GE1305 Foundation Physics - Notes

1. Force motion and gravity

Chapter 1 PDF

Definition of Physical Phenomenon (P5)

One quantity changes due to another quantity change

Definition of motion (P15)

> change of **position** of an object with **time**.

where:

- t-independent
- x-dependent

Velocity

> $v = \frac{\Delta x}{\Delta t}$

Position time graph ($x - t$)

Slope(斜率) = velocity

Newton's First Law: Inertia 慣性 (P11)

> an object will continues its motion of constant velocity or remain at rest if it is not under any force.

Newton's Second Law: Acceleration (P18)

> Force $\propto$ Acceleration
>
> $F = ma$

> $a = \frac{\Delta v}{\Delta t}$

Mass

Larger mass, less acceleration

Velocity time graph ($v-t$) graph

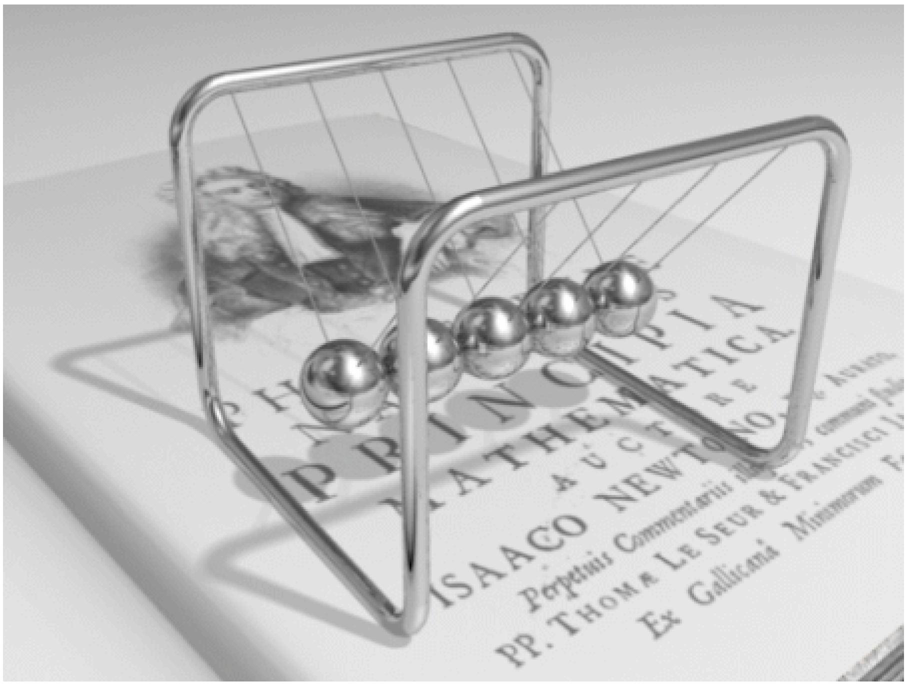
Slope = acceleration

Newton's Second law: Momentum 动量 (P36)

> Force = **rate of change**(Slope) of momentum
>
> $$F = ma = m\frac{\Delta v}{\Delta t} = m\frac{V_f - V_i}{\Delta t}$$

- No external forces,
- between gas and rocket there are **internal force**
- momentum(gas) backward
- momentum(rocket) forward

Example: Newton’s Cradle



Conservation (守恒) of momentum

Example: Gun recoil 子弹反冲

1st Recoil

- Bullet forward, the gun backward
- Bullet go against air, friction heat the air

2nd Recoil

- When bullet leave the gun
- air is suddenly released forward
- gun is heavily pushed back

What affects the recoil

- Heavier gun, less recoil
- Heavier bullet, higher speed, more recoil

Example: Car Crash

View: First law (P9)

- The car suddenly stopped moving forward
- The driver not, due to **inertia**
- The driver bump into wind screen, and crash with it

View: Second law (P21)

- The car deaccelerate fast upon crash
- So the force is immense
- Higher speed, larger force
- The force is applied when driver hit wind screen
- lower speed is safer

How to keep safe (P23)

- **Seat belt**: move with the car, provide you a **stopping** force
- the seat belt is long, to distribute the force
- **Air bag**: when bumped, stop your head motion
- air bag decreases the deacceleration
- **Bumper**: soft, when deformed (can be damaged), slow the car and reduce the force

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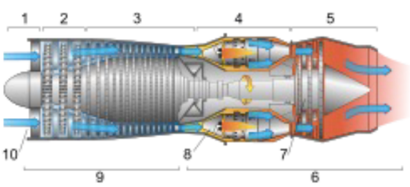
Newton's Third Law: Reaction 反作用力 (P25)

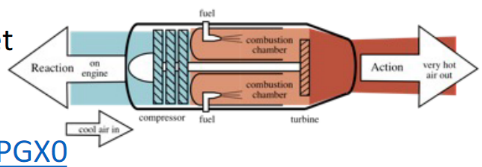
> When you exert a force on an object, the object exerts a force on you.

