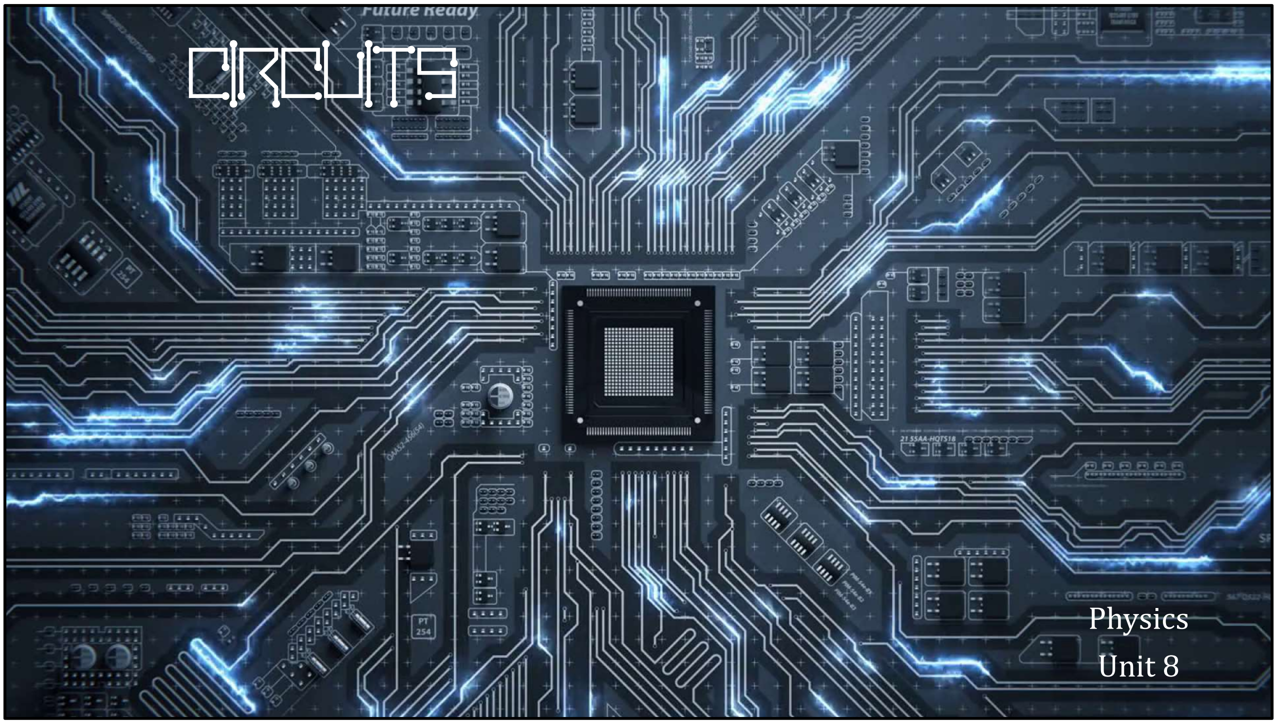

NAD 2023 Standard EM2 (Electric Circuits)

CREDITS

- This Slideshow was developed to accompany the textbook
  - *OpenStax High School Physics*
    - *Available for free at https://openstax.org/details/books/physics*
    - *By Paul Peter Urone and Roger Hinrichs*
    - *2020 edition*
- Some examples and diagrams are taken from the *OpenStax College Physics, Physics,* and *Cutnell & Johnson Physics* 6th ed.

Slides created by
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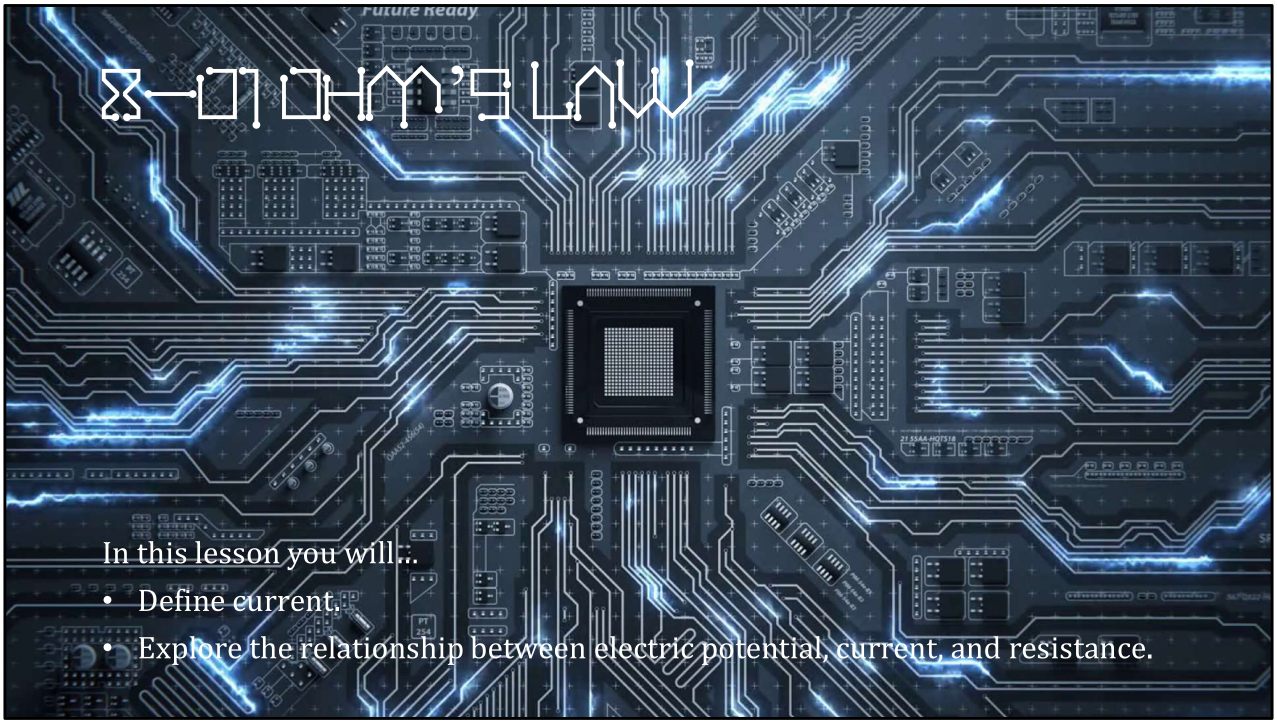


OpenStax High School Physics 19.1
OpenStax College Physics 2e 20.1-20.2

8-01 Ohm's Law

Current

- Rate of flow of charge
  - Amount of charge per unit time that crosses one point

$$I = \frac{\Delta Q}{\Delta t}$$

- Symbol: (I)
- Unit: ampere (A)

8-01 Ohm's Law

- Small computer speakers often have power supplies that give 12 V at 200 mA. How much charge flows through the circuit in 1 hour and how much energy is used to deliver this charge?
- ΔQ = 720 C
- E = 8640 J

Charge in 1 hour:

$$I = \Delta Q / \Delta t \rightarrow \Delta Q = I \Delta t = (.2\ A)(3600\ s) = 720\ C$$

Energy:

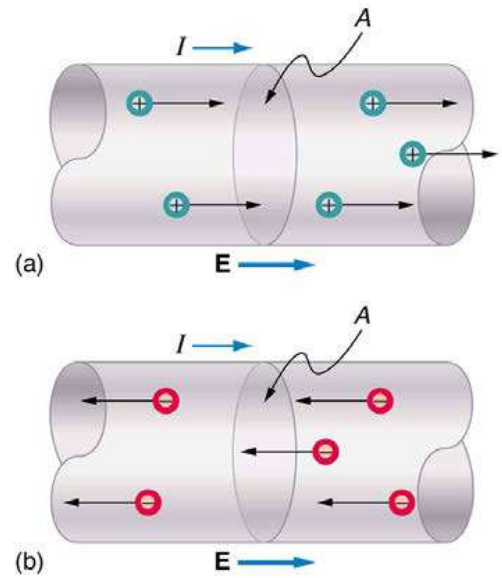
$$EPE = qV = (720\ C) 12\ V = 8640\ J$$

The speakers usually don't draw that much current. They only draw that much current at their maximum volume.

