Current: Dead or Alive

DEATH:

- **NEUROLOGIC CRITERIA:** An individual with irreversible cessation of all brain function, including the brain stem, is dead.
- **CARDIOPULMONARY CRITERIA:** An individual with irreversible cessation of circulatory and respiratory function is dead.
Positive Charges move from HI to LOW potential.
Negative Charges move from LOW to HI potential.
HOW FAST DO ELECTRONS MOVE IN A CURRENT CARRYING CONDUCTING WIRE??
Electron Speed is called the DRIFT Velocity.

\[ v_d = \frac{I}{nqA} \]

Drift velocity \( \sim 0.001 \text{ m/s} \) !!!

Electric Fields travel at the speed of light!
Current

\[ I = \frac{\Delta Q}{\Delta t} \]

I = Coulomb/second = Ampere

- Current flows from a higher potential to a lower potential (electrons flow the opposite way). Current carrying wires are neutral!
- DC current flows in one direction
- AC current oscillates back and forth
- Electrons have a drift velocity of .001m/s!
- Electric Fields travel at speed of light
Engine Current Problem

The starter motor of a car engine draws a current of 150 A from the battery. The copper wire to the motor is 5.0 mm in diameter and 1.2 m long. The starter motor runs for 0.80 s until the car engine starts.

a. How much charge passes through the starter motor?

\[(a)\] Current is defined as \( I = \frac{Q}{\Delta t} \), so the charge delivered in time \( \Delta t \) is
\[ Q = I\Delta t = (150 \text{ A})(0.80 \text{ s}) = 120 \text{ C} \]
Engine Current Problem Again

The starter motor of a car engine draws a current of 150 A from the battery. The copper wire to the motor is 5.0 mm in diameter and 1.2 m long. The starter motor runs for 0.80 s until the car engine starts.

a. How much charge passes through the starter motor?

b. What is the drift speed of the electrons? Show how the units work out!

electron number density \(8.5 \times 10^{28} \text{ m}^{-3}\)

\[
v_d = \frac{I}{nqA}
\]

\[
v_d = \frac{I}{Anq} = \frac{I}{\pi r^2 nq} = \frac{150 \text{ A}}{\pi (0.0025 \text{ m})^2 \left(8.5 \times 10^{28} \text{ m}^{-3}\right)\left(1.60 \times 10^{-19} \text{ C}\right)} = 5.617 \times 10^{-4} \text{ m/s}
\]
Fuse Problem

You need to design a 1.0 A fuse that ‘blows’ if the current exceeds 1.0 A. The fuse material in your stockroom melts at a current density of 500 A/cm². What diameter wire of this material will do the job?

\[
\frac{I}{A} = 500 \text{ A/cm}^2
\]

\[
A = \frac{\pi D^2}{4} = \frac{I}{500 \text{ A/cm}^2} \Rightarrow D = \sqrt{\frac{4(1.0 \text{ A})}{\pi(500 \text{ A/cm}^2)}} = 0.050 \text{ cm} = 0.50 \text{ mm}
\]
Fuses

If the current drawn exceeds safe levels, the fuse melts and the circuit ‘breaks’ – most houses have switches, not fuses.
Resistance

(a) Line
Valve
Pump

(b) Resistance
Switch
Voltage source
Resistance: Resistivity

\[ R = \rho \frac{L}{A} \]

- The LONGER the wire the GREATER the R
- The THINNER the wire the GREATER the R
- The HOTTER the wire the GREATER the R
Resistance: Dependence on Temperature

The HOTTER the wire the GREATER the Resistance:

\[ R = R_0 (1 + \alpha \Delta T) \]

- \( R_0 \) = original resistance
- \( \alpha \) = temperature coefficient of resistivity
- \( \Delta T \) = temperature change \(<100^\circ C\)
### Resistivity Values

