Physics 1200
Lecture 07
Spring 2024

Ohmic and Nonohmic Resistance,
Electromotive Force and Potential,
Series and Parallel Resistances,
Loop and Junction Rules

Ohm's "Law"

- Last class: found when a device of resistance R has current I flowing through it, potential difference ΔV across the device is

$$\boxed{\Delta V = IR}\ .$$

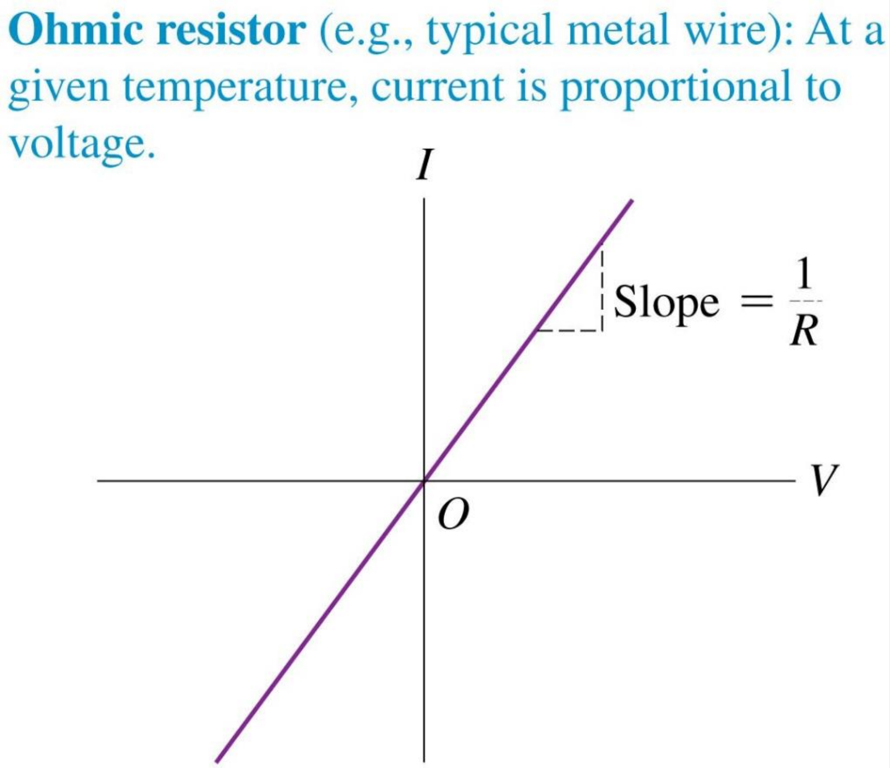
- This is a defining relation for resistance by rewriting it as

$$R = \frac{\Delta V}{I}\ .$$

- When $R = constant$ (i.e., value doesn't change with ΔV or I), the resistance of a device is referred to as "ohmic". For that case, ΔV and I have a <u>linear</u> relationship.
- When linear condition holds, expression $\Delta V = IR$ commonly referred to as "Ohm's Law" (G. Ohm, 1787 – 1854) .
- However, the ΔV - I relation is valid whether R is constant or not.

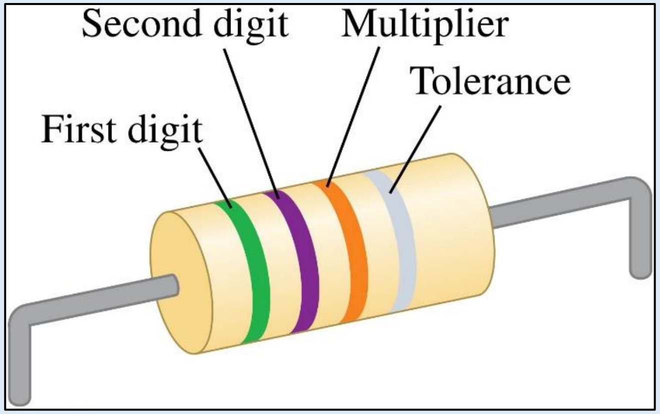
Ohm’s “Law” (2)

- While there are devices that have the behavior $R = constant$ for a certain range of environmental conditions, there is nothing universal or fundamental about this “law.” It is not on the same level as Newton’s laws, Gauss’s law, or Maxwell’s equations (later this semester).



