Review

- If you are watching this video lecture on your mobile device rather than PC, you need to use coursemos app (from Ubion) to be acknowledged for your class attendance.
  - If you use SNU app, your progress won't be recorded.
  - Please check the progress record on ETL.
  - ➔ If the progress is less than 100%, you will be considered as absent.
- Lumped circuit abstraction
  - E.g. bulb ➔ resistor
- Basic concepts in physics
  - Work
  - Power
  - Charge
  - Voltage

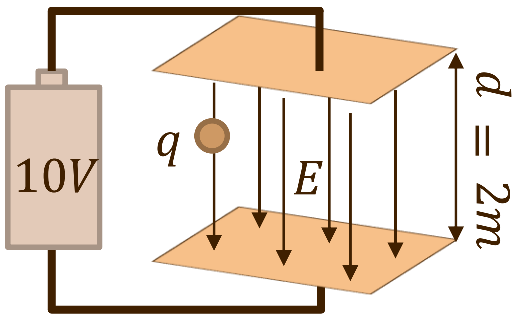
Basic Concepts in Physics

- Work
  - How do you measure the amount of work?
  - Work = Force x Distance
    - Unit of force: N (Newton) ➔ 1N: the weight of ~102 gram mass
    - Unit of work: J (Joule) ➔ 1J: the amount of work to raise a mass of 102 gram by 1 meter
  - Direction matters!
  - Positive work vs. negative work

- Power
  - Amount of work done per unit time
  - Unit of power: W (watt) ➔ 1W: 1Joule per 1 second

Basic Concepts in Physics

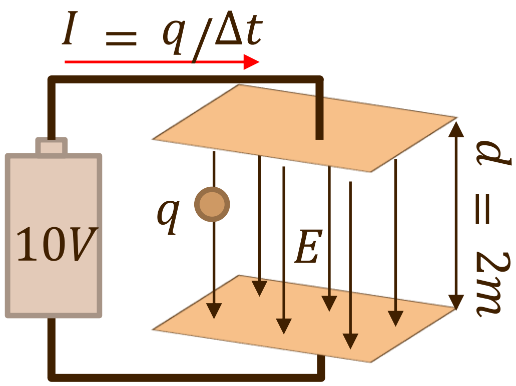
- Charge
  - SI unit for charge is Coulomb, and written as C.
  - 1C: the amount of charge of $\sim 6.2 \times 10^{18}$ electrons



- Voltage
  - What do mean by 1.5V battery?
  - For simplicity, assume $10(V)$.
  - If the distance d is 2 meter, the electric field strength E is $5(V/m)$.
  - If we place a test charge $q = 3C$ inside the electric field, then the force F experienced by the test charge q due to the electric field E is $F = q \cdot E = 3(C) \times 5(V/m) = 15(N)$
  - Work done by the electric field: $\Delta W = F \cdot d = qdE = 30(J)$
  - Voltage is a work to be done on a unit charge: $V = \Delta W / q = Ed$

Basic Concepts in Physics

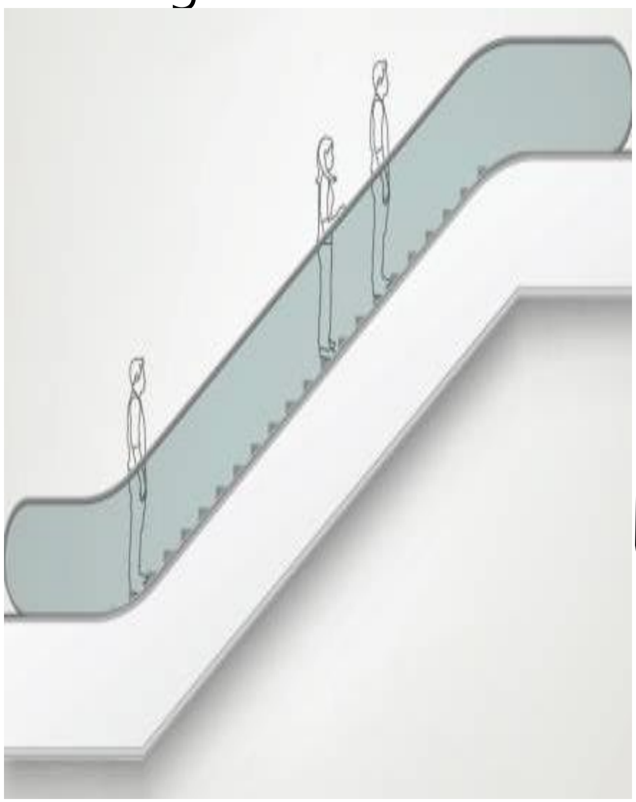
- Current
  - Current is the amount of charge passing through a specific position per unit time
  - $I = q/\Delta t$
  - Unit of current is A (Ampere). 1A=1C/sec

