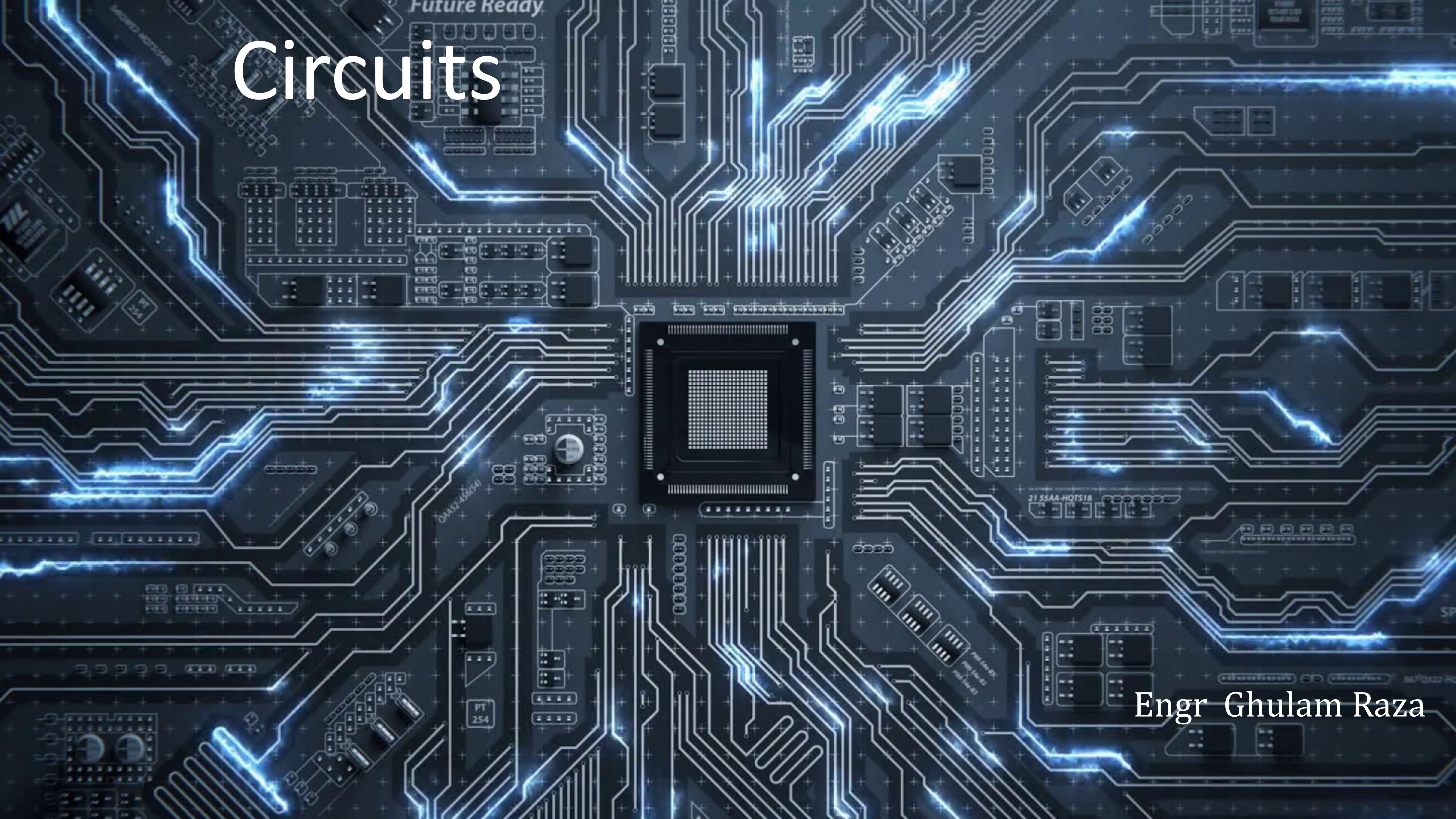
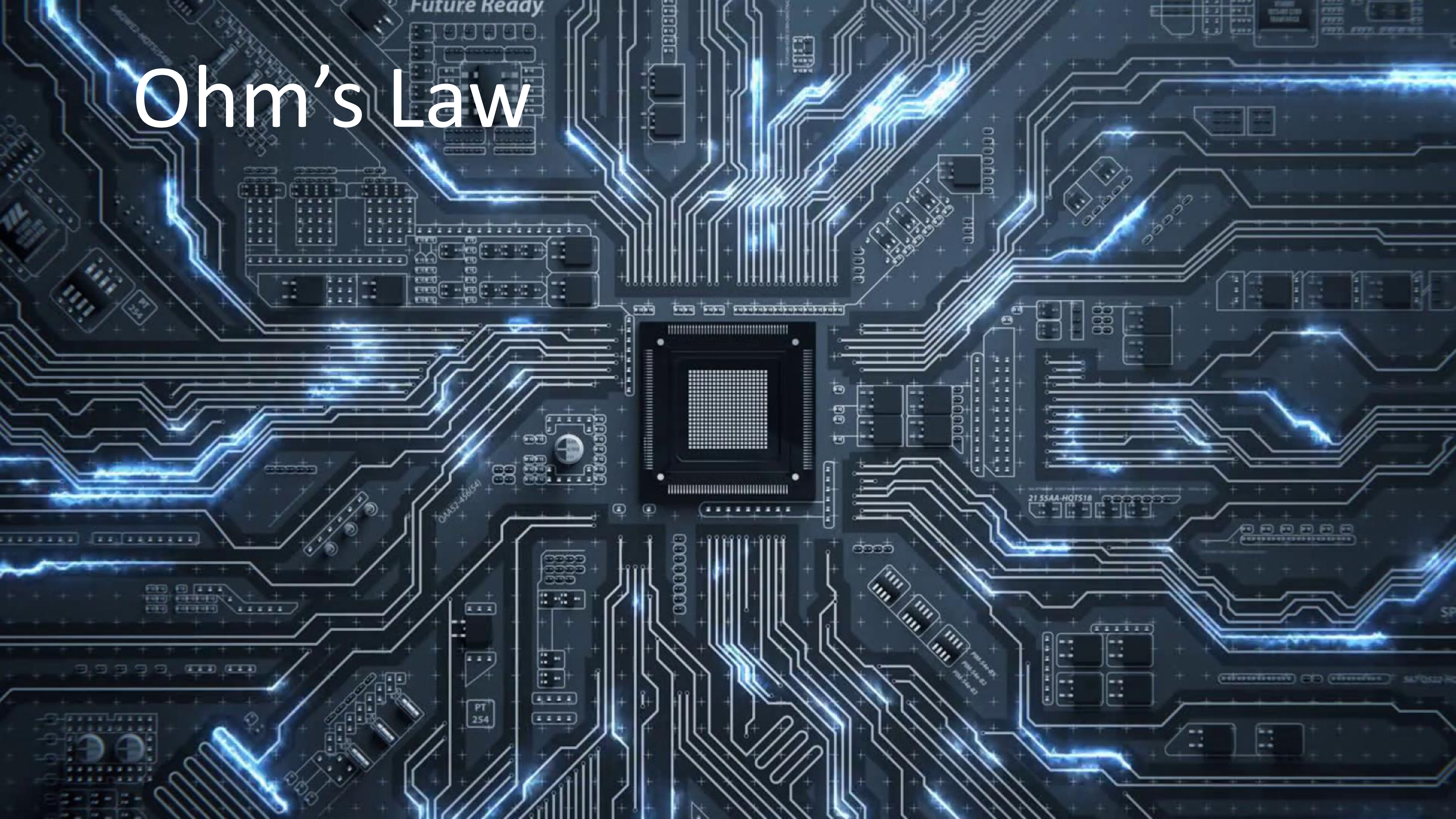
Circuits



Engr Ghulam Raza

Ohm’s Law



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)