Ohmic Resistors

- Common, everyday electronics often use ohmic resistors.
- Conventional ohmic resistors used in electrical circuits have a color-coding scheme.



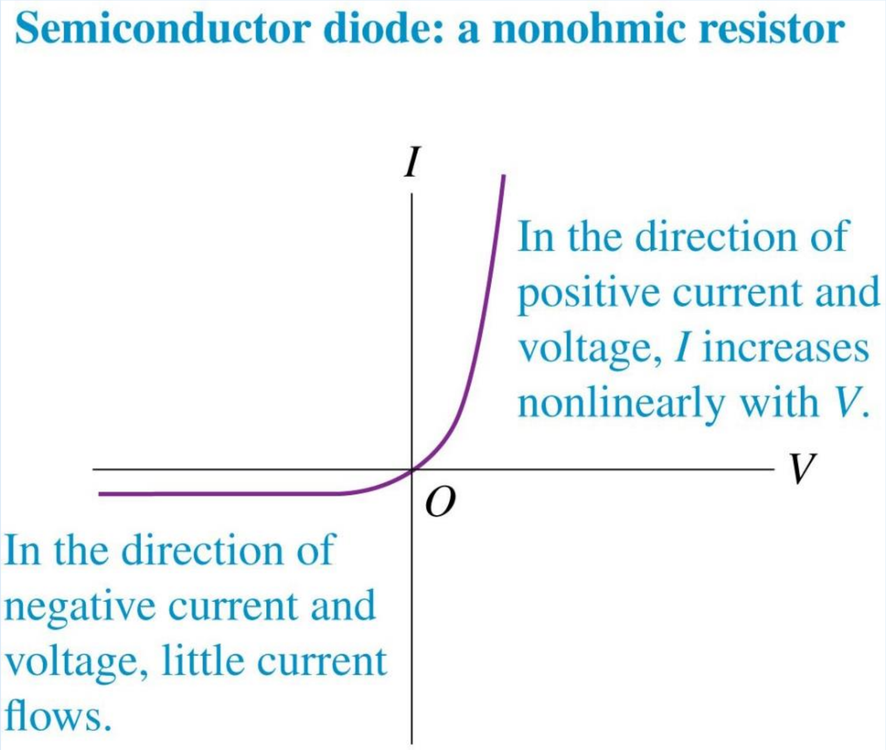
(a 57 kΩ resistor)

Color	Value as Digit	Value as Multiplier
Black	0	1
Brown	1	10
Red	2	10^2
Orange	3	10^3
Yellow	4	10^4
Green	5	10^5
Blue	6	10^6
Violet	7	10^7
Gray	8	10^8
White	9	10^9

- Ohmic resistors behave so only for a range of conditions. Partly due to design (shape) of construction, resistivity of materials from which they're made, etc. If the conditions (temperature, applied voltage, etc.) no longer hold, the resistor will no longer act ohmic.

