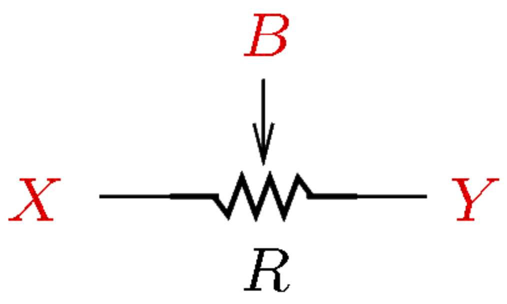
Adjusting Current and Voltage

- If the voltage of a DC source cannot be changed, a simple way to adjust the load current is with a *rheostat*.
- A rheostat is a variable resistor rated for high power levels.
- In a *slide rheostat*:
  - Resistive wire wound around an insulating tube forms a resistor.
  - Let *X* and *Y* be the resistor terminals.
  - A *slider*, also known as *wiper*, slides on a conductive bar *B* while touching the resistive wire.
  - By moving the slider left or right, it is possible to vary the resistance between *B* and *X* or *B* and *Y*.

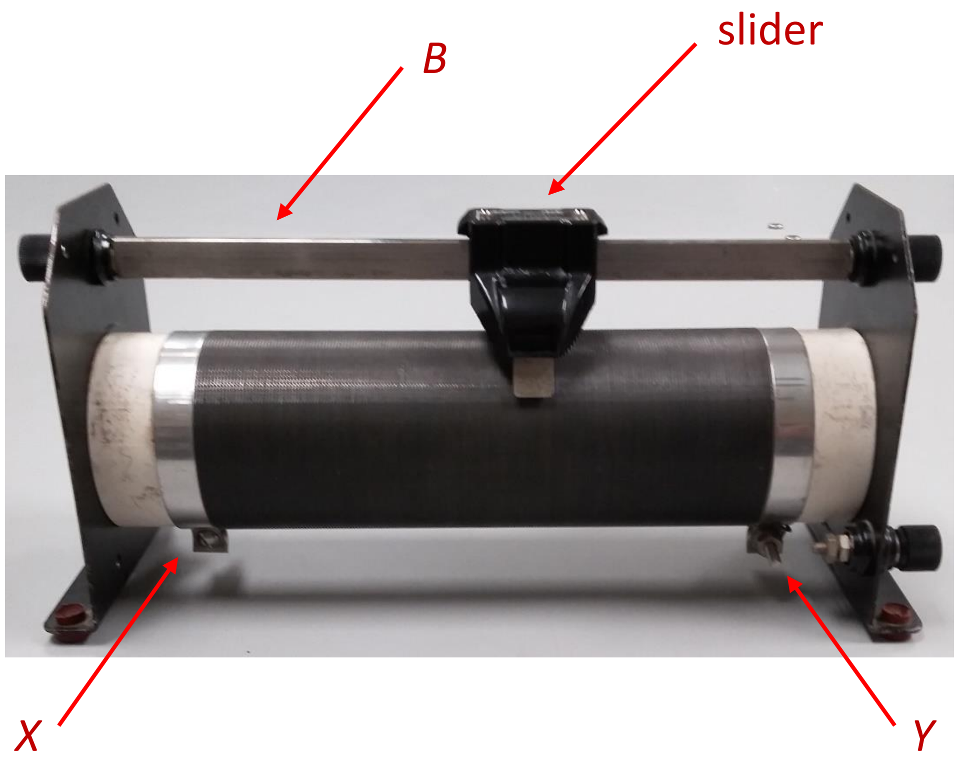


Adjusting Current and Voltage

- A rheostat may be represented by the symbol of a variable resistor.



- Let R be the resistance of the rheostat, that is, the resistance between the points X and Y.
- As the slider is moved from X to Y:
  - The resistance between X and B is varied from 0 to R.
  - The resistance between Y and B is varied from R to 0.

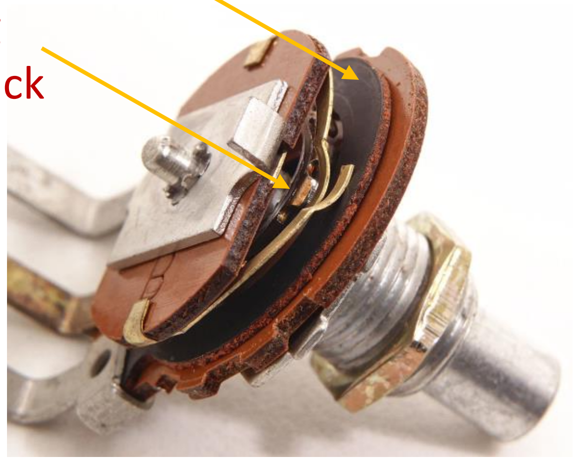


Adjusting Current and Voltage

- When a load requires a small amount of current, a simple way to change its voltage is with a *potentiometer*.
- A potentiometer is a variable resistor rated for low power levels.
- A potentiometer has:
  - A resistive track connected to the left and right terminals.
  - A wiper connected to the middle terminal and attached to a rotating shaft.
- The wiper touches the resistive track.
- By turning the shaft, the resistance between the middle terminal and the right/left terminals is varied.

Resistive track

Wiper touching the resistive track



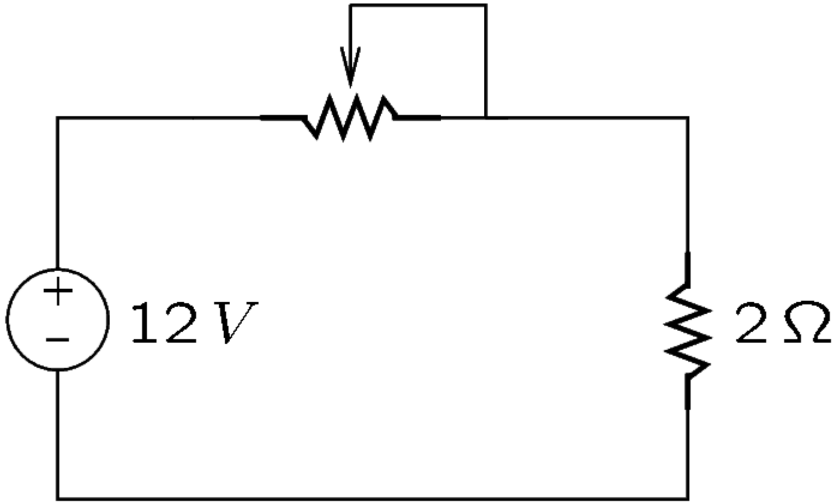
Images from https://commons.wikimedia.org/wiki/File:Electronic-Component-Potentiometer.jpg
and https://commons.wikimedia.org/wiki/File:Single-turn_potentiometer_with_internals_exposed,_oblique_view.jpg

Adjusting Current and Voltage—Example

A 12 V source is connected in series with a 2 Ω load and a 22 Ω rheostat.

- When the rheostat is adjusted to $0\ \Omega$, the load current is $I = \frac{12\ V}{2\ \Omega} = 6\ A$.
- To reduce the current to $I = 1.5\ A$, the rheostat has to be adjusted to a value r satisfying

$$\frac{12\ V}{r + 2\ \Omega} = 1.5\ A \Rightarrow r = 6\ \Omega$$



- The load voltage is $V_L = 2\ \Omega \cdot 1.5\ A = 3\ V$.
- At $I = 1.5\ A$, the efficiency of the system is

$$\eta = \frac{P_{out}}{P_{in}} = \frac{V_L \cdot 1.5\ A}{12\ V \cdot 1.5\ A} = 25\ \%$$

- *A rheostat provides a simple but inefficient way of controlling current.*

Multimeters

Measurement Range

- DMMs perform measurements within a prespecified *range*.
  - For example, typical current ranges are 200 μA, 2 mA, 20 mA, 200 mA, 2 A, 20 A.
- The range indicates the maximum value that can be measured.
  - For example, if the range is set to 20 mA and a $30\ mA$ current is to be measured, then the DMM will indicate OVERLOAD.
  - To measure the $30\ mA$ current, the range must be changed to $200\ mA$.
- A range can be changed by pressing the arrow keys.
  - When an arrow key is pressed, the DMM enters the MANUAL mode.
- If the AUTO key is pressed, the DMM selects automatically the right range.

Current Measurements

- DMMs typically have two current terminals:
  - The terminal for low-current ranges (typically, below 1A).
  - The terminal for high-current ranges (typically, above 1A).

Current Measurements

How to know which terminal the DMM uses when performing a current measurement?

- A DMM in AUTO mode will measure the current of the low-range terminal.
- A DMM in MANUAL mode will measure the current of the low-range terminal when the range is less than 1 A.
- A DMM in MANUAL mode will measure the current of the high-range terminal when the range is over 1 A.
- *DMMs use the high-range terminal only when in MANUAL mode on a range above* $1\ A$.