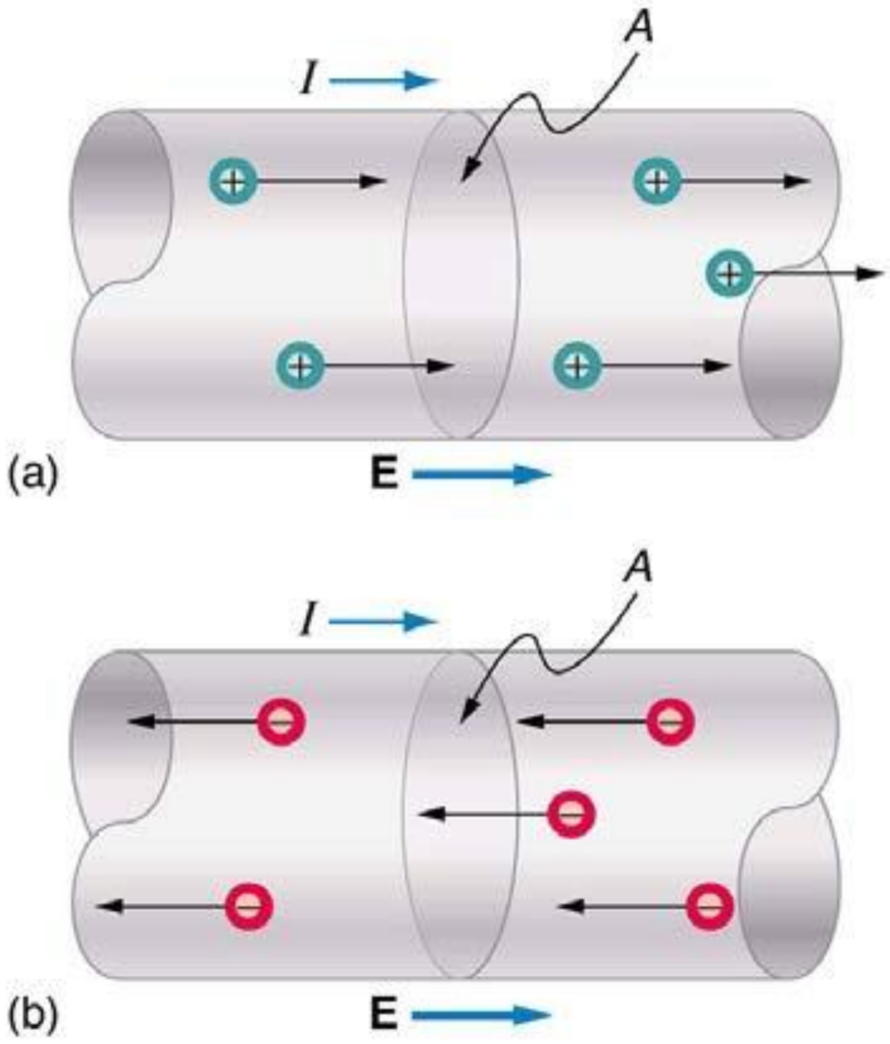
Ohm's Law

- 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

Ohm’s Law

Conventional Current

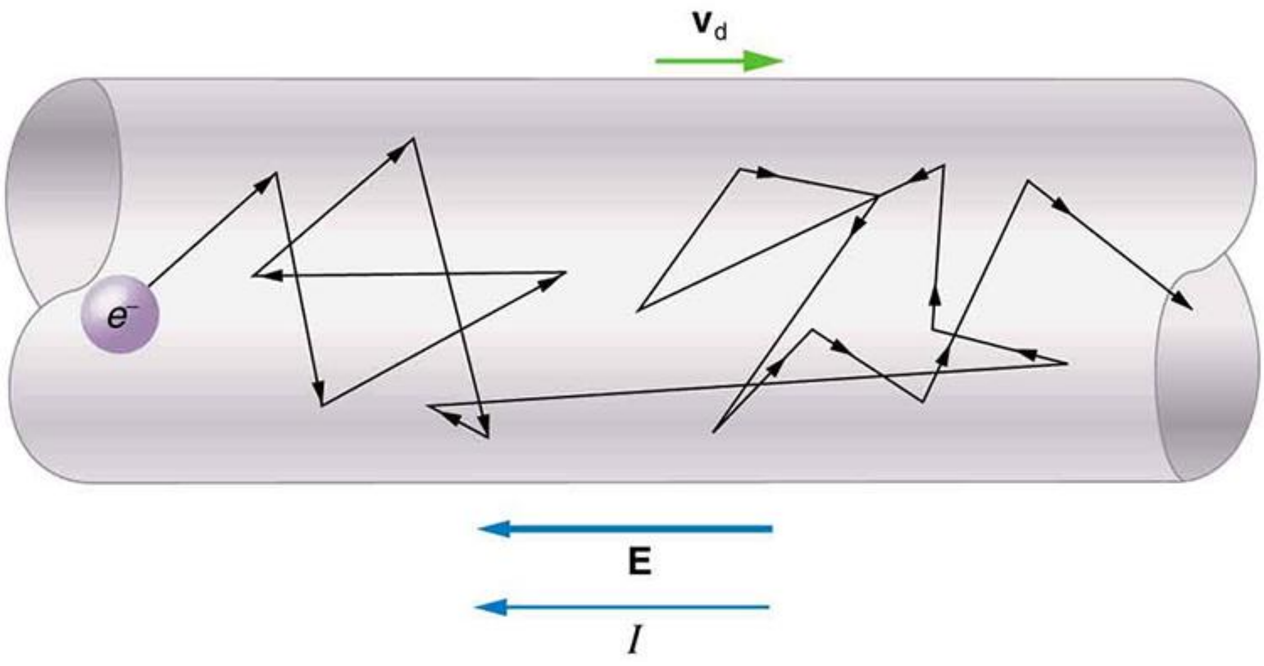
- Electrons are the charge that flows through wires
- Historically thought positive charges move
- Conventional current → imaginary flow of positive charges
  - Flows from positive terminal and into negative terminal
  - Real current flows the opposite way



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



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

Ohm's Law

Ohm's Law

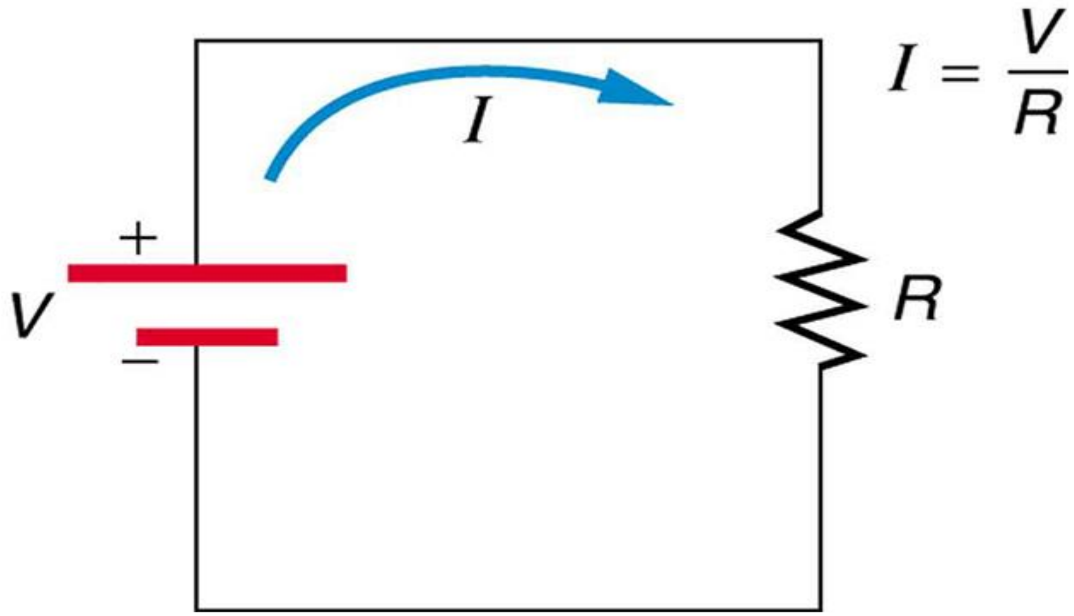
$$I = \frac{V}{R} \text{ or } V = IR$$

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

Ohm's Law

Resistors

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

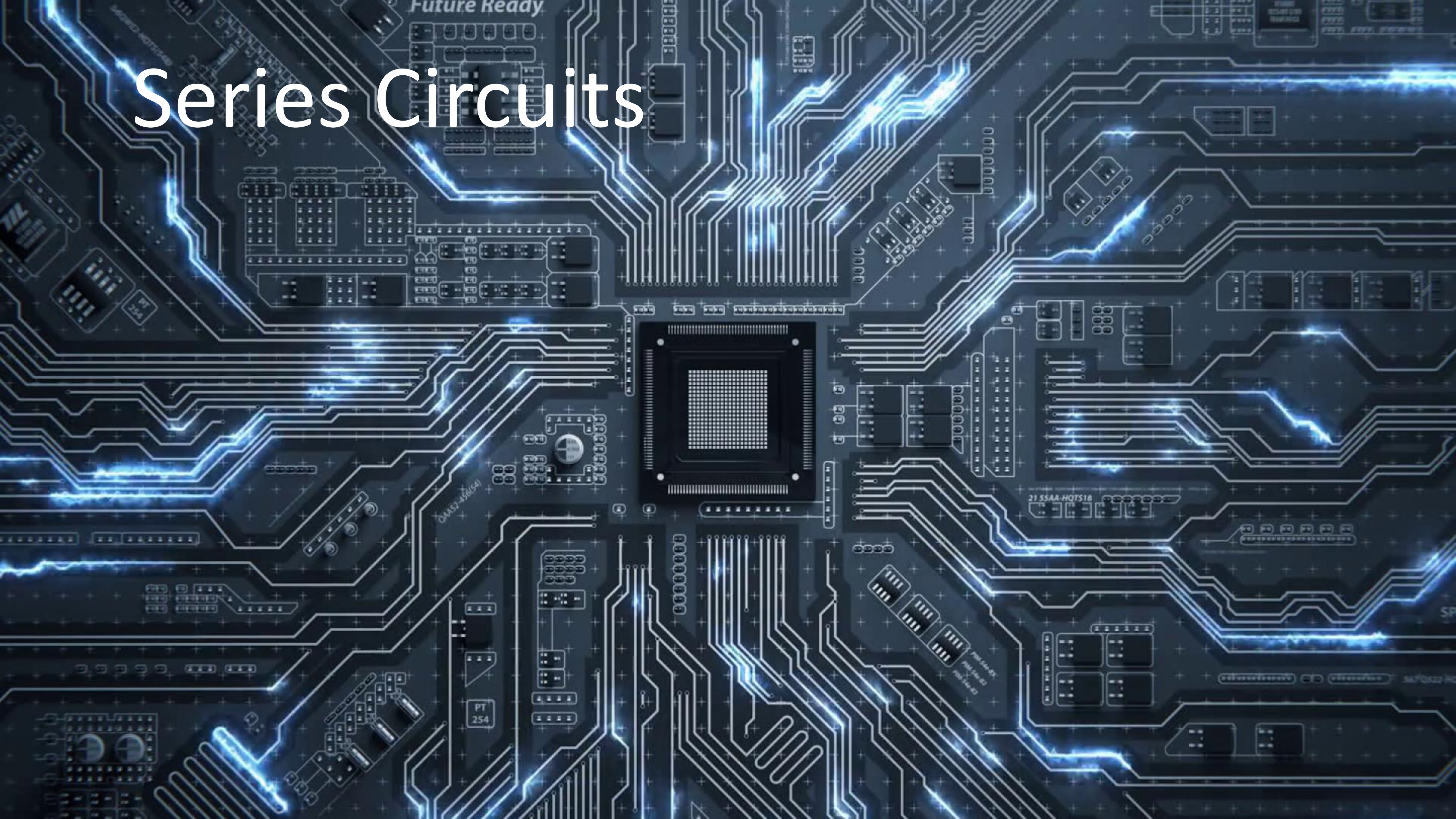


Ohm's Law

- 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.

- $R = 60\ \Omega$

Series Circuits

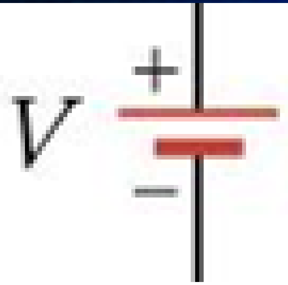


Series Circuits

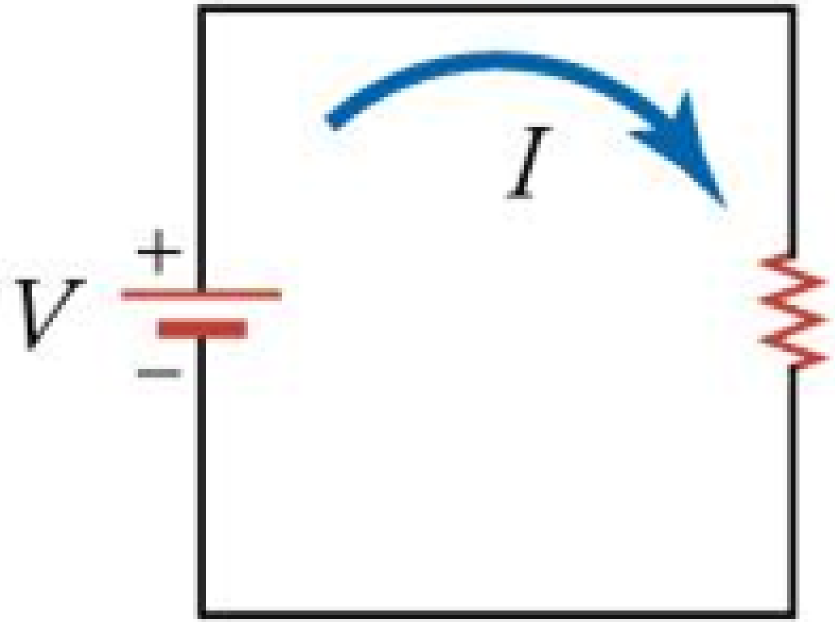
Electric circuit

- 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

Series Circuits



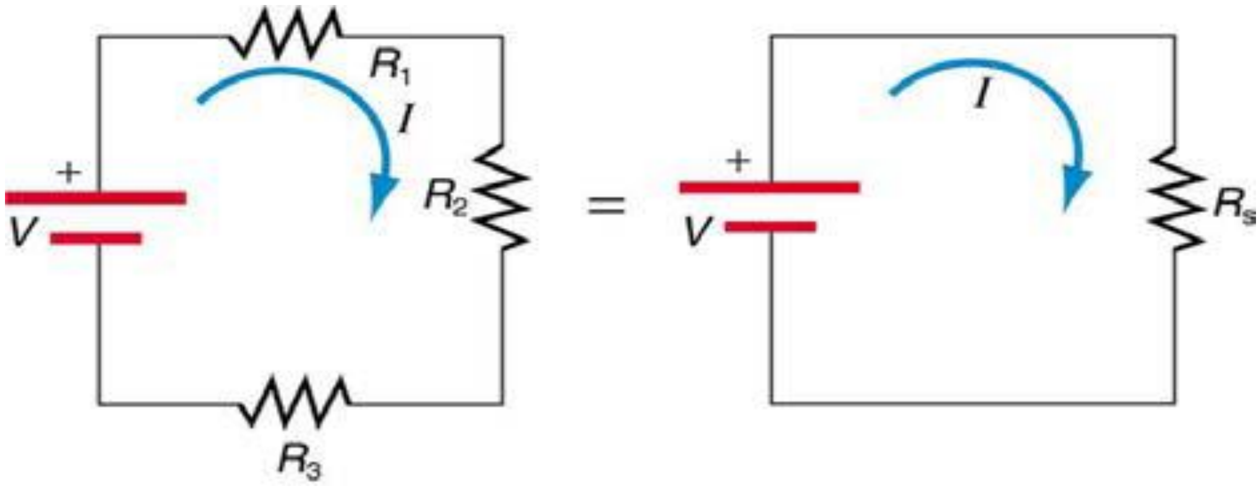
- Battery: Long side is positive, short side is negative
- Provides the potential to make the current flow
- Current flows from positive side to negative side
- Resistor: Uses the potential to do work