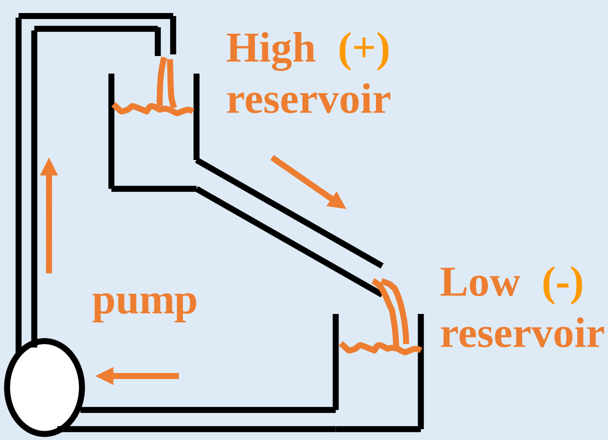
Nonohmic Resistors

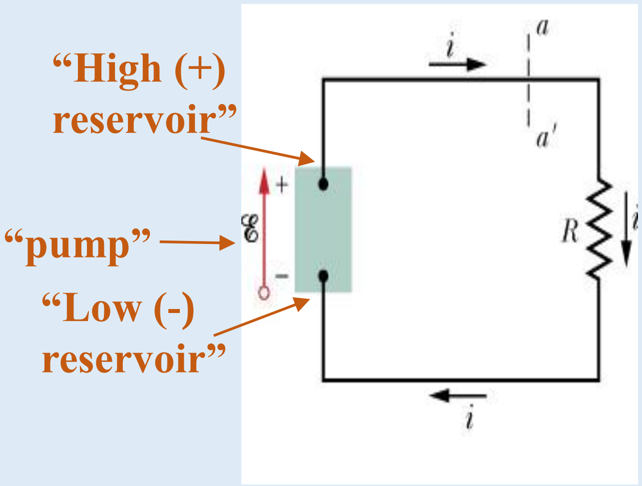
- Many everyday devices are not ohmic. Examples of nonohmic devices are lightbulb filaments, diodes, transistors, etc.
- In lab you will be investigating ohmic and nonohmic resistors, and their behavior under differing temperatures. You get to ‘play’ (a little) with liquid nitrogen ($T = 77\ \mathrm{K}$) in lab.



Electromotive Force (EMF) and Potential

- "Electromotive force" (EMF) is an applied potential by some external agent of work (or, power) to systems, such as an electrical circuit.
- EMF has same SI unit as electrical potential, which is the volt (1 V = 1 J/C). EMF is the work per unit charge created within a source to move a charge from a point of low potential to a point of high potential.
- Analog: a pump moving water in a pipe from a reservoir on the ground to a reservoir some height above:





- Common sources of EMF include batteries, electrical generators, etc.

Electromotive Force (EMF) and Potential (2)

- EMF is routinely shown in circuit diagrams with the symbol "$\mathcal{E}$".
- "Electromotive force" is a bad name, since it deals with potential (V), rather than force (N). We're stuck with it through historical usage.
- Basic idea: EMF "pushes" or drives a current through a circuit. It's what does work that provides a persistent, continued voltage across circuit elements. Remove EMF, electrical circuit action stops.
- Sources of EMF vary. For common household batteries it's non-conservative work done by internal chemical reactions, which are microscopic electrostatic interactions between atoms and molecules.

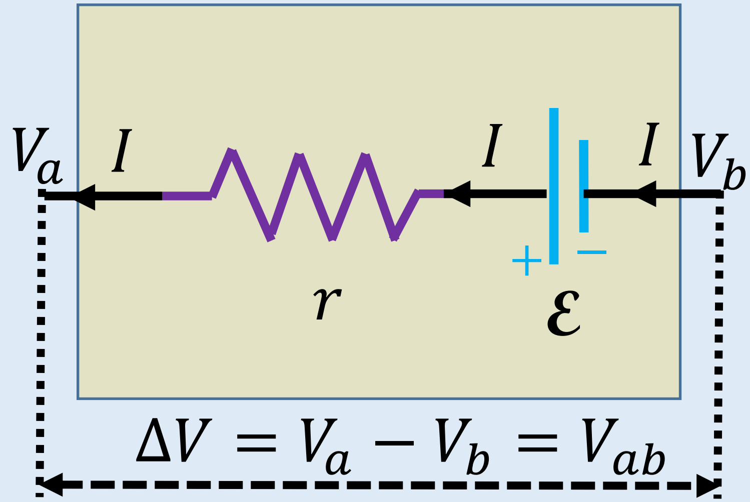
Real EMFs: Internal Resistance & Terminal Voltage

- Real sources of emf actually have some internal resistance, r.

- Terminal voltage is the voltage difference across the terminal leads of an EMF source when it is connected to a circuit having finite resistance. The terminal voltage of the 12-V battery shown is less than 12 V when it is connected to the light bulb.

Terminal Voltage of an EMF Source

- A real battery (or other power supply) can be considered an ideal EMF $\mathcal{E}$ in <u>series</u> with an internal resistance r, supplying some current I to a device or circuit through a terminal voltage V_{ab} across its terminals a and b:



Terminal voltage, source with internal resistance

emf of source

Current through source

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

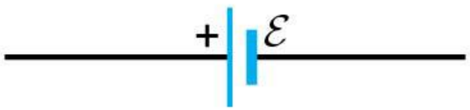
Internal resistance of source

- An <u>ideal</u> battery (or power supply) has zero internal resistance, $r = 0$; $V_{ab} = \mathcal{E}$ for that situation.