- a **pair** of forces
- are **equal and opposite** to each other

Example: Jet propulsion 飞机推进 (P33)

- The Newton's third law can be used to explain the principle of jet propulsion and rocket propulsion
- Gas is heated in the jet engine
- Gas expand and escape through the outlet
- The gas pushes itself out by expansion
- At the same time the gas push on the engine or the rocket
- The push by the gas push the engine or rocket forward.
- How jet engine works: https://www.youtube.com/watch?v=KjiUUJdPGX0



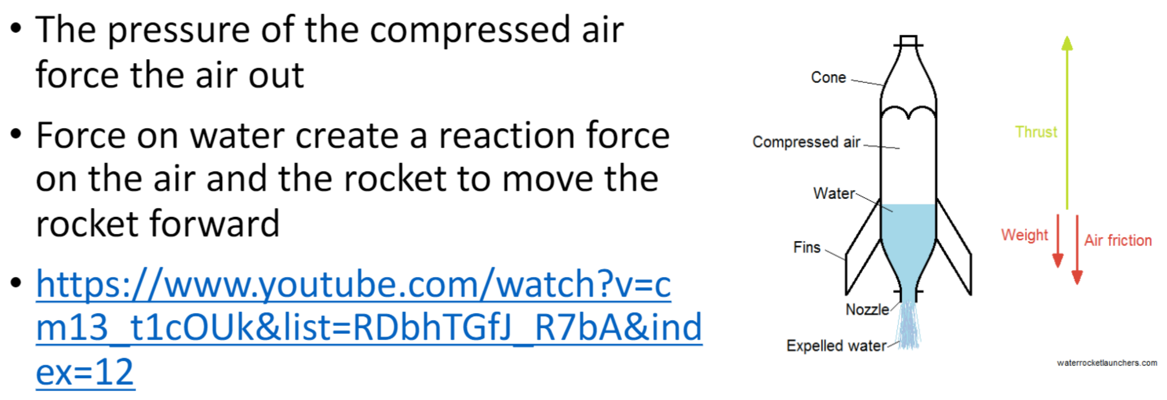


- **Forward**: Engine is pushed by the reaction
- **Backward**: Heated air expands, getting backward and have a action

Example: Rocket engine

Similar to Jet, but use liquid oxygen to provide stronger force

Example: Water rocket



Newton's Third Law: Friction (P27)

> Friction, when two surfaces **want to move relative** each other, friction forces exists. The strength of the friction force depends on the nature of the surfaces

Example: Walking

> - When you push against the ground, you try to move your foot's surface relative to the ground's surface
> - A friction force is created between the two **surface**
> - The friction force from your foot push the ground (backward)
> - The friction force from the ground push your foot and you (forward)
> - So you are pushed forward by the friction force from the ground
> - The acceleration you experienced depends on the friction force between your foot and the ground

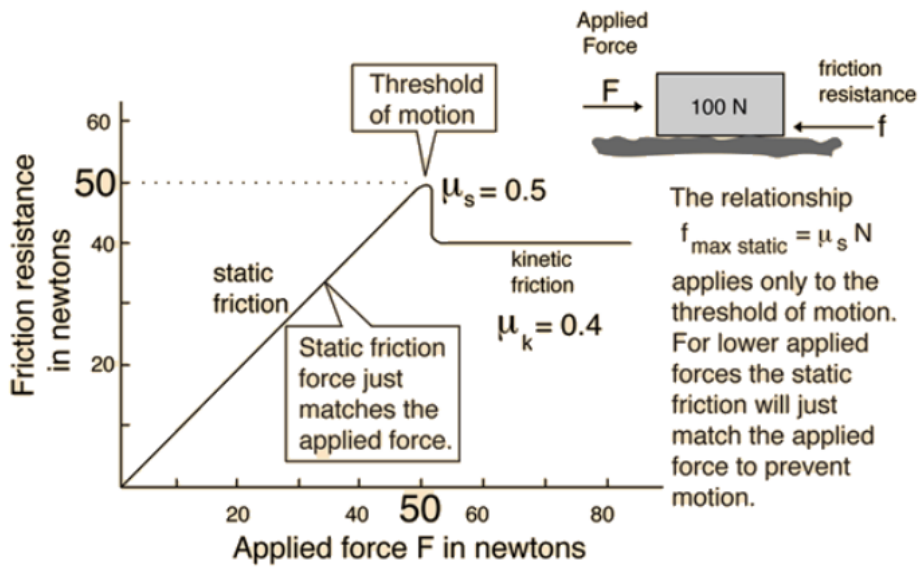
Example: Running Shoes

- Higher friction force can give you higher acceleration
- surface of a running shoes should **increase the friction** between the surface and the ground

