

Physics Note

Matsumotofukashi High School

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form 2026-04-14

1 *Electric Field*

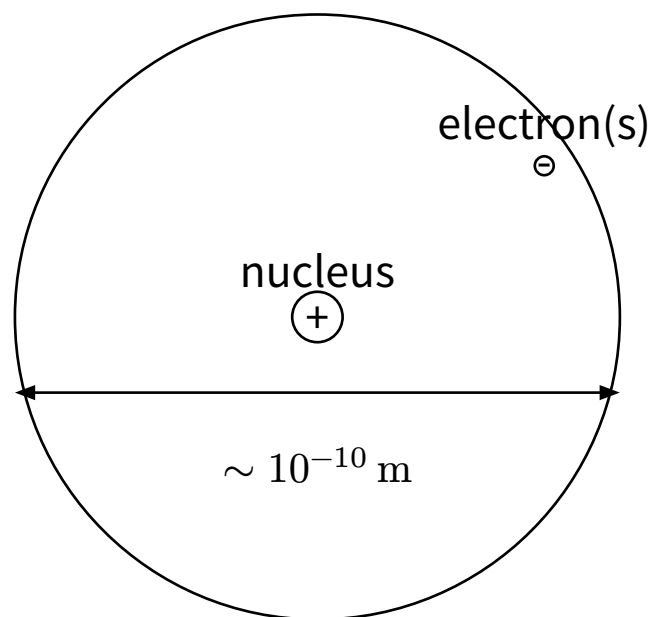
1.1 Electrostatic Force

- **electrification** - A process getting charge
- **static electoricity** - static charge
- **electoric charge** - TI
- **point charge** - charge which can be ignored the size

Electrostatic force is an interraction between charged particles.

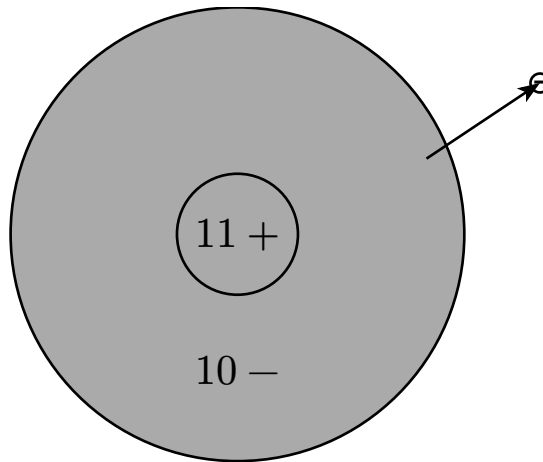
$$|\mathbb{F}| = k \frac{q_1 q_2}{r^2} \quad (1)$$

1.2 Structure of Atom



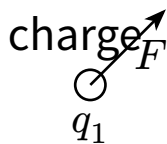
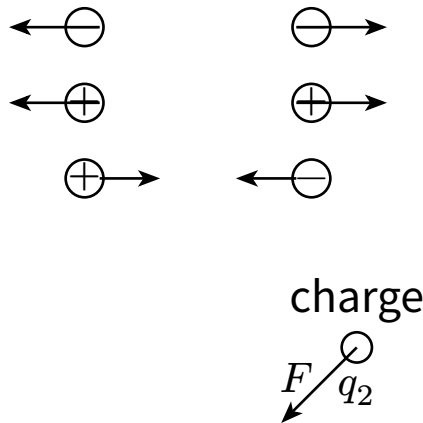
- **elementary charge** $1.6 \cdot 10^{19} \text{ C}$

1.3 Mechanism of Electrification



Total amount of charge is conserved.

- Coulomb's law



$$F = k \frac{q_1 q_2}{r^2} \tag{2}$$

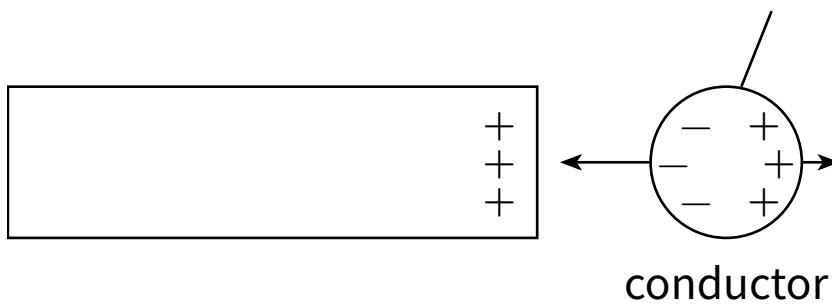
k depends on type of surrounding substance.