8-01 OHM'S LAW

Conventional Current

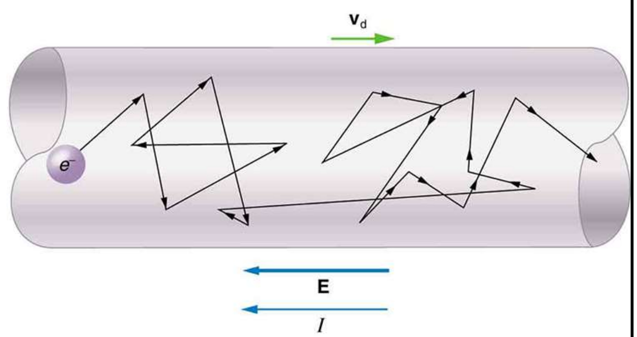
- Electrons are the charge that flows through wires
- Historically thought positive charges move
- Conventional current → imaginary flow of positive charges
  - Flows from positive terminal and into negative terminal
  - Real current flows the opposite way



8-01 Ohm's Law

Drift Velocity

- Electrical signals travel near speed of light, but electrons travel much slower
- Each new electron pushes one ahead of it, so current is actually like wave
- $I = \frac{\Delta Q}{\Delta t} = \frac{qnAx}{\Delta t} = qnAv_d$
  - q = charge of each electron
  - n = free charge density
  - A = cross-sectional area
  - v_d = drift velocity



8-01 Ohm's Law

- Think of water pumps
  - Bigger pumps → more water flowing
  - Skinny pipes (more resistance) → less water flow
- Electrical Circuits
  - Bigger battery voltage → more current
  - Big electrical resistance → less current

8-01 Ohm's Law

Ohm's Law

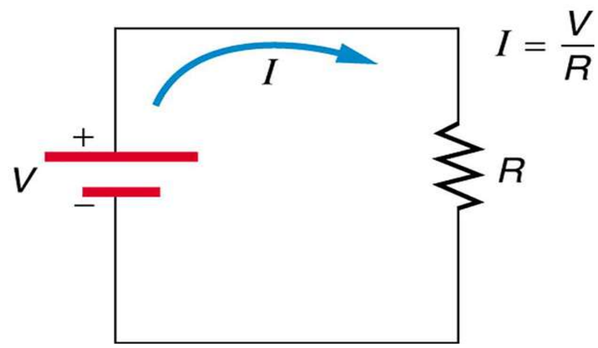
$$I = \frac{V}{R} \text{ or } V = IR$$

- V = emf
- I = current
- R = resistance
  - Unit: V/A = ohm (Ω)

8-01 OHM'S LAW

Resistors

- Device that offers resistance to flow of charges
- Copper wire has very little resistance
- Symbols used for
  - Resistor →
  - Wire →



8-01 Ohm's Law

- Our speakers use 200 mA of current at maximum volume. The voltage is 12V. The current is used to produce a magnet which is used to move the speaker cone. Find the resistance of the electromagnet.

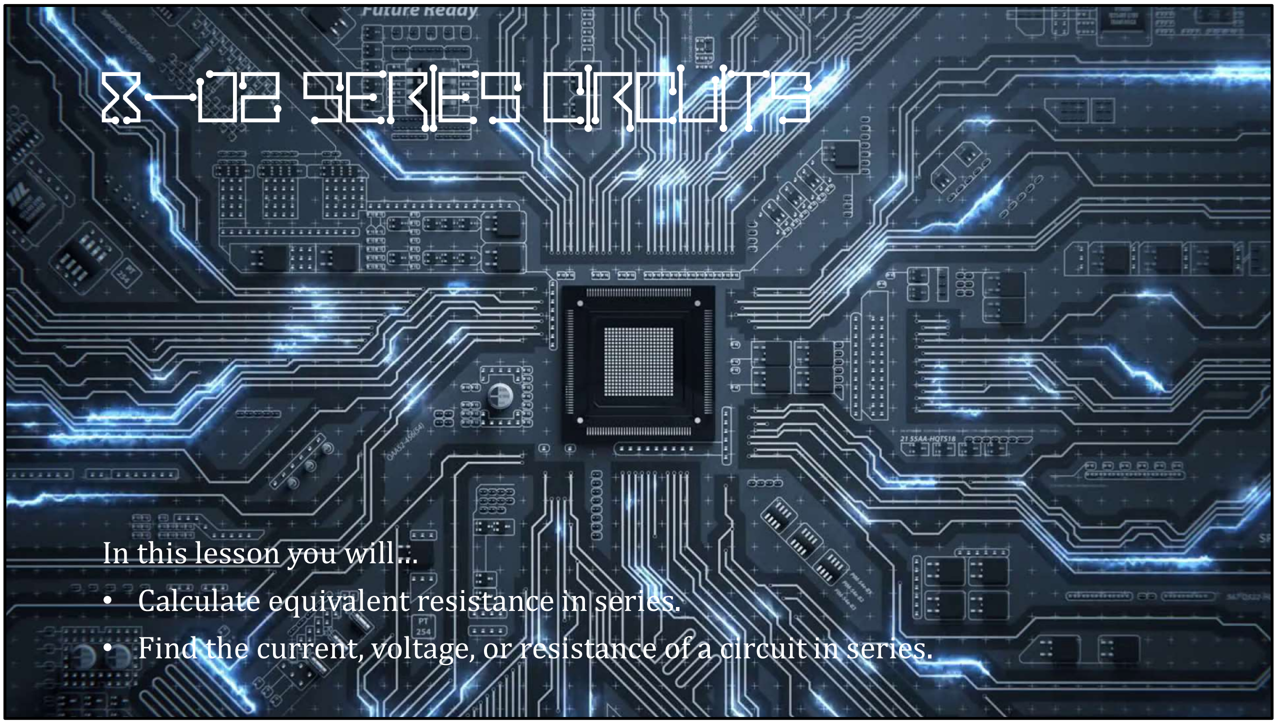
- $R = 60\ \Omega$

$$V = IR \rightarrow 12\ V = (0.20\ A)R \rightarrow 60\ \Omega = R$$

08-01 Homework

- Hopefully these circuit problems won’t have you running around in circles

- Read
  - OpenStax College Physics 2e 21.1
  - OR
  - OpenStax High School Physics 19.2



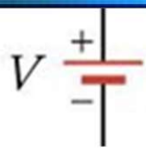
OpenStax High School Physics 19.2
OpenStax College Physics 2e 21.1

8-02 Series Circuits

Electric circuit

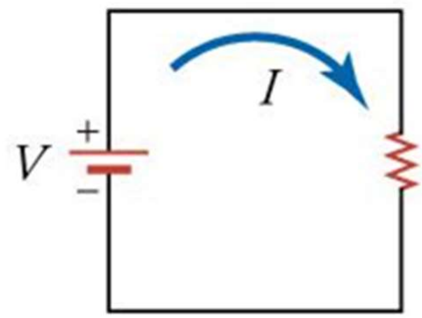
- Must be a complete loop
- The electric potential at battery is high
- The electric charges flow (current) down to the low potential
- Along the way, the electric potential energy is used by the devices on the circuit
- When the charges reach the low potential, there is no potential left. It has all been used.
- Without a complete loop, there is no low potential for the charges to be attracted to

8-02 Series Circuits



- Battery: Long side is positive, short side is negative
- Provides the potential to make the current flow
- Current flows from positive side to negative side