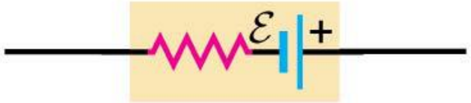
Standard Symbols for Circuit Diagrams

Conductor with negligible resistance (e.g., a wire)

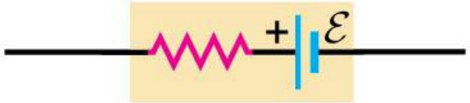
Resistor



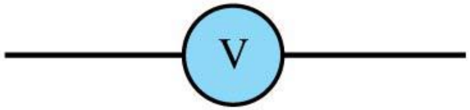
Source of emf (longer vertical line always represents the positive terminal, usually the terminal with higher potential)



or



Source of emf with internal resistance r (r can be placed on either side)



Voltmeter (measures potential difference between its terminals)
An ideal voltmeter has infinite resistance and draws no current.

Ammeter (measures current through it)
An ideal ammeter has zero resistance and no voltage drop.

Power Dissipation

- Change in electrical energy of a system with a potential difference ΔV across it and a current I through it is just the potential energy change due to an amount of charge dq being transported through the potential difference: $\Delta U_E = dq\, \Delta V$
- Energy change per unit time = power being supplied to and dissipated by a device is

$$\boxed{P = I\, \Delta V}\,.$$

  - Electrical power is dissipated in a device only if a current I runs through it <u>and</u> it has a potential difference ΔV across it.
- If device has resistance R, power dissipated by the resistance R is

$$\boxed{P = I^2 R = \frac{V^2}{R}}\,.$$

Question 7.1

- A battery consists of an ideal EMF of 10.0 V with an internal resistance of 0.200 Ω. A current of 8.33 A passes through its two terminal leads and drives an electrical circuit. The power that the battery supplies to the circuit is

A. 69.4 W.

B. 83.3 W.

C. 97.2 W.

D. 347 W.

E. 0 W.

F. None of these.

Kirchoff's Circuit Rules

- Junction rule (last class): sum of the currents into any point in a circuit is zero:

$$\boxed{\sum_{i=1}^{N} I_i = 0}.$$

"Whatever current flows in, also flows out."

  - Consequence of conservation of charge.

- Loop rule: <u>Sum of potential changes going around a closed circuit loop is zero</u>:

$$\boxed{\sum_{i=1}^{N} \Delta V_i = 0},$$

ΔV_i is the potential change across the i-th device.

  - Rule due to electrostatic force being a conservative force:

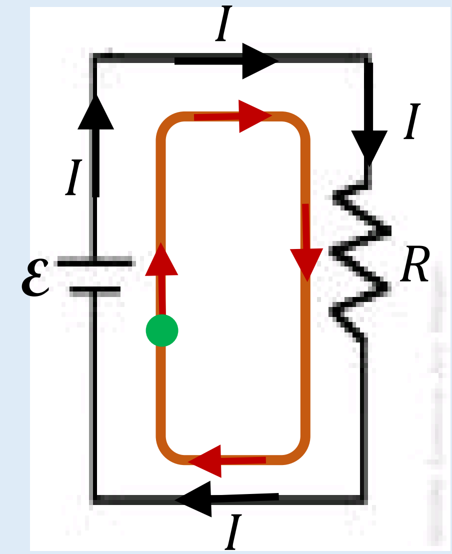
$$\oint \vec{\boldsymbol{F}}_E \cdot d\vec{\boldsymbol{s}} = \oint q\vec{\boldsymbol{E}} \cdot d\vec{\boldsymbol{s}} = q \oint \vec{\boldsymbol{E}} \cdot d\vec{\boldsymbol{s}} = 0 \Rightarrow \oint \vec{\boldsymbol{E}} \cdot d\vec{\boldsymbol{s}} = 0 \text{ for } q \neq 0.$$

By definition, $\Delta V = V_f - V_i = -\int_i^f \vec{\boldsymbol{E}} \cdot d\vec{\boldsymbol{s}} \quad \Rightarrow dV = -\vec{\boldsymbol{E}} \cdot d\vec{\boldsymbol{s}}$.

$$\therefore \oint dV = -\oint \vec{\boldsymbol{E}} \cdot d\vec{\boldsymbol{s}} = 0$$