In vacuum, $k \approx 9.0 \cdot 10^9 \text{ N m}^2 \text{ C}^{-2}$

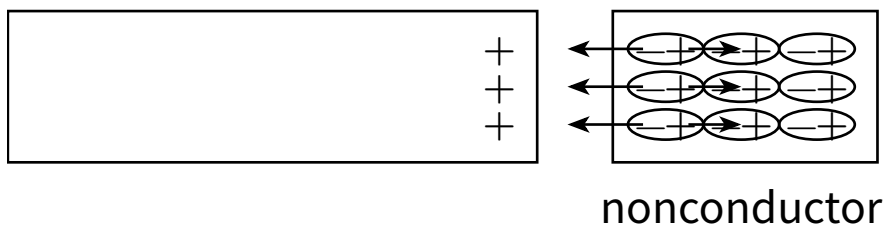
1.4 Electrostatic Induction

- **Conductor** - Substances which can conduct electricity.
ex) metal, carbon
- **Nonconductor** - Substances which cannot conduct electricity.
- **Semiconductor** - Substances which have middle electric resistance between conductor and nonconductor.

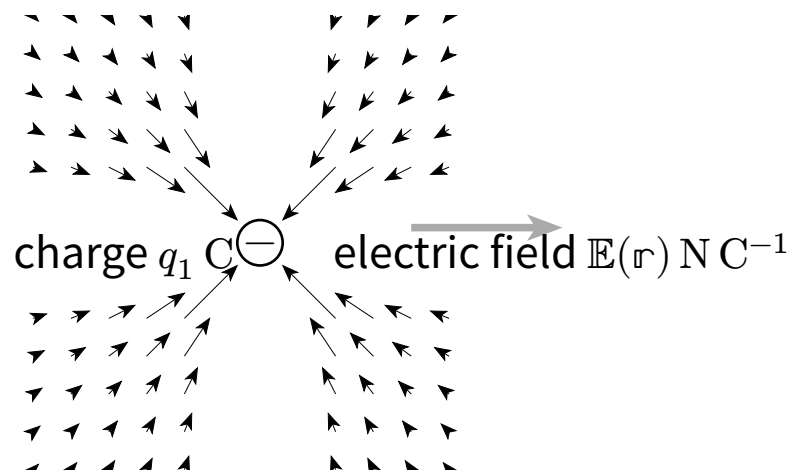
- induction



- Dielectric Polarization



1.5 Electric Field



Electric field is vector field.

Let 1 C charge be a test charge at position \mathbf{r} , $\mathbb{E}(\mathbf{r})$ is the electric force which the test charge receive.

$$\mathbb{E}(\mathbf{r}) = kQ \frac{\mathbf{r}}{|\mathbf{r}|^3} \quad (3)$$

If there are multiple charges, the electric field is equals to sum of each electric fields made by these charges.

1.6 Electric line of force

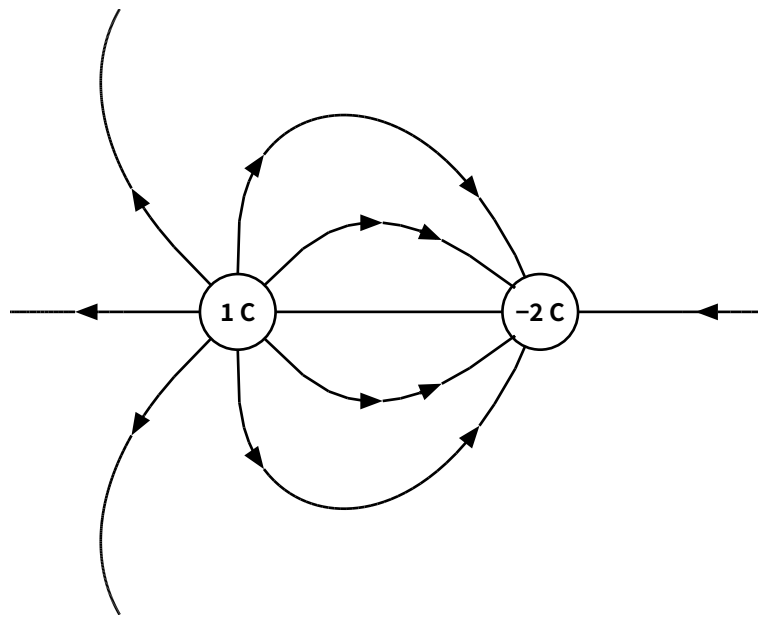
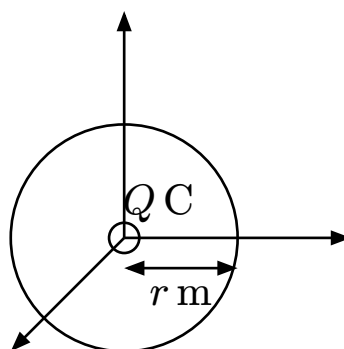


Figure 1: simulator

(it was difficult to draw the figure...)

- the direction of tangent of line is the same as the direction of the field's vector.
- the line appears with plus charge and disappear with minus charge.
- E lines drawn per 1 m^2 , as strength of electric field is $E \text{ N C}^{-1}$.



Let N be number of lines, Q amount of charge.

$$N = E \cdot 4\pi r^2 = k \frac{Q}{r^2} \cdot 4\pi r^2$$

Thus,

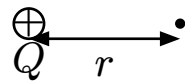
$$N = 4\pi kQ \quad (4)$$

1.7 Electric Potential

Let U potential energy of charge which have q , V electric potential,

$$V := \frac{U}{q} \quad (5)$$

Thus, V is potential energy per unit charge.



