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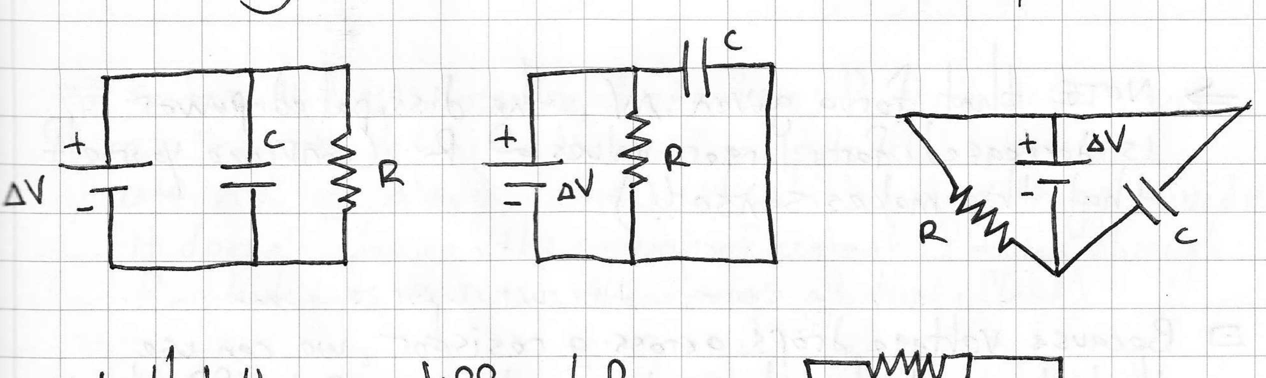
Circuits 101

- Circuits are 'closed' in the sense that current flows in loops (see Giordano's water pump analogy in Fig. 19.11); when a circuit is 'open' (i.e. a switch is not closed), no current will flow (see Giordano's bird-on-wire in Fig. 19.12)

  NOTE: A circuit can be 'closed' by connecting to **ground** (that is, electrons can flow to the earth, which is considered to have zero potential)

- Circuits can have various elements (e.g. batteries, capacitors, resistors, etc...) connected via 'ideal wires'; these connections are crucial to know in order to understand the circuits behavior

  → circuits can have different branches and be drawn in a variety of ways. For example, all the following are equivalent (think about why!):



Note that these are different from (this circuit will have a very different behavior from the others!)

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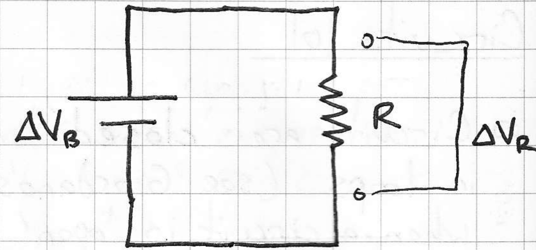
- Consider a simple circuit to start: a battery connected to a resistor



→ battery creates a potential difference across R ($\Delta V_R = \Delta V_B$) such that electrical potential energy fueled by the battery is 'dissipated' (i.e. burned off) due to the current flowing through it

$$\text{power} = \frac{\text{dissipated energy}}{\text{time}}$$

→ During time Δt, we have charge $\Delta q = I \Delta t$ dropping in energy by $\Delta E = \Delta q \Delta V$

$$\text{so } \Delta E = \Delta q \Delta V = I \Delta t \Delta V = \frac{\Delta V}{R} \Delta t \Delta V$$

$$\text{so } P = \frac{\Delta E}{\Delta t} = I \Delta V = \frac{\Delta V^2}{R}$$

⇒ NOTE that for a given ΔV, the dissipated power is decreased for larger values of R (convince yourself that this makes sense!!)

- Because voltage drops across a resistor, we can use that to our advantage to create a useful effect when we have two resistors: a **voltage divider**

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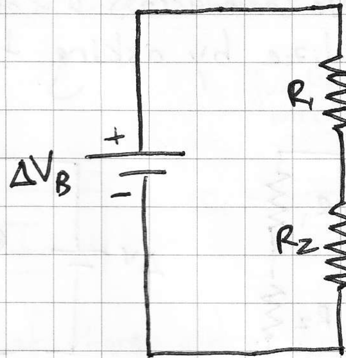
- Voltage drop along the path will deal with both R_1 and R_2 by means of their sum (we'll see why shortly)



$$\Delta V_B = V_1 + V_2$$

(V_1: voltage drop across R1; V_2: voltage drop across R_2)

$$= IR_1 + IR_2$$

(same current goes through both resistors!)

