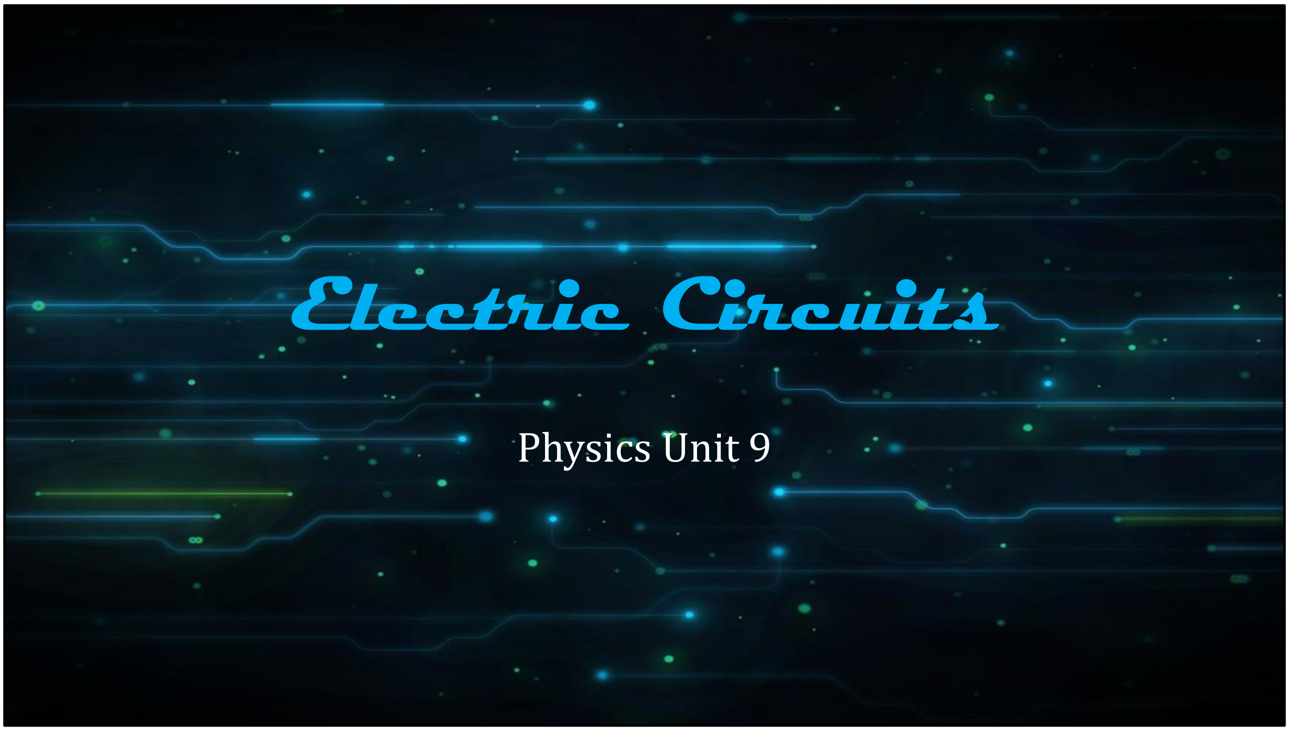

Physics Unit 9

- This Slideshow was developed to accompany the textbook
  - *OpenStax Physics*
    - *Available for free at https://openstaxcollege.org/textbooks/college-physics*
  - *By OpenStax College and Rice University*
  - *2013 edition*
- Some examples and diagrams are taken from the textbook.

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In this lesson you will…

- Define electric current and ampere
- Describe the direction of charge flow in conventional current.
- Explain the origin of Ohm’s law.
- Calculate voltages, currents, or resistances with Ohm’s law.
- Describe a simple circuit.

09-01 Current, Resistance, and Ohm’s Law

09-01 Current, Resistance, and 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)

09-01 Current, Resistance, and Ohm's Law

- Small computer speakers often have power supplies that give 12 VDC 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:

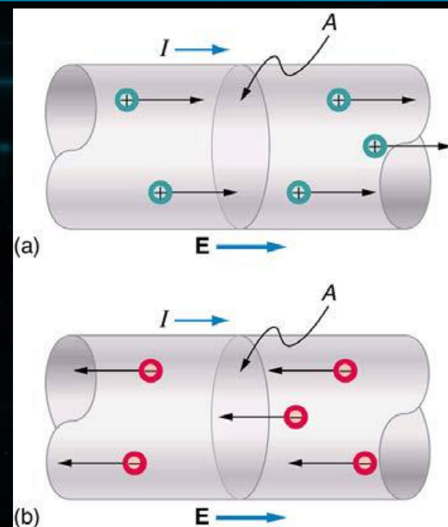
$$EPE = qV = (720\ C)12\ V = 8640\ J$$

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

09-01 Current, Resistance, and Ohm's Law

Conventional Current

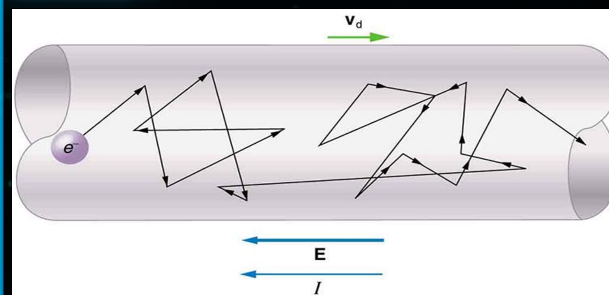
- Electrons are the charge that flows through wires
- Historically thought positive charges move
- Conventional current → imaginary flow of positive charges
  - Flows from positive terminal and into negative terminal
  - Real current flows the opposite way