Kirchoff’s Loop Rule Applied to a Simple Circuit

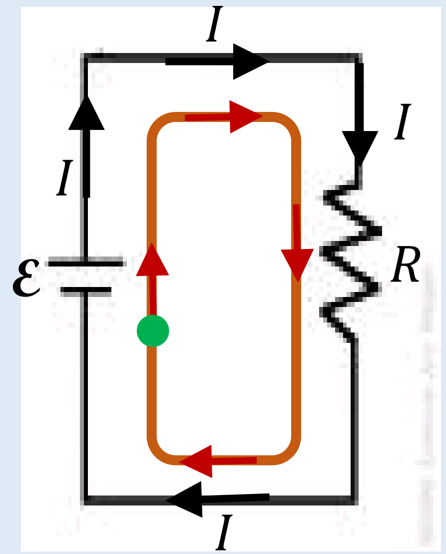
- Can use loop rule to find current I flowing in a simple circuit consisting of an ideal EMF $\mathcal{E}$ and resistor R.
- Choose a direction for current I. Black arrows in the figure show the assumed direction for the current.
  - ➢ If solution for I is positive (> 0), the current is in that direction.
  - ➢ If instead found I to be negative, direction is opposite to what you chose. The magnitude is right, but current is headed the opposite way.



- Pick a direction to make a complete traversal around the loop. If not given, free to choose direction. Clockwise path of travel (brown) choice is shown in the figure.
- Pick a starting point for your path. Again, if not specified, free to choose. Green dot in figure shows (arbitrarily) chosen starting point.

Kirchoff's Loop Rule Applied to a Simple Circuit (2)

- Add up voltage changes as you go along the chosen closed path. Rule for voltage changes:
  - If you travel from the low voltage plate of an EMF to the higher voltage plate, the change is $+\mathcal{E}$. If travel is in the opposite direction (high voltage to low voltage) the change is $-\mathcal{E}$.
  - Wires are assumed ideal, with no resistance. Voltage change in a wire is therefore zero.
  - If travel is in the direction of the current through a resistor, voltage change = $-IR$. If travel through a resistor is opposite to current , voltage change = $+IR$.



For this example, loop rule yields:

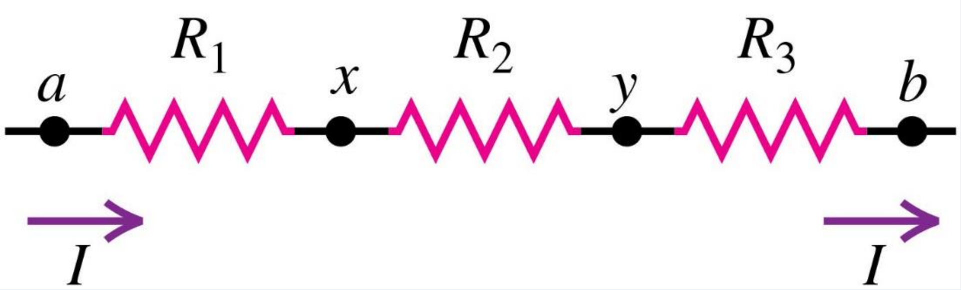
$$+\mathcal{E} - IR = 0 \quad \Rightarrow I = \mathcal{E}/R.$$

- If path chosen is opposite in direction to one shown, loop rule gives:

$$-\mathcal{E} + IR = 0 \quad \Rightarrow I = \mathcal{E}/R.$$ <u>Same answer</u>!

Resistors in Series

- Resistors sequentially connected one after the other are in series if the current going through one resistor also goes through all of the others.



- Total voltage change across the series network is the sum of the voltage change across each individual resistor:

$$\Delta V = \Delta V_1 + \Delta V_2 + \Delta V_3 + \cdots$$

- Using resistance – voltage relation across each resistor:

$$\Delta V = IR_1 + IR_2 + IR_3 + \cdots = I(R_1 + R_2 + R_3 + \cdots)$$

(Same current I through each resistor.)

- Defining effective resistance $R_{eff,s}$ for the entire series network:

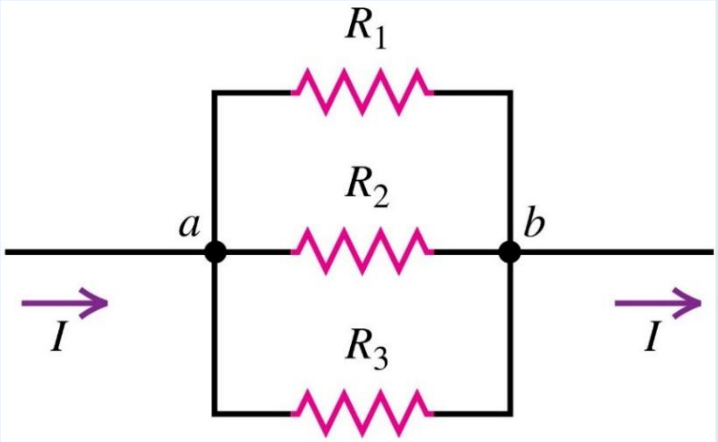
$$\Delta V = IR_{eff,s} = I(R_1 + R_2 + R_3 + \cdots) \quad \Rightarrow \quad R_{eff,s} = R_1 + R_2 + R_3 + \cdots$$