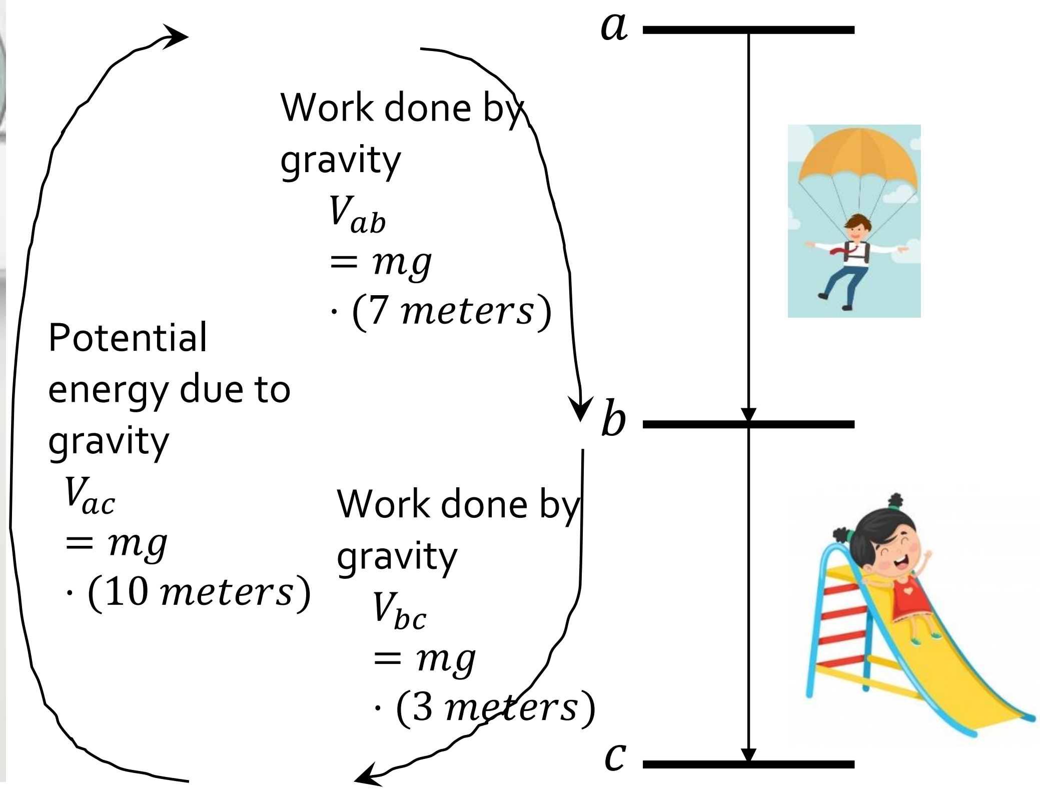


- (Electrical) Power
  - Recall: amount of work done per unit time ➔ 1W: 1J/sec
  - Assume that for 2 seconds charge of 6C flowed through a wire.
    ➔ current $I = \frac{q}{\Delta t} = \frac{6(C)}{2\ (sec)} = 3(A)$
  - The amount of work done by the electric field: $\Delta W = F \cdot d = qdE = qV$
  - Power: $P = \frac{\Delta W}{\Delta t} = V\left(\frac{q}{\Delta t}\right) = V \cdot I$

Potential in gravity

- Analogy to potential by the gravity on the earth
- Potential energy is mgh where m is mass, g is a constant, and h is height.