09-01 Current, Resistance, and 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



09-01 Current, Resistance, and 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

09-01 Current, Resistance, and Ohm's Law

Ohm's Law

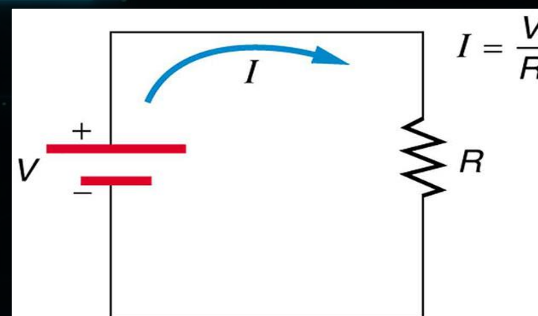
$$I = \frac{V}{R} \text{ or } V = IR$$

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

09-01 Current, Resistance, and Ohm's Law

Resistors

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



09-01 Current, Resistance, and 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 Ω

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

09-01 Homework

- Hopefully these circuit problems won't have you running around in circles
- Read 20.3

In this lesson you will…

- Explain the concept of resistivity.
- Use resistivity to calculate the resistance of specified configurations of material.
- Use the thermal coefficient of resistivity to calculate the change of resistance with temperature.

09-02 Resistance and Resistivity

09-02 Resistance and Resistivity

Another way to find resistance

- The resistance varies directly with length and inversely with width (or cross-sectional area) a wire
  - Kind of like trying to get a lot of water through a pipe
- Short, thick wire → small resistance
- Long, skinny wire → large resistance

09-02 Resistance and Resistivity

$$R = \frac{\rho L}{A}$$

- ρ = resistivity
  - Unit: Ω m
- Table 20.1 lists resistivities of some materials
  - Metals → small resistivity ($1\text{x}10^{-8}$ Ω m)
  - Insulators → large resisitivity ($1\text{x}10^{15}$ Ω m)
  - Semi-conductors → medium resistivity

09-02 Resistance and Resistivity

Why are long wires thick?

- Wire thicknesses are measured in gauges. 20-gauge wire is thinner than 16-gauge wire. If 20-gauge wire has $A = 5.2 \times 10^{-7}\ m^2$ and 16-gauge wire has $A = 13 \times 10^{-7}\ m^2$, find the resistance per meter of each if they are copper.

- 20-guage → $.0331\ \Omega/m$
- 16-guage → $.0132\ \Omega/m$

$$R = \frac{\rho L}{A} \rightarrow \frac{R}{L} = \frac{\rho}{A}$$
$$\rho = 1.72 \times 10^{-8}\ \Omega m$$
$$20 - gauge:$$
$$\frac{R}{L} = \frac{1.72 \times 10^{-8}\ \Omega m}{5.2 \times 10^{-7}\ m^2} = 0.033\ \Omega/m$$
$$16 - gauge:$$
$$\frac{R}{L} = \frac{1.72 \times 10^{-8}\ \Omega m}{13 \times 10^{-7}\ m^2} = 0.013\ \Omega/m$$
$$20 - gauge\ has\ about\ 3\ times\ the\ resistance$$

09-02 Resistance and Resistivity

Resistivity and Temperature

$$\rho = \rho_0(1 + \alpha\Delta T)$$

- ρ = resistivity at temperature T
- ρ_0 = resistivity at temperature T_0
- α = temperature coefficient of resistivity
  - Unit: 1/°C (or 1/K)

09-02 Resistance and Resistivity

- Metals
  - Resistivity increases with temperature
  - α is positive
- Semiconductors
  - Resistivity decreases with temperature
  - α is negative

09-02 Resistance and Resistivity

Resistance and Temperature

$$R = R_0(1 + \alpha \Delta T)$$

- R = resistance at temperature T
- R_0 = resistance at temperature T_0
- α = temperature coefficient of resistivity
  - Unit: 1/°C (or 1/K)

09-02 Resistance and Resistivity

- A heating element is a wire with cross-sectional area of 2×10^{-7} m^2 and is 1.3 m long. The material has resistivity of 4×10^{-5} Ωm at 200°C and a temperature coefficient of 3×10^{-2} 1/°C. Find the resistance of the element at 350°C.

- R = 1430 Ω

Find new resistivity

$$\rho = (4 \times 10^{-5}\ \Omega m)\left[1 + \left(3 \times 10^{-2} \frac{1}{°C}\right)(350\ °C - 200\ °C)\right] = 2.2 \times 10^{-4}\ \Omega m$$