→ Note that even though the same charges pass through each resistor, they can have different energies! (hence the difference in V_1 and V_2)

$$= I(R_1 + R_2)$$

$$\longrightarrow \quad I = \frac{\Delta V_B}{R_1 + R}$$

Now note that $\Delta V_2 = R_2 I$

$$= \frac{R_2}{R_1 + R_2} \Delta V_B$$

⟹ so depending upon the relative values of R_1 and R_2, we can 'step down' or 'dial up' a potential (since $0 \leq \Delta V_2 \leq \Delta V_B$); this is known as a **voltage divider** (it doesn't change the amount of current flowing through R_1, but does decrease the energy of that flow)

[if this seems confusing, try relating back to Giordano's water flow analogies as shown in Fig. 19.1 and Fig. 19.11]

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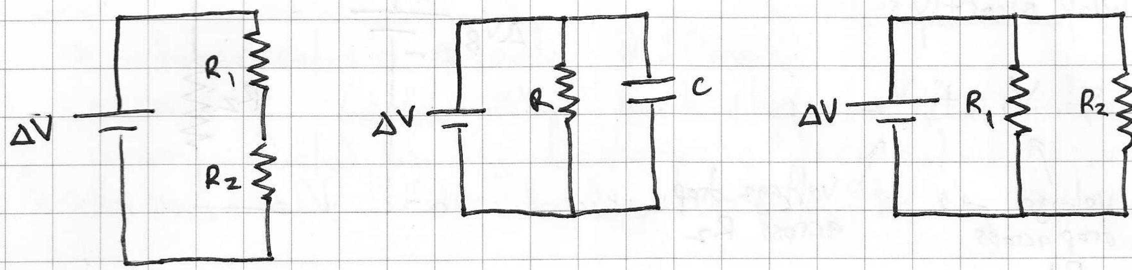
- So we've come across a few concepts that we can further crystallize by asking the following question:



→ How does the behavior of these circuits differ?

- Considering how the behavior of a capacitor-only circuit varied depending upon their connections (i.e. series vs parallel; see 1/23 and 1/29 notes), the above question motivates a series of additional questions:

  - What is the relationship between voltage and current for different 'branching' layouts in the circuit?

  - How does the voltage and/or current change depending upon whether we have a resistor or capacitor (or something else) at a given place?

  - How is energy stored when we have a combination of elements? Dissapated? How does this change when we re-wire things?

⇒ We can get quite a lot of insight by means of two (deceptively simple) rules: Kirchoff's Rules

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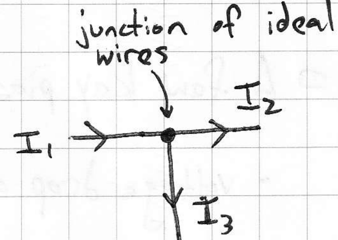
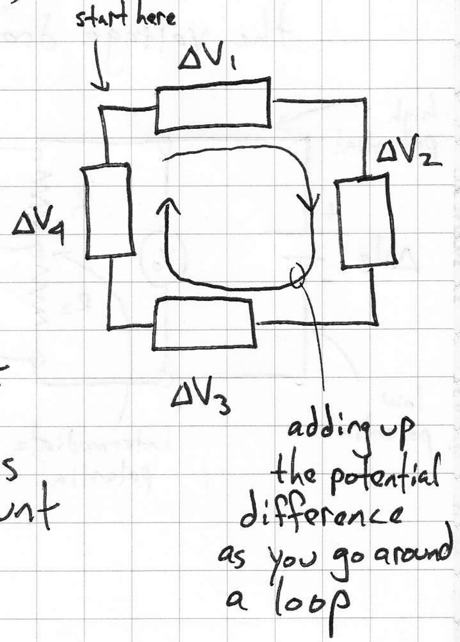
- We will state Kirchoff's Laws, then look at a set of circuits of resistors + battery to understand what they imply and how to use them



Kirchoff's Law

1) Junction Law: $\boxed{\sum I_{in} = \sum I_{out}}$

(this stems from the conservation of charge and current; put another way, what flows in must flow out w/ respect to a junction)



2) Loop Law: $\boxed{\Delta V_{loop} = \sum_i \Delta V_i = 0}$

(this is essentially a statement on the conservation of energy; a charge that moves fully around a closed loop and returns to its starting point has $\Delta U = 0$, i.e. it has the same amount of electrical potential energy)

Historical Aside:

- Kirchoff was a German who formulated these 'laws' while he was still a student in 1845!
- Kirchoff based his work off of Georg Ohm, and later on Maxwell realized Kirchoff's Laws can be derived from a more general set of considerations (known as Maxwell's eqns.)