1. SI Units

We use Système Internationale (SI) d'Unités (International System of Units), which is based on
- meter as the unit length
- kilogram as the unit of mass
- second as the unit of time
- kelvin as the unit of temperature
- ampere as the unit of current
- candela - " - light intensity

2. Unit prefixes

Electrical quantities may range in value over many orders of magnitude.

Standard prefixes	Abbreviation	Magnitude (factor)
femto	(f)	10^{-15}
pico	(p)	10^{-12}
nano	(n)	10^{-9}
micro	(μ)	10^{-6}
milli	(m)	10^{-3}
kilo	(k)	10^{3}
mega	(M)	10^{6}
giga	(G)	10^{9}
tera	(T)	10^{12}

Example:

$$I = 1.5 \times 10^{-4} A = \underbrace{(1.5 \cdot 10^{-1})}_{0.15} \underbrace{10^{-3} A}_{mA} = 0.15 \, mA$$

$$= \underbrace{(1.5 \cdot 10^{2})}_{150} (10^{-2} \cdot \underbrace{10^{-4})}_{\mu A} = 150 \, \mu A.$$

Consistent Set of Units

$$V = R \cdot I \Rightarrow [V] = [\Omega] \cdot [A] \quad \text{in SI units}$$

$$[V] = [10^{3} \Omega] \cdot [10^{-3} A] = [k\Omega] \cdot [mA]$$

$10V = 2(k\Omega) \cdot 5(mA) = 10 V$: ✓ consistent

$10V = 2000(\Omega) \cdot 5(mA) = ?$: X inconsistent!

③ Electric quantities | overview   Take home: $\boxed{v \rightarrow \vec{E} \rightarrow i}$

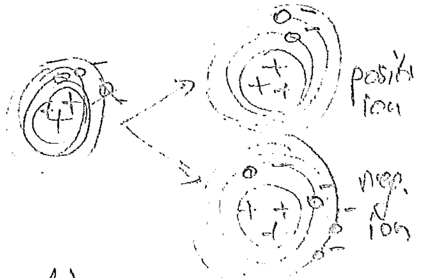
a) Charge

- The electric charge: Q is the fundamental quantity of electricity,

  Q [C] the SI unit is coulomb (C) after the French physicist Charles A. de Coulomb

- Charge may be
  - positive → most elementary positive charge is that of the proton $Q_p = +1.602 \times 10^{-19}$ C
  - negative → —"— the electron $Q_e = -Q_p = -1.602 \times 10^{-19}$ C

- Other examples:
  - positive ion ≙ atom without one/more electron
  - negative ion ≙ —"— with one/more electron.



- Charge is conservative (it cannot be created or destroyed)
  - it can be manipulated in a variety of ways → foundation of electrical engineering
  - The most common tool for the manipulation of charge is the electric field, denoted as $\vec{E}$.

ⓑ Potential energy (Electrostatic potential energy)

- As a consequence of the force exerted by the electric field, a charge possesses potential energy: w [J] Joule (English physicist)
  - depends on
    - the magnitude of the charge
    - its location in space
- Analogy: lifting a mass m to height h above sea-level increases its potential energy to $w = mgh$
- In the electrical case it has been agreed to regard earth/or ground as the zero-level of potential energy for charges.

ⓒ Voltage

(I) - The rate at which the potential energy varies with charge is denoted as v and is called the electric potential

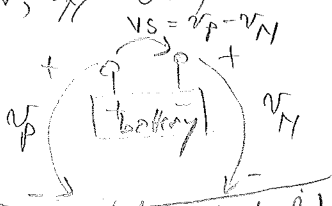
$$(1)\ \boxed{v \triangleq \frac{dw}{dq}}\quad [V]$$ volt after the italian Alessandro Volta.

$$\left(\text{hence note: } 1V = \frac{1J}{1C}\right)$$

- What matters to us is however the potential difference or voltage
- The interpretation of (1) is: if a charge dq gives up an amount of energy dw in going from one point to another in space, then we define the voltage between these points as $v = \frac{dw}{dq}$.
- Example: a potential difference or voltage can be created by a battery.