Find resistance

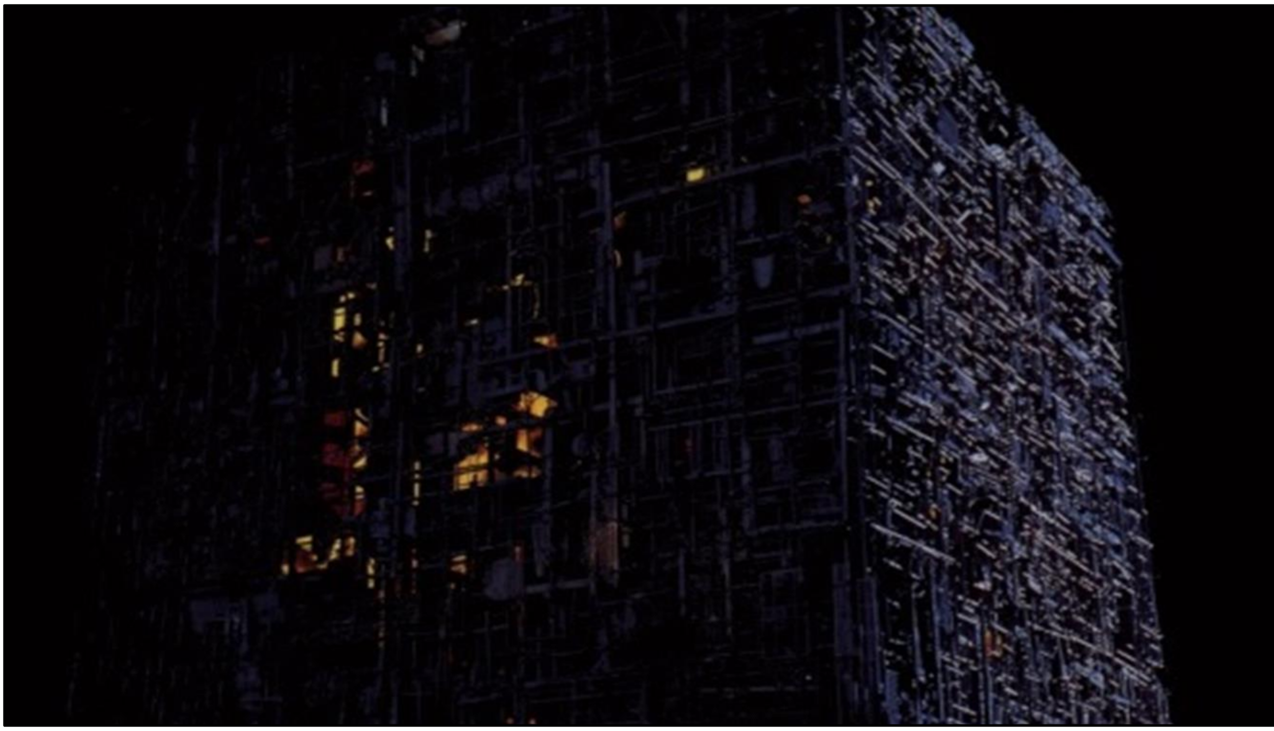
$$R = \frac{\rho L}{A} = \frac{(2.2 \times 10^{-4}\ \Omega m)(1.3 m)}{2 \times 10^{-7}\ m^2} = 1430\ \Omega$$

09-02 Resistance and Resistivity

Superconductors

- Materials whose resistivity = 0
- Metals become superconductors at very low temperatures
- Some materials using copper oxide work at much higher temperatures
- No current loss
- Used in
  - Transmission of electricity
  - MRI
  - Maglev
  - Powerful, small electric motors
  - Faster computer chips

Current in some superconductors have be constant for many years



09-03 Electric Power and AC/DC

In this lesson you will…

- Calculate the power dissipated by a resistor and power supplied by a power supply.
- Calculate the cost of electricity under various circumstances.
- Explain the differences and similarities between AC and DC current.
- Calculate rms voltage, current, and average power.

09-03 Electric Power and AC/DC

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

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

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

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

$$P = IV$$

09-03 Electric Power and AC/DC

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

09-03 Electric Power and AC/DC

- 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

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

09-03 Electric Power and AC/DC

Kilowatt hours

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

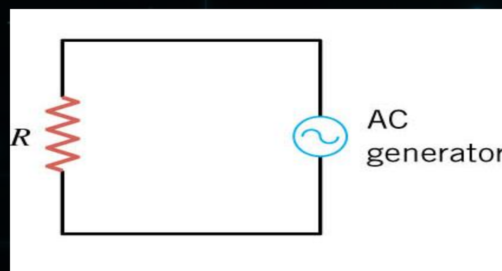
- If electricity costs \$0.15 per kWh how much does it cost to operate the previous heater (P = 10.1 W) for one month?
- \$1.09

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

09-03 Electric Power and AC/DC

Alternating Current

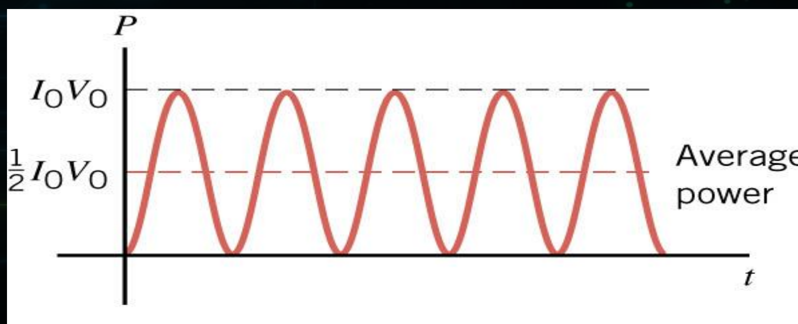
- Charge flow reverses direction periodically
- Due to way that power plants generate power
- Simple circuit



09-03 Electric Power and AC/DC

Periodicity

- Voltage, Current, and Power fluctuate with time



- So we usually talk about the averages

09-03 Electric Power and AC/DC

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

09-03 Electric Power and AC/DC

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 $\sqrt{2}$

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

09-03 Electric Power and AC/DC

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!

09-03 Electric Power and AC/DC

- 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

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

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

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

09-03 Electric Power and AC/DC

- 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

09-03 Homework

- Don’t write down just answers. Alternatively show your work, too.
- Read 20.6, 20.7

In this lesson you will…

- Define thermal hazard, shock hazard, and short circuit.
- Explain what effects various levels of current have on the human body.

