

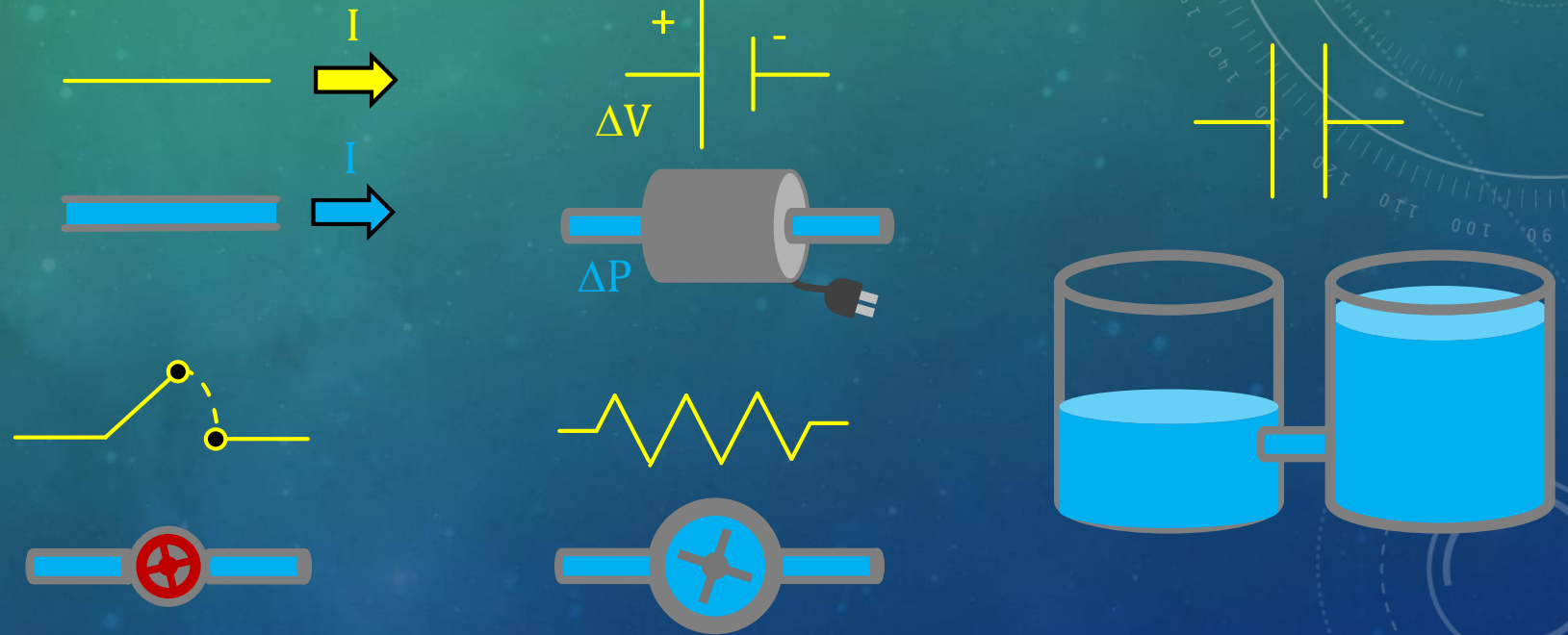
CIRCUIT RULES

PES 1000 – PHYSICS IN EVERYDAY LIFE

WATER ANALOGY OF ELECTRICAL COMPONENTS

- The behavior of charge is analogous to the behavior of water. The following table outlines this analogy.

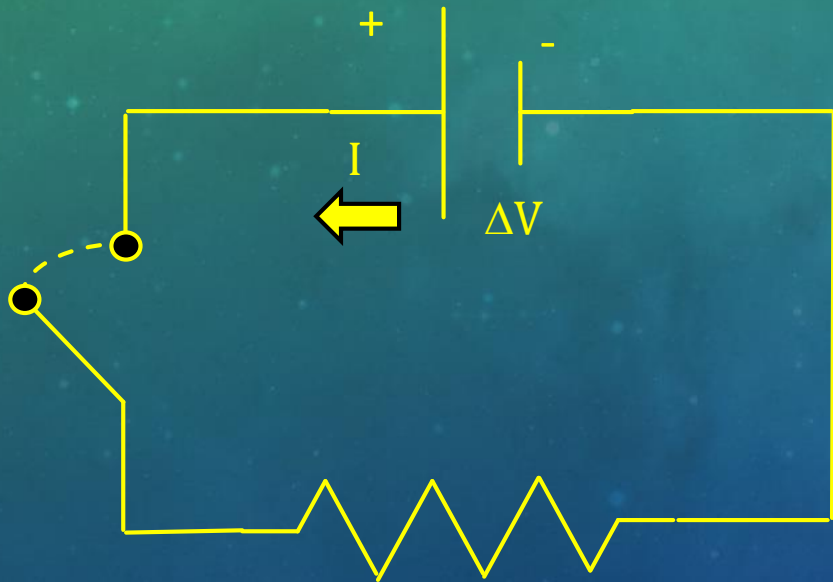
| Electric | Water |
|------------|----------|
| Wire | Pipe |
| Charge | Water |
| Current | Current |
| Battery | Pump |
| Voltage | Pressure |
| Switch | Valve |
| Resistance | Turbine |
| Capacitor | Tanks |