Example: Slippery

- low friction
- wet surface is slippery, because **water reduce friction**
- add **sand increase friction**

Static and Kinetic Friction 静摩擦 弹性摩擦



> static = applied force
>
> kinetic = constant

Rotation Motion (P38)

- Position: θ
- **angular velocity**: $\omega = \frac{\Delta\theta}{\Delta t}$

Centripetal Force 向心力

- Prevent the object from moving in a straight direction
- Moving the object to the direction towards the center
- Using a string tied to the object to provide the centripetal force
- **required** centripetal force: may not equal to actual force provided

$$F = m\omega^2 r$$

Centrifugal Force 离心力

- **DOES NOT EXIST**
- appear to draw the object even further from the center of the roration

Example: Centrifuge 离心机

- The tube and liquid move in uniform circular motion (匀速圆周运动)
- The liquid do not provide enough centripetal force for particle (centrifugal > centripetal)
- **particle** move straight, going down because they are subject to gravity
- particle finally gather at the bottom of the tube

Example: Spin dry in washing machine

- While fabric rotates, the water is not held tight
- Inadequate centripetal force make the water go straight into the drum (筒壁)

Example: Car skid on Ice / Oil

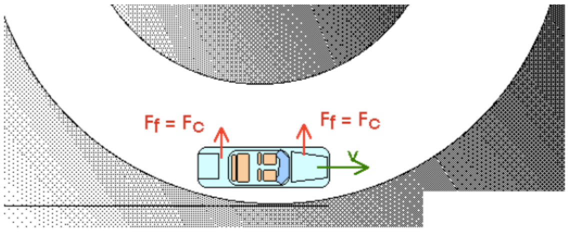
- **friction** serves as the centripetal force
- $F_f = \mu N$ if μ too small, makes friction inadequate
- The car skids, going at its current velocity direction

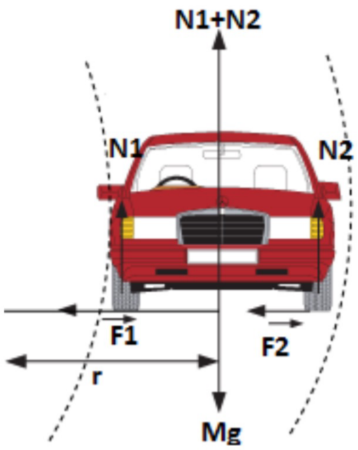
Torque 力矩 (P49)

- $\vec{\tau} = \vec{r} \times \vec{F}$, r is moment arm
- larger the r is, easier for a constant force F to have a rotation effect
- example: exert force at two different points of a pencil make it rotates

Example: Roll Over

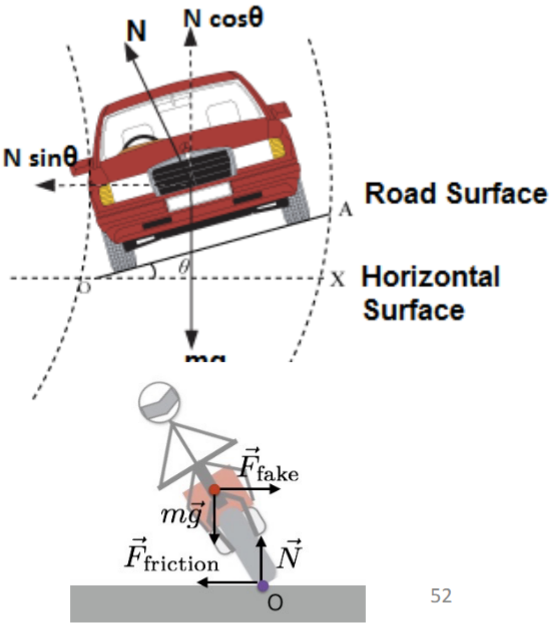
- When going through a turn, F_f also creates a torque
- When the torque is large enough, a rotation effect **in the direction towards center** roll the vehicle over
- Bus, higher, has larger moment arm and are easier to roll over





Example: Sloping race Track 斜坡

- Track's force has a component $N_x = N \sin\theta$ provides centripetal force
- subtorque of track's normal force N **cancel** the torque of F_f
- N_x reduce the F_f required and thus reduce the torque of F_f
- This allows higher speed without tip over



Example: Motorcyclists in a Bend 摩托车过弯

[Reference Blog]

