AP Physics C: Electricity and Magnetism Notes

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1 Circuit

1.1 Circuit Basics

Equipment:

- D-cell battery/cells: with positive and negative terminals.
- Battery holder.
- Ammeter (machine labeled "$\underline{\text{A}}$").
- Multimeter (can be ammeter, voltmeter or ohmmeter): has "test leads" or "probes."
- Single pole single throw switch and single pole double throw switch.
- Wires: alligator-alligator wires (alligator clips on both ends), alligator-banana wires, banana-banana wires.
- Sockets (light bulbs screw into the hole).
- Round bulbs and long bulbs.

There are electrons everywhere in the circuit (all metal solids have delocalized electrons). The battery serves as a "pump" to move electrons around through the circuit. We can use the voltmeter in the multimeter to measure the "pump strength."

We can find the potential difference across the battery $\Delta V_{\text{battery}}$ and across the two light bulbs ΔV_{B_1} and ΔV_{B_2}.

$$\begin{aligned}\Delta V_{\text{battery}} &= 4.34\,\text{V}\\ \Delta V_{\text{B}_1} &= 1.84\,\text{V}\\ \Delta V_{\text{B}_2} &= 1.83\,\text{V}\end{aligned}$$

Since energy is conserved the potential difference of the bulbs should be the same as that of the battery, but it is not. We need to take ΔV of the wires and switch into account as well.

Potential difference (ΔV) is measured in volts (V), and is related to energy. In Ye Olde Times, it is denoted V or emf (electromotive force), and ΔV_{bat} is denoted ε.

Flow rate/current (I) measures the number of electrons that pass a certain point per unit of time, and is measured in amperes (A).

Resistance (R) is how difficult it is for electrons to flow through and is measured in ohms (Ω).

The current is equal across the circuit.

Ohm's Law

$$\Delta V = IR$$

where:

$$\begin{aligned} \Delta V &= \text{potential difference (V)} \\ I &= \text{current (A)} \\ R &= \text{resistance } (\Omega) \end{aligned}$$

Resistors convert electrical energy to thermal energy. Light bulbs are a special case of resistor that convert electrical energy to thermal and light energy.

Resistors in series

When resistors are connected in series, current is equal across any part of the circuit:

$$I_{\text{bat}} = I_1 = I_2 = I_3$$

Assuming no potential is lost anywhere:

$$\begin{aligned} \Delta V_{\text{bat}} &= \Delta V_1 + \Delta V_2 + \Delta V_3 \\ R_{\text{total}} &= R_1 + R_2 + R_3 \end{aligned}$$

Resistance

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

where ρ is the resistivity of the material ($\Omega\,\text{m}$), l is length (m) and A is cross-sectional area (m^2).

A **junction/node** is a point where three or more wires are connected.

A **branch** connects two nodes.

To connect a parallel circuit, multiple junctions need to be made.

Resistors in parallel

The currents are different at different parts of the circuit:

$$I_{\text{bat}} = I_1 + I_2 + I_3$$
$$\Delta V_{\text{bat}} = \Delta V_1 = \Delta V_2 = \Delta V_3$$
$$\frac{1}{R_{\text{total}}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Similar to springs in parallel.

From $I = \Delta V/R$ and $\Delta V_{\text{bat}} = \Delta V_1 = \Delta V_2 = \Delta V_3$:

$$I_{\text{bat}} = I_1 + I_2 + I_3 \implies \frac{\Delta V_{\text{bat}}}{R_{\text{total}}} = \frac{\Delta V_1}{R_1} + \frac{\Delta V_2}{R_2} + \frac{\Delta V_3}{R_3} \implies \boxed{\frac{1}{R_{\text{total}}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}$$

Electron Sea Model

In metals, atoms form metallic bonds: each metal atom releases its valence electrons, which then form a sea of delocalized electrons. These electrons are then attracted to multiple atoms. These bonds are very strong and lead to high melting points for metals.

Delocalized electrons can move in a direction caused by an electric force.

Electrons flow from the negative terminal to the positive terminal. Conventional current is the direction in which positive charges flow, and is opposite to the direction electrons flow. The direction electrons flow is marked e^- and conventional current is marked I. The "long" end of the battery symbol is positive.

Ohmmeters are connected when there are no charges flowing; voltmeter and ammeter need the circuit to be active. Ammeter is connected in a circuit; voltmeter and ohmmeter measure across a circuit component (with a multimeter). In reality, these devices will modify the circuit when they are attached. An ammeter actually has a very small resistance, but we assume it has zero resistance. Also assume that a voltmeter has infinite resistance.

If two components are on different paths to the battery, they have the same potential difference (parallel).

A **combination circuit** is one which is not purely series or purely parallel. We can analyze such a circuit by calculating the total/equivalent resistance.

Power

$$P = I\Delta V = I^2 R = \frac{\Delta V^2}{R}$$

where:

$$P = \text{power (W)}$$
$$I = \text{current (A)}$$
$$\Delta V = \text{potential difference (V)}$$
$$R = \text{resistance } (\Omega)$$

The sum of power in each resistors equals the power in the battery.

Resistors dissipate energy by converting electrical energy to thermal energy at a rate equal to $P = I\Delta V = \ldots$

Light bulb ratings

Suppose a light bulb is rated at $p\,\mathrm{W}$ and $v\,\mathrm{V}$. p relates to the brightness of the light bulb, and v is the ideal conditions of the light bulb. From here, we can find the current and resistance of the light bulb.

Light bulb assumptions:

- The brightness of a light bulb is directly proportional to the power.
- The resistance of a light bulb is constant.

Electric bills

The house is billed by energy used in kWh, which is actually a unit of energy.

$$1\,\mathrm{kWh} = 3.6 \times 10^6\,\mathrm{J}$$

In a short circuit, a path with small/virtually zero resistance forms, adding a parallel path. The overall/equivalent resistance drops even though ΔV_{bat} is constant, increasing the current and therefore the power. A circuit breaker/fuse will trip/melt and open the circuit when current is higher than a certain limit.