Current Measurements—Examples

A DMM has the following current ranges: $200\ \mu A$, $2\ mA$, $20\ mA$, $200\ mA$, $2\ A$, $20\ A$. *A current in the range* $50 \ldots 150\ mA$ *should be measured.*

- *Solution 1: Use the low-range terminal and AUTO mode.*
- *Solution 2: Use the low-range terminal, MANUAL mode, and the* $200\ mA$ *range.*
- *Solution 3: Use the high-range terminal, MANUAL mode, and the* $2\ A$ *range.*

Assume now that the unknown current is in the range $300 \ldots 600\ mA$.

- *Solution: Use the high-range terminal, MANUAL mode, and the* $2\ A$ *range.*

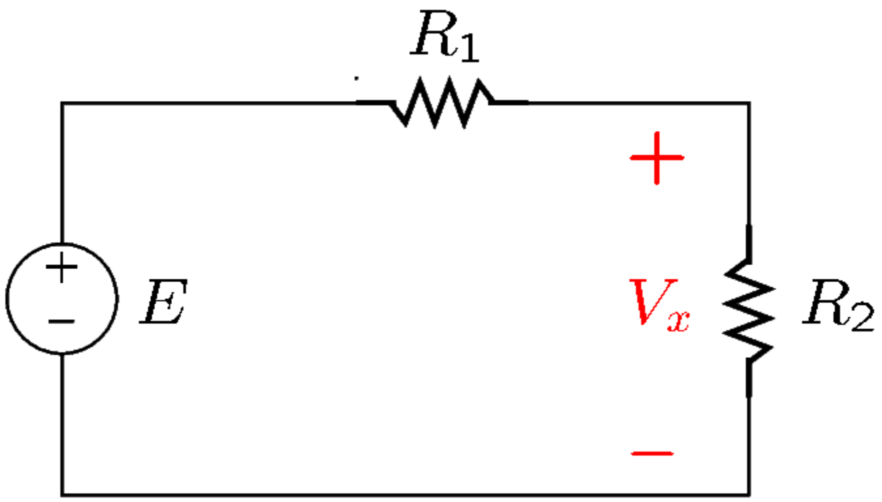
The Loading Effect

- Ideally, an instrument will not change the value of the variable it measures.
- However, DMMs connected to a circuit act as additional circuit loads and change somewhat the currents and voltages they measure.
- This is known as *the loading effect*.
- In most cases, when a DMM is used correctly, the loading effect is not significant.
- To avoid measurement error, it is necessary to determine whether a DMM loads considerably a circuit.

The Loading Effect—Voltage Measurements

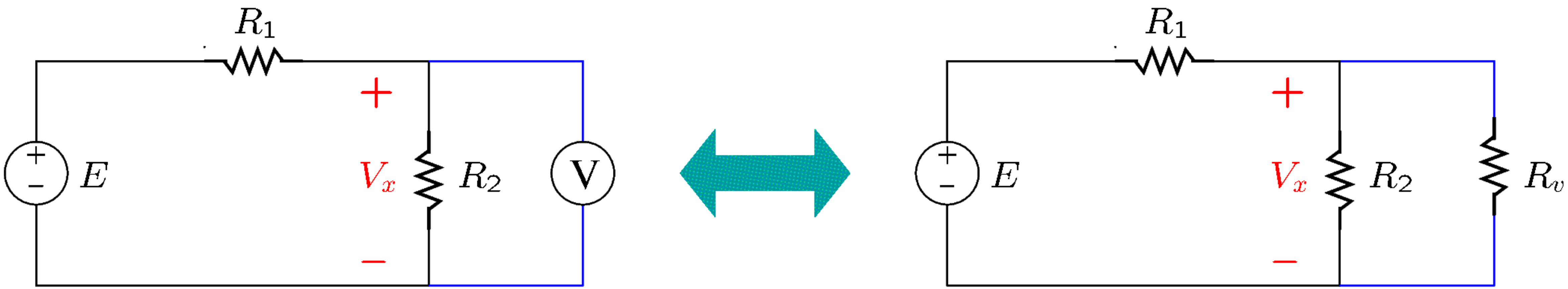
Example: Suppose that the voltage V_x should be measured.

- *A voltmeter is electrically equivalent to a resistor of very large value (such as $10\ M\Omega$).*
- *Let R_v be the internal resistance of the voltmeter.*
- *Adding a voltmeter to the circuit is equivalent to adding a resistor R_v to the circuit.*



The Loading Effect—Voltage Measurements

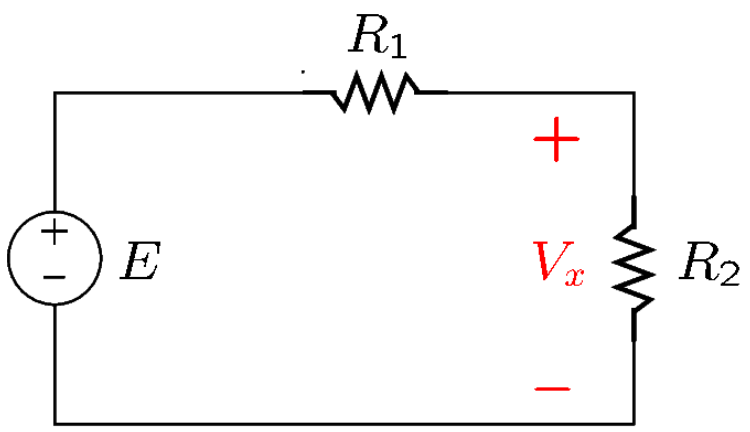
- *Adding a voltmeter to the circuit is equivalent to adding a resistor* R_v *to the circuit.*



The Loading Effect—Voltage Measurements

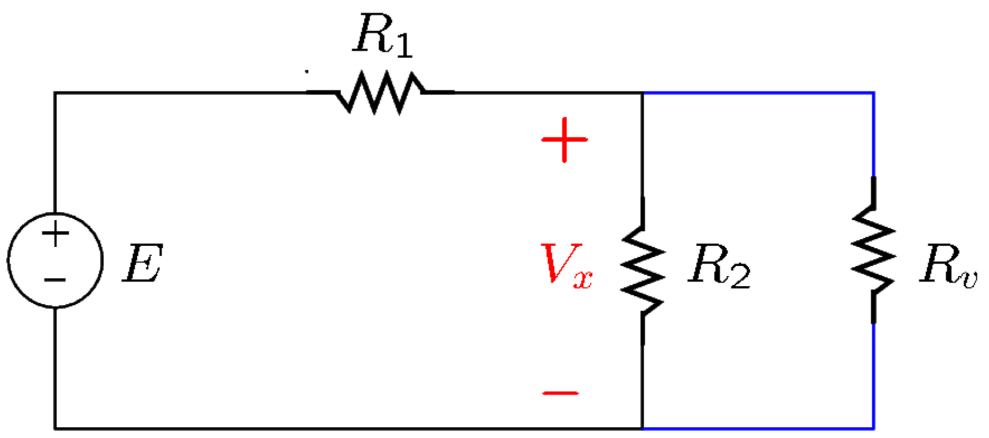
- *Before connecting the voltmeter,*

$$V_x = E \cdot \frac{R_2}{R_1+R_2}.$$



- *After connecting the voltmeter,*

$$V_x = E \cdot \frac{R_2||R_v}{R_1+R_2||R_v}.$$

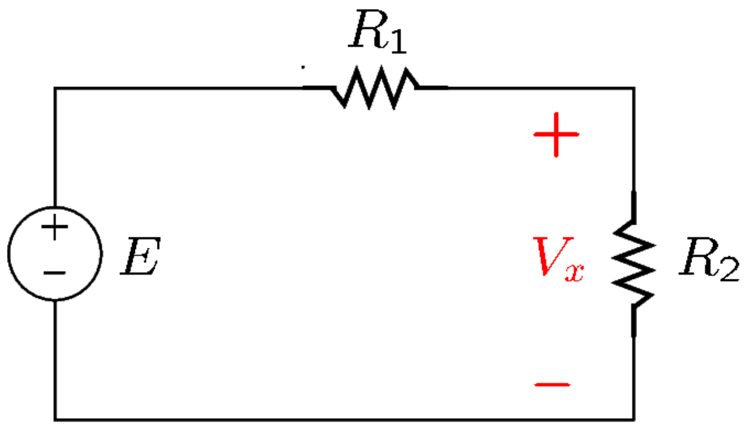


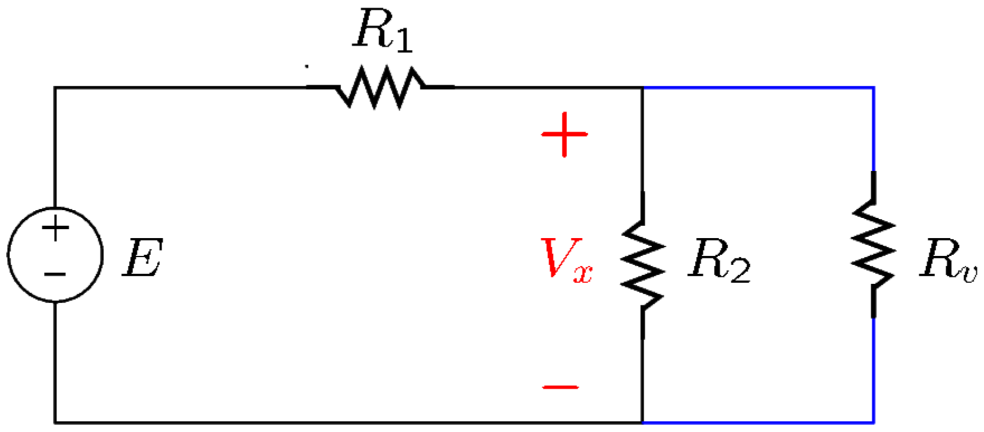
- *The change in voltage is negligible only if R_v is much larger than R_2.*

The Loading Effect—Voltage Measurements

For example, assume $E = 20\ V$, $R_v = 10\ M\Omega$, *and* $R_1 = R_2$.