Let infinity be reference level of potential,

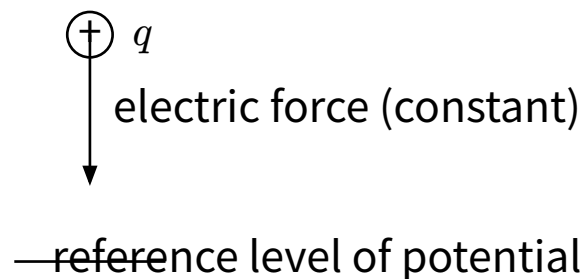
$$V(r) = \int_r^\infty dr \cdot k \frac{Q}{r^2} = kQ [-r^{-1}]_r^\infty = k \frac{Q}{r}$$

$$V(r) = k \frac{Q}{r} \quad (6)$$



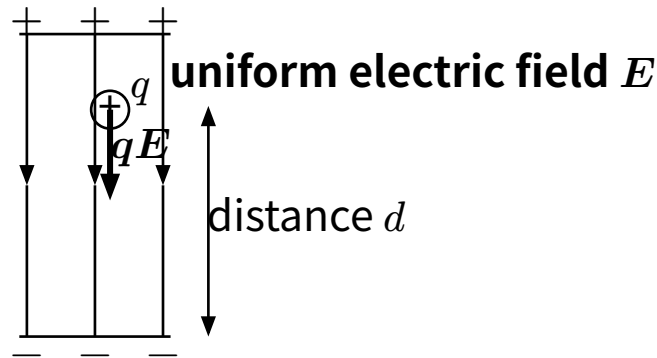
$$V_{AB} = V_A - V_B \text{ (reference is } B)$$

V_{AB} is also called **voltage** $[\text{ML}^2\text{T}^{-3}\text{I}^{-1}]$.



$$W_{AB} = q(V_A - V_B) \quad (7)$$

1.8 Relative of Field and Potential



$$qEd = qV \quad (8)$$

$$\Leftrightarrow V = Ed$$

electric potential is proportional to energy, so it's superposition is calculated by sum.

1.9 Equipotential Surface

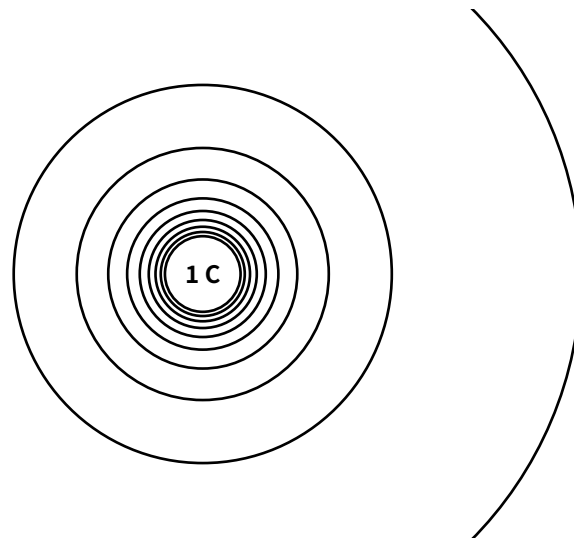


Figure 2: simulator

– **Equipotential Surface** - A surface which was made by joining points that have equal electric potential.

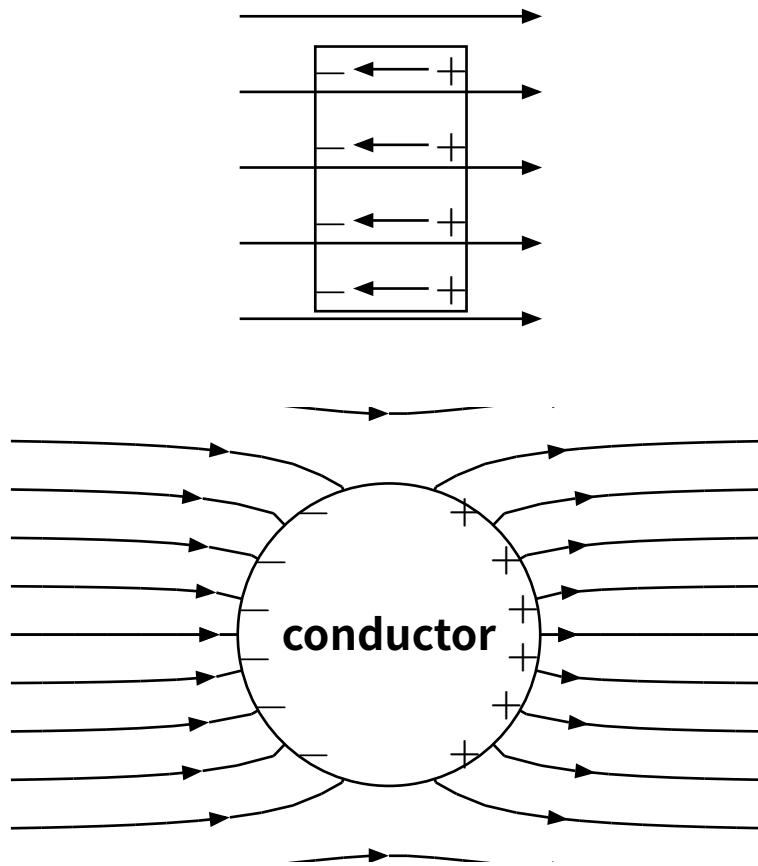
equipotential surface is perpendicular to electric line of force.