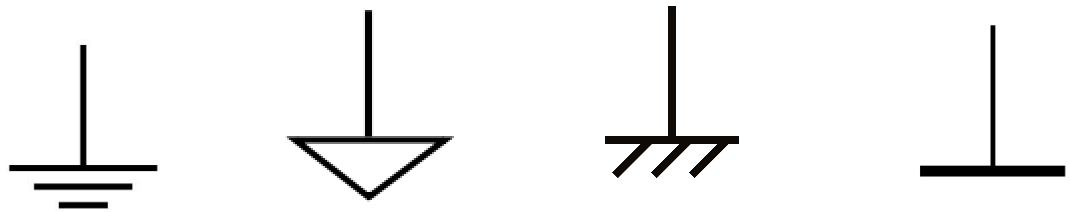


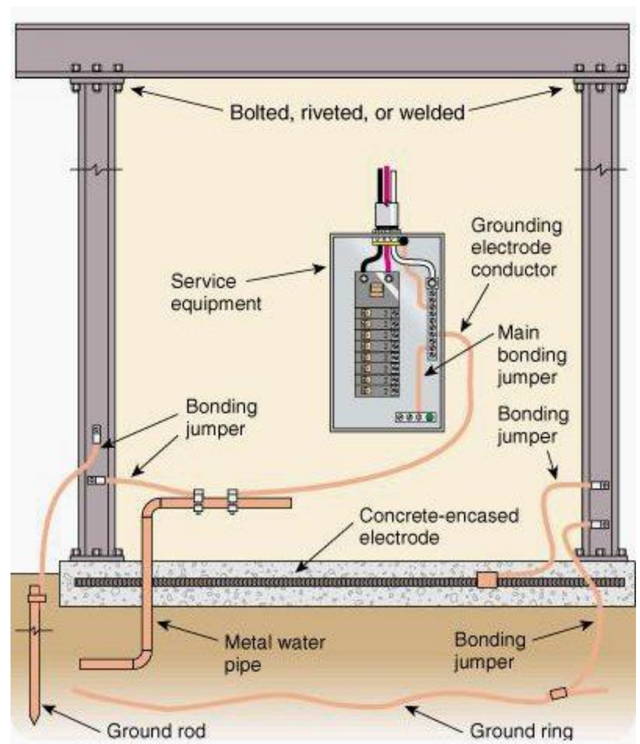
The sum of the amount of work done by the gravity field:

$$V_{ca} + V_{ab} + V_{bc} = 0 \Rightarrow -V_{ac} + V_{ab} + V_{bc} = 0$$

$$-mg \cdot (10\ meters) \ \ +mg \cdot (7\ meters) \ \ +mg \cdot (3\ meters) \qquad = 0$$

Electrical ground



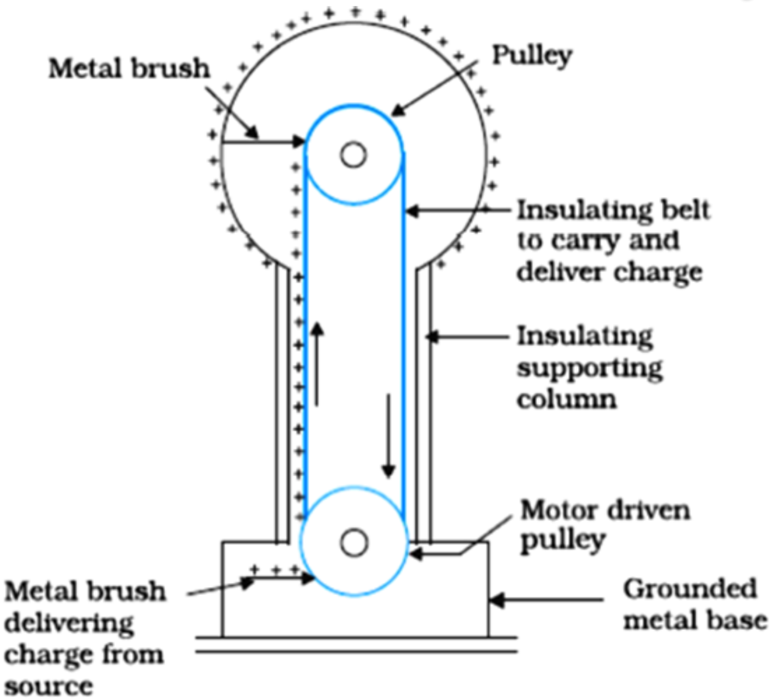


Images from https://electrical-engineering-portal.com/9-recommended-practices-for-grounding

Electrical Potential Difference inside Metal

- There is no electrical potential difference inside any metal
  - If there is no resistance inside the metal, the electric field inside the metal should be zero.
  - When two points are connected by a wire, the electrical potential at those two points should be the same.