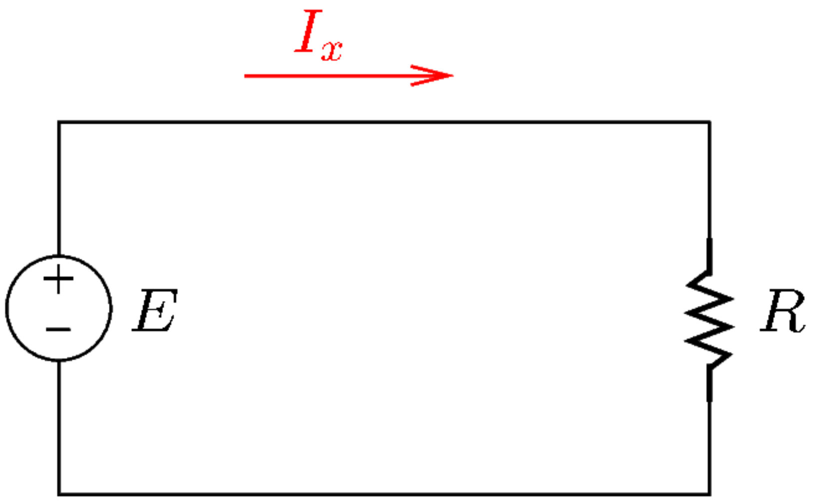
- *The actual value of* V_x *is* $10\ V$.
- *If* $R_1 = R_2 = 100\ \Omega$, *the measured* V_x *will be* $9.99995\ V$.
- *If* $R_1 = R_2 = 10\ k\Omega$, *the measured* V_x *will be* $9.995\ V$.
- *If* $R_1 = R_2 = 1\ M\Omega$, *the measured* V_x *will be* $9.524\ V$.
- *If* $R_1 = R_2 = 100\ M\Omega$, *the measured* V_x *will be* $1.667\ V$!





The Loading Effect—Current Measurements

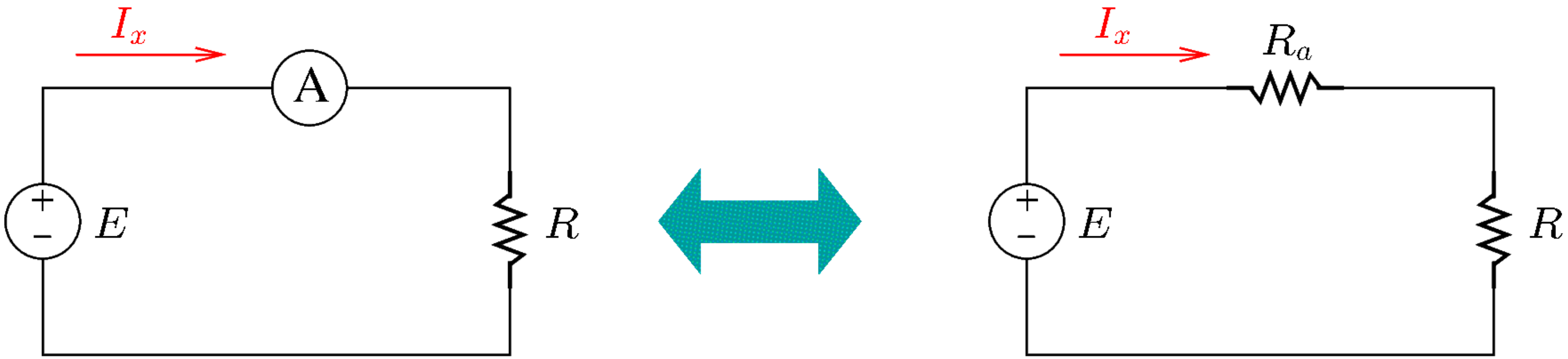
Example: Suppose that the current I_x should be measured.



- *An ammeter is electrically equivalent to a resistor of low value (such as $10\ \Omega$).*
- *Let R_a be the internal resistance of the ammeter.*
- *Adding an ammeter to the circuit is equivalent to adding a resistor R_a to the circuit.*
- *Note that R_a is not a constant but depends on range and current terminal (whether the low-range or high-range terminal is used.)*

The Loading Effect—Current Measurements

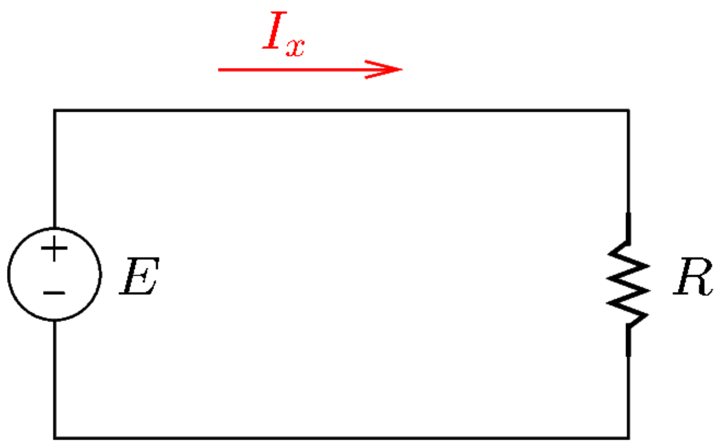
- *Adding an ammeter to the circuit is equivalent to adding a resistor* R_a *to the circuit.*



The Loading Effect—Current Measurements

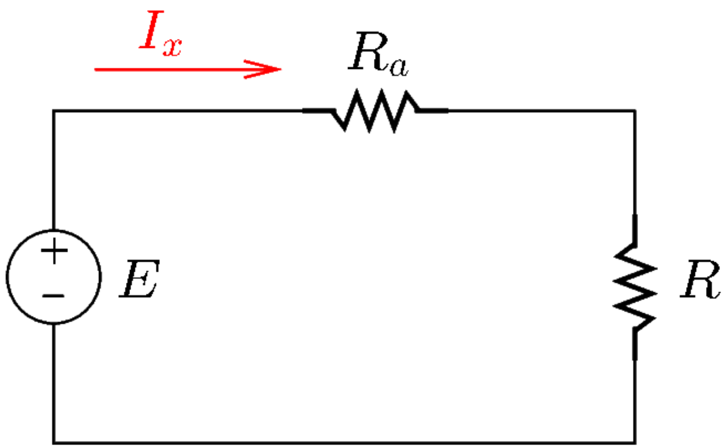
- *Before connecting the ammeter,*

$$I_x = \frac{E}{R}.$$



- *After connecting the ammeter,*

$$I_x = \frac{E}{R+R_a}.$$

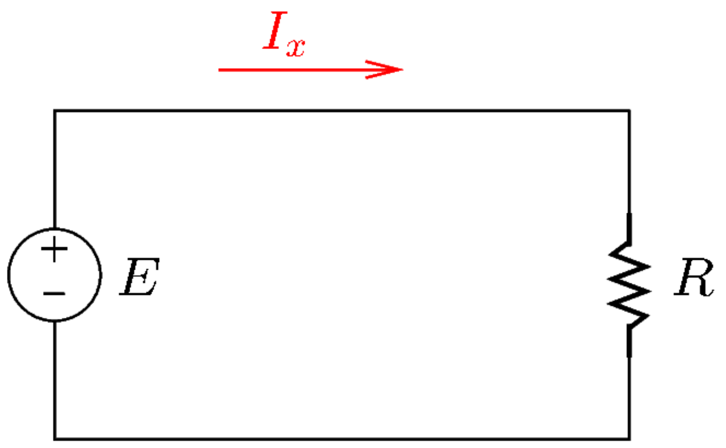


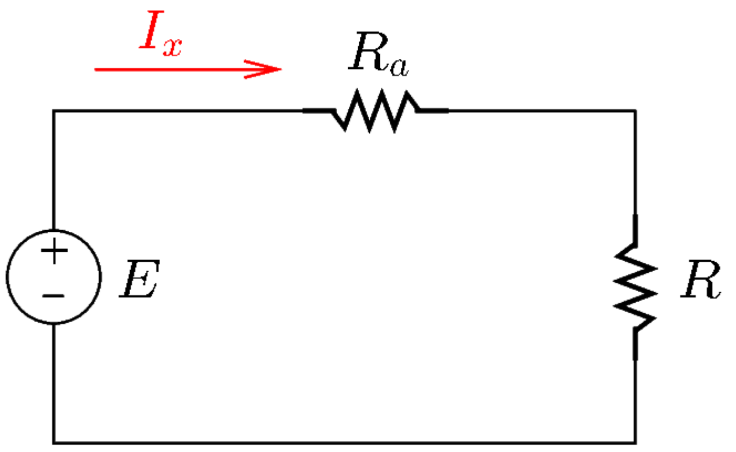
- *The change in current is negligible only if R_a is much smaller than R.*