(if test charge move with a direction perpendicular to electric force , work is $W = \mathbb{F} \cdot \Delta x = 0 \Leftrightarrow$ potential is same constantly.)

$$\frac{1}{2}mv^2 + qV = \text{const.} \quad (9)$$

1.10 Substance and Electric Field

1.10.a Conductor



In conductor, the electric field is 0. (charges continue moving while field is not 0,)

It means that electric potential is the same in metal.

- **Electric field is perpendicular to surface of metal.** (metal distorts surrounding electric field)
- **Electric charges do not appear in internal of metal.** (on surface only)

(why? is not impossible to make field 0 with it having charges in metal? そうかな…そうかも…引力と斥力があるから自動的に表面にできるかね。べつに全電荷が打ち消しに貢献する必要はなく、正負が surface に交互に並んでいればいい?)

- **Electric Shielding** - In cavities in conductor, electric field is ~ 0 . It means field in the cavity is not affected by the outside field.

(これマジでなんで??)

1.10.b Nonconductor

In nonconductor, the electric field is smaller than the outside field.
 (due to the electric field generated by dielectric polarization)

1.11 Capacitor

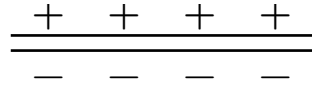


Figure 3: parallel-plate capacitor

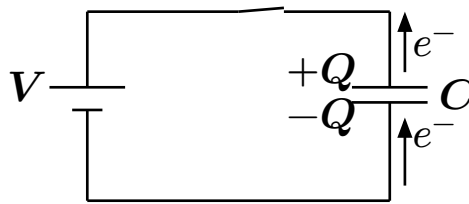


Figure 4: charging

$$C := \frac{Q}{V} \quad (10)$$

C is called **electric capacity** [$M^{-1}L^{-2}T^{-2}I^2$]

なにこに次元は…電磁気の次元解析ってけっこう魔境…? 独自文字で置いてやろうか

Parallel-plate capacitor makes uniform electric field.

It makes $4\pi kQ$ lines of electric force .

(電気力線って superposition できるの? uniform であることは積分で証明?)

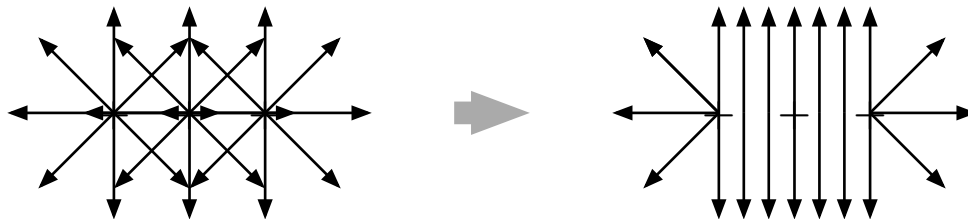


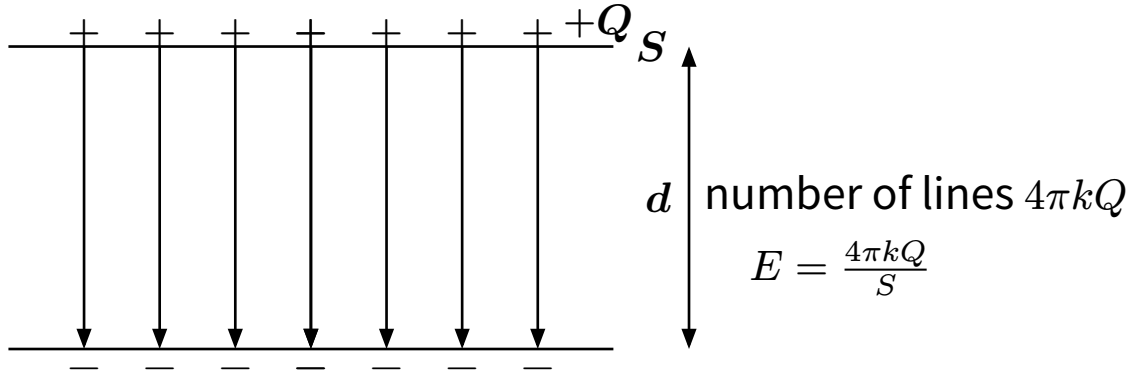
Figure 5: superposition of electric field which made by lined charges

Let

surface area of one side plate S ,

amount of electric charge Q ,

distance between plates d



$$V = Ed = \frac{4\pi kQ}{S}d$$

$$Q = \frac{1}{4\pi k} \cdot \frac{S}{d} \cdot V$$

$$\therefore C = \frac{1}{4\pi k} \cdot \frac{S}{d} \tag{11}$$

Electric capacity depends on k , S , and d .