09-04 Electricity and the Human Body

09-04 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

09-04 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

09-04 Homework

- Don’t let these problems shock you.
- Read 21.1

In this lesson you will…

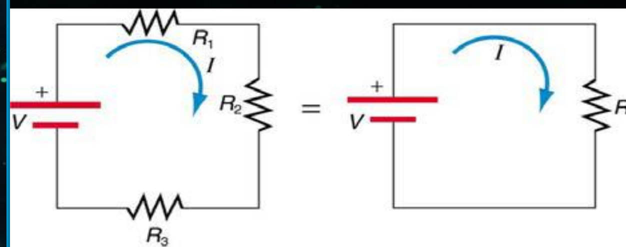
- Draw a circuit with resistors in parallel and in series.
- Calculate the voltage drop of a current across a resistor using Ohm's law.
- Contrast the way total resistance is calculated for resistors in series and in parallel.
- Explain why total resistance of a parallel circuit is less than the smallest resistance of any of the resistors in that circuit.
- Calculate total resistance of a circuit that contains a mixture of resistors connected in series and in parallel.

09-05 Resistors in Series and Parallel

09-05 Resistors in Series and Parallel

Series Wiring

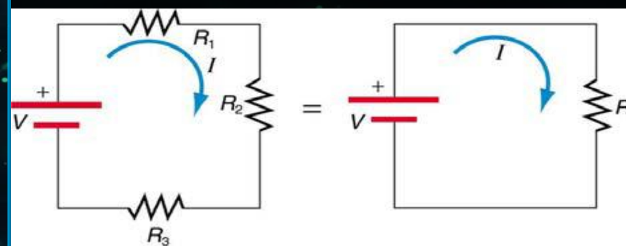
- More than one device on circuit
- Same current through each device
- Break in device means no current
- Form one “loop”
- The resisters divide the voltage between them



09-05 Resistors in Series and Parallel

- 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

09-05 Resistors in Series and Parallel

- 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

09-05 Resistors in Series and Parallel

- 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, voltage of each bulb, and the total power used?

- I = 3.33 A
- V = 26.7 V, 40 V
- P_{total} = 400 W

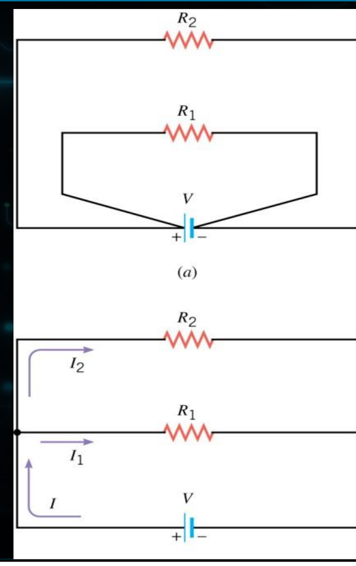
$$R_S = 3(8\ \Omega) + 12\ \Omega = 36\ \Omega$$
$$V = IR \rightarrow 120\ V = I(36\ \Omega) \rightarrow I = 3.33\ A$$
$$V = IR \rightarrow V = (3.33\ A)(8\ \Omega) = 26.7\ V$$
$$\rightarrow V = (3.33\ A)(12\ \Omega) = 40\ V$$
$$P = I^2R \rightarrow P = (3.33\ A)^2(8\ \Omega) = 88.9\ W$$
$$\rightarrow P = (3.33\ A)^2(12\ \Omega) = 133.3\ W$$
$$P_{total} = 3(88.9\ W) + 133.3\ W = 400\ W$$
$$\rightarrow P = I^2R = (3.33\ A)^2(36\ \Omega) = 400\ W$$