> $\vec{F}_{\text{fake}} = -m\vec{a}$, centrifugal force here, grants a temporary equilibrium
>
> **Equilibrium** means $\sum \vec{F} = 0$ but not that $\sum \vec{\tau} = 0$
>
> nonzero $\vec{\tau}$ can change ω.
>
> In the figure above, $\sum \vec{\tau} = 0$, because all moment arm is 0
>
> Another explanation:
>
> considering the **center of mass** in red
>
> torque of friction makes it rotate **clockwise**
>
> while torque of fake force makes it rotate counterclockwise, canceling that

- friction as the centripetal force
- torque of F_f outward
- body **inward** created a normal force F **cancel** the torque of F_f

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Type of Forces (P53)

- Push and Pull: **direct contact**
- Friction
- Weight (gravitational force)
- Tension: reaction
- Normal force: reaction, **perpendicular to the surface**

> N stands for **normal force**

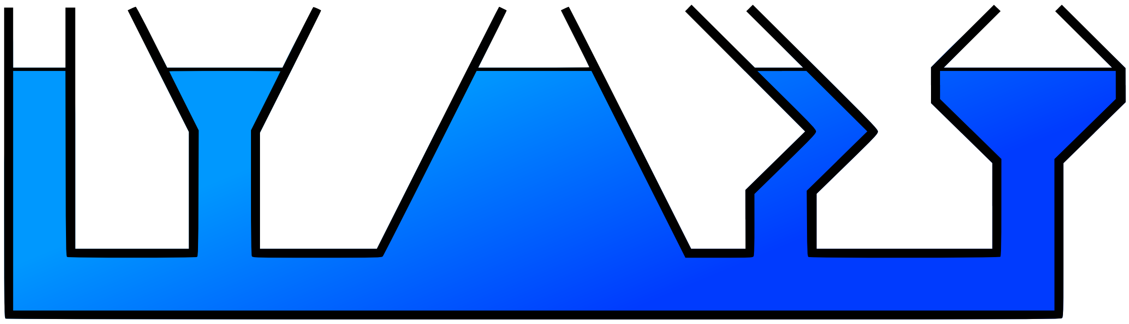
> in a **pulley** system employs tension, strings can divide the force

Gravitational Attraction (P60)

$$F = \frac{Gm_1m_2}{r^2}$$

Water Pressure (P63)

- **pressure = force / area** $p = \frac{F}{S}$
- water is under pressure of the water **above**
- lower the water level, higher the depth above and higher the water pressure



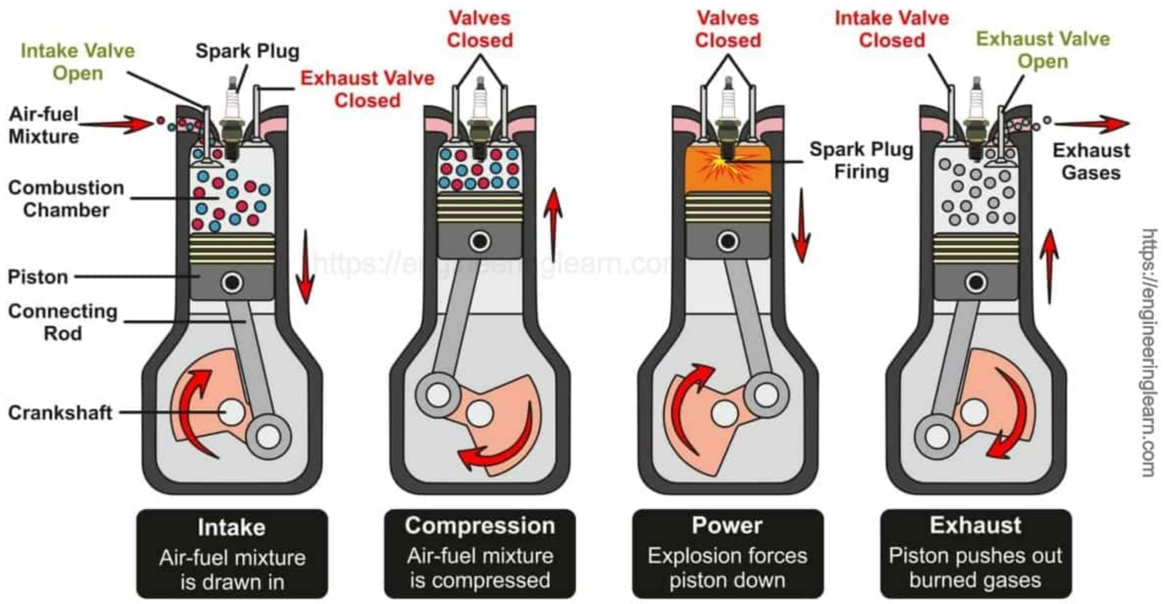
Diver's Disease

- Deep water have high pressure
- more nitrogen **dissolves** in water **under high pressure**
- lungs have higher pressure than blood so nitrogen **get into blood**
- when suddenly go up, nitrogen cannot get out from lungs and will form bubbles in blood
- go up slowly solve this problem