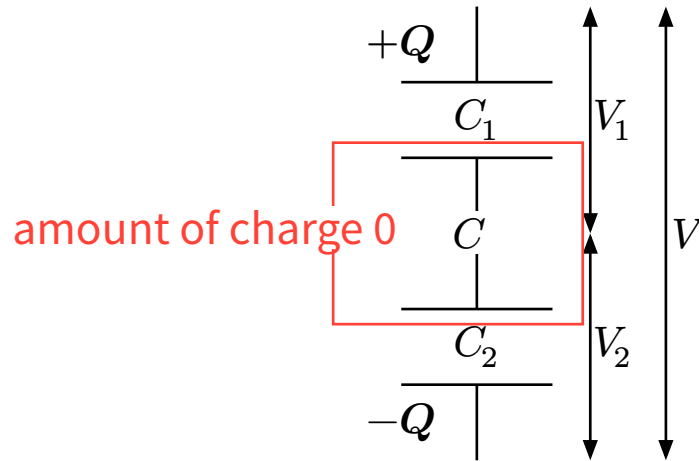
Where, let $\epsilon = \frac{1}{4\pi k}$, ϵ is called permittivity $[M^{-1}L^{-3}T^4I^2]$.

$$C = \epsilon \cdot \frac{S}{d} \tag{12}$$

In a lower permittivity substance, strength of the electric field is smaller. From $V = k \cdot \frac{Q}{r}$, even with the same voltage, the amount of charge is greater.

dielectric constant : $\epsilon_r = \frac{\epsilon}{\epsilon_0}$

1.11.a Series Connection



The amount of charge is 0, because one side plate of each is connected by the conductor.

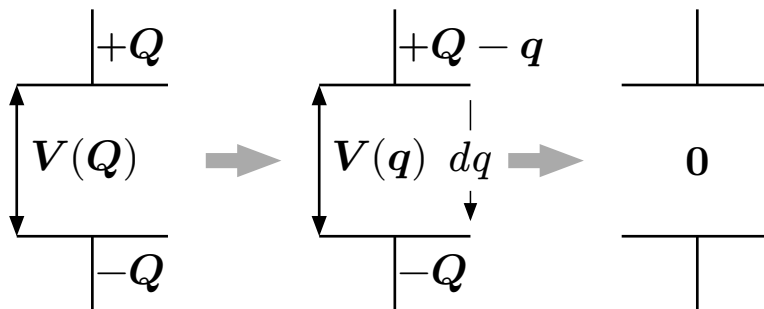
$$V = V_1 + V_2$$

$$\frac{Q}{C} = \frac{Q}{C_1} + \frac{Q}{C_2} \quad (\because V = \frac{Q}{C})$$

$$\therefore C^{-1} = C_1^{-1} + C_2^{-1} \quad (13)$$

- V is proportional to C^{-1}

1.11.b Energy of capacitor



$$V(q) = \frac{q}{C}$$

$$W = \int_0^Q dq \cdot V(q) = \int_0^Q dq \cdot \frac{q}{C} = \frac{1}{2} \frac{Q^2}{C} = \frac{1}{2} QV \quad (14)$$

$$\therefore W = \frac{1}{2} QV \quad (15)$$

**The work which battery has done : $W = QV$. ($V = \text{const.}$) Therefore
Work: $\frac{1}{2}QV$ is wasted.**

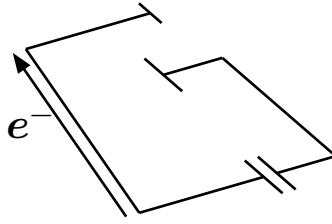


Figure 6: The start of charging

2 *Electric Current*

2.1 Current

Electric Current[I] - A flow of charged particles.

- **Direct Current** - a current that is one-directional
- **Alternating Current** - a current that periodically reverses direction

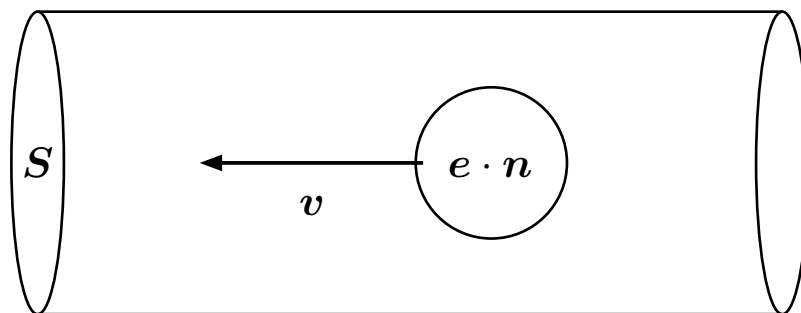
I : current (constant), Q : amount of charge, t : time