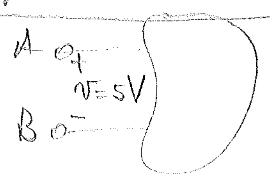
$9V = V_S = v_p - v_N$ v_p, v_N the electric potential with respect to ground.

some possible situations: $(v_p = 9V, v_N = 0V)$ $(v_p = 6V, v_N = -3V)$
$(v_p = 18V, v_N = 9V)$



(II) Another way to look at things: (this definition skips the concept of electric potential)

Consider a general circuit element: and a dc current entering in A and exiting in B.

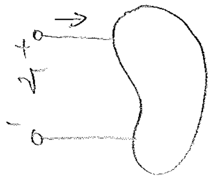


Note: v indicates that A si v volts positive to terminal B.

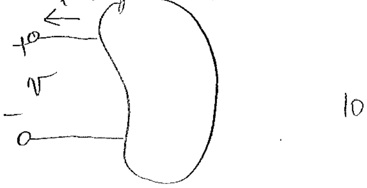
- Pushing charge through this element requires an expenditure of energy and we say that an electrical voltage exists between terminals, or that there is a voltage drop across the element. So, the voltage is a measure of the work required to move charge thru the element. (this definition doesnot give an expression for voltage)

- An element can (a) $\boxed{\text{be}}$ supplied with energy (absorbs, consumes)
(b) supply energy (provide, deliver)

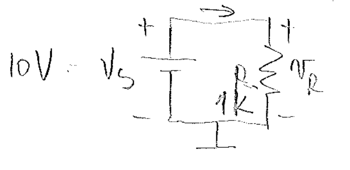
(a)



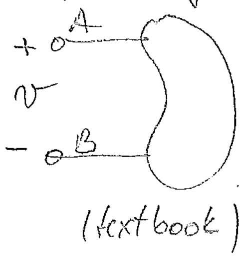
(b)



Example:

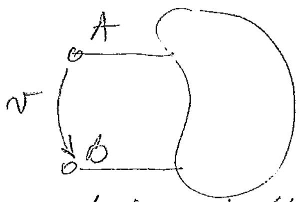


- Notation of voltage has to specify the "+" and "−":



(textbook)

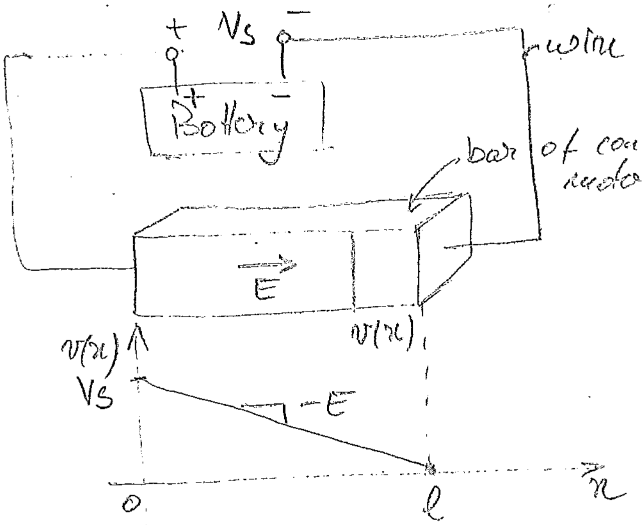
we'll use often also:



(other textbooks)

- "+" and "−" tell us that the potential of A is higher than the potential of B!

Relation between electric field and Potential



− The battery establishes a potential difference. It generates an electric field related by the law of physics:

$$\vec{E} = -\text{grad}\, v$$

− if we set-up this system so that the direction of E coincides with the x axis, this relation simplifies to:

$$(*) \quad E = -\frac{dv}{dx}$$

magnitude

$\vec{E}$ points in the direction of decreasing potential

− if the bar is homogeneous and constant cross-section, then $\vec{E}$ will be constant throughout. Hence the differentials can be replaced with finite differences:

$$E = -\frac{v(l) - v(0)}{l - 0} = -\frac{(-V_s)}{l} = \boxed{\frac{V_s}{l} = E}$$

− Equation (*) can be written as:

$$v(x) = \int_0^x -E\, d\zeta + v(0) = -\frac{V_s}{l}\cdot x + v(0)$$

which is a straight line.