Notice you can total the power and the voltage

09-05 Resistors in Series and Parallel

Parallel Wiring

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



09-05 Resistors in Series and Parallel

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

09-05 Resistors in Series and Parallel

$$I = I_1 + I_2$$

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

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

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

09-05 Resistors in Series and Parallel

Parallel Resistors

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

09-05 Resistors in Series and Parallel

- 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

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

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

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

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

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

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

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

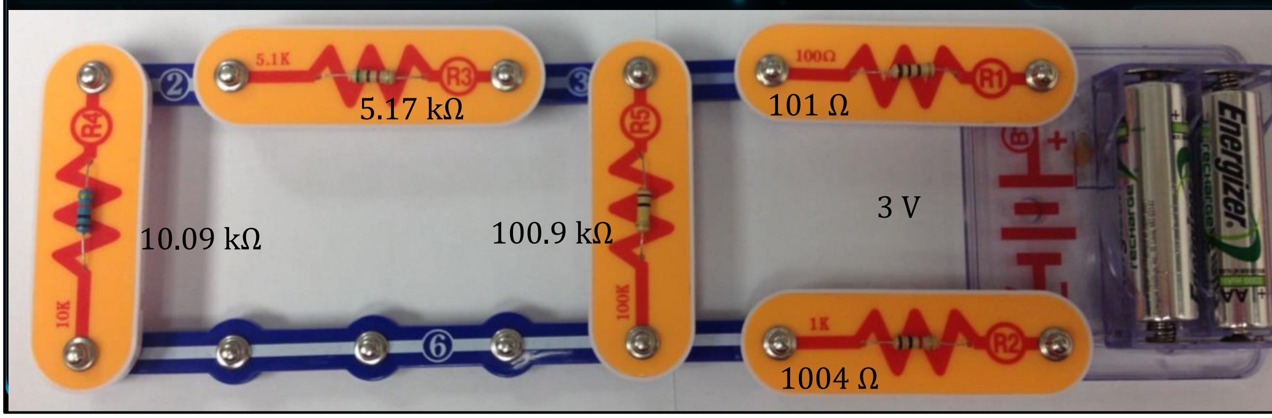
09-05 Resistors in Series and Parallel

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

09-05 Resistors in Series and Parallel

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



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

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

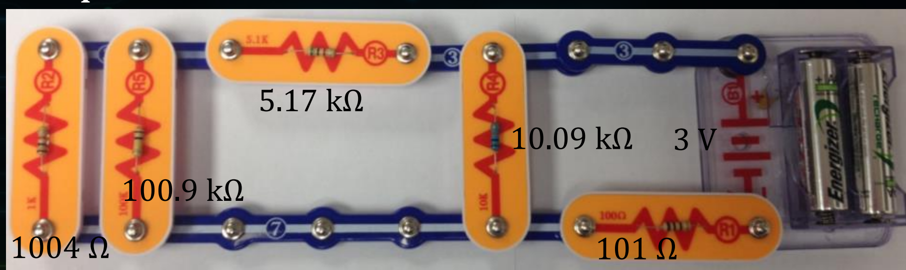
$$= 7.54 \times 10^{-5} \frac{}{\Omega} \rightarrow R = 13255\ \Omega$$

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

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

09-05 Resistors in Series and Parallel

- 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: $R = 3826.5\ \Omega + 101\ \Omega = 3927\ \Omega$

09-05 Homework

- These series of problems parallel the lesson.
- Read 21.2

In this lesson you will…

- Compare and contrast the voltage and the electromagnetic force of an electric power source.
- Describe what happens to the terminal voltage, current, and power delivered to a load as internal resistance of the voltage source increases (due to aging of batteries, for example).
- Explain why it is beneficial to use more than one voltage source connected in parallel.

09-06 Electromotive Force: Terminal Voltage

09-06 Electromotive Force: Terminal Voltage

- Emf
  - Electromotive force
  - Not really a force
  - Really voltage produced that could drive a current

09-06 Electromotive Force: Terminal Voltage

Internal Resistance

- Batteries and generators have resistance

- In batteries → due to chemicals
- In generators → due to wires and other components

- Internal resistance is connected in series with the equivalent resistance of the circuit

09-06 Electromotive Force: Terminal Voltage

- Internal resistance causes terminal voltage to drop below emf
- Internal resistance is not necessarily negligible
- $V = \mathcal{E} - Ir$
  - V = terminal voltage
  - $\mathcal{E}$ = emf
  - I = current of circuit
  - r = internal resistance

09-06 Electromotive Force: Terminal Voltage

- A string of 20 Christmas light are connected in series with a 3.0 V battery. Each light has a resistance of 10 Ω. The terminal voltage is measured as 2.0 V. What is the internal resistance of the battery?
- 100 Ω

$$V = IR \ (circuit\ w/o\ battery)$$
$$2\ V = I(20 \times 10\ \Omega) \rightarrow I = 0.01\ A$$

$$V = IR \ (internal\ resistance)$$
$$Voltage\ drop\ across\ internal\ resistance$$
$$3\ V - 2\ V = 1\ V$$
$$1\ V = (0.01\ A)R \rightarrow 100\ \Omega = R$$

09-06 Electromotive Force: Terminal Voltage

- A battery has an internal resistance of 0.02 Ω and an emf of 1.5 V. If the battery is connected with five 15 Ω light bulbs connected in parallel, what is the terminal voltage of the battery?
- 1.49 V

Combine parallel circuits

$$\frac{1}{R} = 5\left(\frac{1}{15\ \Omega}\right) \rightarrow R = 3\ \Omega$$

Combine with internal resistance

$$R = 3.02\ \Omega$$

Find current draw

$$V = IR$$

$$1.5\ V = I(3.02\ \Omega) \rightarrow I = 0.497\ A$$

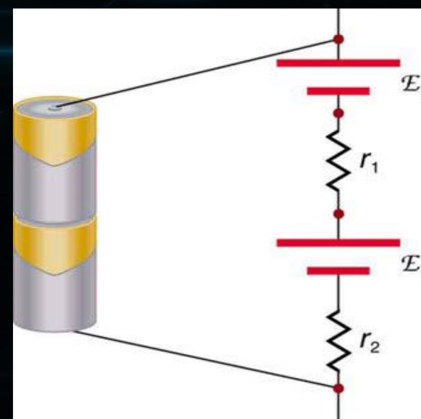
Use the circuit w/o battery to find terminal voltage

$$V = IR$$

$$V = (0.496\ A)(3\ \Omega) = 1.49\ V$$

09-06 Electromotive Force: Terminal Voltage

- If batteries are connected in series, their emfs add, but so do the internal resistances
- If batteries are connected in parallel, their emfs stay the same, but the currents add and the combined internal resistance is less



Think of resisters in series and parallel

09-06 Homework

- Hard work takes lots of emf!
- Read 21.3

09-07 Kirchhoff's Rules

In this lesson you will…

- Analyze a complex circuit using Kirchhoff's rules, using the conventions for determining the correct signs of various terms.