**Table 27.1**

<table>
<thead>
<tr>
<th>Material</th>
<th>Resistivity&lt;sup&gt;a&lt;/sup&gt; (Ω·m)</th>
<th>Temperature Coefficient&lt;sup&gt;b&lt;/sup&gt; α [°C]&lt;sup&gt;−1&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silver</td>
<td>$1.59 \times 10^{-8}$</td>
<td>$3.8 \times 10^{-3}$</td>
</tr>
<tr>
<td>Copper</td>
<td>$1.7 \times 10^{-8}$</td>
<td>$3.9 \times 10^{-3}$</td>
</tr>
<tr>
<td>Gold</td>
<td>$2.44 \times 10^{-8}$</td>
<td>$3.4 \times 10^{-3}$</td>
</tr>
<tr>
<td>Aluminum</td>
<td>$2.82 \times 10^{-8}$</td>
<td>$3.9 \times 10^{-3}$</td>
</tr>
<tr>
<td>Tungsten</td>
<td>$5.6 \times 10^{-8}$</td>
<td>$4.5 \times 10^{-3}$</td>
</tr>
<tr>
<td>Iron</td>
<td>$10 \times 10^{-8}$</td>
<td>$5.0 \times 10^{-3}$</td>
</tr>
<tr>
<td>Platinum</td>
<td>$11 \times 10^{-8}$</td>
<td>$3.92 \times 10^{-3}$</td>
</tr>
<tr>
<td>Lead</td>
<td>$22 \times 10^{-8}$</td>
<td>$3.9 \times 10^{-3}$</td>
</tr>
<tr>
<td>Nichrome&lt;sup&gt;c&lt;/sup&gt;</td>
<td>$1.50 \times 10^{-6}$</td>
<td>$0.4 \times 10^{-3}$</td>
</tr>
<tr>
<td>Carbon</td>
<td>$3.5 \times 10^{-5}$</td>
<td>$-0.5 \times 10^{-3}$</td>
</tr>
<tr>
<td>Germanium</td>
<td>0.46</td>
<td>$-48 \times 10^{-3}$</td>
</tr>
<tr>
<td>Silicon</td>
<td>640</td>
<td>$-75 \times 10^{-3}$</td>
</tr>
<tr>
<td>Glass</td>
<td>$10^{10}$ to $10^{14}$</td>
<td></td>
</tr>
<tr>
<td>Hard rubber</td>
<td>$\sim 10^{13}$</td>
<td></td>
</tr>
<tr>
<td>Sulfur</td>
<td>$10^{15}$</td>
<td></td>
</tr>
<tr>
<td>Quartz (fused)</td>
<td>$75 \times 10^{16}$</td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup> All values at 20°C.
Engine Current Problem

The starter motor of a car engine draws a current of 150 A from the battery. The copper wire to the motor is 5.0 mm in diameter and 1.2 m long. The starter motor runs for 0.80 s until the car engine starts.

c. What is the resistance in the copper wire?

\[
R = \rho \frac{l}{A} = \rho \frac{l}{\pi \frac{D^2}{4}} = 4 \times 1.7 \times 10^{-8} \Omega m \frac{1.2 m}{\pi (.005 m)^2} = 1.04 \times 10^{-3} \Omega
\]
What makes the Glow?
Ohmic Heat Loss

• The resistor is normally in contact with the air, so its increased temperature will result in a transfer of energy by heat into the air.
• The resistor also emits thermal radiation which can make it glow.
• After some time interval, the resistor reaches a constant temperature.
• The rate at which the system loses potential energy as the charge passes through the resistor is equal to the rate at which the system gains internal energy in the resistor.

The **power** is the rate at which the energy is delivered to the resistor.
When are light bulbs more likely to blow?
When hot or cold?

The HOTTER the wire the GREATER the R!

\[ R = R_0 (1 + \alpha \Delta T) \]

At lower Resistance, the bulb draws more current and it blows the filament!
Ohmic Material

- An ohmic device
- The resistance is constant over a wide range of voltages
- The relationship between current and voltage is linear
- The slope is related to the resistance

\[ \text{Slope} = \frac{1}{R} \]
Nonohmic Material

- Nonohmic materials are those whose resistance changes with voltage or current.
- The current-voltage relationship is nonlinear.
- A diode is a common example of a nonohmic device.
Ohms Law: $\Delta V = IR$

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

How much current will flow through a lamp that has a resistance of 60 Ohms when 12 Volts are impressed across it?