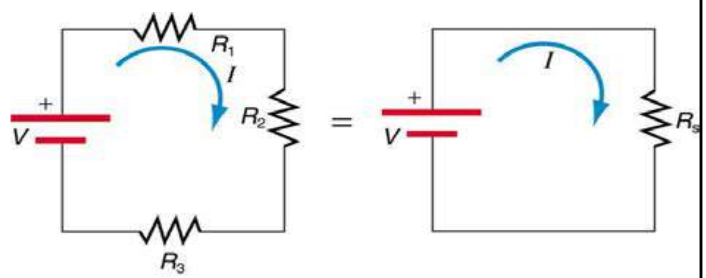
- Resistor: Uses the potential to do work



8-02 Series Circuits

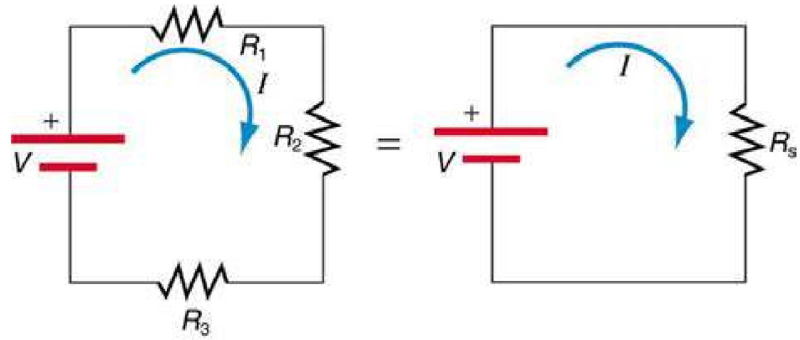
Series Wiring

- More than one device on circuit
- Same current through each device
- Break in device means no current
- Form one "loop"
- The resisters divide the voltage between them



8-02 Series Circuits

- V divide among resistors
- $V = V_1 + V_2 + V_3$
- $V = IR$
- $V = IR_1 + IR_2 + IR_3$
- $V = I(R_1 + R_2 + R_3)$
- $V = IR_S$
- $R_S = R_1 + R_2 + R_3 + \ldots$

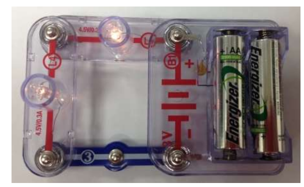


R_s is the equivalent resistance in ***S***eries

8-02 Series Circuits

- A 5.17 kΩ resistor and a 10.09 kΩ resistor are connected in series. What is the equivalent resistance?

- 15.26 kΩ



Circuit board and multimeter to measure

5.17 kΩ + 10.09 kΩ = 15.26 kΩ

8-02 Series Circuits

- Bathroom vanity lights are occasionally wired in series. V = 120 V and you install 3 bulbs with R = 8Ω and 1 bulb with R = 12Ω. What is the current and voltage of each bulb?

- I = 3.33 A
- V = 26.7 V, 40 V

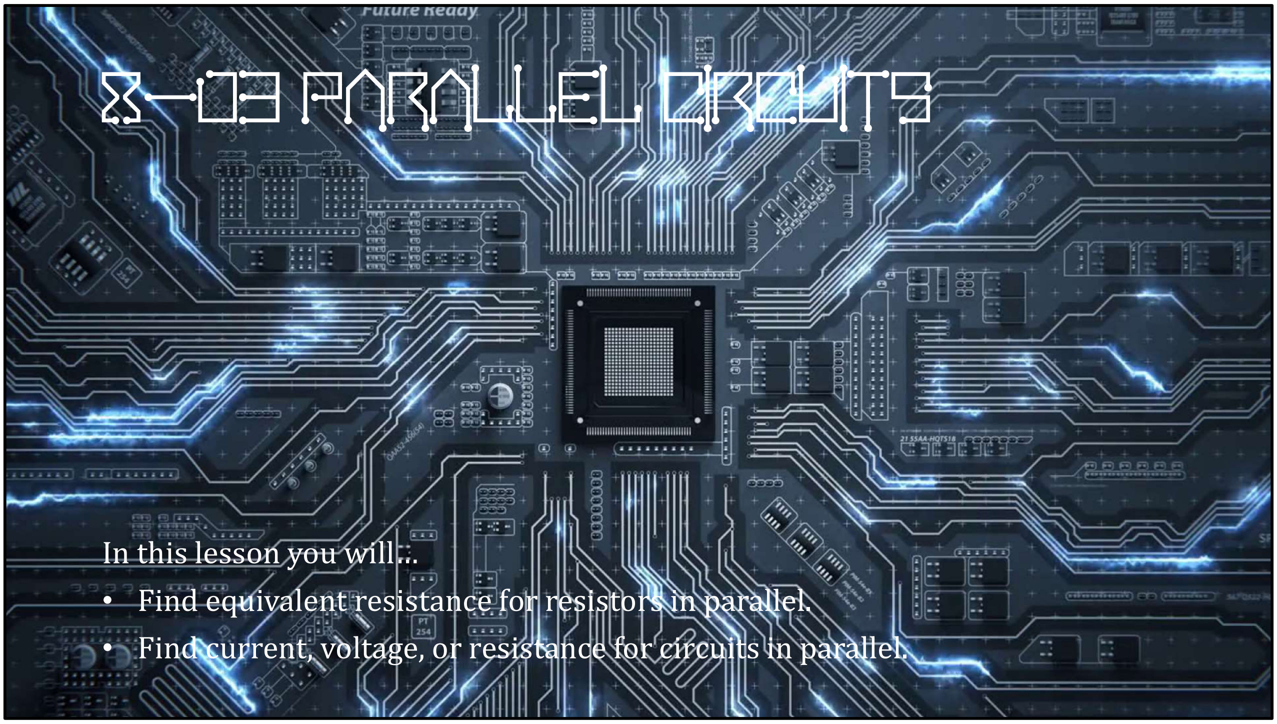
$$R_S = 3(8\ \Omega) + 12\ \Omega = 36\ \Omega$$

$$V = IR \rightarrow 120\ V = I(36\ \Omega) \rightarrow I = 3.33\ A$$

$$V = IR \rightarrow V = (3.33\ A)(8\ \Omega) = 26.7\ V$$
$$\rightarrow V = (3.33\ A)(12\ \Omega) = 40\ V$$

08-02 Homework

- This is series-ous practice.
- Read
  - OpenStax College Physics 2e 21.1
  - OR
  - OpenStax High School Physics 19.3

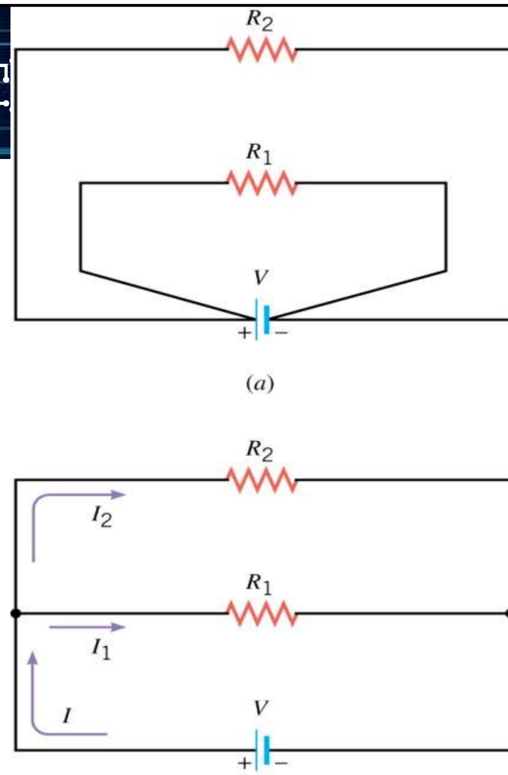


OpenStax High School Physics 19.3
OpenStax College Physics 2e 21.1

8-03 PARALLEL C

Parallel Wiring

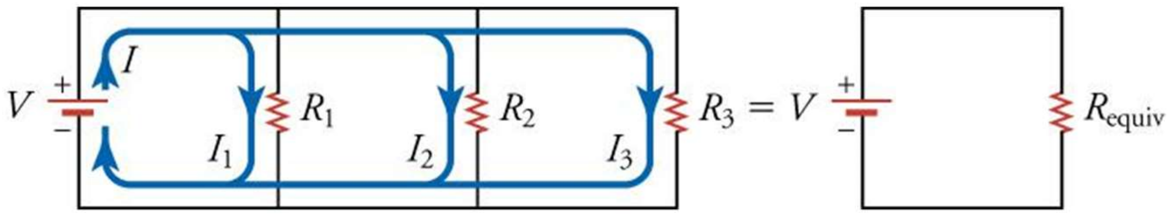
- Same voltage across several devices
- Typical house wiring
- Break in device has no effect on current
- Resistors divide current