Work and Energy (P66)

- $W = Fd\cos\theta$
- when $F \perp d$ the work is 0
- moving item have **kinetic energy** (动能)

Four stroke cycle engine



Wave Motion (P72)

- **Longitudinal Wave** 纵波: like coils
  - $\vec{v}_{\text{particle}} \parallel \vec{v}_{\text{wave}}$
  - ~~Expansion~~ Compression 疏部
  - Rarefaction 密部
- **Transverse Wave** 横波： like strings
  - $\vec{v}_{\text{particle}} \perp \vec{v}_{\text{wave}}$
  - Crest 波峰
  - Trough 波谷
  - **Period**: The time a particle complete a cycle
  - **Wavelength**: The distance between successive crests / troughs

$$v = \frac{\lambda}{T} = \lambda f$$

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2. Electricity & Magnetisms

[Chapter 2.1 PDF]

Charges (P2)

Atom: Bohr's Model

- Electron (in shell of atom): -
- Proton (in nucleus): +
- Neutron (in nucleus): 0

Charging by Friction

- positive proton can't move
- negative electrons are transferred by friction
- glass: +, plastic: -

Static Electricity

- Example: Static cling 静电吸附

Example: Combing Hair

- comb get negative charges
- they **repel** the negative and **attract** the positive of the paper
- this makes the negative move farther from the comb

Example: Static Spark

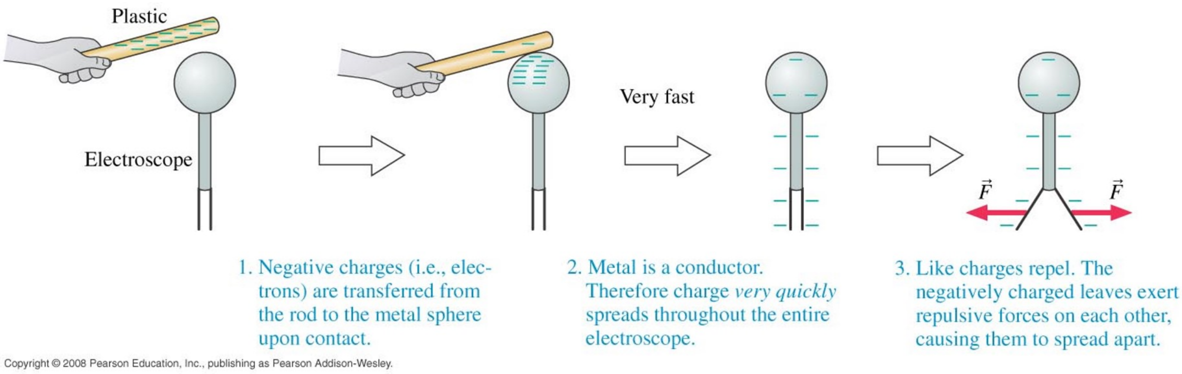
- the clothes rub against your body
- positive and negative are separated between body and clothes
- charges are **attracted**, they go through **dry air** and **combine**