The Loading Effect—Current Measurements

For example, assume $E = 20\,V$, $R = 200\,\Omega$, $R_a = 0.1\,\Omega$ *on the high range terminal, and* $R_a = 1\,\Omega$ *on the low range terminal for the* $200\,mA$ *range.*

- *The actual value of* I_x *is* $100\,mA$.
- *The value of* I_x *when measured on the high range terminal is* $99.95\,mA$.
- *The value of* I_x *when measured on the low range terminal is* $99.5\,mA$.

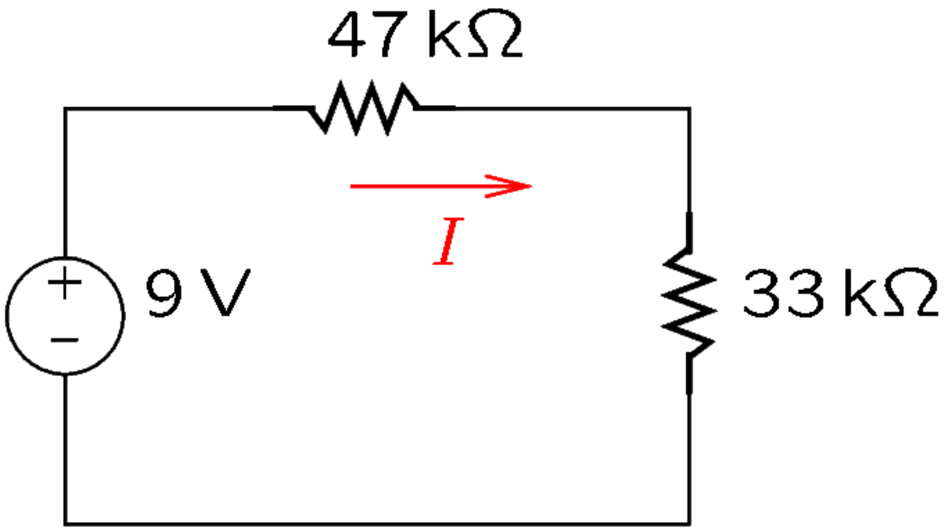


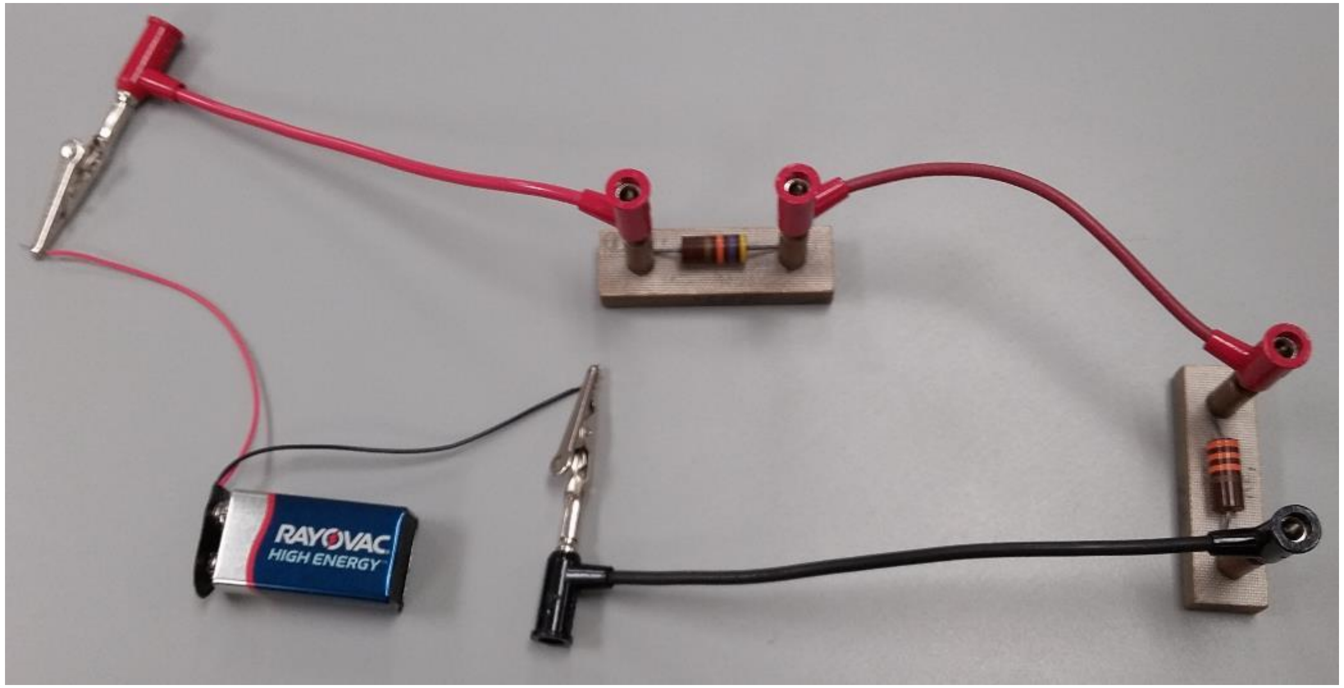


Ammeters—Review

- The current of a component is measured by placing the ammeter in series with the component.

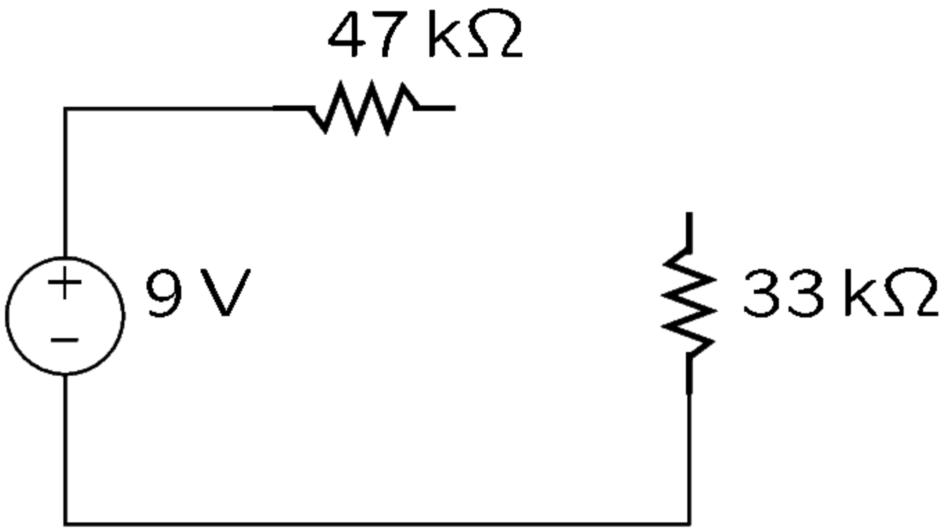
Example: The current of the $47\ k\Omega$ resistor should be measured.