09-07 Kirchhoff's Rules

Kirchhoff's Rules

- Junction Rule
  - Total current into a junction must equal the total current out of a junction
- Loop Rule
  - For a closed-circuit loop, the total of all the potential rises – total of all potential drops = 0
  - (or the total voltage of a loop is zero)

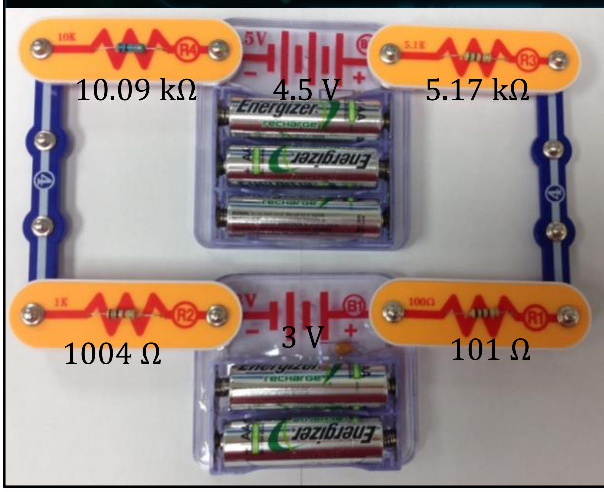
09-07 Kirchhoff's Rules

Reasoning Strategy

- Draw the current in each branch of the circuit (flows out of positive terminal of battery). Choose any direction. If you are wrong you will get a negative current.
- Mark each element with a plus and minus signs at opposite ends to show potential drop. (Current flows from + to – through a resistor)
  - If the current leaves the element at +, voltage rise
  - If the current leaves the element at -, voltage drop
- Apply junction rule and loop rule to get as many independent equations as there are variables.
- Solve the system of equations.

09-07 Kirchhoff's Rules

- Find the current through the circuit

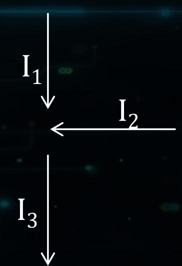


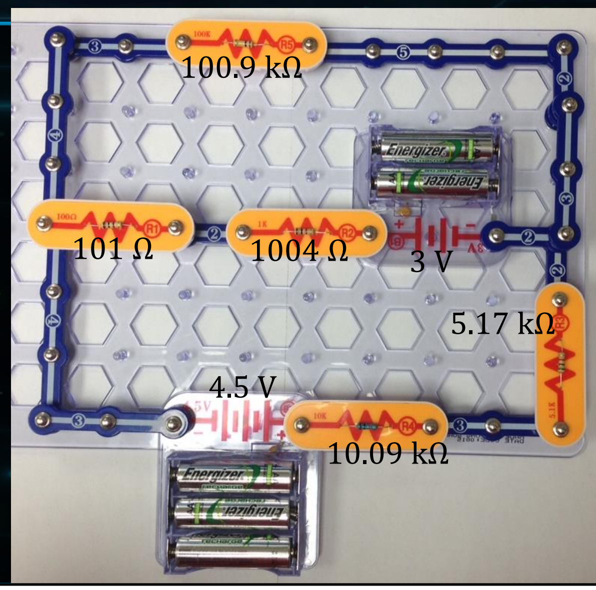
Loop Rule (starting top left going CCW)

$$I(10090\ \Omega) + 4.5\ V + I(5170\ \Omega) + I(101\ \Omega) + I(1004\ \Omega) = 3\ V$$
$$16365\ \Omega\ I + 4.5\ V = 3\ \mathrm{V}$$
$$16365\ \Omega\ I = -1.5\ V$$
$$I = -9.17 \times 10^{-5}\ A = 91.7\ \mu A$$

09-07 Kirchhoff's Rules

- Find the currents through each element.





$$\mathit{Left\ Junction}:\ I_3 = I_1 + I_2$$

$$\mathit{Top\ Loop\ CCW}: 3\ V = (I_2)(1004\ \Omega) + (I_2)(101\ \Omega) - (I_1)(100900\ \Omega)$$

$$\mathit{Bottom\ Loop\ CW}:\ 4.5\ V + 3\ V$$
$$= (I_3)(10090\ \Omega) + (I_3)(5170\ \Omega) + (I_2)(1004\ \Omega) + (I_2)(101\ \Omega)$$

$$\mathit{System}$$
$$I_1 + I_2 - I_3 = 0$$
$$-100900\ \Omega(I_1) + 1105\ \Omega(I_2) = 3\ V$$
$$1105\ \Omega(I_2) + 15260\ \Omega(I_3) = 7.5\ \text{V}$$

$$I_1 = -2.45 \times 10^{-5}\ A, I_2 = 4.81 \times 10^{-4}\ A, I_3 = 4.57 \times 10^{-4}\ A$$

09-07 Homework

- Currently, you need to work on these problems
- Read 21.4

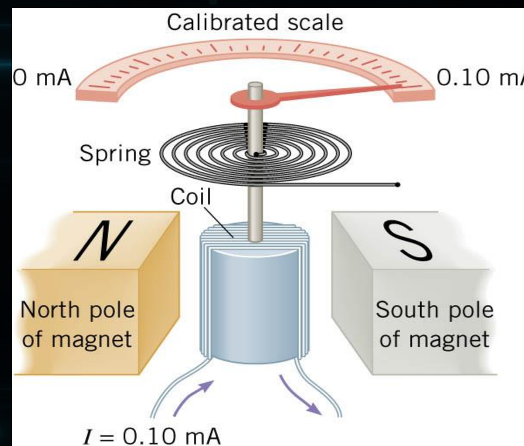
In this lesson you will…

- Explain why a voltmeter must be connected in parallel with the circuit.
- Draw a diagram showing an ammeter correctly connected in a circuit.
- Describe how a galvanometer can be used as either a voltmeter or an ammeter.
- Find the resistance that must be placed in series with a galvanometer to allow it to be used as a voltmeter with a given reading.
- Explain why measuring the voltage or current in a circuit can never be exact.