USE OHMS LAW: $\Delta V = IR$

$$I = \frac{\Delta V}{R} = \frac{12V}{60\Omega} = \frac{12V}{60V / A} = .2 A$$
Resistance Question

• Two cylindrical resistors, $R_1$ and $R_2$, are made of identical material. $R_2$ has twice the length of $R_1$ but half the radius of $R_1$.
  – These resistors are then connected to a battery $V$ as shown:

  ![Circuit Diagram]

  – What is the relation between $I_1$, the current flowing in $R_1$, and $I_2$, the current flowing in $R_2$?

  (a) $I_1 < I_2$  (b) $I_1 = I_2$  (c) $I_1 > I_2$

• The resistivity of both resistors is the same ($\rho$).
• Therefore the resistances are related as:

\[
R_2 = \rho \frac{L_2}{A_2} = \rho \frac{2L_1}{(A_1 / 4)} = 8 \rho \frac{L_1}{A_1} = 8R_1
\]

• The resistors have the same voltage across them; therefore

\[
I_2 = \frac{V}{R_2} = \frac{V}{8R_1} = \frac{1}{8}I_1
\]
POWER

\[ P = I \Delta V \]

\[
[P] = \frac{\text{Energy}}{\text{time}} = \frac{J}{s} = \text{Watt}
\]

\[ P = I \Delta V = I (IR) = I^2 R \]

\[ P = I \Delta V = \left( \frac{\Delta V}{R} \right) V = \frac{\Delta V^2}{R} \]

• You pay for ENERGY not for ELECTRONS!
• Kilowatt-hour is the energy consumed in one hour: [kWh]=J NOT TIME! Power x Time
If V = 120V, What is I?
USE P = IV => I = P/V

<table>
<thead>
<tr>
<th>Appliance</th>
<th>Power</th>
<th>Current (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hair Dryer</td>
<td>1600 Watts</td>
<td></td>
</tr>
<tr>
<td>Electric Iron</td>
<td>1200 Watts</td>
<td></td>
</tr>
<tr>
<td>TV</td>
<td>100 Watts</td>
<td></td>
</tr>
<tr>
<td>Computer</td>
<td>45 Watts</td>
<td></td>
</tr>
</tbody>
</table>
If $V = 120V$, What is $I$?

USE $P = IV \Rightarrow I = P/V$

<table>
<thead>
<tr>
<th>Appliance</th>
<th>Power</th>
<th>Current (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hair Dryer</td>
<td>1600 Watts</td>
<td>13.3 A</td>
</tr>
<tr>
<td>Electric Iron</td>
<td>1200 Watts</td>
<td>10 A</td>
</tr>
<tr>
<td>TV</td>
<td>100 Watts</td>
<td>.83 A</td>
</tr>
<tr>
<td>Computer</td>
<td>45 Watts</td>
<td>.38 A</td>
</tr>
</tbody>
</table>
Electric Bill:
Cost to run for 1 hr @ $.05 per 1 kw-hr?

\[ \text{Cost} = \text{Power} \times \text{Time} \times \text{Rate} \]

<table>
<thead>
<tr>
<th>Appliance</th>
<th>Power</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hair Dryer</td>
<td>1600 Watts</td>
<td></td>
</tr>
<tr>
<td>Electric Iron</td>
<td>1200 Watts</td>
<td></td>
</tr>
<tr>
<td>TV</td>
<td>100 Watts</td>
<td></td>
</tr>
<tr>
<td>Computer</td>
<td>45 Watts</td>
<td></td>
</tr>
</tbody>
</table>
Electric Bill:
Cost to run for 1 hr @
$.05 per 1 kw-hr ?
Cost = Power x Time x Rate