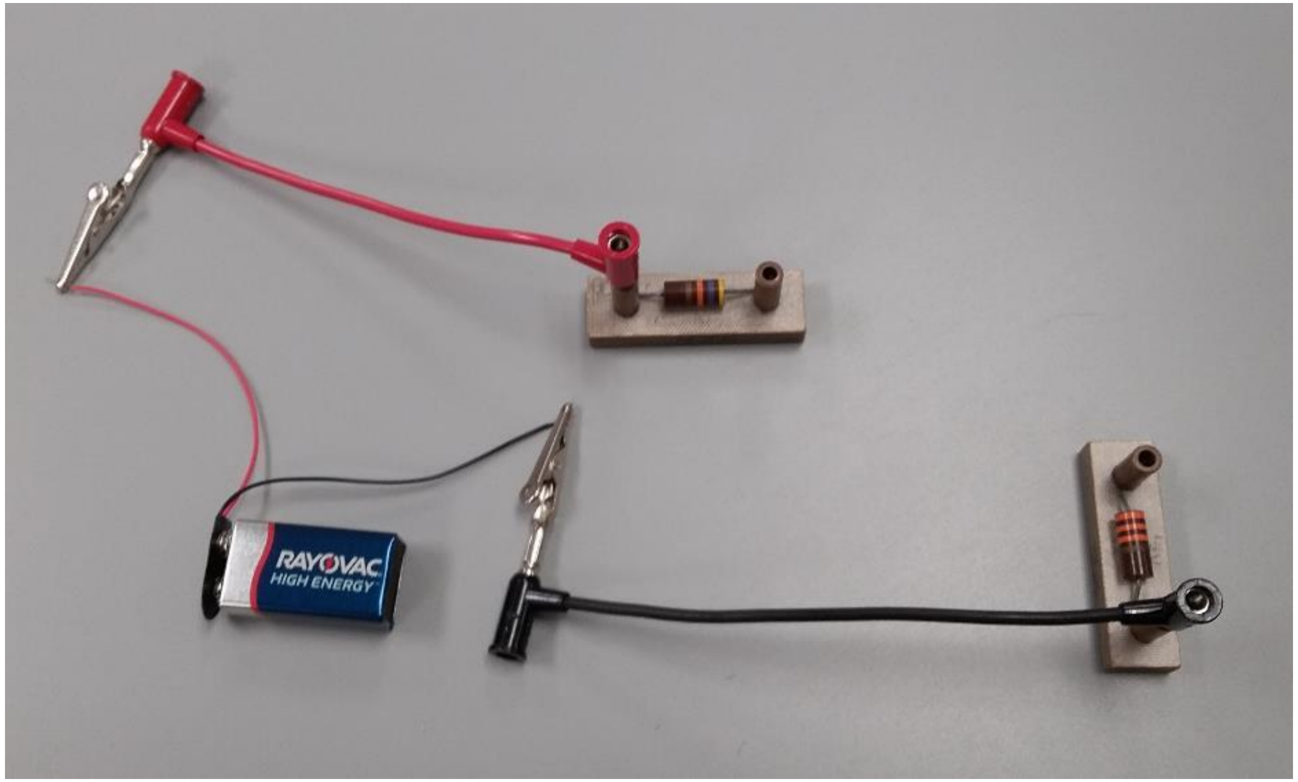




How to Measure Current—Example (Continued)

Step 1: Disconnect the resistor at one of its ends.

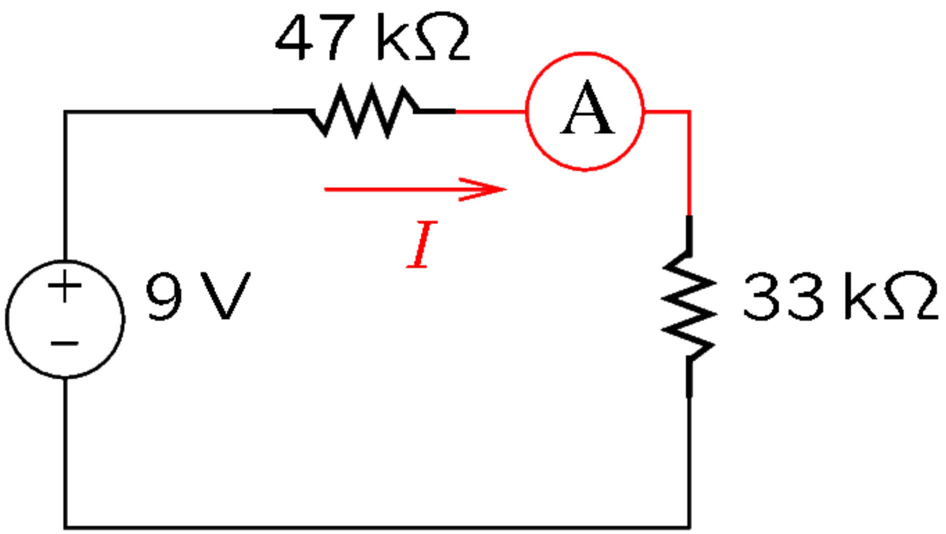


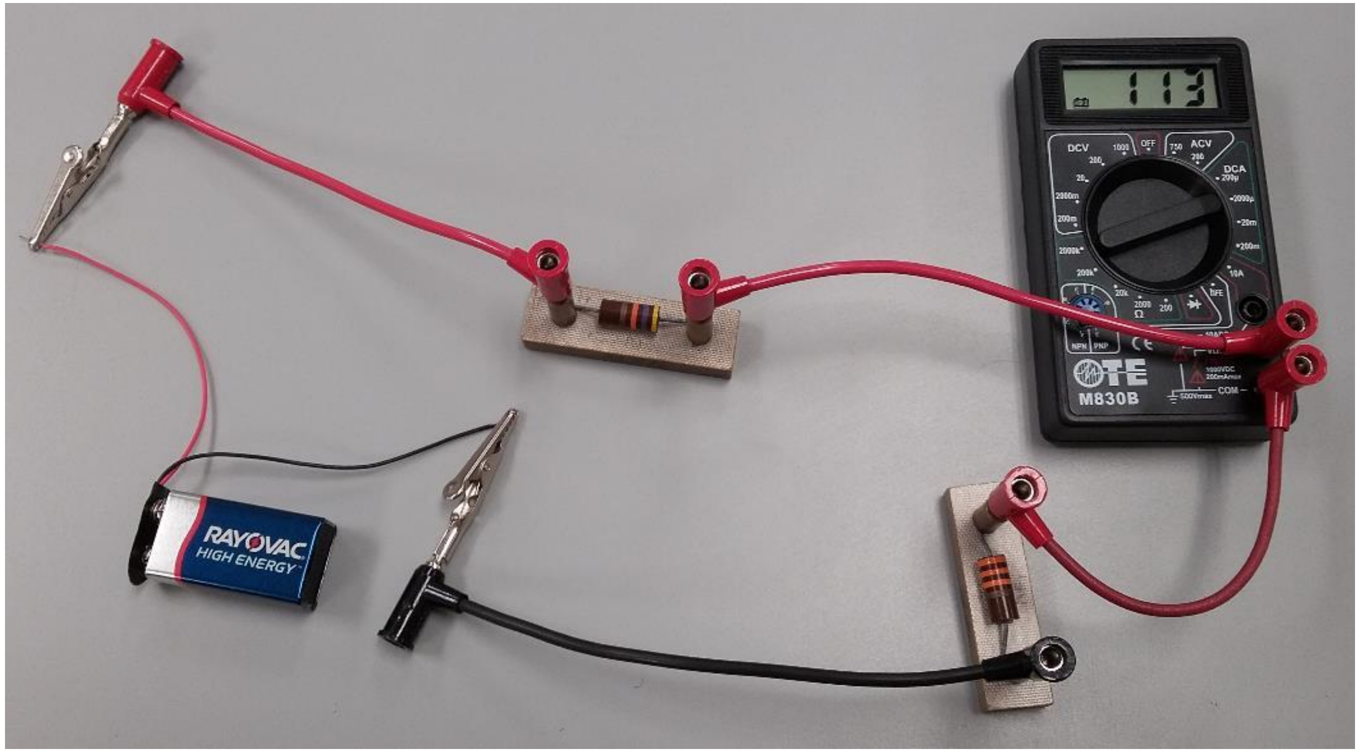


How to Measure Current—Example (Continued)

Step 2: Reconnect the resistor by means of an ammeter, so that the current to or from the resistor flows through the ammeter.

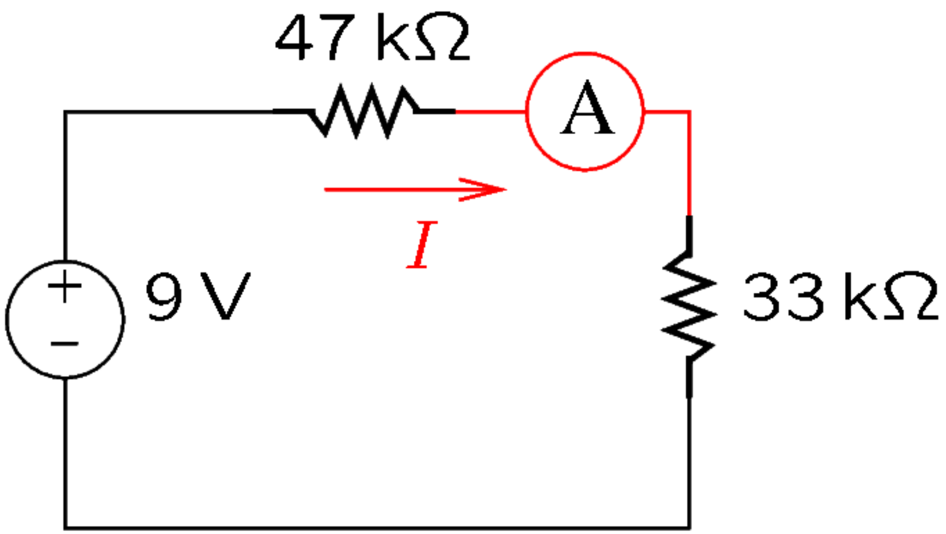
The ammeter shows a current $I = 113\ \mu A$.