09-08 DC Voltmeters and Ammeters

09-08 DC Voltmeters and Ammeters

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



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

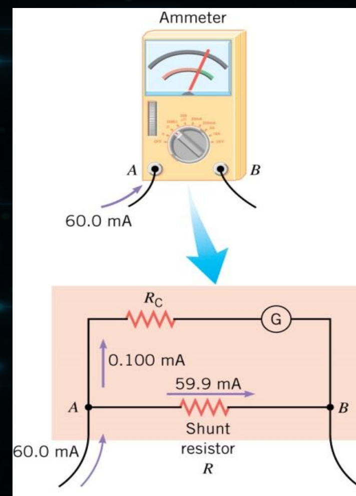
Current flowing through the coil makes it magnetic, so it wants to move. The stronger the current the more the coil will rotate.

09-08 DC Voltmeters and Ammeters

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

09-08 DC 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

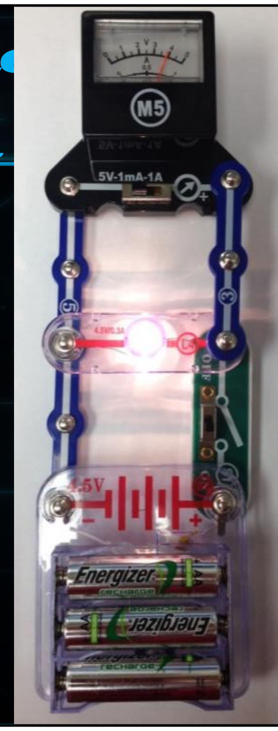
- Want to measure 100 mA, but meter's coil only reads 0.100 mA.
- Have shunt resistor take 99.9 mA and the coil only gets .1 mA
- To know how big to make the shunt resistors, the resistance of the coil needs to be known.

09-08 DC 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

09-08 DC Voltmete Ammeters

- 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

09-08 DC 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

09-08 Homework

- See if you measure up to these meter problems
- Read 21.6

In this lesson you will…

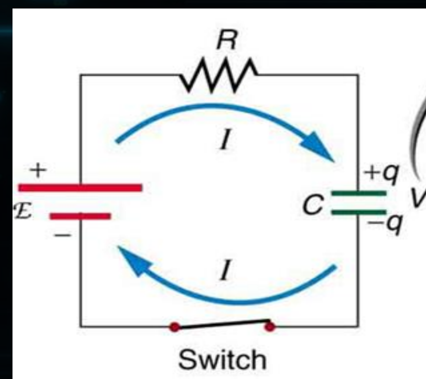
- Explain the importance of the time constant, τ , and calculate the time constant for a given resistance and capacitance.
- Describe what happens to a graph of the voltage across a capacitor over time as it charges.
- Explain how a timing circuit works and list some applications.

09-09 DC Circuits Containing Resistors and Capacitors

09-09 DC Circuits Containing Resistors and Capacitors

Charging a Capacitor

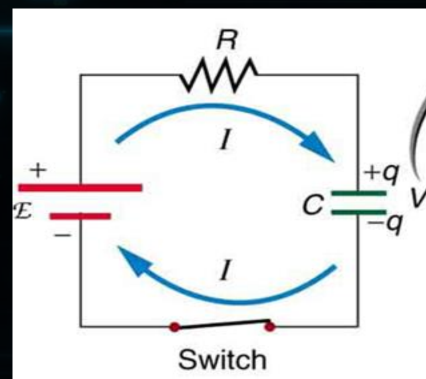
- Circuit with a capacitor, battery, and resistor
- Initially capacitor is uncharged
- When battery connected current flows to charge capacitor
- As charges build up, there is increased resistance because of the repulsion of the charges on the parallel plates
- When capacitor is fully charged, no current will flow



Current no longer flows because the parallel plates aren't connected and it can't accept anymore charge

09-09 DC Circuits Containing Resistors and Capacitors

- Loop Rule
  - $\mathcal{E} = \frac{q}{C} + IR$
- Solve for I
  - $I = \frac{V}{R} - \frac{q}{RC}$
- I is rate of change of q
- Differential Calculus says



Draw the circuit with Battery, capacitor, and resistor

09-09 DC Circuits Containing Resistors and Capacitors

Charging a Capacitor

- $q = CV\left(1 - e^{-\frac{t}{RC}}\right)$

- RC = τ (time constant – The time required to charge the capacitor to 63.2%)
- CV = Q (maximum charge)

- $V = \mathcal{E}\left(1 - e^{-\frac{t}{RC}}\right)$
- Where
  - V is voltage across the capacitor
  - $\mathcal{E}$ is emf
  - t is time
  - R is resistance of circuit
  - C is capacitance

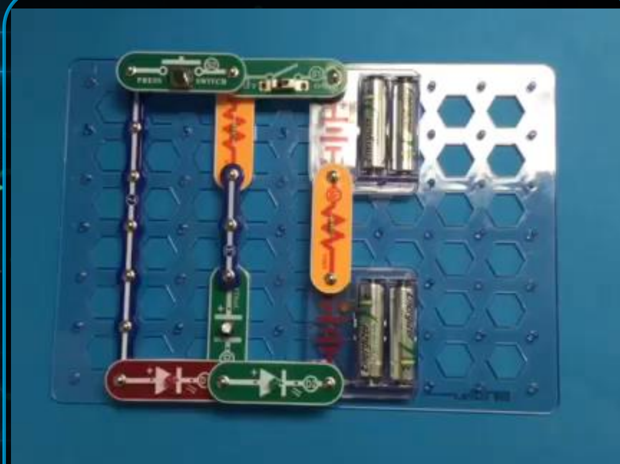
09-09 DC Circuits Containing Resistors and Capacitors

Discharging a Capacitor

- The battery is disconnected
- The capacitor acts like a battery supplying current to the circuit
- Loop Rule
  - $IR = \frac{q}{C}$
  - $I = \frac{q}{RC}$
- $q = Qe^{-\frac{t}{RC}}$
- $V = V_0 e^{-\frac{t}{RC}}$
- Often capacitors are used to charge slowly, then discharge quickly like in camera flash.
- Done by have different values for R in charging and discharging.