Series Circuits

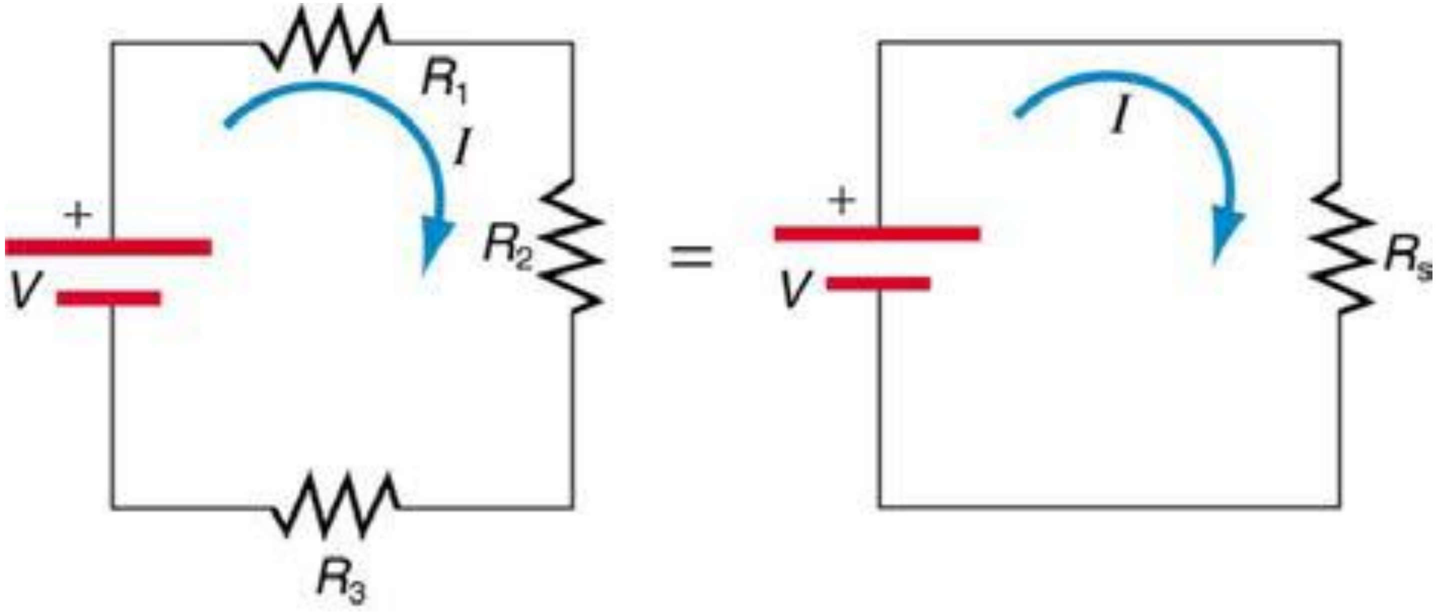
Series Wiring

- 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



Series Circuits

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



- $R_S = R_1 + R_2 + R_3 + \dots$

Series Circuits

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

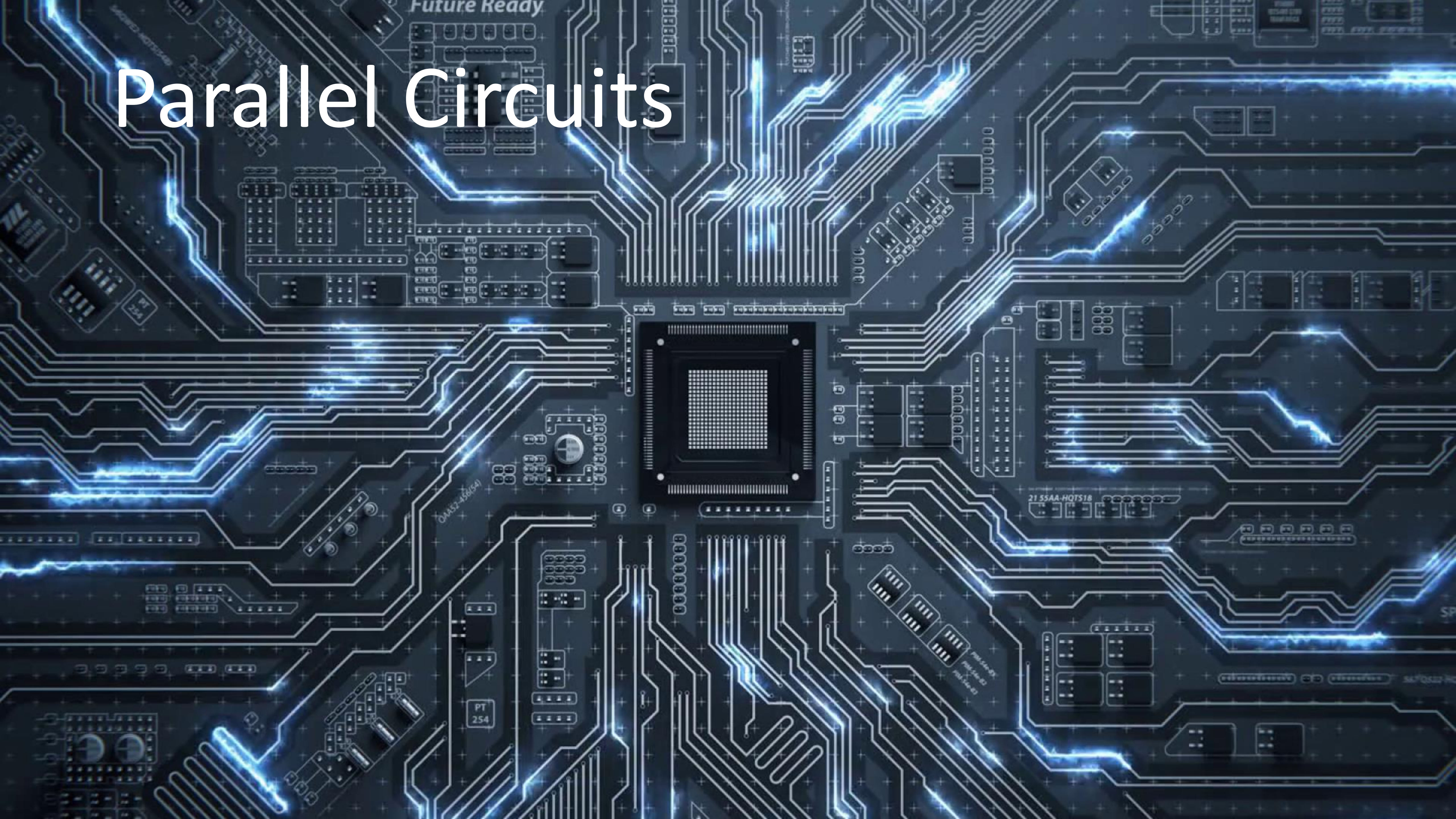
- 15.26 kΩ

Series Circuits

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

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

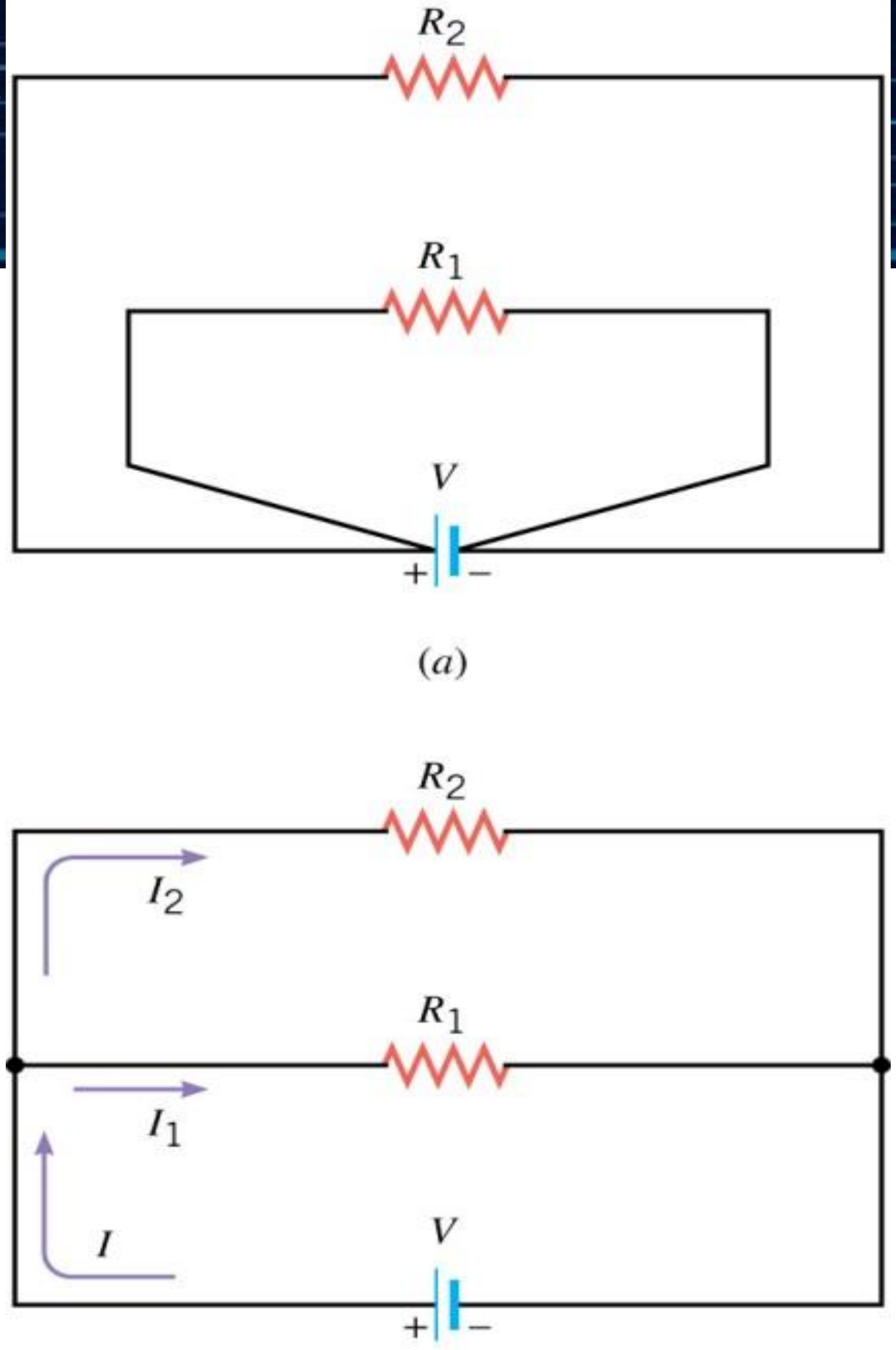
Parallel Circuits



Parallel Circui

Parallel Wiring

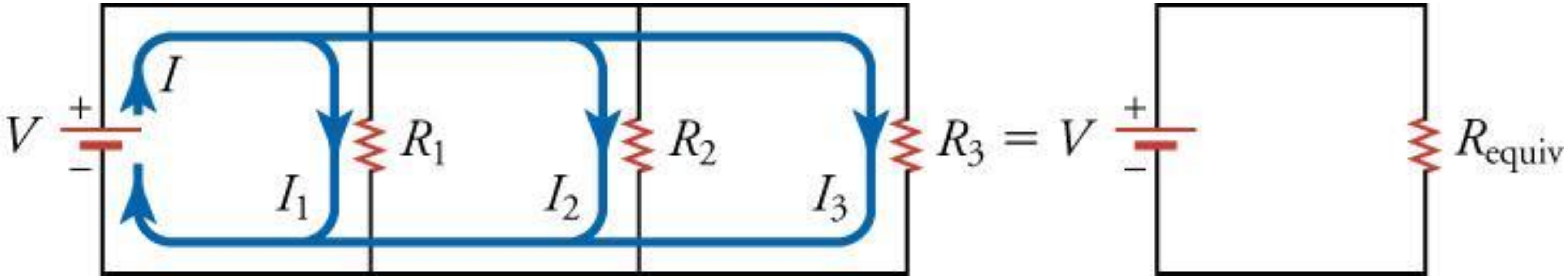
- Same voltage across several devices
- Typical house wiring
- Break in device has no effect on current
- Resistors divide current



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



Parallel Circuits

$$I = I_1 + I_2$$

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