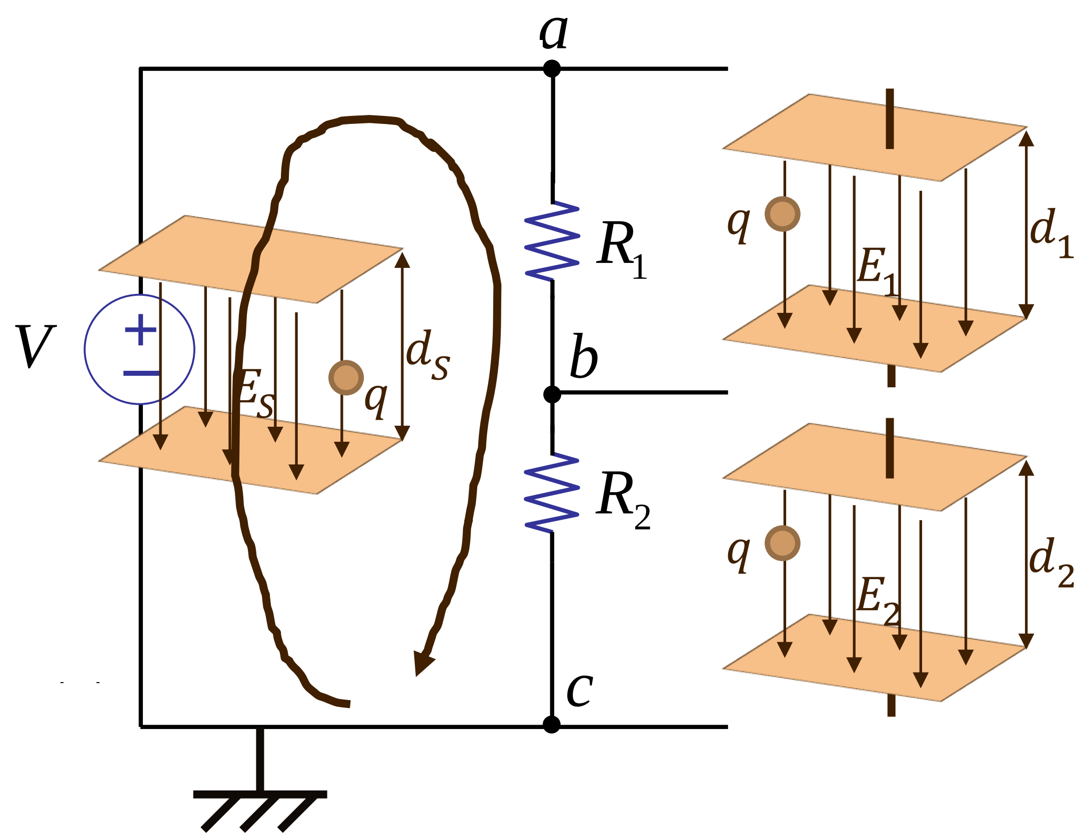
Potential in electricity



Van de Graaf Generator

Image from https://www.cleanpng.com/png-van-de-graaff-generator-van-der-graaf-generator-dr-5738296/download-png.html

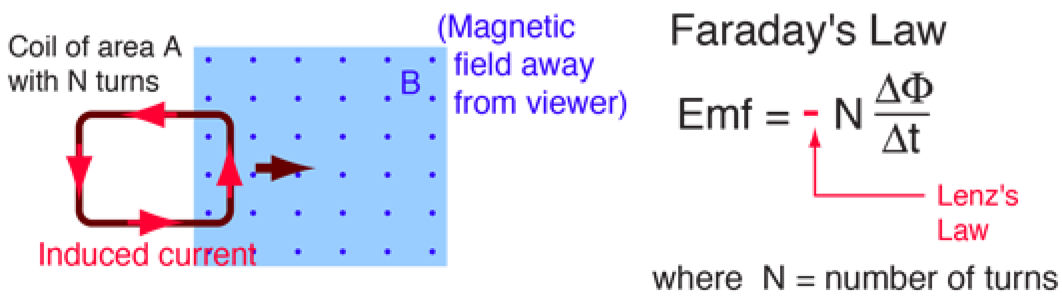
- The convention
  - As we move along the loop, if the circuit needs to do some work, then add,
  - If the circuit requires some work from outside, then subtract.