09-09 DC Circuits Containing Resistors and Capacitors

- Camera flashes work by charging a capacitor with a battery.
  - Usually has a large time constant because batteries cannot produce charge very fast
- The capacitor is then discharged through the flashbulb circuit with a short time constant



09-09 DC Circuits Containing Resistors and Capacitors

- An uncharged capacitor and a resistor are connected in series to a battery. If V = 12 V, C = 5 μF, and R = 8×10[5] Ω. Find the time constant, max charge, max current, and charge as a function of time.
  - $Time\ constant\colon\ \tau = RC = (800000\ \Omega)(0.000005\ F) = 4\ s$
  - $Max\ Charge\colon\ Q = CV = (0.000005\ F)(12\ V) = 0.000060\ C = 60\ \mu C$
  - $Max\ Current\colon\ I = \frac{V}{R} = \frac{12\ V}{800000\ \Omega} = 0.000015\ A = 15\ \mu A$
  - $Charge\ function\colon\ q(t) = 60\left(1 - e^{-\frac{t}{4}}\right)\ \mu C$
  - $Current\ function\colon\ I(t) = 15e^{-\frac{t}{4}}\ \mu$

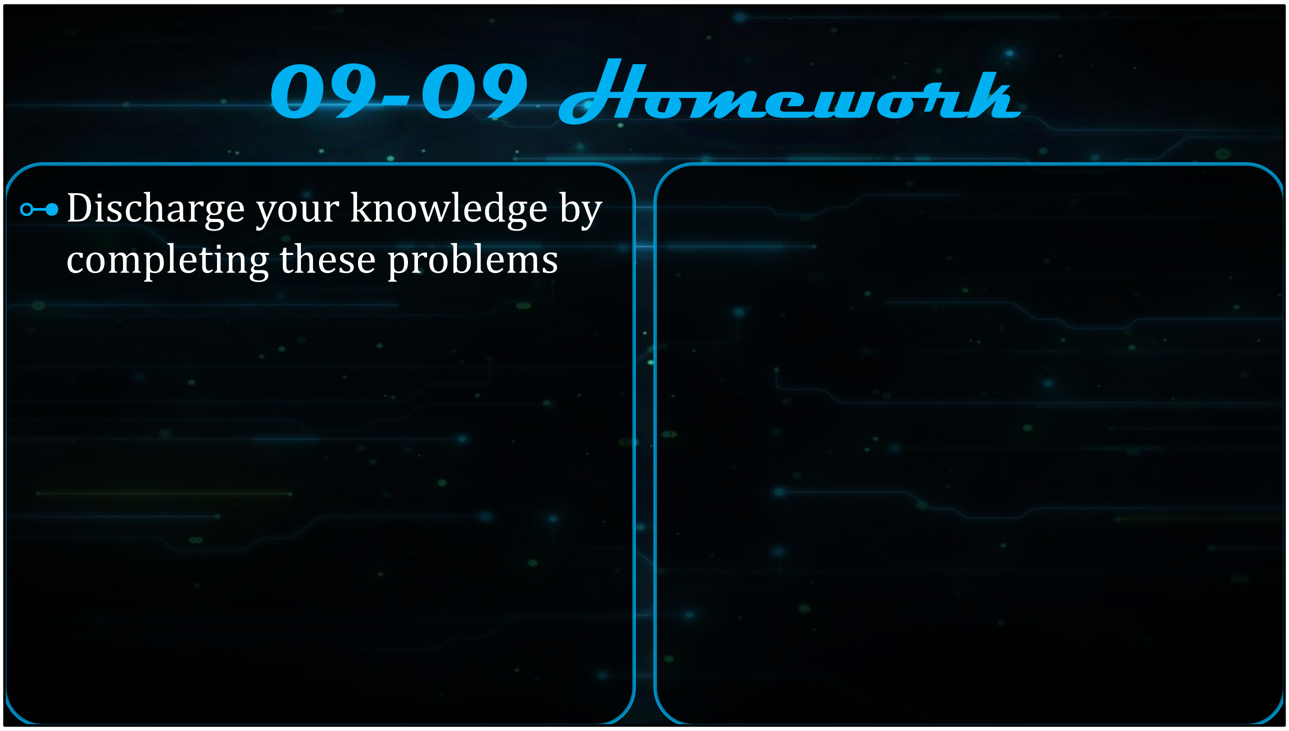
$$Time\ constant\colon\ \tau = RC = (800000\ \Omega)(0.000005\ F) = 4\ s$$

$$Max\ Charge\colon\ Q = CV = (0.000005\ F)(12\ V) = 0.000060\ C = 60\ \mu C$$

$$Max\ Current\colon\ I = \frac{V}{R} = \frac{12\ V}{800000\ \Omega} = 0.000015\ A = 15\ \mu A$$

$$Charge\ function\colon\ q(t) = 60\left(1 - e^{-\frac{t}{4}}\right)\ \mu C$$

$$Current\ function\colon\ I(t) = 15e^{-\frac{t}{4}}\ \mu A$$


09-09 Homework
Discharge your knowledge by completing these problems