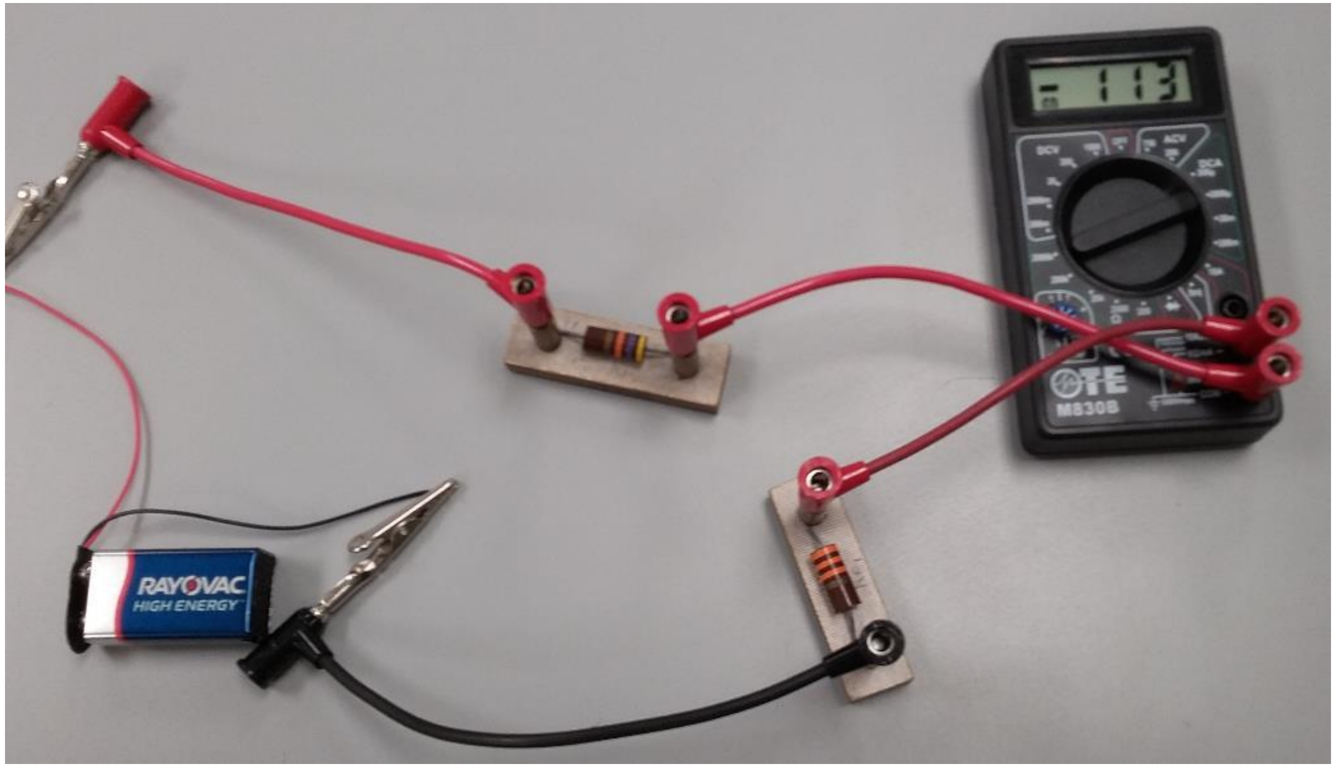




How to Measure Current—Example (Continued)

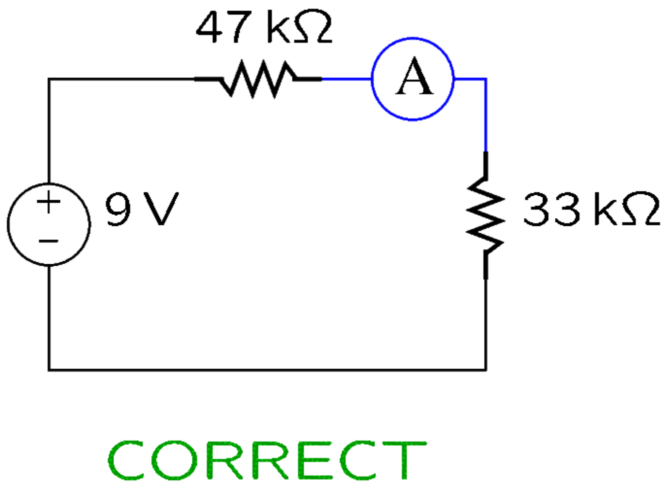
Note that by interchanging the connections of the ammeter, the sign of the measured current changes: $-113\ \mu A$ *instead of* $+113\ \mu A$.

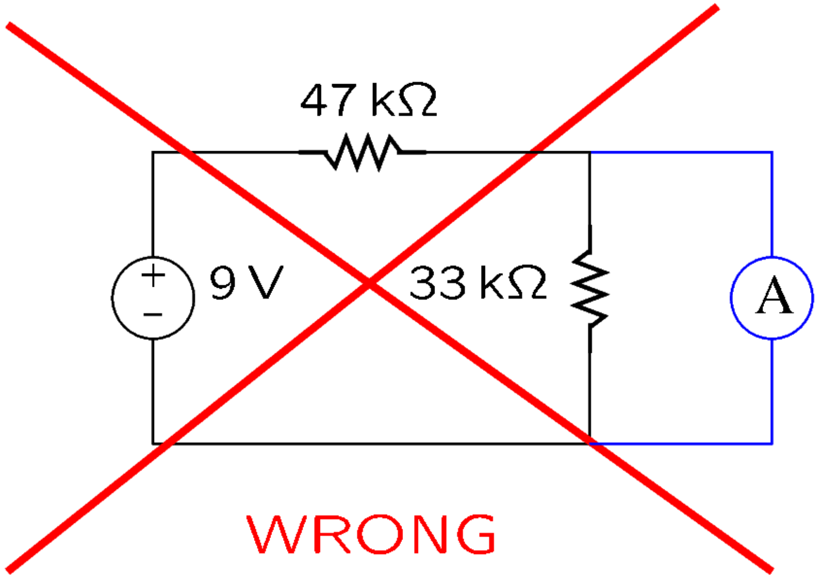




How to Measure Current—Review

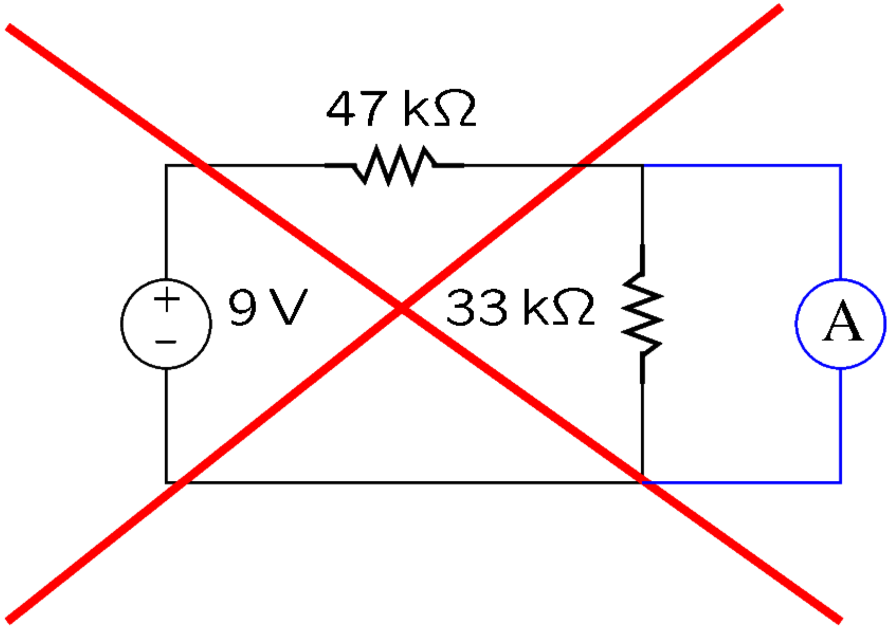
- *Ammeters are always connected in series.*
- *An ammeter may not be connected across a component.*
- *Otherwise, the ammeter will show an incorrect value and the ammeter fuse may get blown.*
- *Note that when the fuse is blown, the ammeter indicates a zero current (since no current can flow through it).*