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

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

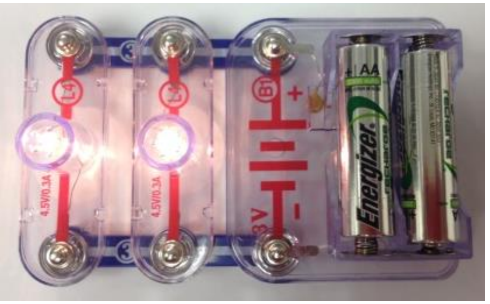
Parallel Circuits

Parallel Resistors

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

Parallel Circuits

- A 1004 Ω resistor and a 101 Ω resistor are connected in parallel. What is the equivalent resistance?

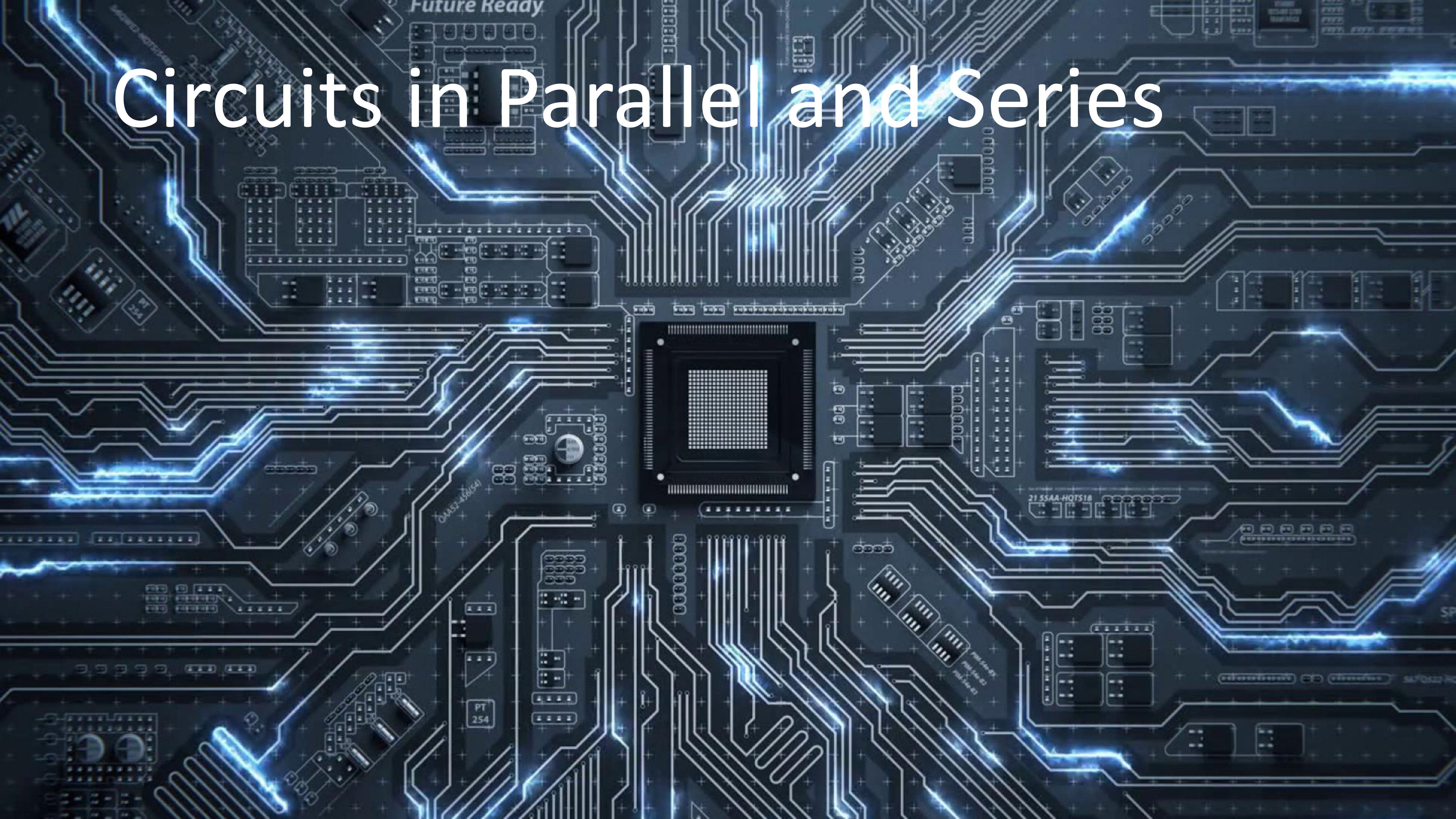


- 91.8 Ω
- If they were connected to a 3 V battery, how much total current would the battery supply?

- 32.7 mA
- How much current through each resistor?

- 3.0 mA and 29.7 mA

Circuits in Parallel and Series



Circuits in Parallel and Series

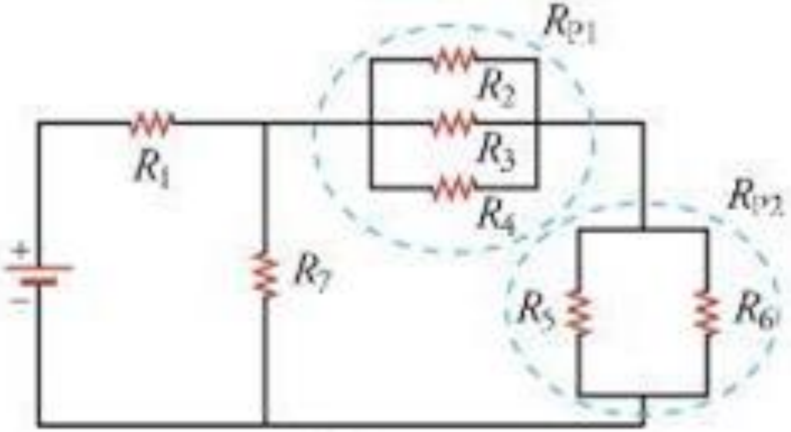
Circuits Wired Partially in Series and Partially in Parallel

- Simplify any series portions of each branch

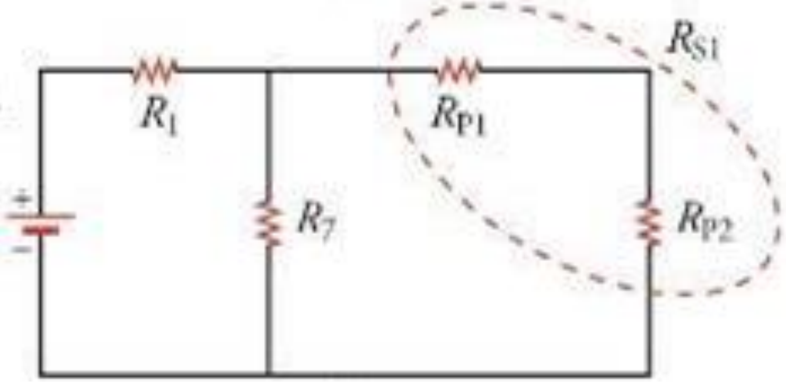
- Simplify the parallel circuitry of the branches

