Up to now, we've been looking at pieces or chunks
of wire, so let's out and look at complete
(resistors) circuits to see how we under current
flow in them. *Here, we will expand on 1st nature

- If current flows around a circuit, it must be
  driven in some way → we've described the
  $\vec{E}$ field inside the wire /resistors.
- A measure of this driving is called EMF
    (Historically, the electromotive force,
       which is a terrible name as it's not a force!)

EMF

$$\mathcal{E} \equiv EMF \equiv \oint \vec{f} \cdot d\vec{l} \quad \left[\begin{array}{l} \text{gives this measure} \\ \text{at one instant in time} \\ \text{when } \vec{f} \text{ is known} \end{array} \right]$$

a circuit
loop
$\vec{f}$ is the usual force/charge.

The definition of EMF looks kind of like
a ~~force~~ work/unit charge taken once around
the loop.

$\vec{f}$ here can be
any force that
drives charges

- Electric $\quad \vec{f} = \vec{E}$
- Magnetic $\quad \vec{f} = \vec{v} \times \vec{B}$
- physical pushes $\quad \vec{f} = \vec{F}_{ant}/q$
  (like "ants")

Sometimes it's the case that $\vec{f}$ is hard to
define for us (like in a battery where chemistry & QM
are needed to understand the physics of $\vec{f}$)

Units of EMF : $[EMF] = \left[\dfrac{Work}{Charge}\right] = J/c = Volt.$

Where does the EMF come from?

If your circuit involved only electrostatic forces
then

$$\mathcal{E}_{\substack{pure \\ e\text{-}static}} = \oint \vec{E}_{\substack{electro \\ static}} \cdot \vec{dl} = 0$$

Because $\vec{\nabla} \times \vec{E}_{electrostatic} = 0$

So to drive a current around a circuit, you
need another force!
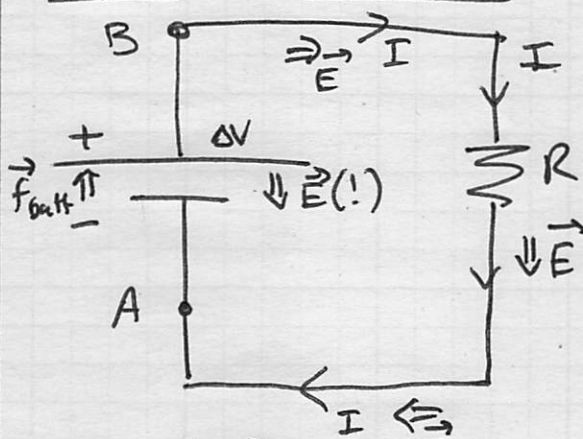
In a battery $\rightarrow$ it's chemical
In Van de Graaff $\rightarrow$ it's mechanical
* In a generator $\rightarrow$ it's magnetic $(\vec{V} \times \vec{B}, \text{"motional}$
$\quad \hookrightarrow$ (We will study this in some detail soon.) $\quad EMF")$

A simple Circuit

$\mathcal{E} = \oint \vec{f} \cdot \vec{dl}$

In this simple circuit,
the Battery drives
a current I through
the wires / resistor R.

the field in the wires are
due to static charges on the
surface of the wires, so
this $\vec{E}$ is electrostatic.

So the only "non-electrostatic" force is inside the
battery, $\vec{f}_{batt}$. In the battery, charges are
driven from $-$ to $+$ by chemical force
we are not investigating.

If the current is steady AND there's no resistance in the battery (Assume: Ideal Battery) then

$$* \quad \vec{f}_{batt} = -\vec{E}$$

so that f_{net} in the battery is 0, no charge acceleration they have a steady flow.

⊛ Note how this model differs from the Drude Model in the wires/resistor (collisions) with the same result → steady current.

− Everywhere else in the circuit the field/force is electrostatic. $\vec{f} = \vec{E}$ electrostatic.

So the EMF can be computed thusly,

$$\mathcal{E} = \oint \vec{f}_{total} \cdot d\vec{l} = \int_A^B (\vec{f}_{batt} + \vec{E}) \cdot d\vec{l} + \int_B^A \vec{E} \cdot d\vec{l}$$

though battery ↑   rest of circuit ↑

chemistry   no chemistry

$$\mathcal{E} = \int_A^B \vec{f}_{batt} \cdot d\vec{l} + \oint \vec{E} \cdot d\vec{l}$$ } this term is zero b/c $\nabla \times \vec{E} = 0$

So the EMF is determined by the battery force.

$$\mathcal{E} = \int_A^B \vec{f}_{batt} \cdot d\vec{l}$$

We can manipulate the expression differently to show $\mathcal{E} = \Delta V_{batt}$.

$$\mathcal{E} = \int_A^B (\vec{f}_{batt} + \vec{E}) \cdot d\vec{l} + \int_B^A \vec{E} \cdot d\vec{l}$$

in batt   0 b/c $f_{batt} = \vec{E}$ Outside

$$= \int_B^A \vec{E} \cdot d\vec{l} = -\int_A^B \vec{E} \cdot d\vec{l} = \Delta V_{batt}!$$

So the EMF is derived from the force delivered to charges by the battery and is equal to the potential difference between the terminals of the battery (in the case of an ideal battery).
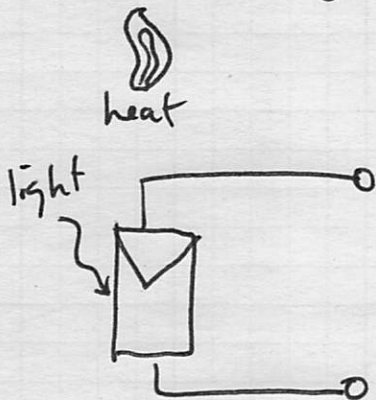
There are a number of common sources of EMF

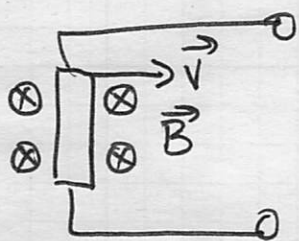- Anything that converts energy input into the ability to do work.
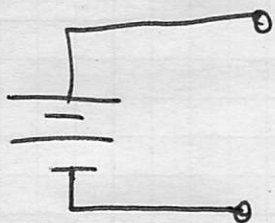
A **battery** that through <u>chemical</u> reactions creates a potential difference
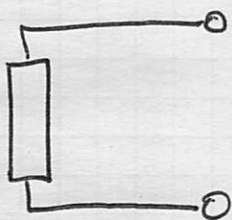
A <u>thermoelectric device</u> that konverts thermal energy into electrical energy

heat

light

A photovoltaic device that converts light (photons) into electrical energy

A <u>motional EMF</u> that is generated by moving charges through B-fields *

* And in other ways, too.

All of these methods could do work !