8-03 Parallel Circuits

Derivation

- Each branch draws current as if the other wasn't there
- Each branch draws less current than the power supply gives
- *R* = *V* / *I*
- Overall circuit: Large *I* → Small *R*
  - Smaller resistance than either branch



8-03 Parallel Circuits

$$I = I_1 + I_2$$

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

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

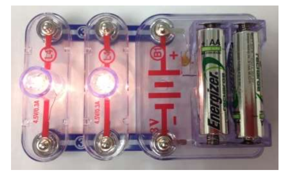
$$I = V\left(\frac{1}{R_1} + \frac{1}{R_2}\right) = V\left(\frac{1}{R_P}\right)$$

8-03 Parallel Circuits

Parallel Resistors

$$\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots$$

8-03 Parallel Circuits



- A 1004 Ω resistor and a 101 Ω resistor are connected in parallel. What is the equivalent resistance?
- 91.8 Ω
- If they were connected to a 3 V battery, how much total current would the battery supply?
- 32.7 mA
- How much current through each resistor?
- 3.0 mA and 29.7 mA

$$\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2}$$

$$1/R_P = \frac{1}{1004\ \Omega} + \frac{1}{101\ \Omega} = 0.000996/\Omega + 0.00990/\Omega = 0.010897/\Omega$$

$$R_P = \frac{1}{0.010897/\Omega} = 91.8\ \Omega$$

$$V = IR \rightarrow 3\ V = I(91.8\ \Omega) \rightarrow I = 0.0327\ A = 32.7\ mA$$

$$V = IR \rightarrow 3\ V = I(1004\ \Omega) \rightarrow I = 0.0030\ A$$

$$V = IR \rightarrow 3\ V = I(101\ \Omega) \rightarrow I = 0.0297\ A$$

$$Add\ them\ together \rightarrow 0.0327\ A$$

08-03 Homework

- These problems parallel the lesson.

- Read
  - OpenStax College Physics 2e 21.1
  - OR
  - OpenStax High School Physics 19.3

8-04 Circuits in Parallel and Series

In this lesson you will…

- Find equivalent resistance for circuits a combination of parallel and series.
- Find current or voltage over various parts of the circuit.

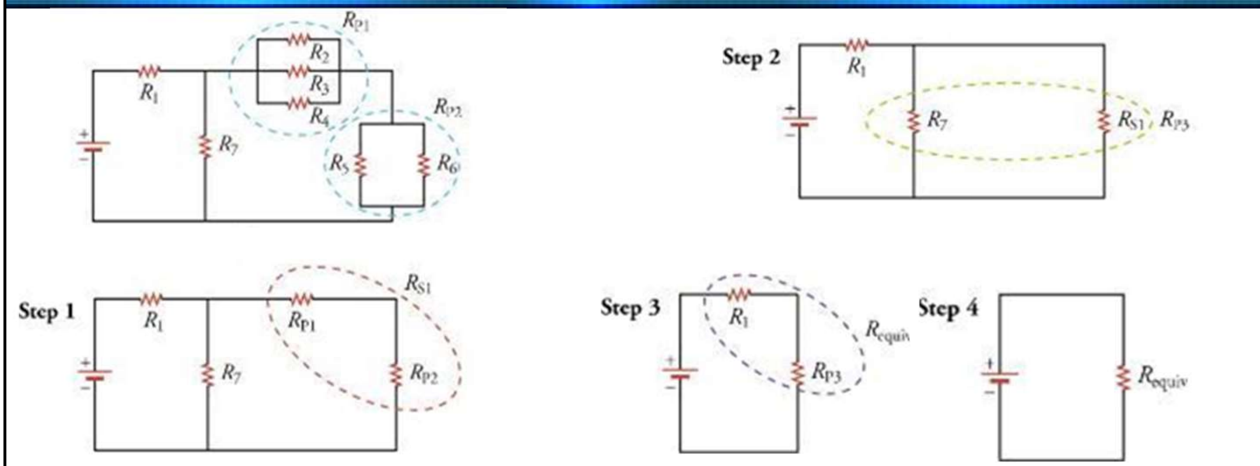
OpenStax High School Physics 19.3
OpenStax College Physics 2e 21.1

8-04 Circuits in Parallel and Series

Circuits Wired Partially in Series and Partially in Parallel

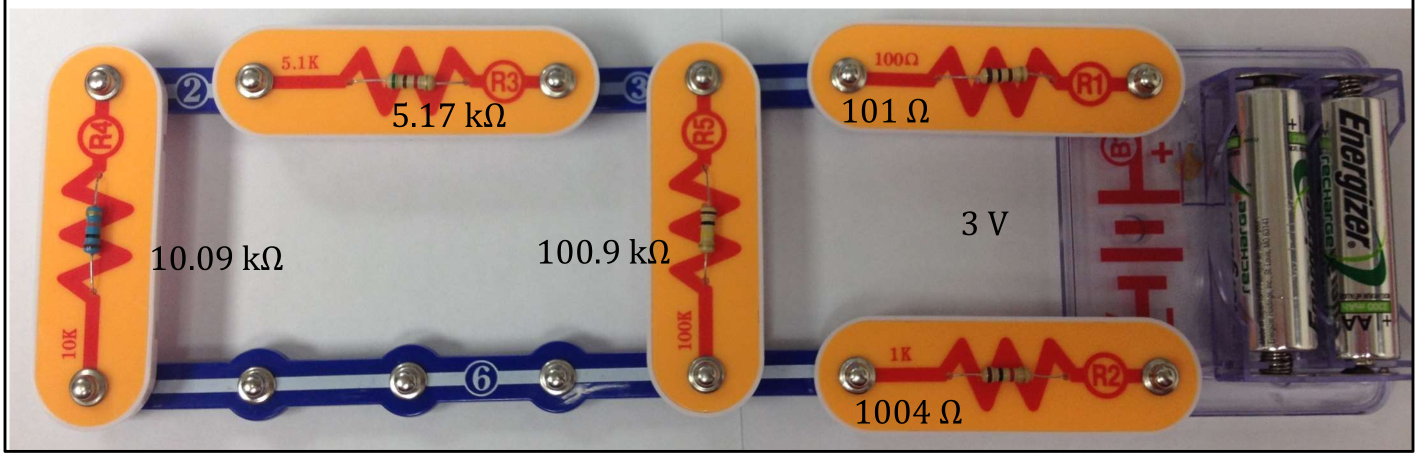
- Simplify any series portions of each branch
- Simplify the parallel circuitry of the branches
- If necessary, simplify any remaining series

8-04 Circuits in Parallel and Series



8-04 Circuits in Parallel and Series

- Find the equivalent resistance and the total current of the following circuit.



$$Combine\ far\ left\ branch\ (series) \rightarrow 10090\ \Omega\ + 5170\ \Omega\ = 15260\ \Omega$$