- If necessary, simplify any remaining series

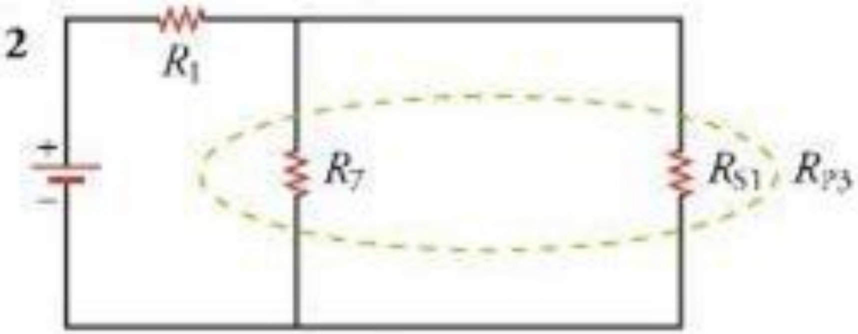
Circuits in Parallel and Series



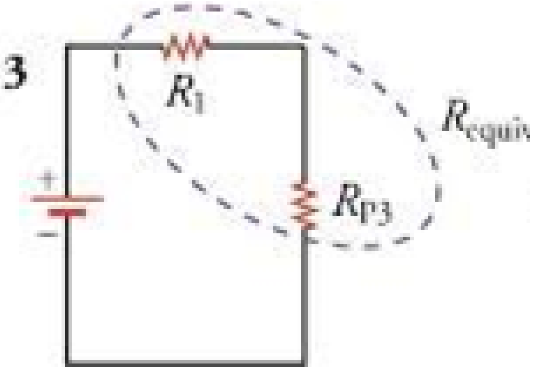
Step 1



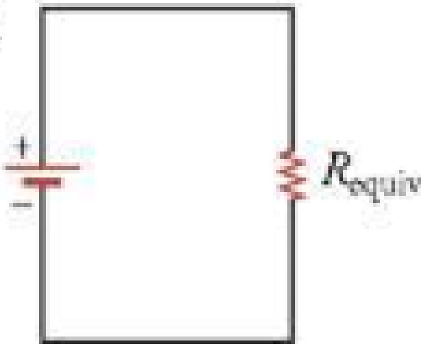
Step 2



Step 3

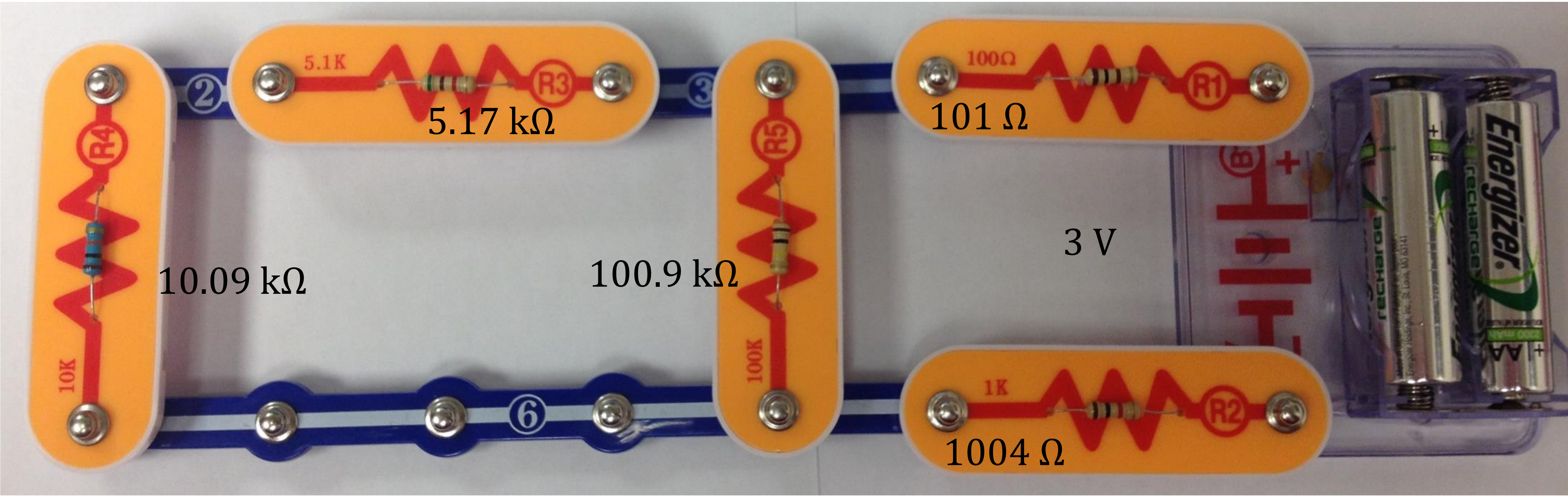


Step 4

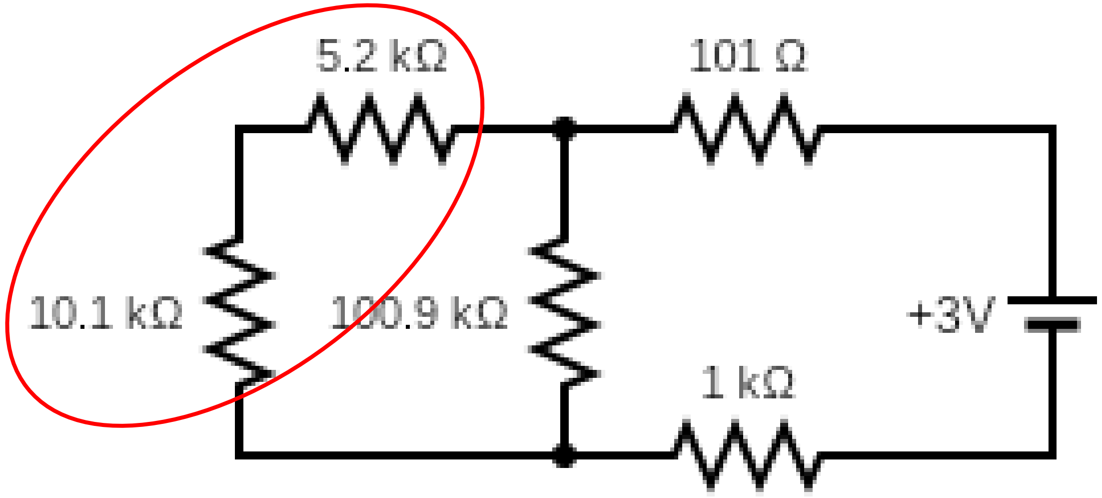


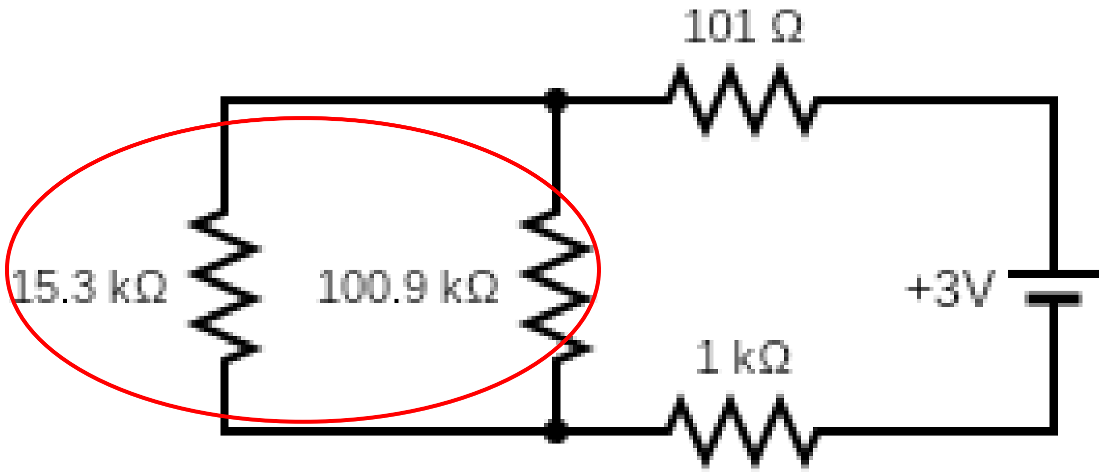
Circuits in Parallel and Series

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

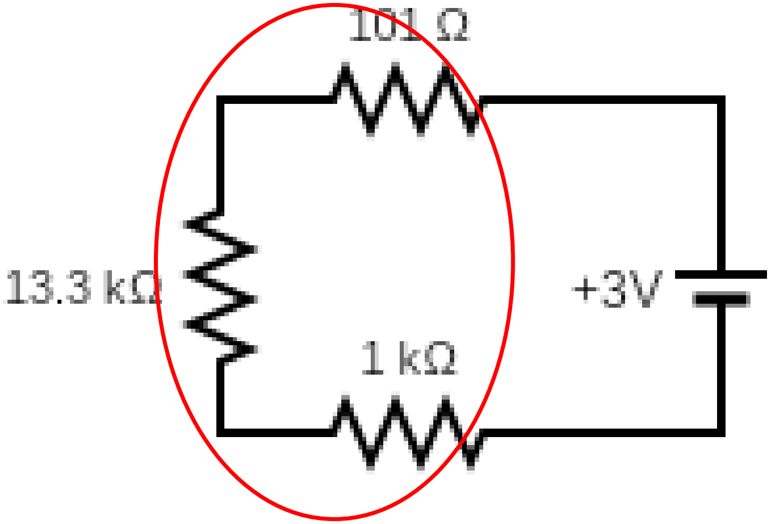


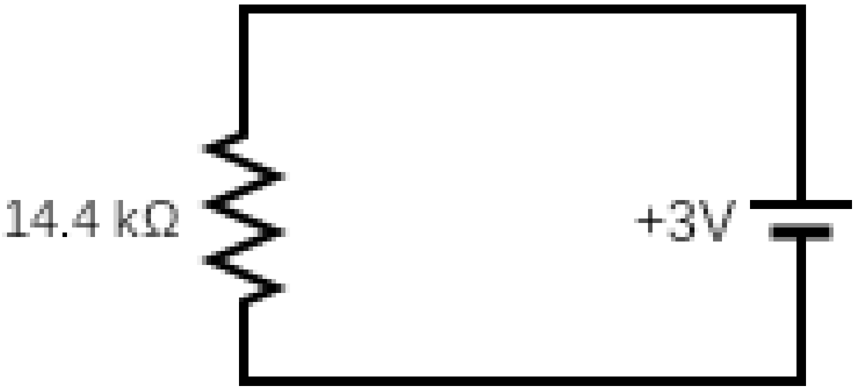
Circuits in Parallel and Series





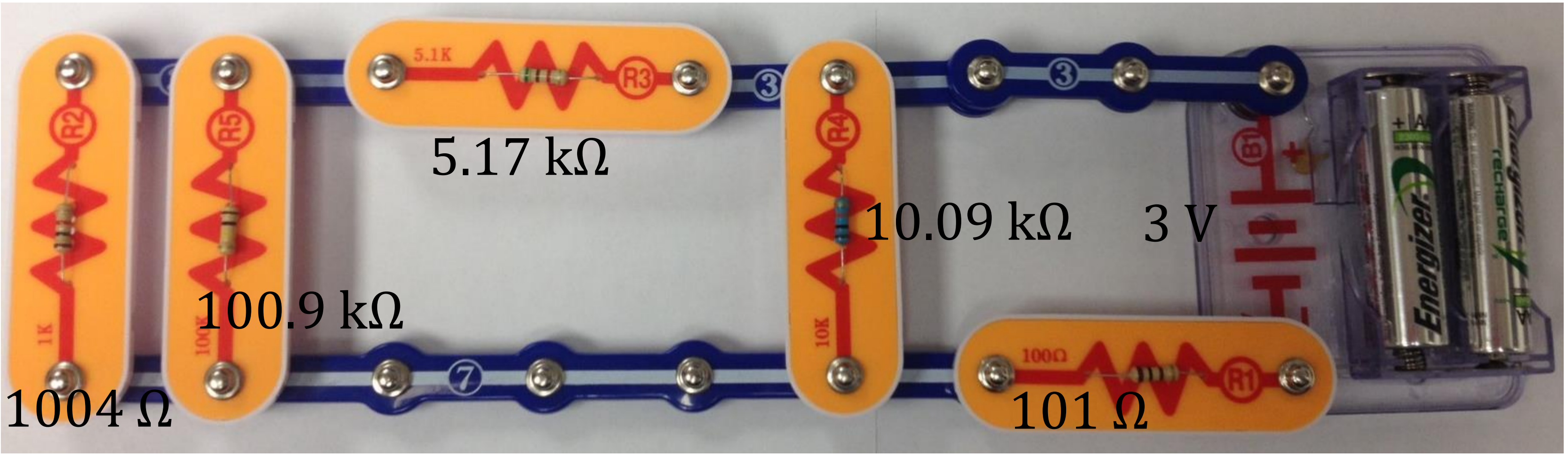
Circuits in Parallel and Series



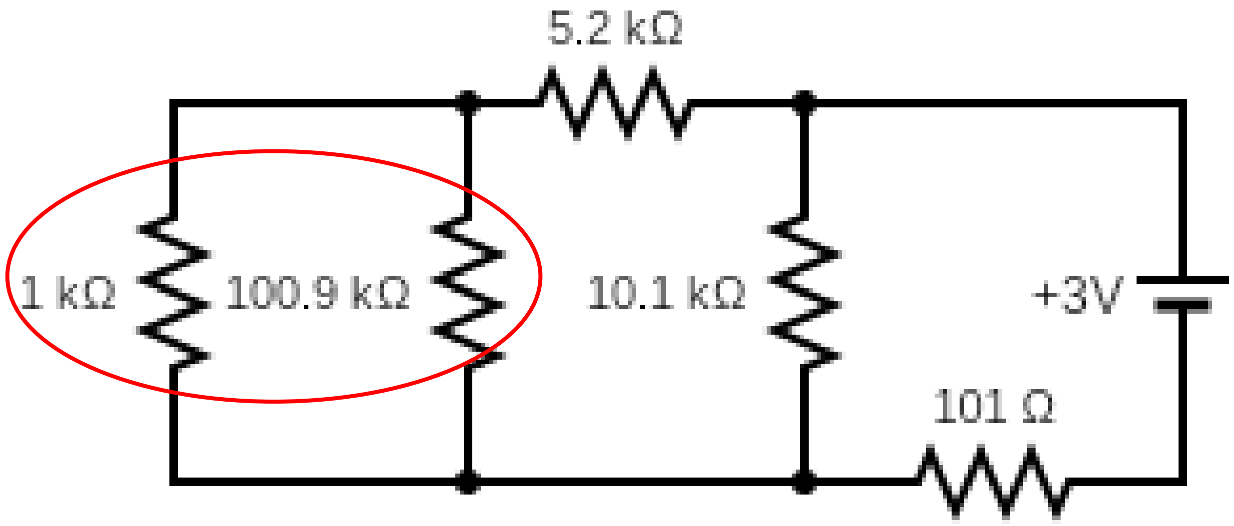


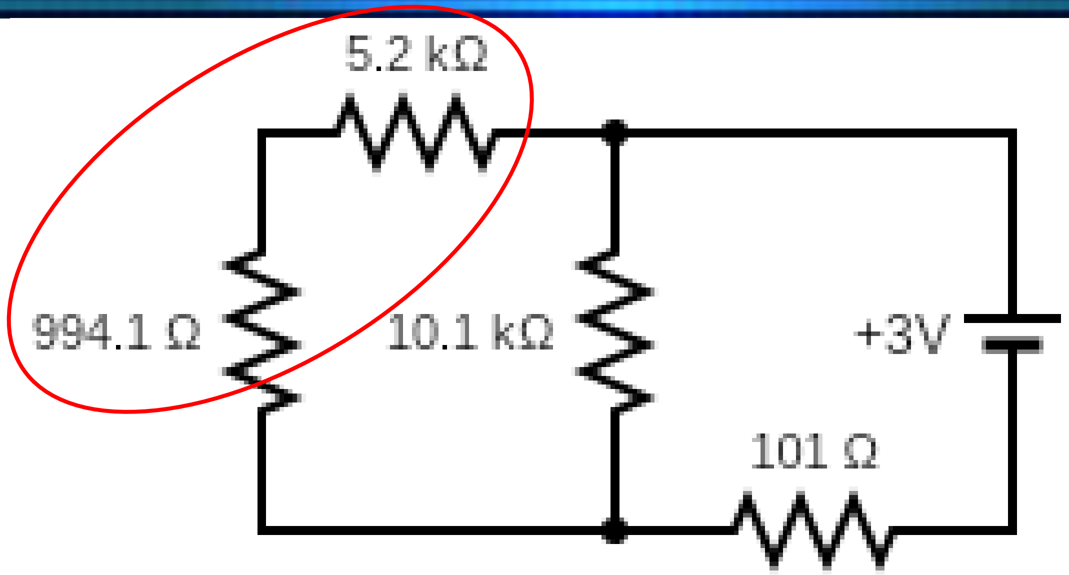
Circuits in Parallel and Series

- Find the equivalent resistance.