We can select $v(0)$ to be V_s because gives us $v(l) = 0$, which is neat!

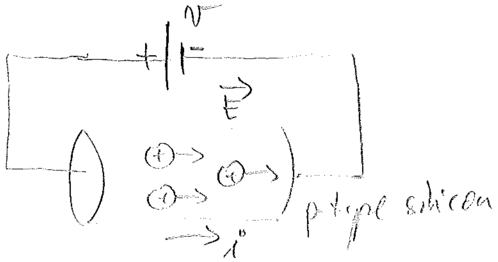
and therefore: $\boxed{v(x) = V_S\left(1 - \frac{x}{\ell}\right)}$

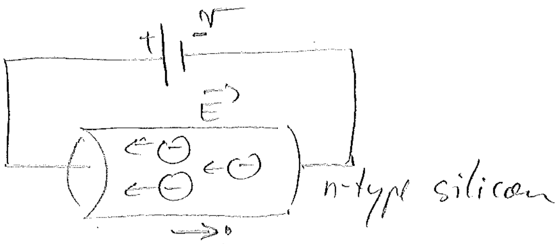
- Voltage inside the bar varies linearly from Vs to 0V! (this is how the potentiometer works!)

ⓓ Current

- If charges are free to move, exposing them to an electric field will force them to drift either along or opposite to $\vec{E}$. The resulting stream of charges is called current.
- The rate at which charge crosses some reference plane, perpendicular to the stream is denoted as i and is called the instantaneous current or current

(2) $\boxed{i \triangleq \frac{dq}{dt}}$ [A] ampere after André M. Ampère





- Applying voltage v across the bar establishes a field $\vec{E}$ inside the bar, which in turn causes the charges (holes, positive OR electrons, negative) to drift in the direction/opposite-direction of the field to produce the current i.

$$\boxed{v \to \vec{E} \to i}$$

- in both figures: { negative charge is accumulated on the positive terminal of the battery
  positive charge is accumulated on the negative terminal

So, from the battery's point of view both situations are indistinguishable! and i is in the same direction.

- Turn around equation (2) to find the amount of charge that passes thru the reference plane between t_1 and t_2:

$$\boxed{Q = \int_{t_1}^{t_2} i(t)\,dt}$$

- The ability of the battery to store charge is referred to as the battery capacity. [ampere-hour] [Ah]

Example: car batteries have capacities in the order of 10^2 Ah.

ⓔ Power

- To sustain current inside a piece of material takes an expenditure of energy, or work. (in previous figure this work is performed by the battery).
- The rate at which $\boxed{w}$ is expended is denoted p and is called the instantaneous power:

(3) $\boxed{p \triangleq \frac{dw}{dt}}$ [W] watt after Scottish James Watt

$$[1W] = \frac{[1J]}{[1s]}$$

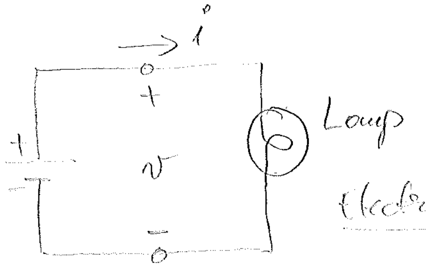
$$p = \frac{dw}{dt} = \underbrace{\frac{dw}{dq}}_{=v} \cdot \underbrace{\frac{dq}{dt}}_{=i} = v \cdot i$$

(4) $\boxed{p = v \cdot i}$ whenever a current i flows between 2 points having a potential difference of v, the corresponding instantaneous power, p

- Turn around (3) to get the energy expended over the time interval from t_1 to t_2:

$$\boxed{W = \int_{t_1}^{t_2} p(t)\,dt}$$ [watt-seconds] or [kilowatt-hour]

Example :



electric energy is converted to light and heat.
↑
Comes from the battery, where it is generated by conversion from chemical energy.

- Here, the current serves as a vehicle to transfer power from the battery to the bulb.
- We say that the battery releases electric power and that the bulb absorbs electric power. That is why the battery is called active and the bulb passive.