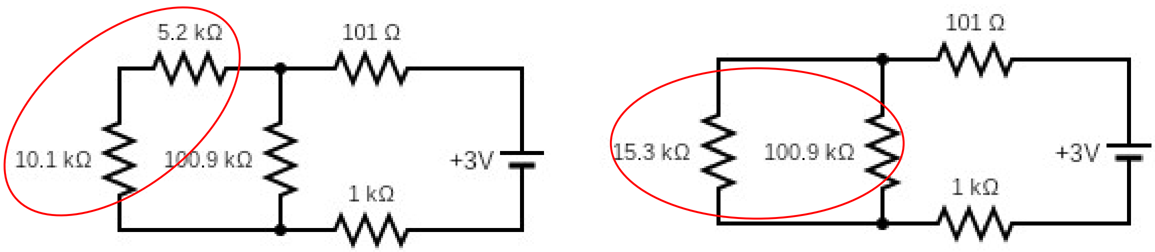
$$Combine\ left\ two\ branches\ (parallel) \rightarrow \frac{1}{R} = \frac{1}{15260\ \Omega} + \frac{1}{100900\ \Omega} \rightarrow \frac{1}{R}$$

$$= 7.54 \times 10^{-5} \frac{}{\Omega} \rightarrow R = 13255\ \Omega$$

$$The\ rest\ is\ series \rightarrow 13255\ \Omega + 1004\ \Omega + 101\ \Omega = \mathbf{14360\ \Omega}$$

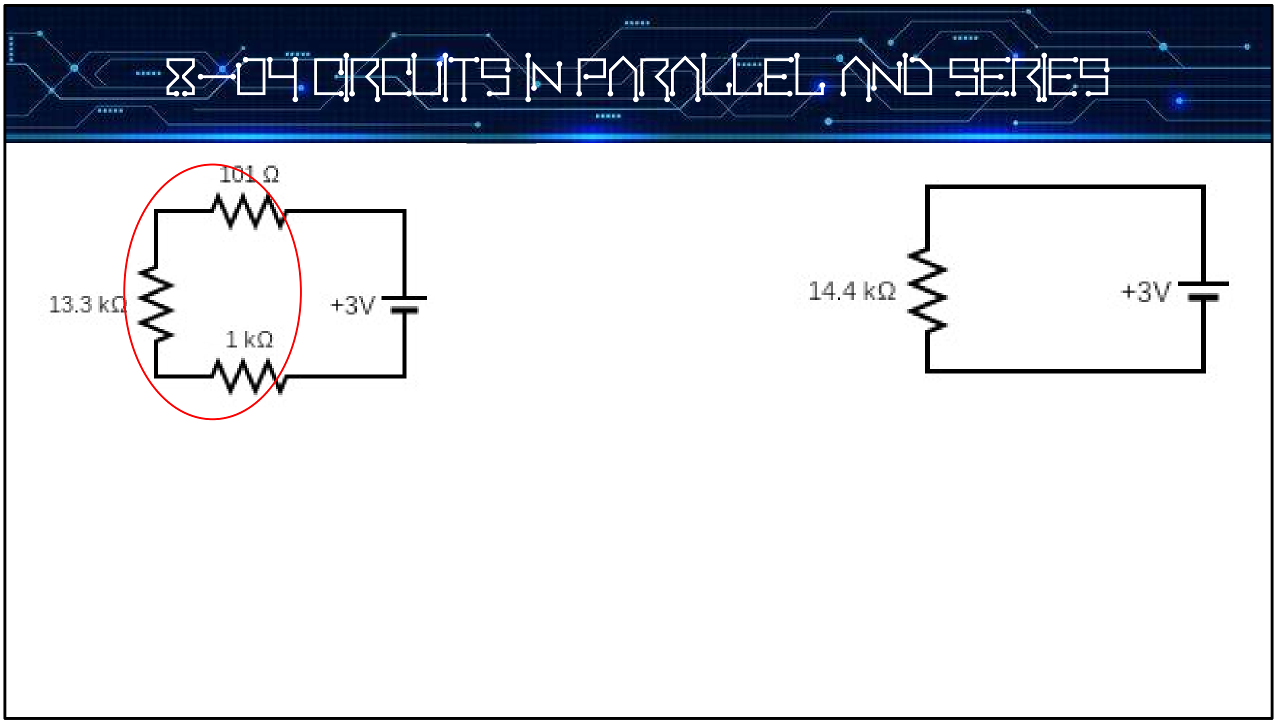
$$V = IR \rightarrow 3\ V = I(14360\ \Omega) \rightarrow I = 2.09 \times 10^{-4}\ A = 209\ mA$$

8-04 Circuits in Parallel and Series



$$Combine\ far\ left\ branch\ (series) \rightarrow 10090\ \Omega\ + 5170\ \Omega\ = 15260\ \Omega$$

$$Combine\ left\ two\ branches\ (parallel) \rightarrow \frac{1}{R} = \frac{1}{15260\ \Omega} + \frac{1}{100900\ \Omega} \rightarrow \frac{1}{R} = 7.54 \times 10^{-5}\frac{}{\Omega} \rightarrow R = 13255\ \Omega$$



$\textit{The rest is series} \rightarrow 13255\ \Omega + 1004\ \Omega + 101\ \Omega = \mathbf{14360\ \Omega}$

$V = IR \rightarrow 3\ V = I(14360\ \Omega) \rightarrow I = 2.09 \times 10^{-4}\ A = 209\ mA$

8-04 Circuits in Parallel and Series

- Find the equivalent resistance.

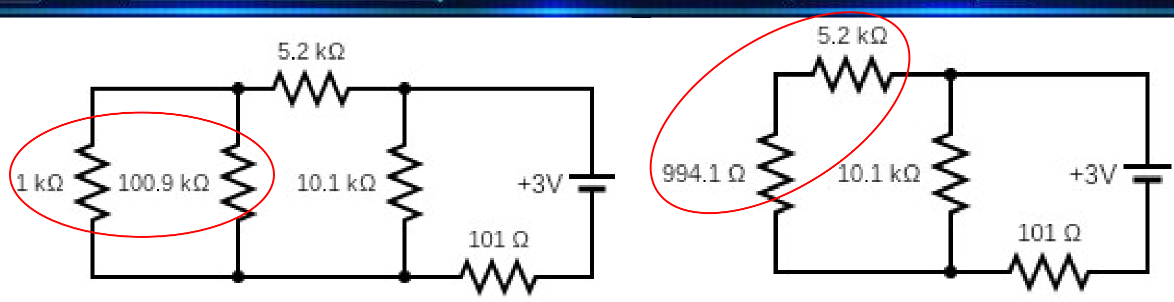
Far left two branches (parallel): $\frac{1}{R} = \frac{1}{1004\ \Omega} + \frac{1}{100900\ \Omega} \rightarrow R = 994.1\ \Omega$

Combine series: $R = 994.1\ \Omega + 5170\ \Omega = 6164.1\ \Omega$

Combine parallel: $\frac{1}{R} = \frac{1}{6164.1\ \Omega} + \frac{1}{10090\ \Omega} \rightarrow R = 3826.5\ \Omega$