<table>
<thead>
<tr>
<th>Appliance</th>
<th>Power</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hair Dryer</td>
<td>1600 Watts</td>
<td>$0.08</td>
</tr>
<tr>
<td>Electric Iron</td>
<td>1200 Watts</td>
<td>$0.06</td>
</tr>
<tr>
<td>TV</td>
<td>100 Watts</td>
<td>$0.005</td>
</tr>
<tr>
<td>Computer</td>
<td>45 Watts</td>
<td>$0.003</td>
</tr>
</tbody>
</table>
QUESTION

The power rating for two light bulbs read 30W and 60W. Which bulb has the greatest resistance at 120V?

\[ P = \frac{V^2}{R} \rightarrow R = \frac{V^2}{P} \]

\[ R = \frac{(120V)^2}{30W} = 480\Omega \]

\[ R = \frac{(120V)^2}{60W} = 240\Omega \]

Which burns brighter and why?
QUESTION

The voltage and power on a light bulb read “120 V, 60 W” How much current will flow through the bulb?

USE: $P = IV$

$I = \frac{P}{V} = \frac{60 \text{ W}}{120 \text{ V}} = 1/2 \text{ Amp}$
QUESTION

The power and voltage on a light bulb read “120 V, 60 W” What is the resistance of the filament? (I = .5 A)

Hint: USE OHMS LAW: \( V = IR \)

\[ R = \frac{V}{I} = \frac{120 \text{ V}}{.5 \text{ A}} = 240 \Omega \]
Direct Current (DC) Circuits

- Current Flows in one direction
- Current direction given by + charge
- Electrons REALLY flow
- Ammeter must be in the circuit
- Net charge is ZERO
- Circuit must be complete
Batteries: DC EMF

Simple Batteries: Two plates of different metals (usually zinc & copper) are separated by an electrolyte solution (sulphuric acid). Electrolysis produces electric current.

- **6 Lead Acid Cells**: 12 V
- **Carbon-Zinc Dry Cell**: 1.5 V
Series Circuits

- The current is the same in each device.
- The equivalent resistance of the circuit is the sum of the individual resistances. \( R = R_1 + R_2 \)

\[
V_{total} = IR_{total}
\]

\[
= I(R_1 + R_2) = IR_1 + IR_2 = V_1 + V_2
\]

\[
V = V_1 + V_2, \quad R_S = R_1 + R_2 + R_3 + \ldots
\]
Series Circuits

- The current is the same in each device.
- The equivalent resistance of the circuit is the sum of the individual resistances. $R = R_1 + R_2$

$$V = V_1 + V_2, \quad R_S = R_1 + R_2 + R_3 + \ldots$$

To find the current, use the total voltage and equivalent resistance:

$$I = \frac{V}{R_S}$$
Parallel Circuits

- The voltage of each device is the full voltage of the EMF source (the battery)
- The total current is divided between each path:

\[ I = I_1 + I_2 = \frac{V}{R_1} + \frac{V}{R_2} = V \left( \frac{1}{R_1} + \frac{1}{R_2} \right) = \frac{V}{R_P} \]

Equivalent Resistance:

\[ \frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots \]
Circuits Problem: Bulbs in Series vs Parallel

A circuit contains a 48-V battery and two 240Ω light bulbs. In which circuit does each bulb burn brighter?

RULE: THE MORE POWER DISSIPATED IN A BULB, THE BRIGHTER IT IS.

\[ P = IV \]

Find the power in each bulb when in series and in parallel.

- Series wiring
  - 240 Ω 240 Ω
  - 48 V

- Parallel wiring
  - 240 Ω
  - 48 V
Circuits Problem: Bulbs in Series vs Parallel

In Series:
The Voltage is divided in series: each bulb gets half: \( V = 24V \).

\[
P = IV = \frac{V}{R} = \frac{V^2}{R} = \frac{(24V)^2}{240\Omega} = 2.4W
\]

In Parallel:
Voltage is the same in each bulb: 48V.

\[
P = \frac{V^2}{R} = \frac{(48V)^2}{240\Omega} = 9.6W
\]

Parallel Bulbs Burn Brighter!
Circuits Problem: Bulbs in Series vs Parallel

If a bulb burns out - what happens to the other bulb in each circuit? Does it go out? Is it brighter? Dimmer? Or?