$$I := \frac{Q}{t} \quad (16)$$

$$A = C s^{-1}$$

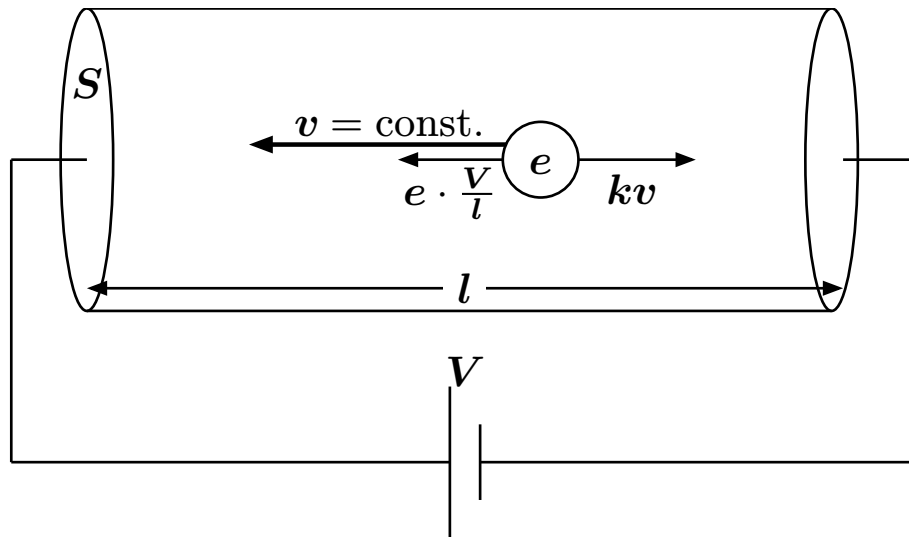
2.2 Ohm's law

Let elementary charge e , speed of charges v , number of charges per unit volume n , surface of wire S ,



$$Q = e \cdot n \cdot vt \cdot S$$

$$\therefore I = envS$$



There should be force kv ($k = \text{const.}$) which against electric force $e \cdot \frac{V}{l}$, because velocity of electron $v = \text{const.}$

※ energy が低い ≠ 安定

$$kv = e \frac{V}{l}$$

$$\Leftrightarrow v = e \frac{V}{lk} \quad (v \propto E)$$

$$\Leftrightarrow I = en \cdot e \frac{V}{lk} \cdot S \quad (\because I = envS)$$

$$\Leftrightarrow I = e^2 n \frac{S}{kl} \cdot V$$

Let $k \frac{l}{e^2 n S}$ as R ,

$$I = \frac{V}{R}$$

$$\therefore V = RI \quad (17)$$

V : a.k.a voltage dump

$$R = \frac{1}{e^2 n} \cdot \frac{l}{S} \quad \text{Let } \frac{1}{e^2 n} \text{ as } \rho,$$

$$R = \rho \frac{l}{S} \quad (18)$$

ρ is called **resistivity** and depends on substances. (resistivity of aluminium is $\sim 2.7 \cdot 10^{-8}$)

ちうがくせいのところよく分からなかったのが解消されていったのしー !!

いまさらだが保存力ってけっこう難しい。field を解析してどうなったら保存力なんだろう。位置にのみ依存することが必要条件になってはいそう。十分条件はなんなの 直感的な理解が足りていません。百足らず様がお通りになられたせいでしょうか。

Resistivity also depends on templatrue due to thermal motion.

This is related to ratio of electron's moving speed to poisitve ion's moiton speed.

constant な電圧をかけたら、抵抗値は時間発展するの？する？

$$\rho(t) \approx \rho_0 \cdot (1 + \alpha t) \quad (19)$$

ρ_0 is resistivity at $t = 0$, t is templatrue. α is called **templature coefficient of resistivity**.

たまに千石電商の服きてたらついに指摘されてちょっとうれしい。普通のこの服はデザインセンスがあると思う。高いだけある

2.3 Joule heat

W : generating heat by current - **Joule heat**

$$W = QV = IVt \quad (20)$$

– **Electrical Energy** [MLT^{-2}] (電力量) - Work which is done by current(charge)