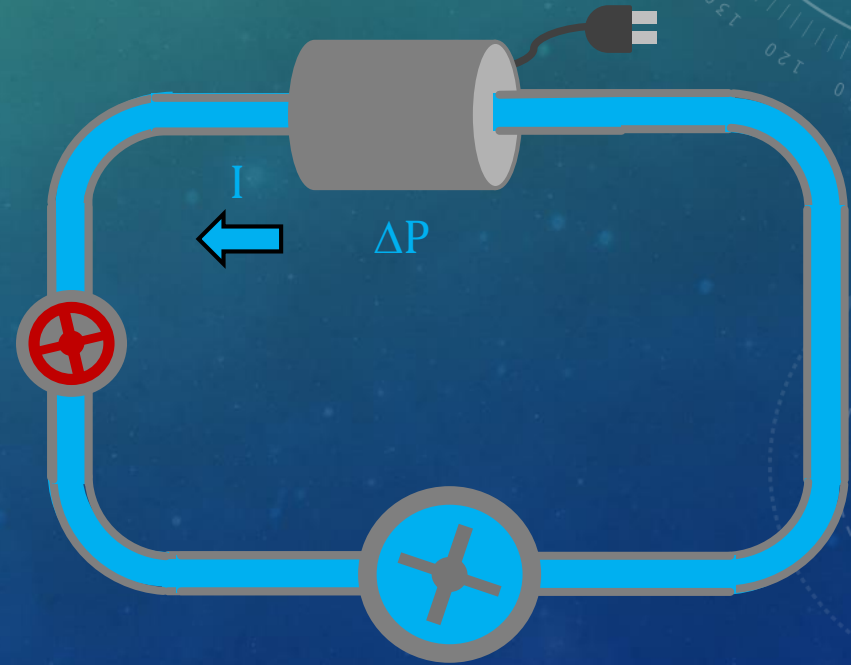
- Of course, *analogous* does not mean identical. For instance, water has a lot of inertia, but the low mass electrons have very little inertia. Also, there is no analogy for the different signs of charge in the water analogy.

WATER ANALOGY OF A CIRCUIT

- Here are some equivalent components hooked up into a circuit.



The battery doesn't make charge, it moves charge already in the circuit.



The pump doesn't make water, it moves water already in the circuit.

CONSERVATION OF CHARGE

- Since charge can't be destroyed or created in a circuit, any charge that flows **in one end** of a wire must flow **out the other end**.
 - So the current into a wire equals the current out of the wire.
- Any charge that flows into a junction, or branching point of a circuit, must flow out of the junction.
 - So the **total current into a junction must equal the total current out of the junction**.
 - $I_{in} = I_{out1} + I_{out2}$



Junction Rule:
Total current into
and out of a
junction must
sum to zero.

CONSERVATION OF ENERGY

- **Energy** cannot be created or destroyed. It can only change forms.
 - **Batteries** provide energy to a circuit.
 - **Resistors** convert energy to another form.
 - The energy used by the resistor is exactly that supplied by the battery.
 - The sum of the energy around a closed circuit is equal to zero.

- **Voltage** is **energy per unit charge**.

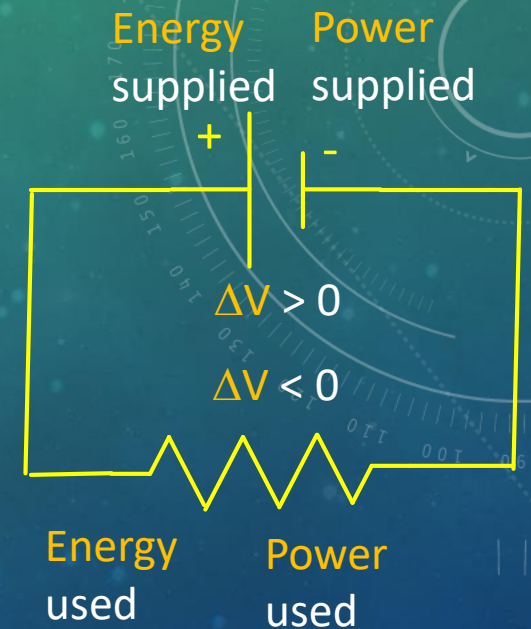
- Since the charge through a circuit is constant, then the voltage gain provided by the battery and the voltage drop across the resistor must sum to zero.

- The voltage around a closed circuit sums to zero. $\Delta V_{\text{battery}} + \Delta V_{\text{resistor}} = 0$

- **Power** is **energy supplied per unit time**.

- Since the energy supplied by the battery is used by the resistor in the same interval of time, then the power supplied is equal to the power used.