Induced Charge in Metal 静电感应

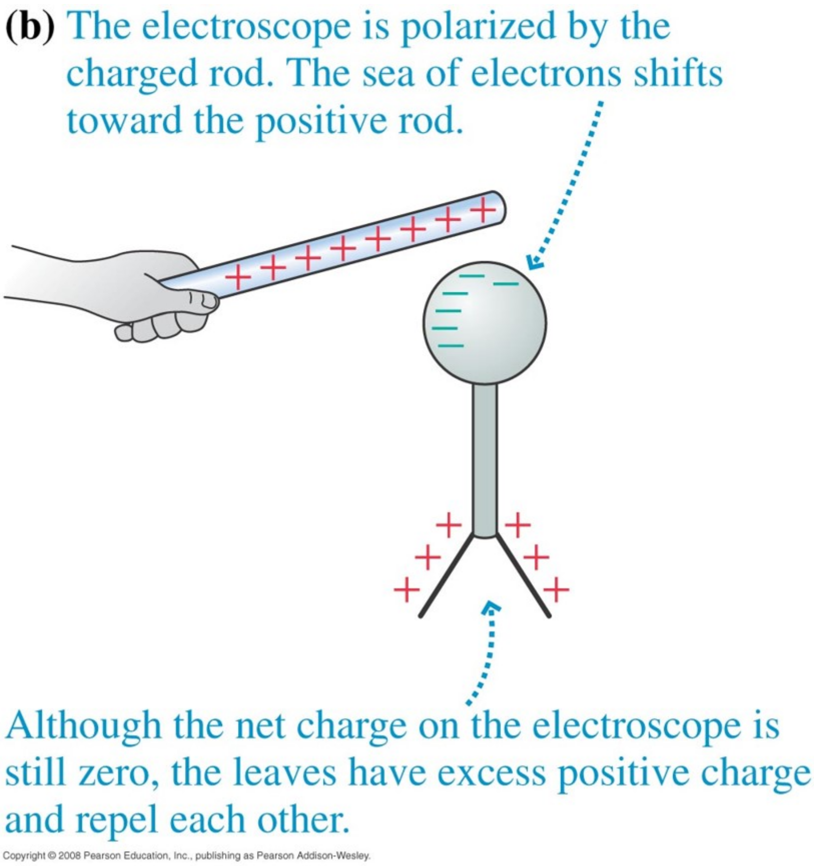
- metal is **conductor**, where charges can move freely
- paper and plastics are **insulator**, where charges can move within a limited distance
- one end of the **metal rod** will be attracted by another charged rod.
- this end get the opposite charge, while another end get the same (by transferring the electron, the + end will have less e)
- the metal rod is **polarized**, one end + and another -
- the net charge of the metal is **zero**

Electroscope

Detect by Charge Transfer (touching)



Detect by Polarization (non-touching)



Coulomb's law (P15)

Electric Force

- the forces beetween q_1 and q_2 are equal in magnitude and have the opposite direction
- q_1 and q_2 aren't in contact. This is **action at a distance**.

$$F = k\frac{|q_1 q_2|}{r^2}$$
$$k = \frac{1}{4\pi\epsilon_0} = 9 \times 10^9 \mathrm{Nm}^2\mathrm{C}^{-1}$$
$$\epsilon_0 = 8.85 \times 10^{-12} \mathrm{C}^2\mathrm{N}^{-1}\mathrm{m}^{-2}$$
$$k \gg G = 6.67 \times 10^{-11} \mathrm{m}^3\mathrm{kg}^{-1}\mathrm{s}^{-2}$$

Electric Field

- q_2 is in the electric field q_1 sets up
- assume a test charge $q_0 > 0$ in the field
- $\vec{E} = \frac{\vec{F}}{q_0}$ **defines** $\vec{E}$ as a vector, its direction same as the force that test charge experiences

Electric Field Lines

- **imaginary**, visualize electric fields
- **in three dimensions**
- originate on the (imaginary distant) positive charges, extending to the negative charge
- electric field direction **tangent to the field line**
- **higher density means stronger field**
- between + and +: they repel each other, all lines arrowing out
- between + and -: they attract each other, some lines from + to -

Potential Energy and Voltage (P26)

Definition

- **stored energy of position**
- called potential because it **can do work**: when position changes, it can be converted to other forms like E_k
- called potential because it **don't do work** at current form

Definition: Electric Potential Energy

- 2 charges have force between each other
- they can move each other
- $Fs = W = E$, so electric field possesses potential energy
- + charge: positive plate, high E_p
- - charge: negative plate, high E_p
  - - charge are automatically attracted to positive plate. This consumes potential energy and adds to E_k

Formula: Electric Potential Energy

$$U = k\frac{q_1 q_2}{r}$$
$$V = \frac{U}{q_1} = k\frac{q_2}{r}$$

- this **defines** V about the field of q_2 and irrelevant to q_1.
- when $r \to \inf$, $U \to 0$
- positive means repel, negative means attract
- example: move $q_1 < 0$ from $\inf$ distance closer to $q_2 < 0$.
  - $U > 0$ so they repel
  - $r \downarrow,\ U \uparrow$
  - potential energy lose, equal E_k gain

Electric Potential Difference 电势差

$$\Delta V = V_f - V_i = \frac{U_f - U_i}{q} = \frac{\Delta U}{q} = -\frac{W}{q} = \frac{W_{\text{external}}}{q}$$
$$\Delta U = -W = W_{\text{external}} = q\left(V_f - V_i\right) = q\Delta V$$