– **Electrical Power** [MLT^{-3}] (電力) - work per unit time

教員：電力量という訳はうれしくない。日本語は science に向かない。 ←それ

$$P(\text{power}) = IV = I^2 R \quad (21)$$

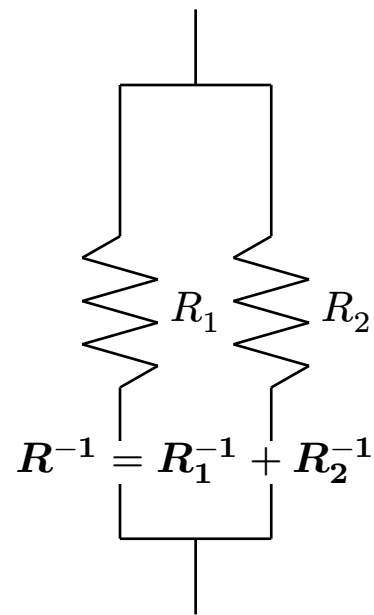
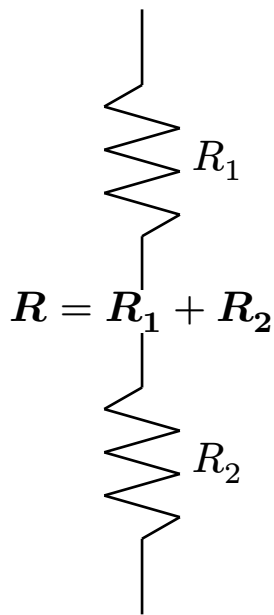
work which done by field $W = e \cdot \frac{V}{l} \cdot vt \cdot nSl = envS \cdot V \cdot t = IVt$

※ Thermal energy は、定義が“ambiguous”なため議論には使えない(使いづらい)

heat は「macroscopic な力学で説明できない energy の移動(energy transfer)」と定義されている

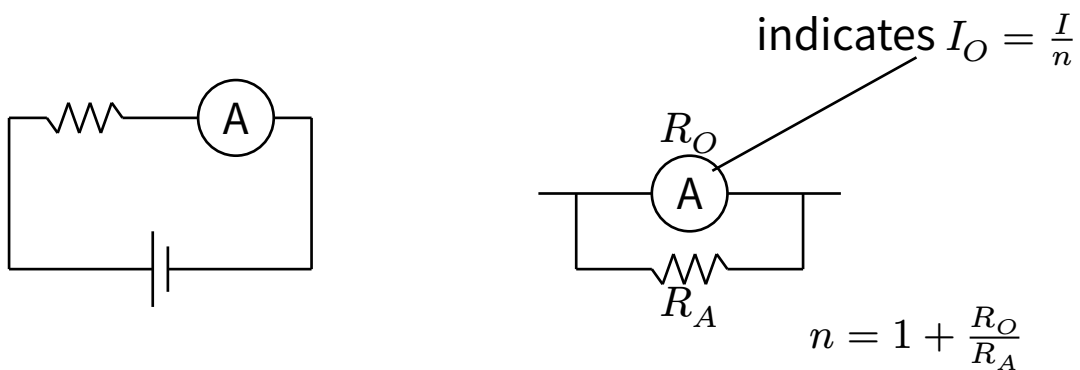
“heat が発生する”という記述ができる 高温な物体は何かしらの方法(emision など)で“heat を発生させる”から、“抵抗のある導体に電流が流れると熱が発生する。これをジュール熱と呼ぶ。”という記述ができるっぽい。「熱」って高校物理で直感的じゃない定義ナンバーワンじゃないか…？

2.4 Composite of Resistors

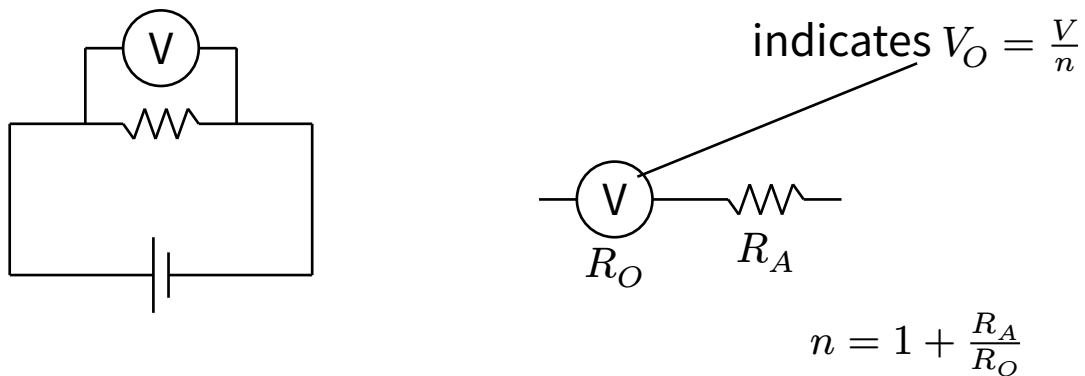


2.5 Ammeter and Voltmeter / 電流計と電圧計

2.5.a Ammeter / 電流計

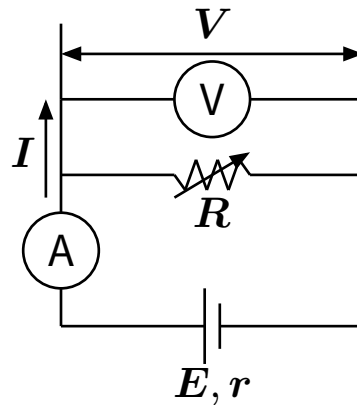


2.5.b Voltmeter / 電圧計



2.5.c How to Determine Electromotive Force

– Electromotive Force - “起電力”