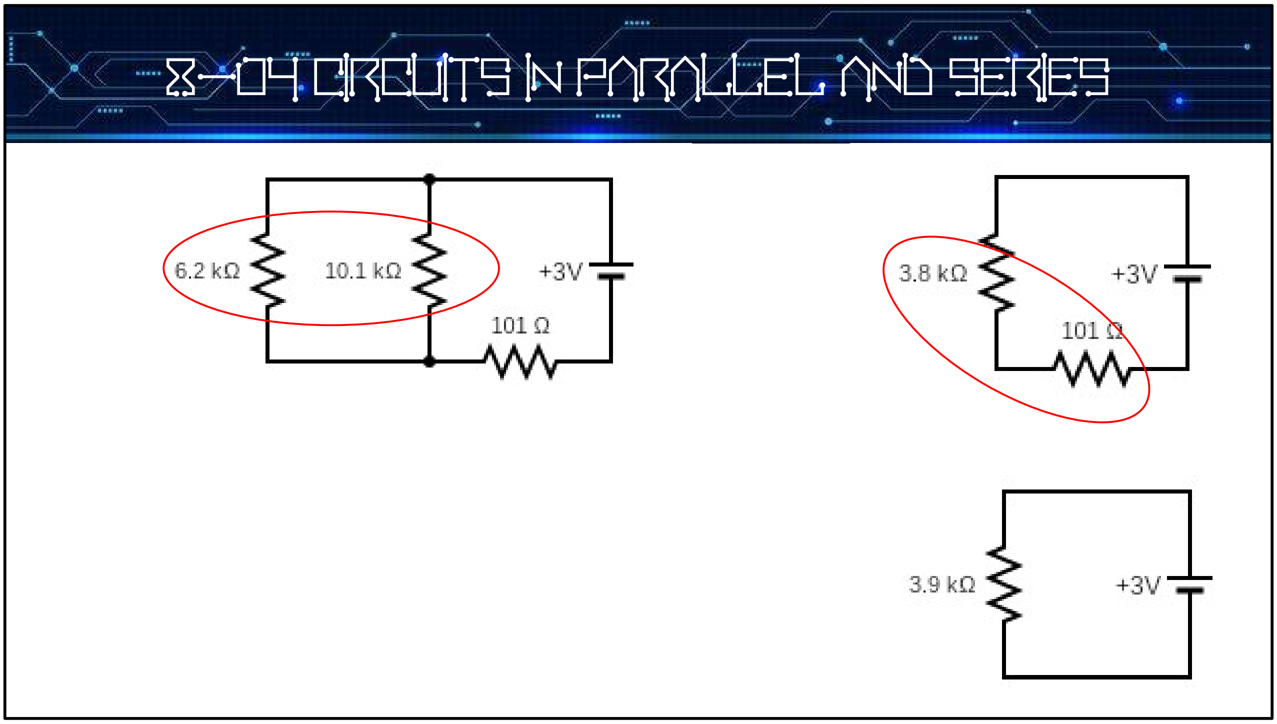
Combine series: $R = 3826.5\ \Omega + 101\ \Omega = 3927\ \Omega$

8-04 Circuits in Parallel and Series



Far left two branches (parallel): $\frac{1}{R} = \frac{1}{1004\ \Omega} + \frac{1}{100900\ \Omega} \rightarrow R = 994.1\ \Omega$

Combine series: $R = 994.1\ \Omega + 5170\ \Omega = 6164.1\ \Omega$



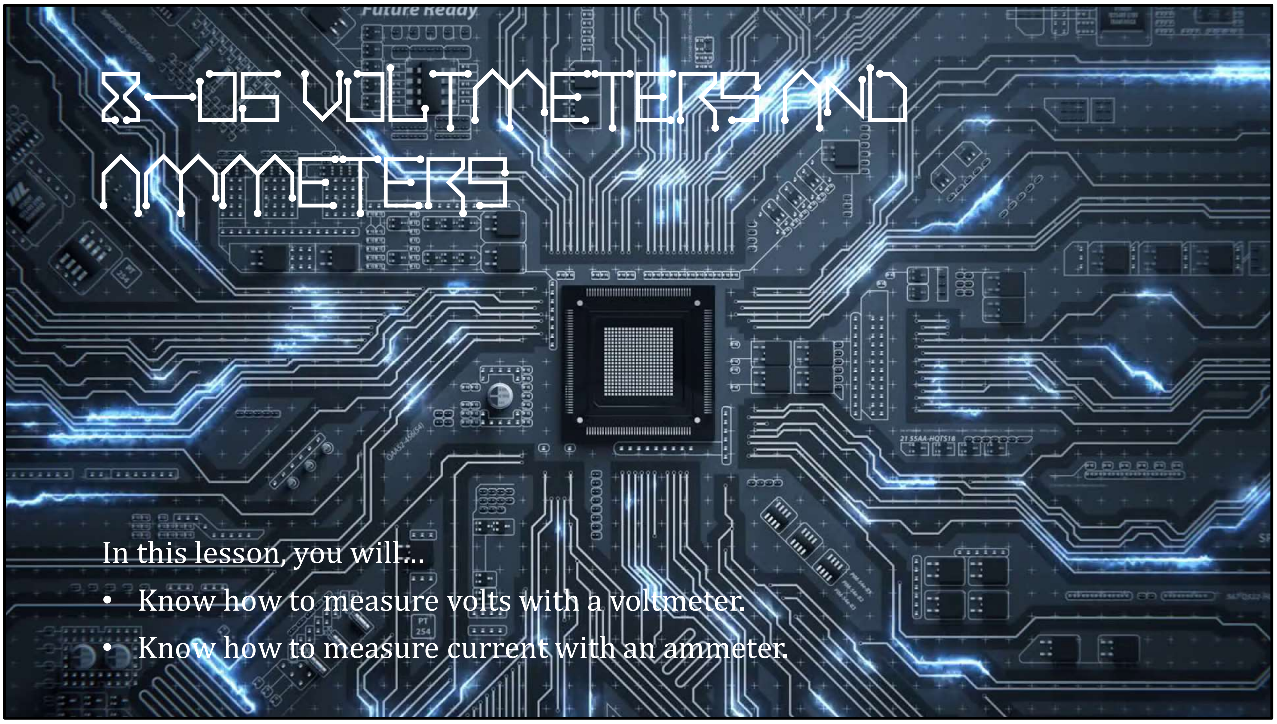
Combine parallel: $\frac{1}{R} = \frac{1}{6164.1\ \Omega} + \frac{1}{10090\ \Omega} \rightarrow R = 3826.5\ \Omega$

Combine series: $R = 3826.5\ \Omega + 101\ \Omega = 3927\ \Omega$

08-04 HOMEWORK

- I cannot think of a joke currently…

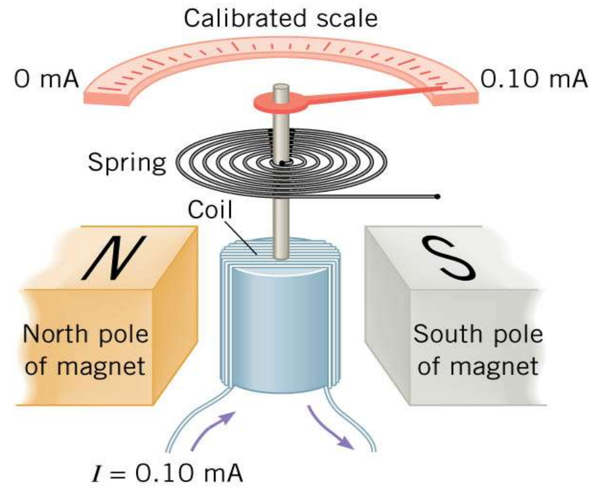
- Read
  - OpenStax College Physics 2e 21.4
  - OR
  - Read about voltmeters and ammeters



Not in OpenStax High School Physics
OpenStax College Physics 2e 21.4

8-05 Voltmeters and Ammeters

- Analog (non-digital) meters
- Main component → galvanometer



Made of magnets, wire coil, spring, pointer and calibrated scale.

Current flowing through the coil makes it magnetic, so it wants to move. The stronger the current the more the coil will rotate.