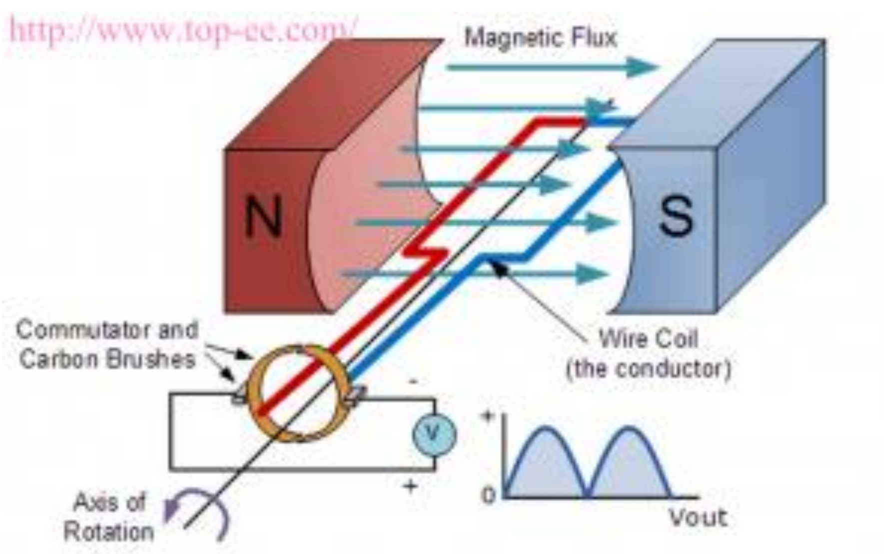
$$\Rightarrow \int_{ca} E \cdot dl + \int_{ab} E \cdot dl + \int_{bc} E \cdot dl = 0$$

$$\Rightarrow + V_{ca} + V_{ab} + V_{bc} = 0$$

Faraday's law of induction



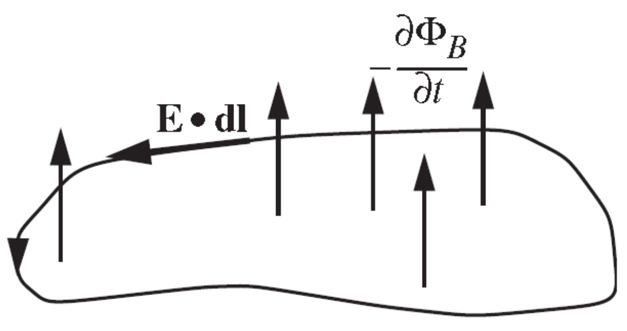
- Similar to energy conversation law
- Recall how the electricity is generated by a generator



Lumped Matter Discipline (LMD)

Voltage $\boxed{V}$ must be defined

- Voltage should be the same when we come back to the same position
- True when $\dfrac{\partial \phi_B}{\partial t} = 0$ around the circuit



$$\oint \mathrm{E} \cdot \mathbf{dl} = -\frac{\partial \Phi_B}{\partial t}$$

$$V_{AB} = \int_{AB} E \cdot dl$$

V_{AB} defined when $\oint \mathrm{E} \cdot \mathbf{dl} = 0.$

$$\frac{\partial \phi_B}{\partial t} = 0$$

So let's assume this

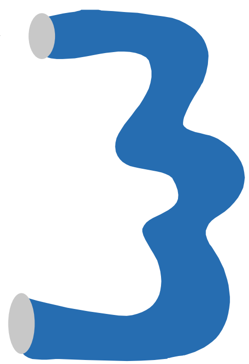
Lumped Matter Discipline (LMD)

Current $\boxed{\mathbf{I}}$ must be defined

$\mathbf{I}$ into S_A = $\mathbf{I}$ out of S_B

True only when $\dfrac{\partial q}{\partial t} = 0$ in the filament!