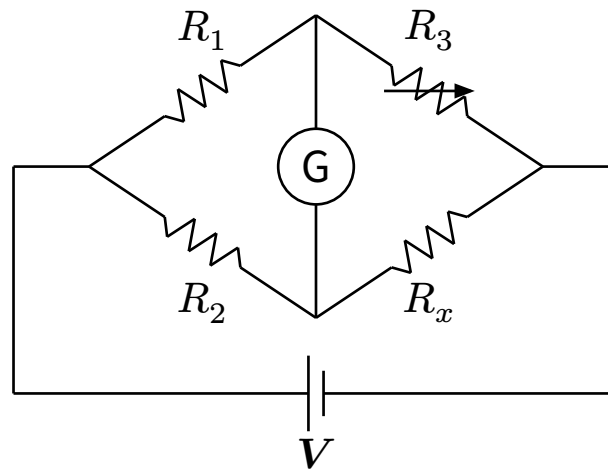


$$V = E - rI$$

Observing multiple (V, I) points, we can determine E and I .

2.5.d How to Determine Resistance

Wheatstone bridge



When current at G equals to 0,

$$R_1 I_1 = R_2 I_2$$

$$R_3 I_1 = R_x I_2$$

⇔

2.6 Charge of Capacitor

When a capacitor is connected with a battery, charge of capacitor is proportional to $\exp(-\frac{t}{RC})$ (R is resistance of circuit, C is capacity)

3 Semiconductor

- **Intrinsic Semiconductor** 真性半導体 - Simple substance of Si or Ge. In low temperature, they cannot conduct electron. In high temperature, They can conduct electron.
- **Extrinsic Semiconductor** 不純物半導体 - Substance which have trace amount of P or Al in Si or Ge.

- **n-type semiconductor** (negative)

P have 4 + 1 electrons on outermost shell.

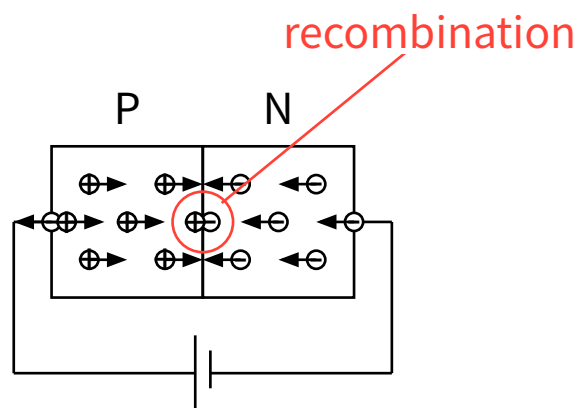
⇒ They have extra electrons.

- **p-type semiconductor** (positive)

Al have 4 - 1 electrons on outermost shell.

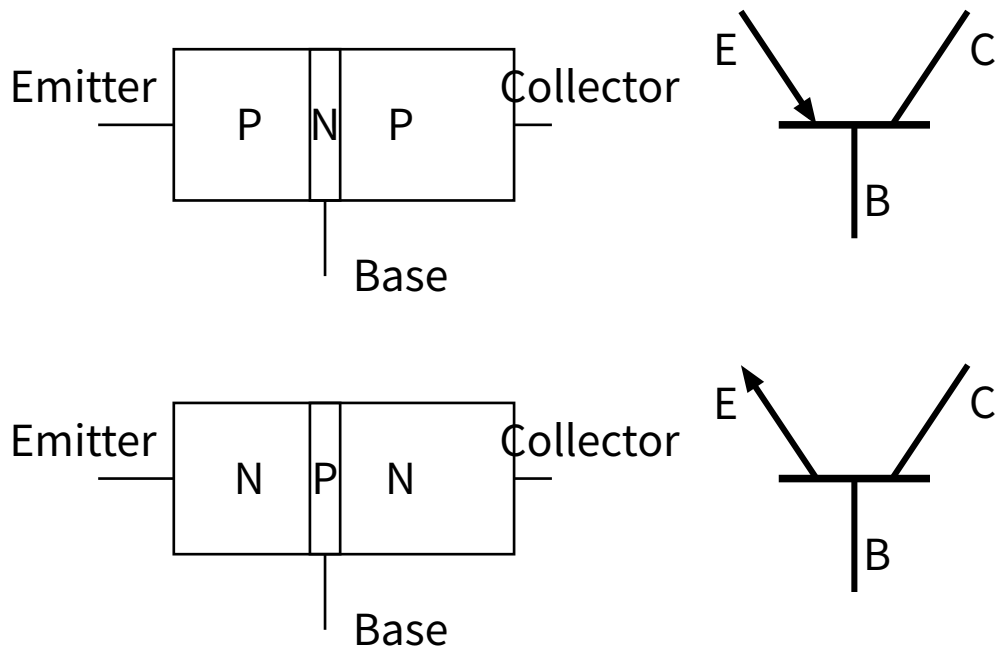
⇒ They have hole of electrons (positive hole). (なんでこれ共有結合できるの?の??
オクテッドソクみたさなひ)

3.1 P-N Junction / Diode



3.2 Transistor

3.2.a P-N-P Transistor



– Base semiconductor is very thin.

(なんでこれスイッチングできる?? difficult)