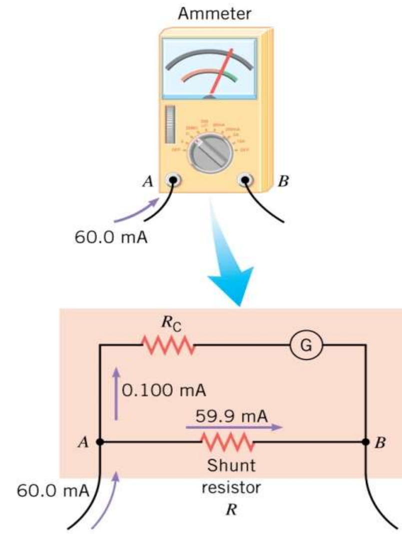
8-05 Voltmeters and Ammeters

Ammeters

- Measures current
- Inserted into circuit so current passes through it
    - Connected in series

8-05 Voltmeters and Ammeters

- Coil usually measures only little current
- Has shunt resistors connected in parallel to galvanometer so excess current can bypass
  - A knob lets you select which shunt resistor is used



Example of Shunt resistors

•Want to measure 100 mA, but meter's coil only reads 0.100 mA.

•Have shunt resistor take 99.9 mA and the coil only gets .1 mA

•To know how big to make the shunt resistors, the resistance of the coil needs to be known.

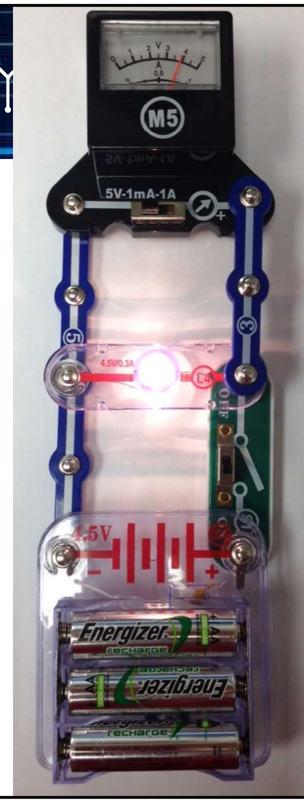
8-05 Voltmeters and Ammeters

- Problems with Ammeters
  - The resistance of the coil and shunt resistors add to the resistance of the circuit
  - This reduces the current in the circuit
  - Ideal ammeter has no resistance
    - Real-life good ammeters have small resistance so as only cause a negligible change in current

8-05 Voltmeters and Am

Voltmeters

- Connected in parallel to circuit since parallel has same voltage
- The coil works just like in the ammeter
- Given the current and the resistance of the coil → $V = IR$
- To give more range, a large resistor is connected in series with the coil



Large resistor is added because if V is constant Big R means small I

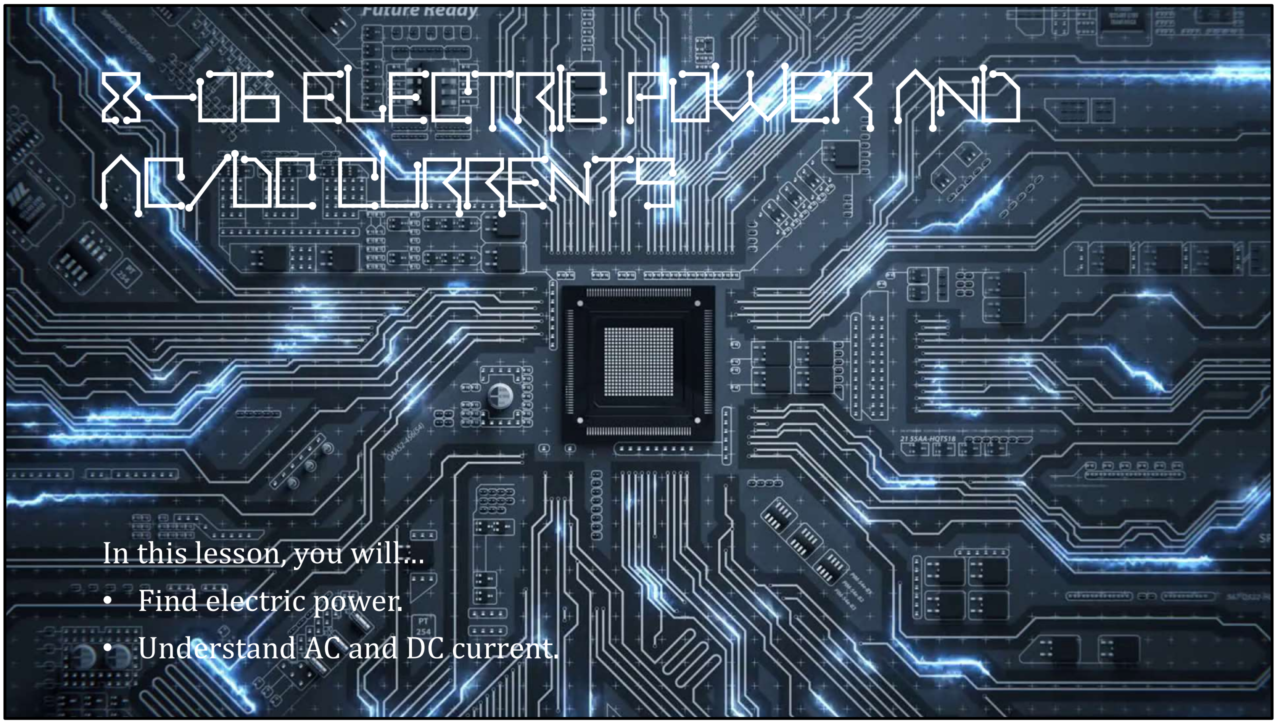
8-05 Voltmeters and Ammeters

- Problems with Voltmeters
  - The voltmeter takes some the voltage out of the circuit
  - Ideal voltmeter would have infinitely large resistance as to draw tiny current
  - Good voltmeter has large enough resistance as to make the current draw (and voltage drop) negligible

08-05 Homework

- See if you measure up to these meter problems

- Read
  - OpenStax College Physics 2e 20.4-20.5
  - OR
  - OpenStax High School Physics 19.4



OpenStax High School Physics 19.4
OpenStax College Physics 2e 20.4-20.5

8-06 Electric Power and AC/DC Currents

$$P = \frac{W}{t}$$

$$W = \Delta EPE = (\Delta q)V$$

$$P = \frac{(\Delta q)V}{t}$$

$$I = \frac{\Delta q}{t}$$

$$P = IV$$

8–06 Electric Power and AC/DC Currents

Power

$$P = IV$$

- Unit: Watt (W)
- Other equations for electrical power
  - $P = I(IR) = I^2R$
  - $P = \left(\frac{V}{R}\right)V = \frac{V^2}{R}$

V=IR → I = V/R

8-06 Electric Power and AC/DC Currents

- Let's say an electric heater has a resistance of 1430 Ω and operates at 120V. What is the power rating of the heater? How much electrical energy does it use in 24 hours?
- P = 10.1 W
- E = 873 kJ

Power

$$P = \frac{V^2}{R} = \frac{(120\ V)^2}{1430\ \Omega} = 10.1\ W$$

Energy use

$$P = \frac{W}{t} \rightarrow W = Pt = (10.1\ W)(86400\ s) = 872640\ J$$

8-06 Electric Power and AC/DC Currents

Kilowatt hours

- Electrical companies charge you for the amount of electrical energy you use
- Measured in kilowatt hours (kWh)

- If electricity costs \$0.15 per kWh how much does it cost to operate the previous heater (P = 10.1 W) for one month?
- \$1.09

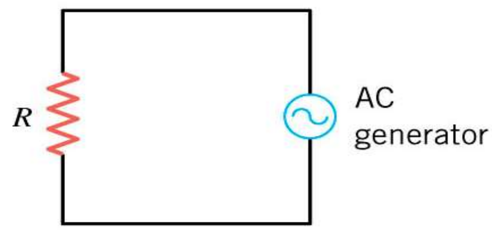
$$E = (0.0101\ kW)(720\ h) = 7.272\ kWh$$
$$Cost = (7.272\ kWh)(\$0.15) = \$1.09$$