$\displaystyle\int_{S_A} J \cdot dS \longrightarrow$



$\displaystyle\int_{S_B} J \cdot dS \longleftarrow$

$$\underbrace{\int_{S_A} J \cdot dS}_{I_A} - \underbrace{\int_{S_B} J \cdot dS}_{I_B} = \frac{\partial q}{\partial t}$$

from Maxwell

$I_A = I_B$ only if $\dfrac{\partial q}{\partial t} = 0$

So let's assume this as well

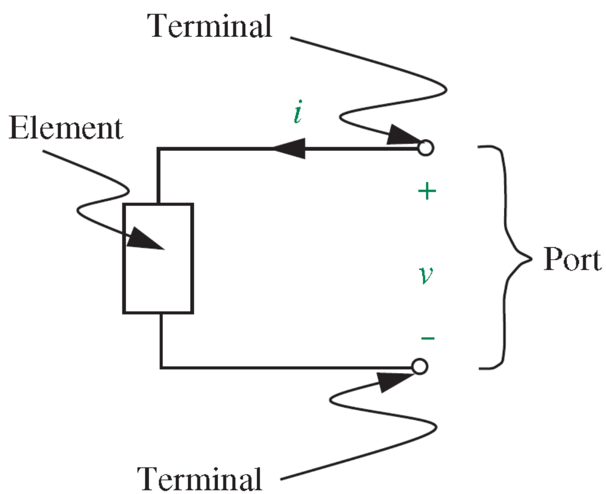
Lumped Matter Discipline (LMD)

Time scale

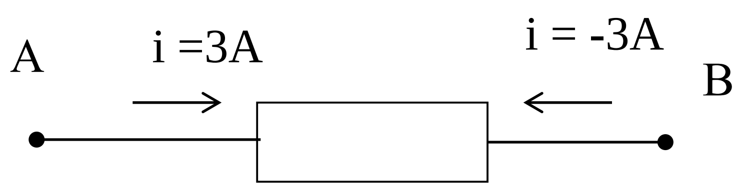
- Operate in the regime in which signal timescales of interest are much larger than the propagation delay of electromagnetic waves across the lumped elements

- 1GHz clock?

Two-terminal elements



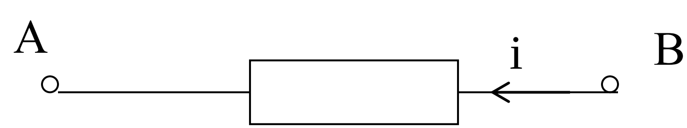
Direction of Current and Voltage



$+ \quad v_{AB} = 3V \quad -$

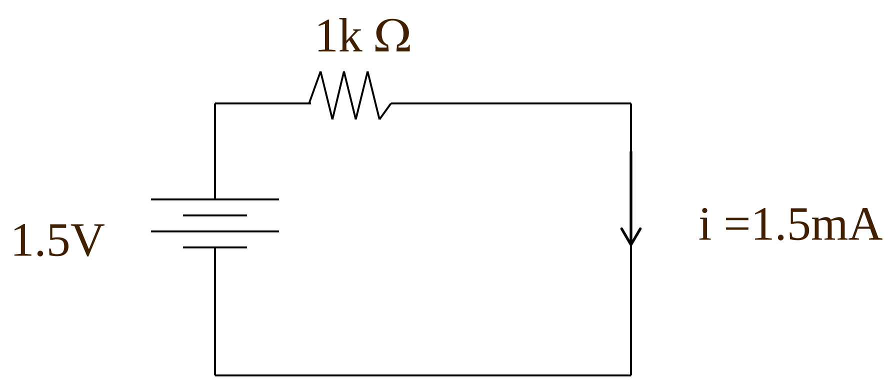
$- \quad v_{BA} = -3V \quad +$

5A Current flows from A to B. What is the value of current i?



Power and Energy

- Power = work/time
  = work/charge * charge/time
  = voltage * current
- P = VI



Power consumed by the resistor: 2.25 mW

Power consumed by the battery? -2.25 mW

- Energy: $\int \text{power}\ dt$