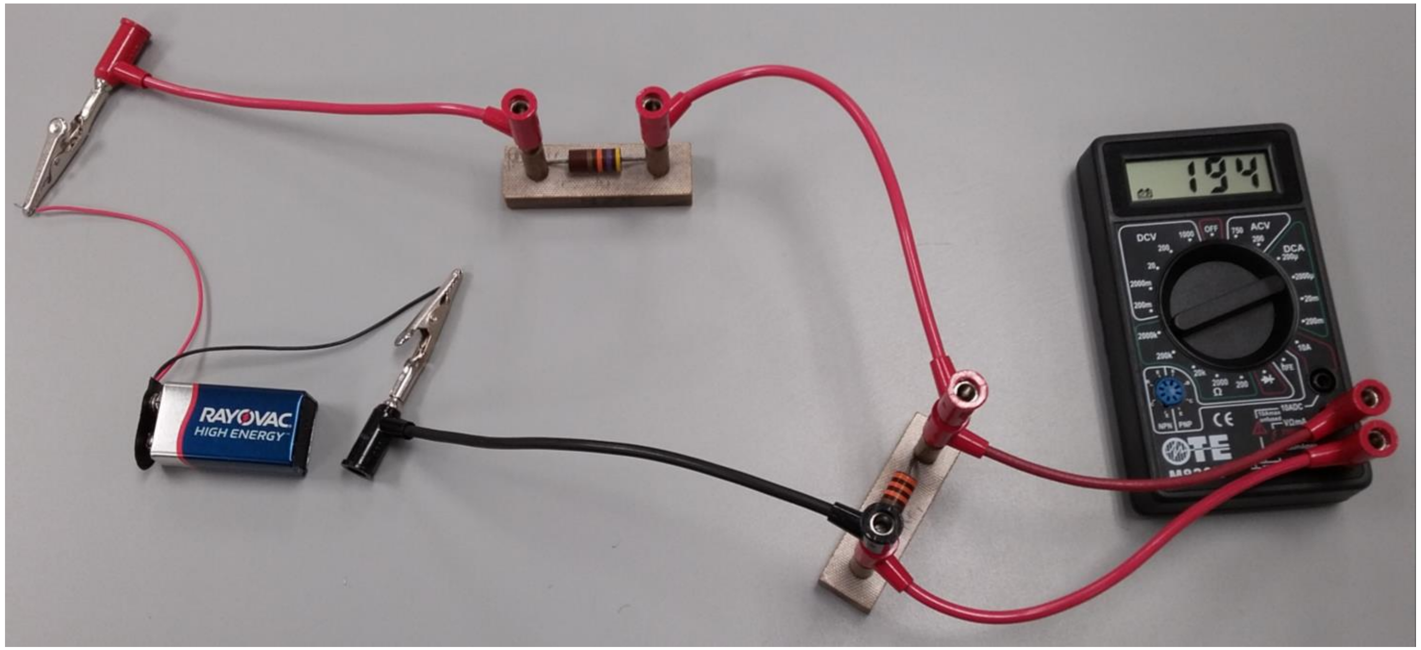




How to Measure Current—Example (Continued)

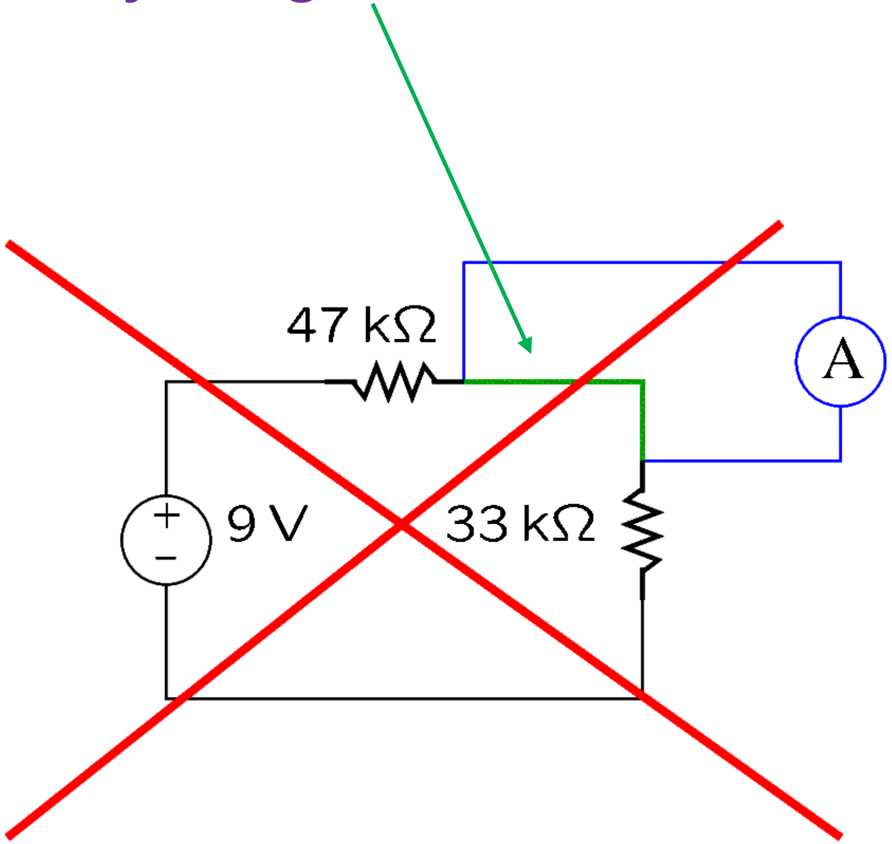
- *In the previous example, the current of the* $33\ k\Omega$ *resistor was* $113\ \mu A$.
- *The figure below shows an incorrect way to measure this current.*
- *The measurement is wrong because the ammeter is in parallel, not in series.*

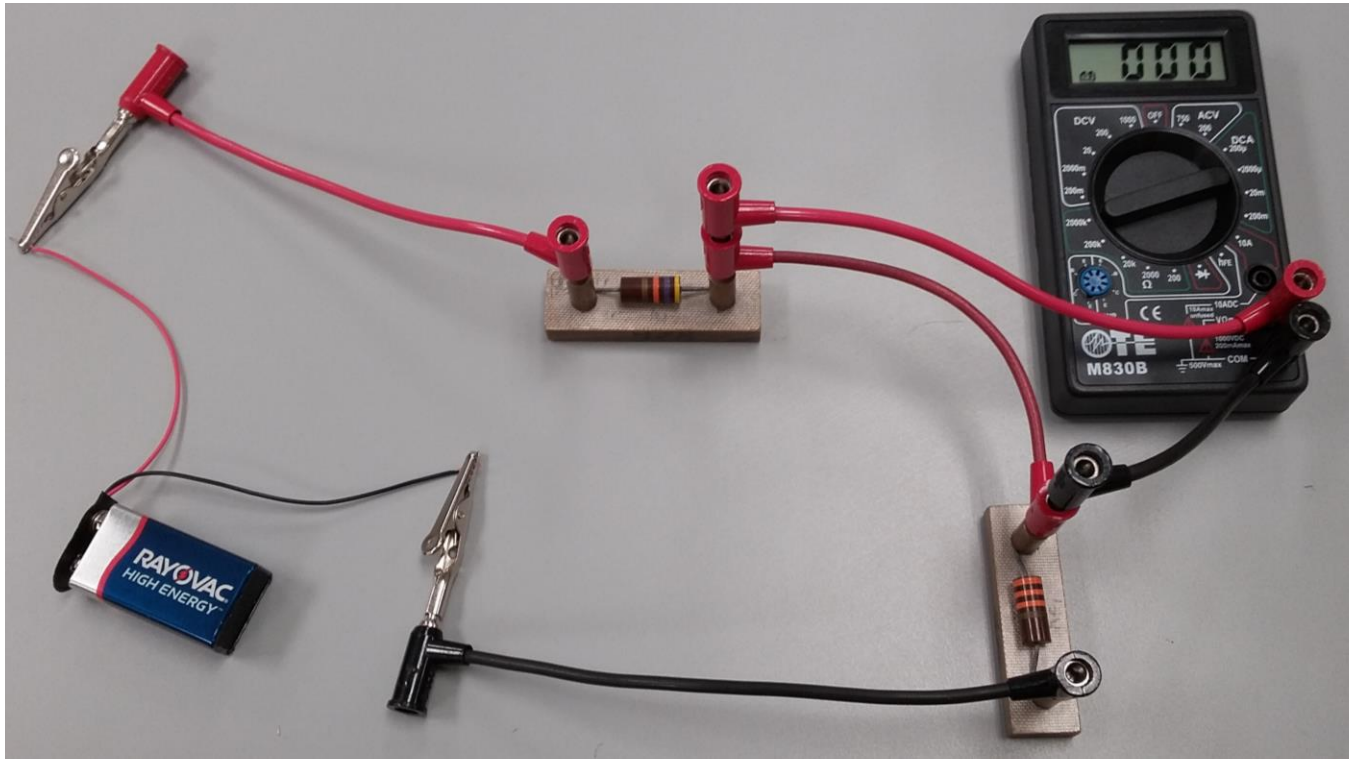




How to Measure Current—Example (Continued)

- *Current cannot be measured across a wire.*
- *If the green wire is removed, the DMM will display the correct value.*





Transformers

Transformers

- A transformer is an **AC** device that transfers energy between electrically isolated circuits by means of magnetically coupled coils of wire.
- A transformer consists of several coils placed on the same magnetic core.
- Power is applied to the *primary* coil of the transformer and is transmitted by means of the magnetic field to the other coils, which are called *secondary* coils.