8-06 Electric Power and AC/DC Currents

Alternating Current

- Charge flow reverses direction periodically
- Due to way that power plants generate power

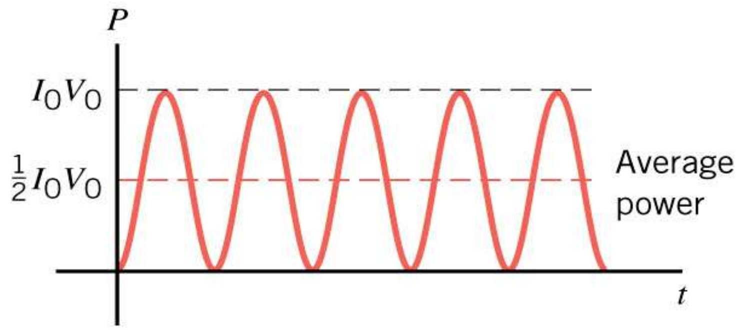
- Simple circuit



8–06 Electric Power and AC/DC Currents

Periodicity

- Voltage, Current, and Power fluctuate with time



- So we usually talk about the averages

8-06 Electric Power and AC/DC Currents

Average Power

- DC
  - $P = IV$
- AC
  - $P_{max} = I_0 V_0$
  - $P_{min} = 0$
  - $P_{ave} = \frac{1}{2} I_0 V_0$
- Often P is used to represent average power in all AC circuits.

I_0 and V_0 stand for the maximum value

8-06 Electric Power and AC/DC Currents

Root Mean Square (rms)

$$P_{ave} = \frac{1}{2} I_0 V_0 = \left(\frac{I_0}{\sqrt{2}}\right)\left(\frac{V_0}{\sqrt{2}}\right) = I_{rms} V_{rms}$$

- I_{rms} and V_{rms} are called root mean square current and voltage
- Found by dividing the max by $\sqrt{2}$

$$I_{rms} = \frac{I_0}{\sqrt{2}} \qquad V_{rms} = \frac{V_0}{\sqrt{2}}$$

8–06 Electric Power and AC/DC Currents

Convention in USA

- V_0 = 170 V
- V_{rms} = 120 V
- Most electronics specify 120 V, so they really mean V_{rms}

- We will always (unless noted) use average power, and root mean square current and voltage
- Thus, all previously learned equations work!

8-06 Electric Power and AC/DC Currents

- A 60 W light bulb operates on a peak voltage of 156 V. Find the V_{rms}, I_{rms}, and resistance of the light bulb.

- V_{rms} = 110 V
- I_{rms} = 0.55 A
- R = 202 Ω

$$V_{rms} = \frac{156\ V}{\sqrt{2}} = 110\ V$$

$$I_{rms}\colon\ P = IV \rightarrow 60\ W = I(110\ V) \rightarrow I_{rms} = 0.55\ A$$

$$P = \frac{V^2}{R} \rightarrow 60\ W = \frac{(110\ V)^2}{R} \rightarrow R = \frac{(110\ V)^2}{60\ W} \rightarrow 202\ \Omega$$

8-06 Electric Power and AC/DC Currents

- Why are you not supposed to use extension cords for devices that use a lot of power like electric heaters?

- $P = IV$
  - P is large so I is large
- The wire has some resistance
- The large current and little resistance can cause heating
- If wire gets too hot, the plastic insulation melts

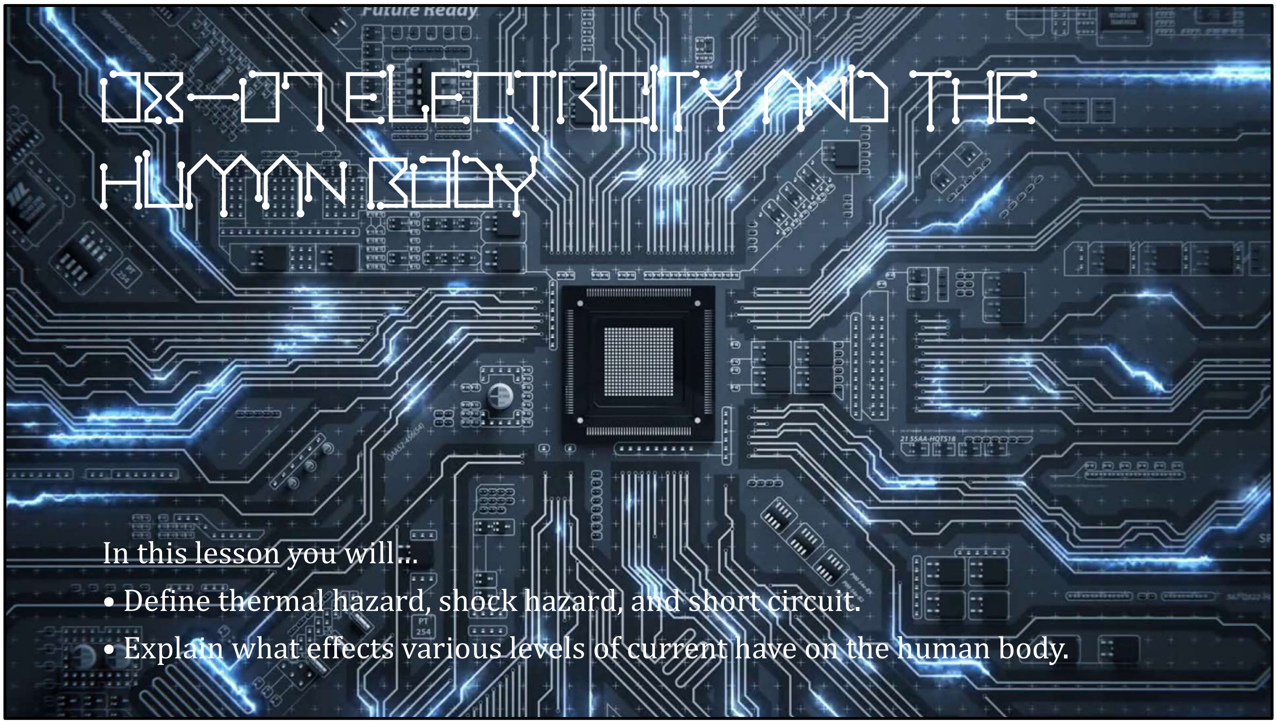
Wire resistance varies directly with L and inversely with A

If you use an extension cord, use one with thick wires and short length to reduce resistance
Remember small gauge means big wires

08-06 Homework

- Don’t write down just answers. Alternatively show your work, too.

- Read
  - OpenStax College Physics 2e 20.6
  - Or
  - Read about electrical safety



Not in OpenStax High School Physics
OpenStax College Physics 2e 20.6

08-07 Electricity and the Human Body

- Thermal Hazards
  - Electric energy converted to thermal energy faster than can be dissipated
  - Happens in short circuits
    - Electricity jumps between two parts of circuits bypassing the main load
    - $P = \frac{V^2}{R}$
    - Low R so high P
    - Can start fires
    - Circuit breakers or fuses try to stop
  - Or long wires that have
    - High resistance (thin)
    - Or are coiled so heat can't dissipate

Thin wires have higher R than thick wires

Heat can't escape from coiled wires and they melt

08-07 Electricity and the Human Body

- Shock Hazards
  - Factors
    - Amount of Current
    - Path of current
    - Duration of shock
    - Frequency of current
- Human body mainly water, so decent conductor
- Muscles are controlled by electrical impulses in nerves
- A shock can cause muscles to contract
  - Cause fist to close around wire (muscles to close, stronger than to open)
- Can cause heart to stop
- Body most sensitive to 50-60 Hz

08-07 Homework

- Don’t let these problems shock you.