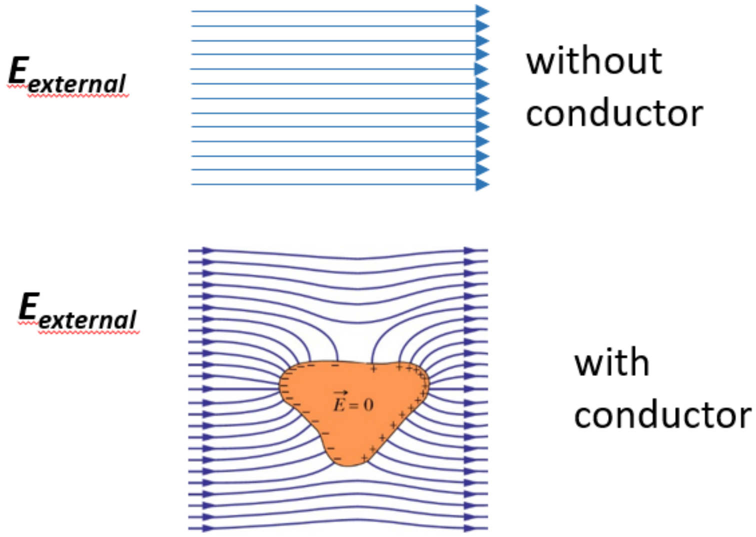
Equipotential Surfaces 等势面

- equipotential surfaces always $\perp$ field lines, thus always $\perp$ $\vec{E}$
- in a **uniform** electric field:
  - $\vec{E} \perp$ the surface
  - field lines are evenly spaced and parallel
  - thus equipotential surfaces **parallel** to the surface

Examples

Shielding Effect of a Conducting Shell 静电屏蔽

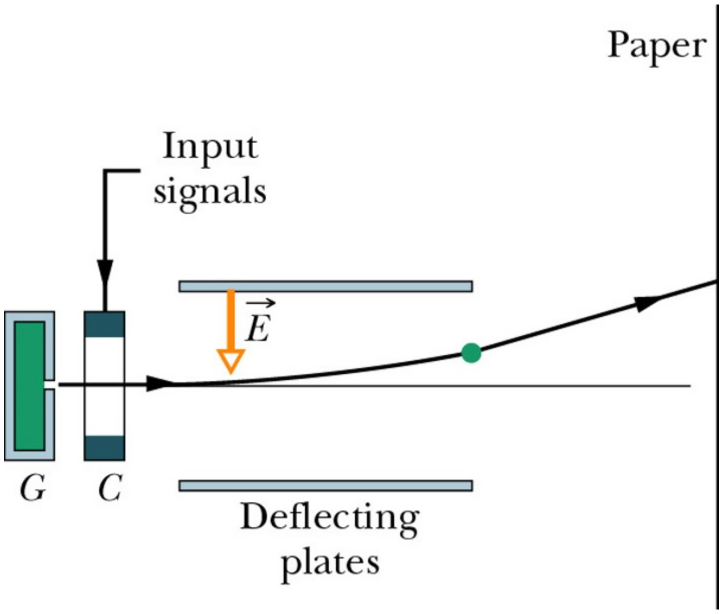
- a uncharged **conductor** expose in an external electric field
- the charges on the conductor become one end + and the other - (in the picture below, left - and right +, corresponds with the tendency of the external field lines)
- **net electric field** inside conductor is zero



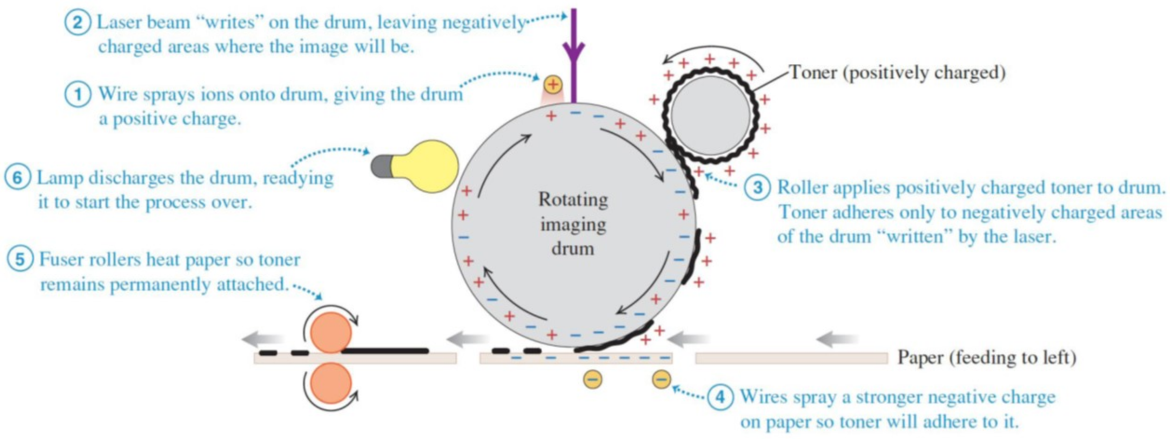
Charging by Cloud

- sharper the surface is, denser the equipotential surfaces are
- with a highly charged cloud overhead
- your head has electric field **pointing out to cloud**
- electrons are conducted down through the body
- hair strands will be positively charged

Ink-jet Printing



Laser Printing



C, I and R (P37)

Capacitor

- **two isolated conductor**, regardless of shapes
- when capacitor is **charged**, two conductor(**plate**) have equal but **opposite** charges($+q, -q$).