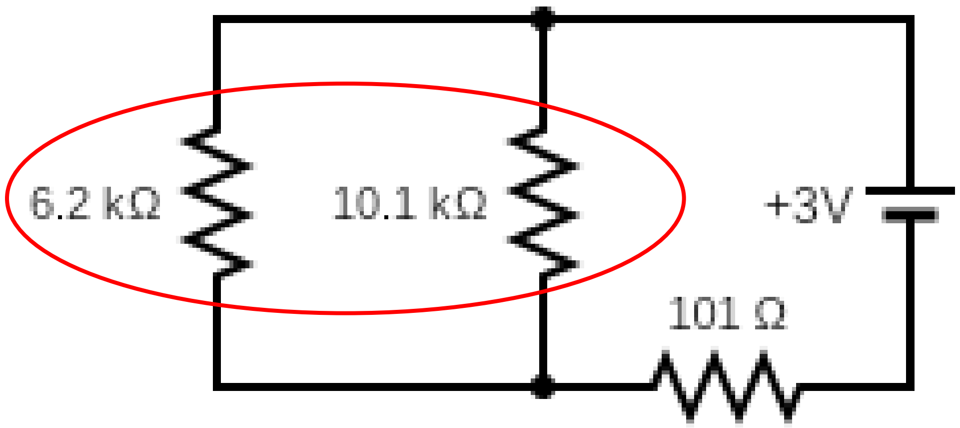


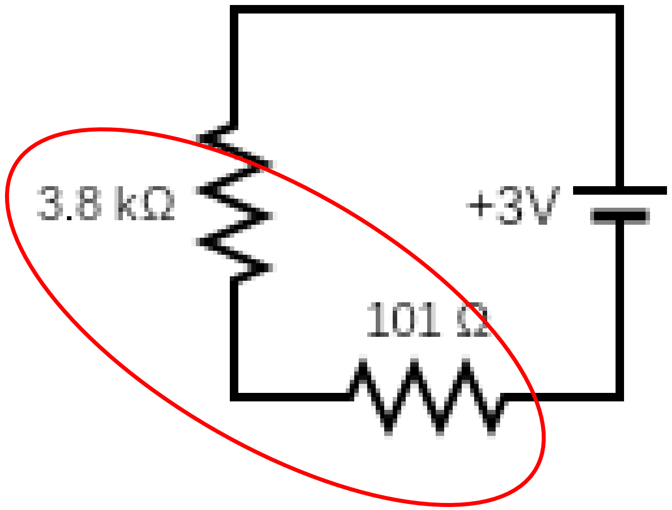
Circuits in Parallel and Series

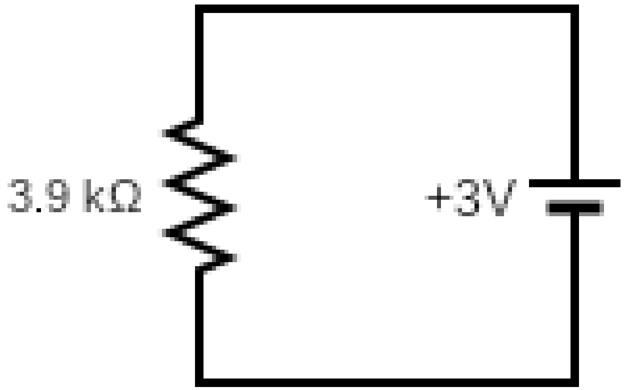




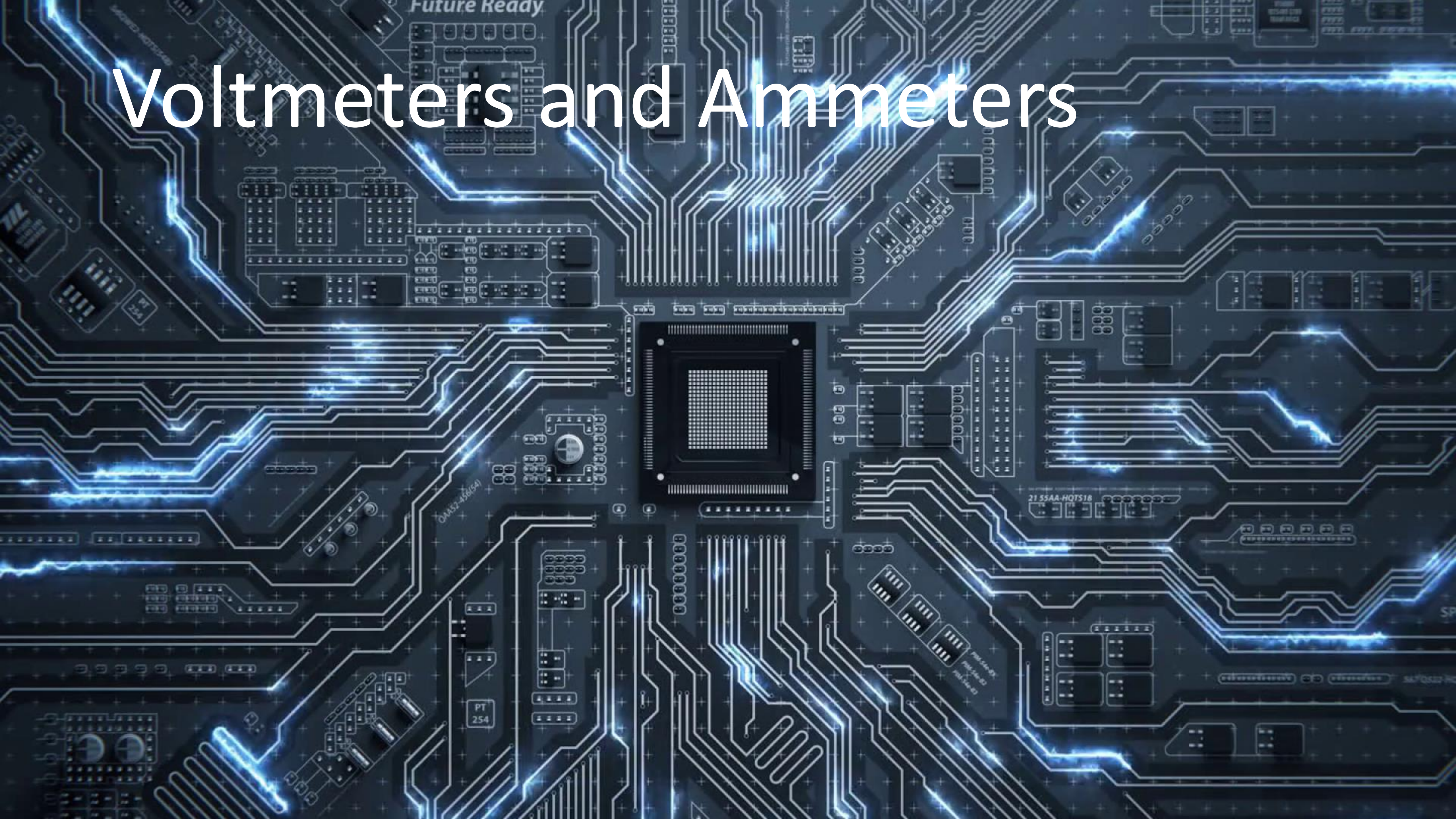
Circuits in Parallel and Series





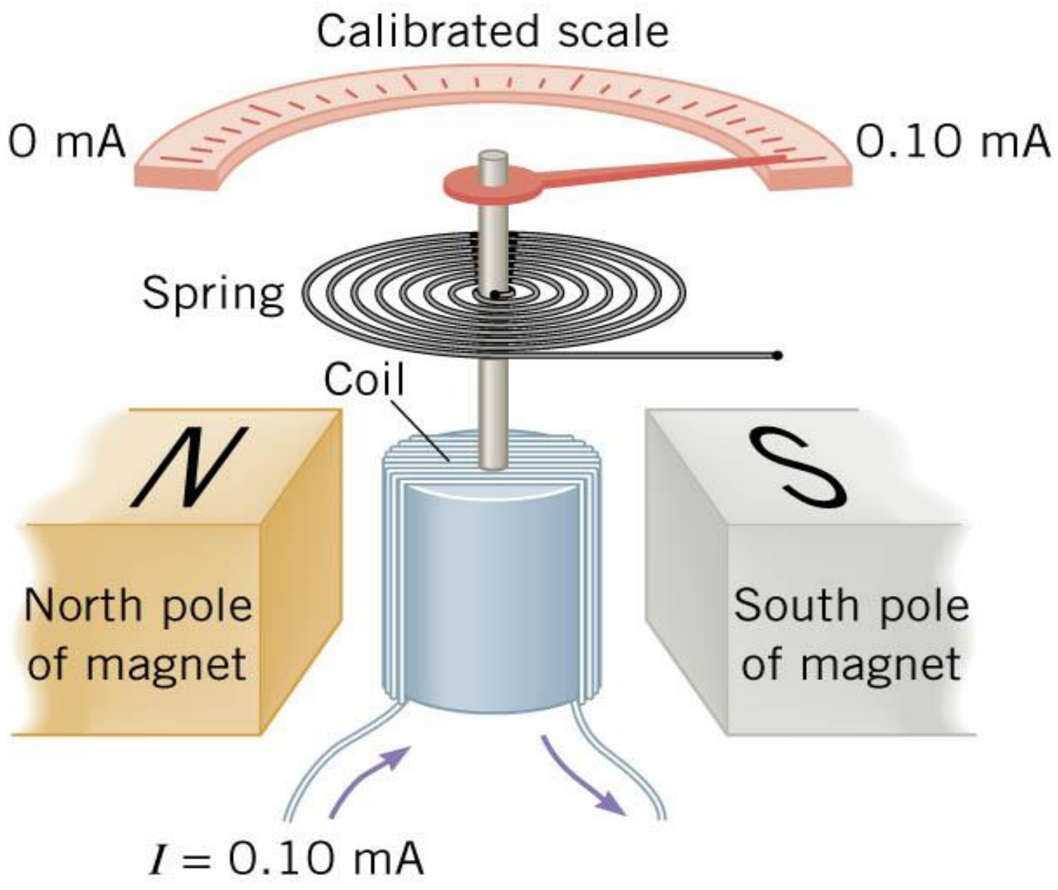


Voltmeters and Ammeters



Voltmeters and Ammeters

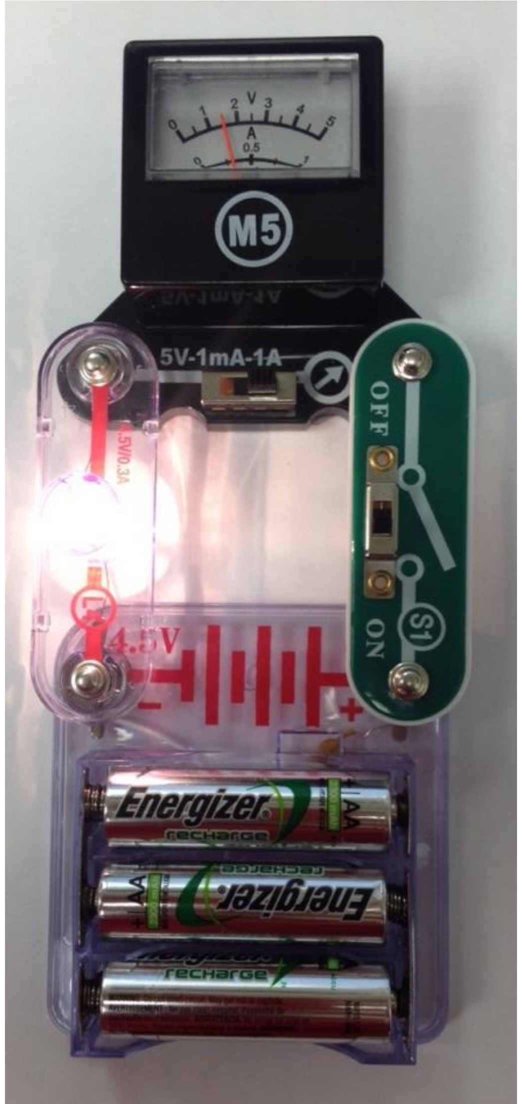
- Analog (non-digital) meters



Voltmeters and Ammeters

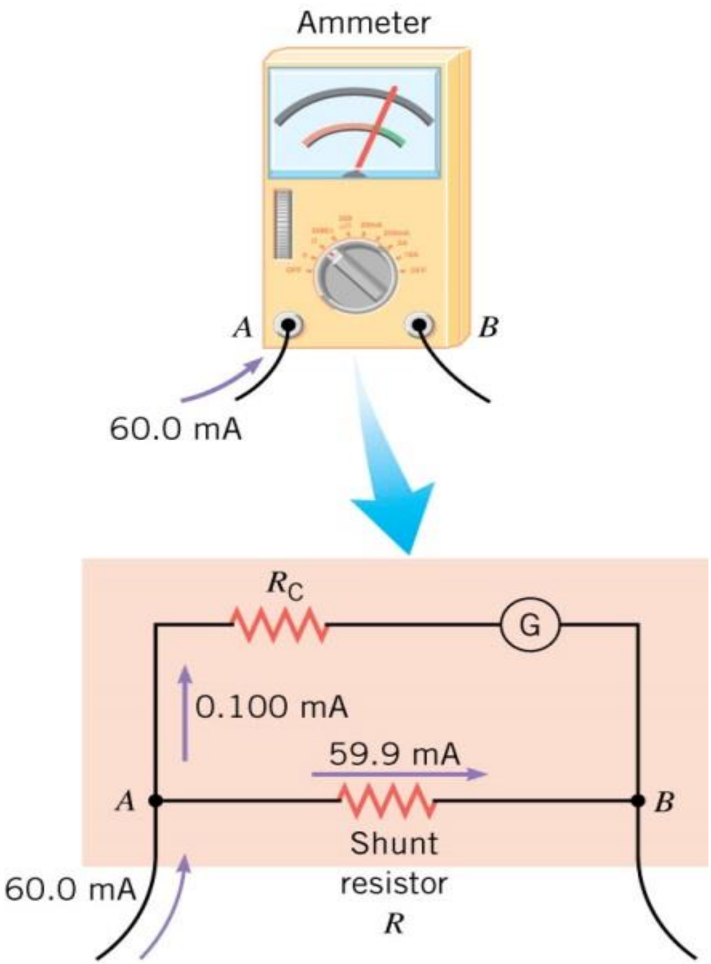
Ammeters

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



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



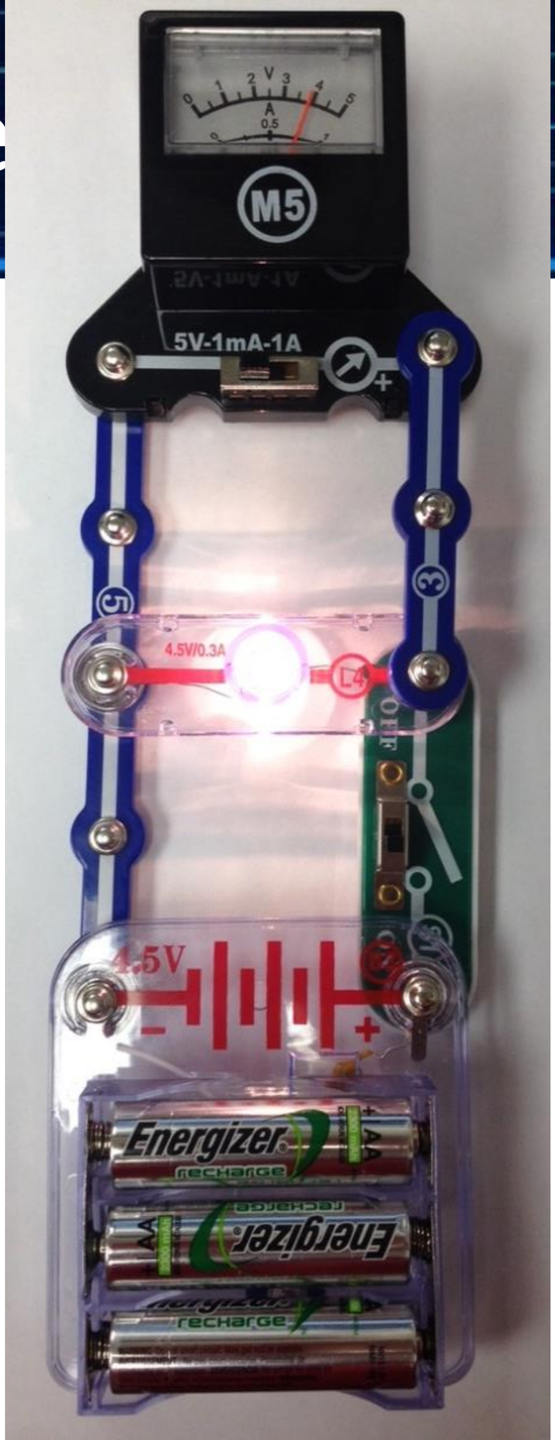
Voltmeters and Ammeters

- 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

Voltmeters and Amme

Voltmeters

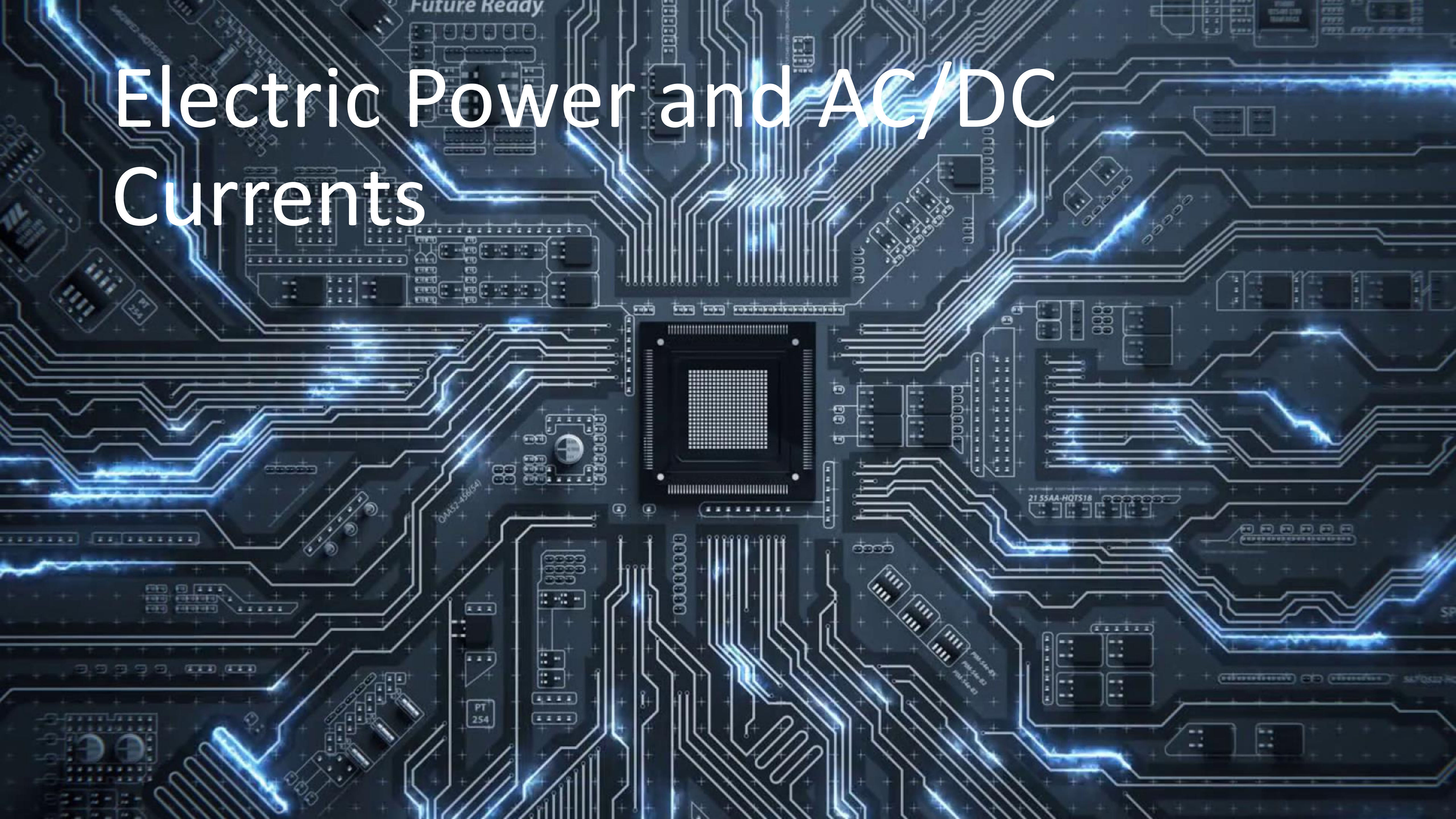
- Connected in parallel to circuit since parallel has same voltage