In the series circuit, the burned out bulb will short the circuit and the other bulb will go out.

In the parallel circuit the other bulb will have the same brightness.
Circuits Problem: 3 Bulbs in Series

If one more bulb is added to each circuit (3 bulbs total), how does the brightness of the bulbs change? Or not?

In the series circuit, the bulbs DIM. WHY?

\[ V = V_1 + V_2 + V_3 \]

In series, each of the three equal bulbs gets one third of the Voltage \( (V/3) \) that a single bulb would get.

\[ P = \frac{V^2}{R} = \frac{(V/3)^2}{R} = \frac{1}{9} \frac{V^2}{R} = \frac{P_{\text{single bulb}}}{9} \]

Note: \( P=VI \) but \( I \) is due to the equivalent Resistance: \( I = \frac{V}{R_s} = \frac{V}{3R} \).
So the Current through each is 1/3 the current through a single bulb and \( P=VI=\frac{V}{3} \times \frac{I}{3} = \frac{VI}{9} = \frac{P}{9} \). The bulbs burn 1/9 as bright!
Circuits Problem: 3 Bulbs in Parallel

If one more bulb is added to each circuit (3 bulbs total), how does the brightness of the bulbs change? Or not?

In the parallel circuit, the bulbs DO NOT DIM. WHY?

In parallel, each of the three equal bulbs gets the full voltage of the battery source.

\[ P = \frac{V^2}{R} = P_{\text{single bulb}} \]

Is this getting something for nothing?

NO! Parallel circuits drain the battery faster!
Parallel Circuits

• As the number of branches is increased, the overall resistance of the circuit is DECREASED.

• Overall resistance is lowered with each added path between any two points of the circuit.

• This means the overall resistance of the circuit is less than the resistance of any one of the branches!!!! (Weird?)

• As overall resistance is lowered, more current is drawn. This is how you blow fuses!
You Try!

\[ V = 15.0 \text{V}, \quad R_1 = 10.0 \Omega, \quad R_2 = 20.0 \Omega, \quad R_3 = 30.0 \Omega, \]

\[(a) \quad (b)\]

a) Find the equivalent resistance of each circuit.
b) Find the total current through each circuit.
c) Find the total power dissipated by each circuit.
d) Find the current through the R2 in the parallel circuit (b).
Electric Shock

What causes electric Shock in the human body, Voltage or Current?

• Electric Shock occurs when current is produced in the body, which is caused by an impressed voltage.

• Voltage is the CAUSE
• Current does the DAMAGE
## Electric Shock

<table>
<thead>
<tr>
<th>Current (A)</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.001</td>
<td>Can be felt</td>
</tr>
<tr>
<td>0.005</td>
<td>Painful</td>
</tr>
<tr>
<td>0.010</td>
<td>Causes involuntary muscle spasms</td>
</tr>
<tr>
<td>0.015</td>
<td>Causes loss of muscle control</td>
</tr>
<tr>
<td>0.070</td>
<td>If through heart, serious!</td>
</tr>
<tr>
<td></td>
<td>If current lasts for 1 s - FATAL!</td>
</tr>
</tbody>
</table>

Dry Skin Body Resistance: 500,000 Ω  
Wet Skin Body Resistance: 1000 Ω
Question
What current would you draw if you were unfortunate to short-circuit a 120 V line with dry hands? Wet hands?
Use Ohm’s Law! $V = IR$

**DRY:** $I = \frac{V}{R} = \frac{120 \text{ V}}{500,000 \, \Omega} = \, .00024 \, \text{(live!)}$

**WET:** $I = \frac{V}{R} = \frac{120 \text{ V}}{1000 \, \Omega} = \, .12 \, \text{(dead!)}$
Question
What current would you draw if you were unfortunate to short-circuit a 120 V line with dry hands? Wet hands?
Use Ohm’s Law! $V = IR!$

Dry Skin Body Resistance: 500,000 Ω
Wet Skin Body Resistance: 1000 Ω
Why is Power Transmitted with AC instead of DC?

Viva La Resistance!