$$\boxed{R_{eff,s} = \sum_{i=1}^{N} R_i}\ .$$

A network of resistors in series is equivalent to a single resistor with resistance $R_{eff,s}$.

Resistors in Parallel

- Connected resistors are in parallel when they have the same voltage applied across them. Or, equivalently, when the current going into the network is split up amongst all of them and recombines to the original incoming current after immediately passing through each resistor.



- From junction rule, we know current I going into the network:

$$I = I_1 + I_2 + I_3 + \cdots, \quad I_i \text{ is the current going through resistor } R_i.$$

- From voltage – resistance relation:

$$I = \frac{\Delta V}{R_1} + \frac{\Delta V}{R_2} + \frac{\Delta V}{R_3} + \cdots = \Delta V\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots\right),$$ ΔV is common voltage change across each resistor in the network.

- Defining the effective resistance for a parallel network of resistors $R_{eff,p}$:

$$I = \frac{\Delta V}{R_{eff,p}} = \Delta V\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots\right) \quad \Rightarrow \frac{1}{R_{eff,p}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots$$

$$\boxed{\frac{1}{R_{eff,p}} = \sum_{i=1}^{N} \frac{1}{R_i}}.$$

A network of parallel resistors can be replaced by a single resistor of resistance $R_{eff,p}$.

Instruments to Analyze Circuits

- Resistors and circuits investigated in next two lab classes.
- Instruments used for analysis are things already used in the class:
  - Agilent/HP direct current (DC) power supply can used to convert alternating current (AC) from a standard wall outlet into either a steady voltage source or a steady current source. Dials can each be set to limit the maximum current and voltage that it will supply.
  - Fluke digital multimeter (DMM) has an ammeter setting that can measure current in a circuit. To measure current, ammeter must be connected in <u>series</u> with a circuit element, so that it can measure the current passing through itself and the other device. An ideal ammeter has zero resistance, and therefore zero voltage change across it.
  - The DMM can also measure voltages in a circuit. To do that, it must be in <u>parallel</u> with the device that it will be measuring the voltage across. An ideal voltmeter has infinite resistance and draws no current through itself.
  - Fluke DMM can also directly measure the resistance and capacitance of a device. To do that, the DMM must be connected in <u>parallel</u> with the device.
- Our LMS Item file “Images of Common Lab Equipment” can be found in the “Lab Information and Software” folder. It shows pictures of the equipment.
- A .zip file containing the figures from an earlier edition of the lab manual can be found in our LMS “Lab Information and Software Folder”. Has color versions of figures, including circuit diagrams.

A Common Resistor: Incandescent Light Bulbs

- A resistor people may have everyday experience with is the incandescent light bulb.
- Normally powered by AC wall outlets. In the US, the rms (= “root mean square”) voltage is 120 V (a voltage amplitude $\simeq$ 170 V) at a frequency of 60 Hz. (We’ll explain what these terms mean later when we discuss alternating current circuits in class.)
- Incandescent light bulbs are nonohmic. Their resistance changes with current as they get very hot.
- Brightness of the bulb is related to the power dissipated by the bulb.
    - More power $\Rightarrow$ brighter.
    - More current $\Rightarrow$ brighter.
    - More voltage $\Rightarrow$ brighter.

Question 7.2

- Are the lightbulbs in your home wired in series or in parallel?

A. Series.

B. Parallel.

C. Neither! Everybody knows that lightbulbs are made with extraterrestrial alien technology recovered from the 1947 Roswell crash site that is hidden in the top-secret Area 52 (the **real** super-secret place – because anybody that knows anything also knows that Area 51 is a scam for the posers and wannabes).

D. The person next to me picked ‘C’ and I’m scared because they really, really, really **believe** their answer. Help me!!

Nice demo video at:

https://mediaplayer.pearsoncmg.com/assets/secs-vtd37_seriesparallel