- The coil works just like in the ammeter
- Given the current and the resistance of the coil → $V = IR$
- To give more range, a large resistor is connected in series with the coil



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

Electric Power and AC/DC Currents



Electric Power and AC/DC Currents

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

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

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

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

$$P = IV$$

Electric Power and AC/DC Currents

Power

$$P = IV$$

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

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

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)

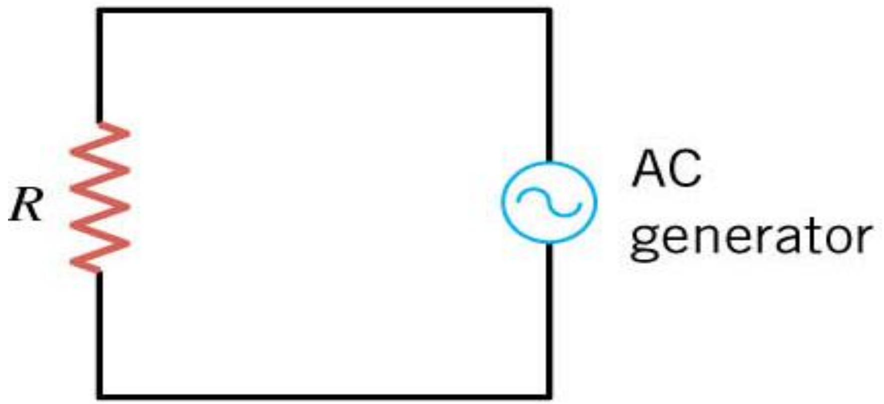
- If electricity costs \$0.15 per kWh how much does it cost to operate the previous heater (P = 10.1 W) for one month?