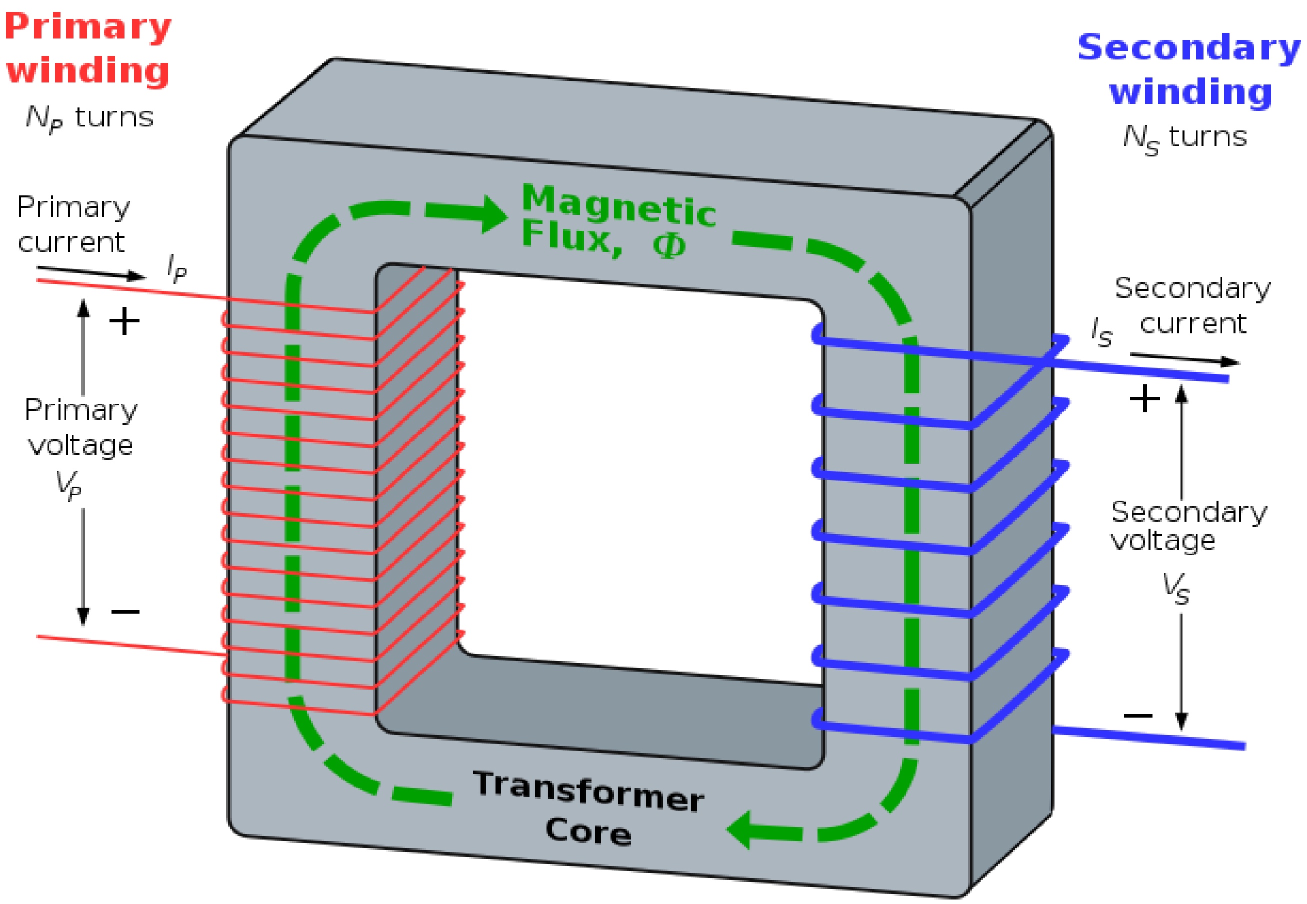
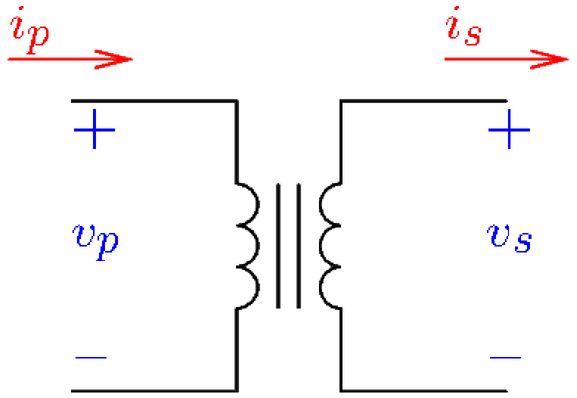


Figure downloaded from http://en.wikipedia.org/wiki/Transformer

Transformers



- The symbol of a transformer is shown in the figure.
- Typically, transformers transfer energy at different voltage levels; a transformer can reduce or increase the input voltage.
- Ideally,

$$\boxed{\frac{V_P}{V_S} = \frac{I_S}{I_P} = \frac{N_P}{N_S}}$$

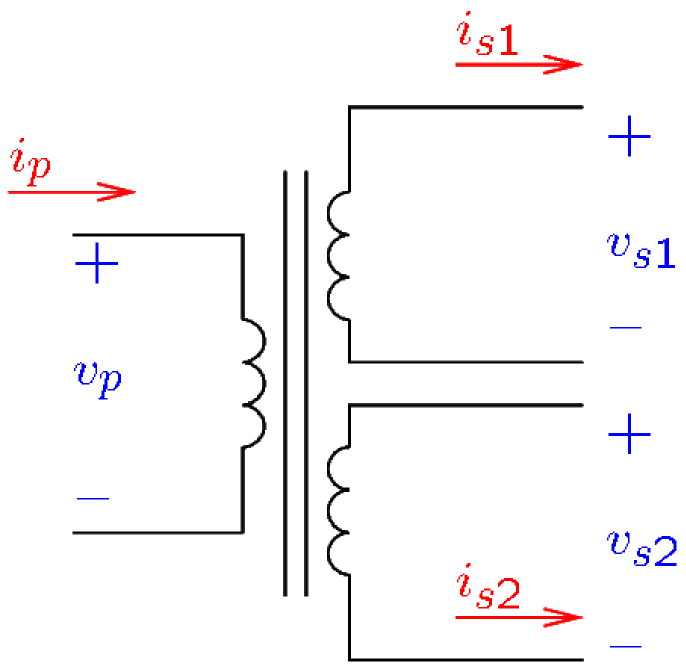
  where
  - V_P and V_S are the rms values of the primary and secondary voltages.
  - I_P and I_S are the rms values of the primary and secondary currents.
  - N_P and N_S are the number of turns of the primary and secondary coils.
- For example, if $N_P = 800$, $N_S = 80$, and $V_p = 120\ V$, then $V_S = 12\ V$.
- For example, if $N_P = 1000$, $N_S = 50$, and $I_S = 12\ A$, then $I_P = 600\ mA$.

Transformers

- Transformers may have more than one secondary coil.
- Under simplifying assumptions, the operation of a transformer with m secondary coils is described by the equations:

$$\frac{V_P}{V_{S1}} = \frac{N_P}{N_{S1}} \qquad \frac{V_P}{V_{S2}} = \frac{N_P}{N_{S2}} \qquad \cdots \qquad \frac{V_P}{V_{Sm}} = \frac{N_P}{N_{Sm}}$$

$$N_P I_P = N_{S1} I_{S1} + N_{S2} I_{S2} + \cdots + N_{Sm} I_{Sm}$$



where

- $V_P, V_{S1}, \ldots, V_{Sm}$ are the rms values of the primary and secondary voltages.
- $I_P, I_{S1}, \ldots, I_{Sm}$ are the rms values of the primary and secondary currents.
- $N_P, N_{S1}, \ldots, N_{Sm}$ are the number of turns of the primary and secondary coils.

Clamp-on Ammeters

- Clamp-on ammeters measure the current of a conductor without physical contact.
- Some clamp-on ammeters use Hall sensors to measure the magnetic field generated by the current of the conductor. They can work with both DC and AC.
- Other clamp-on ammeter operate on the principle of the transformer: the measured conductor forms the primary, while an internal coil forms the secondary. Such ammeters work only with AC.
- Although very convenient for making rapid current measurements, clamp-on ammeters are limited to relatively high current levels.

Clamp-on Ammeters

- Current is measured correctly when the conductor goes between the two jaws of the instrument.

Jaws