(Modern transmission grids use AC voltages up to 765,000 volts.)
Limitations of DC Transmission

• Large currents in wires produce heat and energy losses by $P = I^2R$.

• Large expensive conductors would be needed or else very high voltage drops (and efficiency losses) would result.

• High loads of direct current could rarely be transmitted for distances greater than one mile without introducing excessive voltage drops.

• Direct current can not easily be changed to higher or lower voltages. Separate electrical lines are needed to distribute power to appliances that used different voltages, for example, lighting and electric motors.
Advantages of AC Transmission

• Alternating Current can be transformed to ‘step’ the voltage up or down with transformers.
• Power is transmitted at great distances at HIGH voltages and LOW currents and then stepped down to low voltages for use in homes (240V) and industry (440V).
• Convert AC to DC with a rectifier in appliances.

AC is more efficient for Transmission & Distribution of electrical power than DC!
In The Future…

Long Distance AC Power Transmission may not be needed!!!
War of Currents 1880’s

**Thomas Edison**, American inventor and businessman, pushed for the development of a DC power network.

**George Westinghouse**, American entrepreneur and engineer, backed financially the development of a practical AC power network.

**Nikola Tesla**, Serbian inventor, physicist, and electro-mechanical engineer, was instrumental in developing AC networks.
Edison's Publicity Campaign

Edison wired NYC with DC. He carried out a campaign to discourage the use of AC, including spreading information on fatal AC accidents, killing animals, and lobbying against the use of AC in state legislatures. Edison opposed capital punishment, but his desire to disparage the system of alternating current led to the invention of the electric chair. Harold P. Brown, who was at this time being secretly paid by Edison, constructed the first electric chair for the state of New York in order to promote the idea that alternating current was deadlier than DC.

The first electric chair, which was used to execute William Kemmler in 1890
The first electric chair, which was used to execute William Kemmler in 1890.

Nebraska: Only state that requires it. 15-second-long jolt of 2,450 volts of electricity (~ 8 Amps)

GE & Edison: *We bring good things to light.*
More than a 1000 killed since 1890!
Any practical distribution system will use voltage levels quite sufficient for a dangerous amount of current to flow, whether it uses alternating or direct current. Ultimately, the advantages of AC power transmission outweighed this theoretical risk, and it was eventually adopted as the standard worldwide after Nikola Tesla designed the first AC hydroelectric power plant at Niagara Falls, New York which started producing electrical power in 1895.

Is AC Deadlier than DC?

They are BOTH Deadly!
Is AC Deadlier than DC?

- Low frequency (50 - 60 Hz) AC currents can be more dangerous than similar levels of DC current since the alternating fluctuations can cause the heart to lose coordination, inducing ventricular fibrillation, which then rapidly leads to death.

- High voltage DC power can be more dangerous than AC, however, since it tends to cause muscles to lock in position, stopping the victim from releasing the energised conductor once grasped.
Frequency Matters

![Graph showing the relationship between frequency (Hz) and current (mA). The graph illustrates that higher frequencies require higher currents to reach a threshold of sensation. The graph also indicates that frequency matters in terms of electrical stimulation.](graph)

- **Threshold of sensation**
- **Can't let go**

![Diagram showing an electrically “hot” wire](wire_diagram)

- **Electrically “hot” wire**

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Electrical Safety

Diagram showing a two-prong plug connected to a heater through a ground connection.
Electrical Safety: Grounding

Wire touches metal casing
Electrical Safety: Grounding
Fuses

If the current drawn exceeds safe levels, the fuse melts and the circuit ‘breaks’ – most houses have switches, not fuses.
Electric Shock Therapy

**ELECTRO CONVULSIVE THERAPY**

An electric shock is applied to produce a convulsive seizure. The shock is typically between 140 - 170 volts and lasts between 0.5 and 1 seconds. No explanation of how it works.

Used in the treatment of:
1. Chronic endogenous depression
2. Bipolar disorder.
3. Acute mania.
4. Certain types of schizophrenia

In the U.S. 33,000 - 50,000 people receive ECT each year