- \$1.09

Electric Power and AC/DC Currents

Alternating Current

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

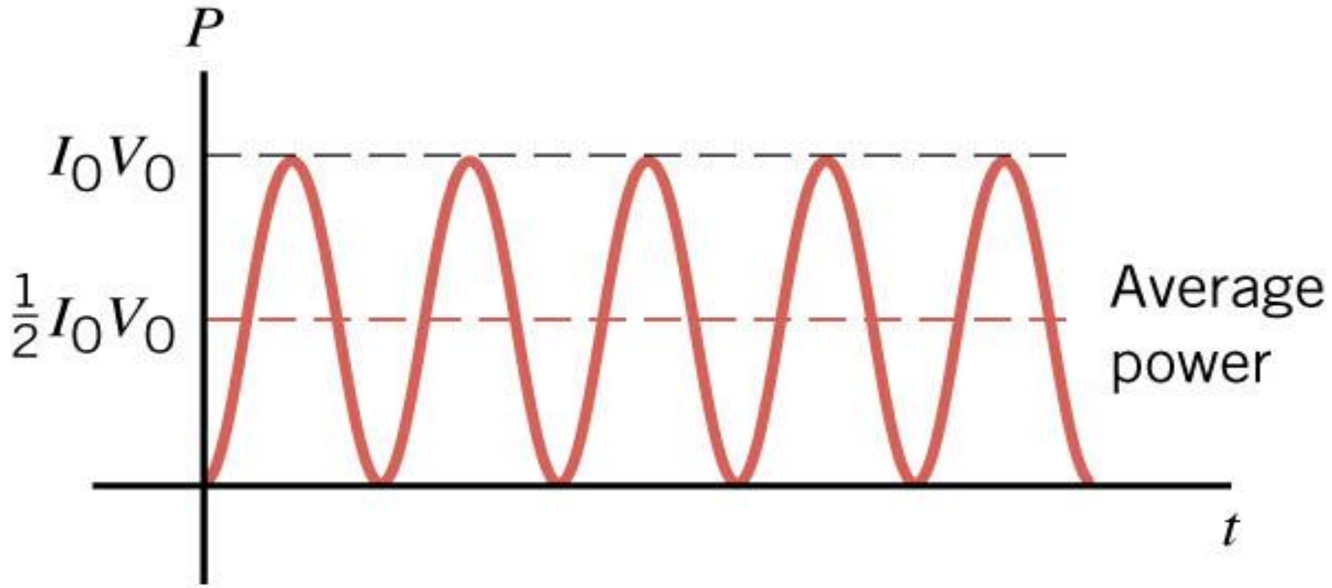
- Simple circuit



Electric Power and AC/DC Currents

Periodicity

- Voltage, Current, and Power fluctuate with time



- So we usually talk about the averages

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.

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 $\sqrt{2}$

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

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.

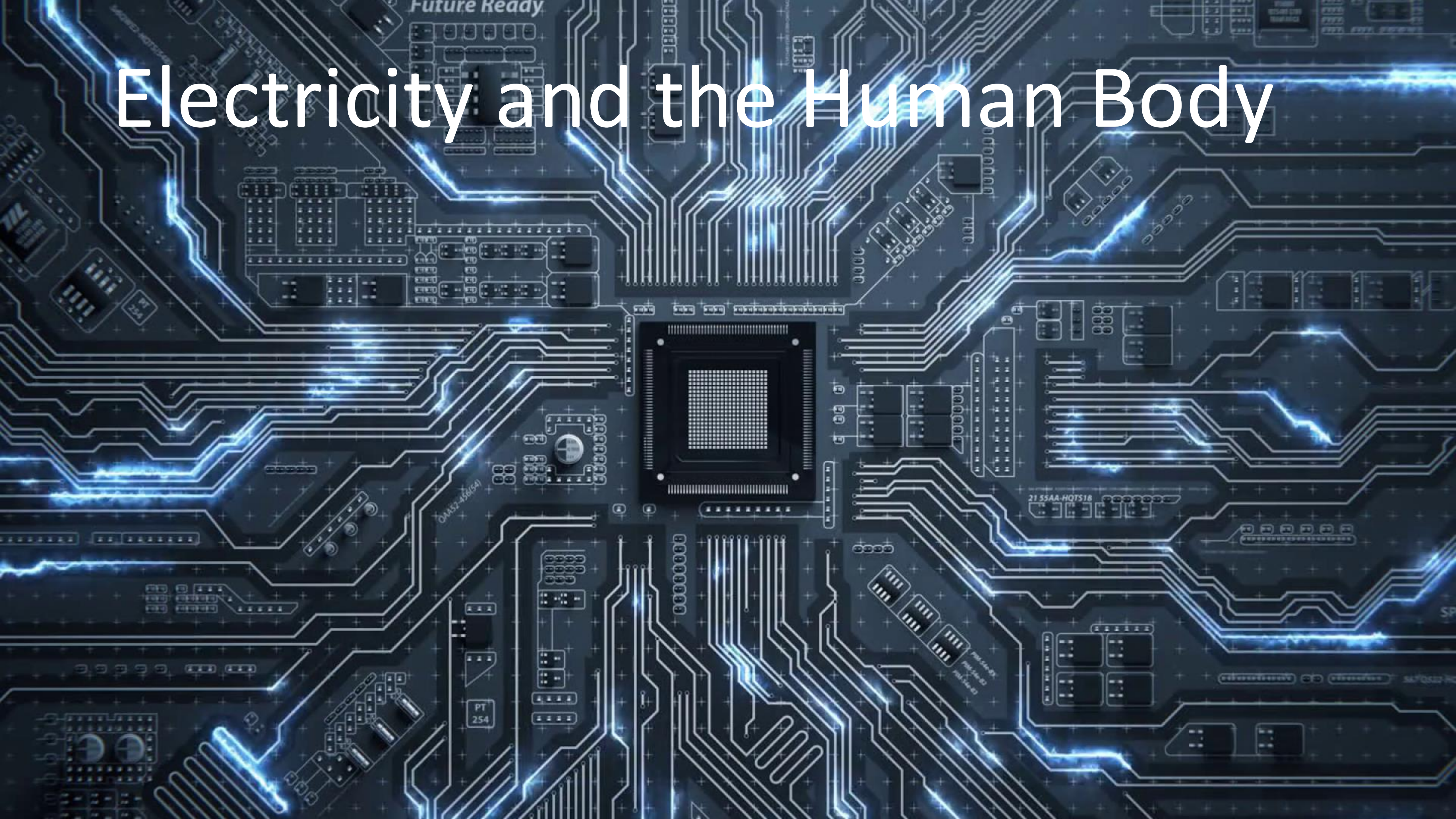
- $V_{rms} = 110$ V
- $I_{rms} = 0.55$ A
- $R = 202\ \Omega$

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

Electricity and the Human Body



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

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