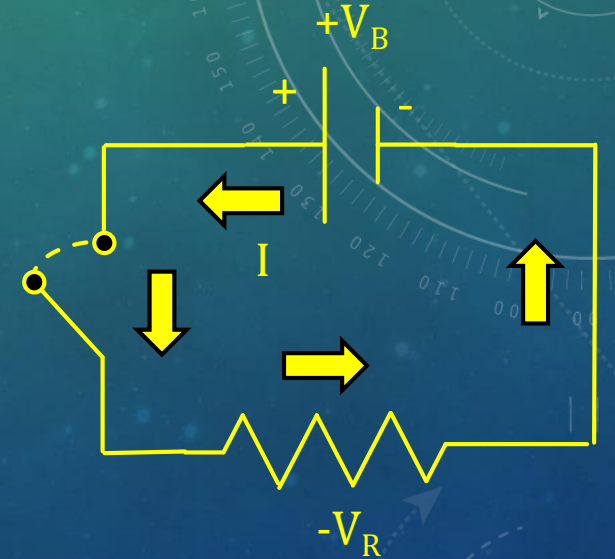
$$P_{\text{supplied}} = P_{\text{used}}$$



Loop Rule:
Total voltage around a loop must sum to zero.

CIRCUIT EXAMPLES

- Circuit 1: A **battery**, **switch**, and **resistor** all connected in series
 - When the switch is closed, **equal current** flows through all components and wires (**junction rule**).
 - The **voltage rise across the battery is equal to the voltage drop across the resistor** (**loop rule**).
 - The battery boosts the energy in the current. The resistor converts the energy in the current into some other form.
 - Examples: Light, heat, mechanical motion, etc.



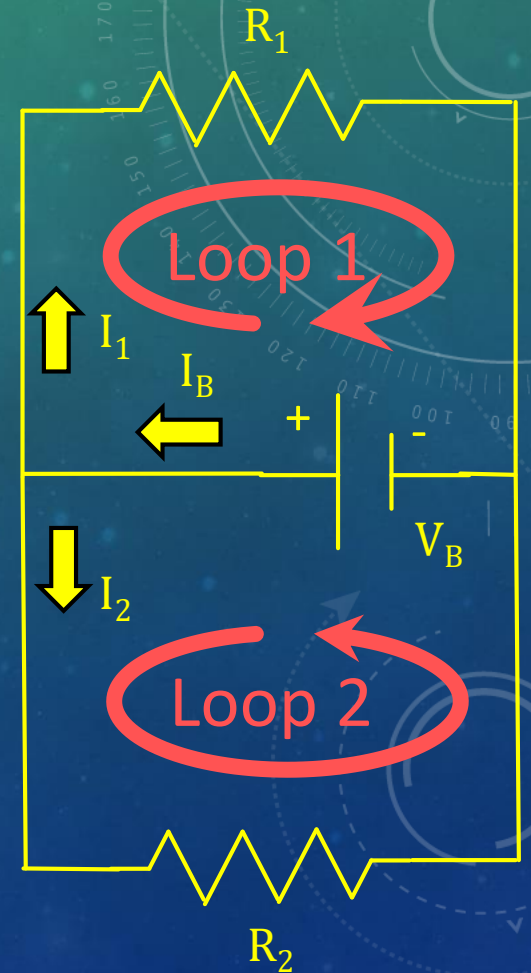
CIRCUIT EXAMPLES

- Circuit 2: A **battery** and a **capacitor** connected in series
 - When the switch is first closed, **current initially flows**.
 - **Positive charge builds up** on one side of the capacitor, and **negative charge builds up** on the other.
 - As the charge builds up on the resistor plates, the battery has more and more trouble pushing more charge onto it, **slowing the current**.
 - Eventually, the voltage between the capacitor plates is equal to the battery's maximum voltage, and the **current ceases to flow**.
 - This is how a capacitor is 'charged'.
 - Energy from the battery is being stored in the electrical field of the capacitor.
 - The capacitor can then be **discharged across a resistor**, releasing its energy in some other form.



CIRCUIT EXAMPLES

- Circuit 3: **Battery** and **two resistors** in two branches.
 - **Current splits** at the junction ($I_B = I_1 + I_2$). It rejoins at the other junction.
 - The voltage around the top loop sums to zero.
 - The voltage around the bottom loop sums to zero, as well.
 - The amount of current through the upper path depends on the resistance of that resistor compared to the resistor in the lower path.
- Given the battery voltage and the two resistances:
 - You can use **Ohm's Law** to figure out the **two branching currents**.
 - You can use the power equations to figure out:
 - Power delivered by the battery: $P_{\text{supplied}} = V \cdot I_B$
 - Power used by each resistor: $P_{\text{used}} = I^2 \cdot R$
 - **Conservation of energy** says that **power supplied = total power used**.



CONCLUSION

- Two of the fundamental **conservation laws** have been applied to electrical charge in a circuit.
 - In this context, they are sometimes called 'Kirchhoff's Laws'.
 - **Conservation of charge** says that the **total current that enters and exiting a junction must sum to zero**. (Also called the 'junction rule'.)
 - Alternatively, **current in must equal current out of a junction**.
 - **Conservation of energy** says that the **sum of the voltage rises and falls around a closed loop within a circuit is zero**. (Also called the 'loop rule'.)
- These rules work within any circuit, no matter how complex or what its components are.