Parallel Plate Capacitor

- two plates of Area A separated by a distance d
- the electric field between two plates is **uniform**, parallel and evenly spaced

Capacitance

- $C = \frac{q}{V}$ defines C
  - thus $q = CV$
- C depends only on **geometry** of the plates, irrelevant of their charge and potential difference.
- Capacitors with higher C require more q to charge with a constant voltage
- two plates have different potential thus **different potential energy**
- when charges go from one plate to another, the potential energy is released
- charges do not go directly from plate to plate

Examples: Flash Camera

- energy release from the capacitor is very fast
- so flash is bright for very short moment

Battery

- $V = \frac{\text{Energy}}{q}$
- High potential (+ end), low potential (- end)
- **potential difference** V is supported by **chemical energy**
- positive charge flow from + to - and carries energy

Electric Current

- add battery to a electric circular **creates a electric field** and cause charges to move in the loop
- Direction of **current flow** is against the electron flow (as in metal)
- $I = \frac{q}{t}$
- in one conductor I is the same, regardless of the seeing/cutting plane

Ohm's Law

$$\begin{aligned} \because I &\propto V \\ I &\propto \frac{1}{R} \\ \therefore V &= IR \end{aligned}$$

Chapter 2.2 PDF

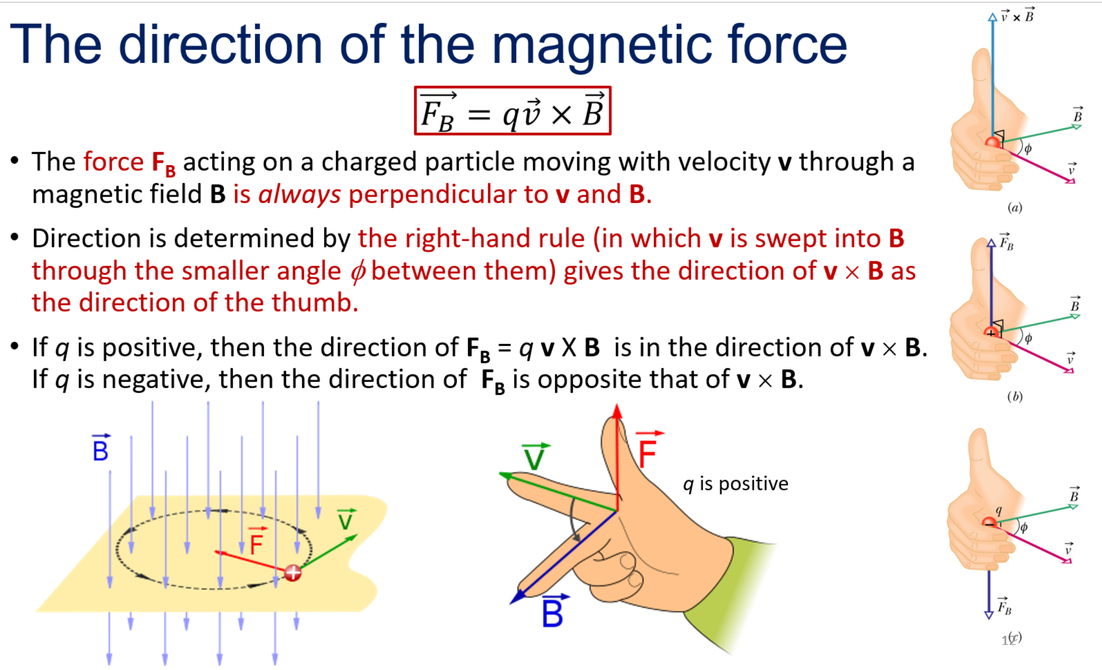
Magnetic Dipole (P3)

- N and S
- must exist at the same time

Magnetic Field (P6)

- $\vec{F_B} = q\vec{v} \times \vec{B}$ as a vector.
- Unit: $1T = 1N \cdot A^{-1} \cdot m^{-1}$

> - $\vec{F} \perp$ the plane defined by $\vec{v}$ and $\vec{B}$.
> - If $\vec{v} \times \vec{B} = 0$, there is no $\vec{F_B}$. This can be cause by:
>   - $\vec{v} = 0$
>   - $\vec{v}\vec{B} = |\vec{v}||\vec{B}| \sin 0°$, **move along the direction of B**



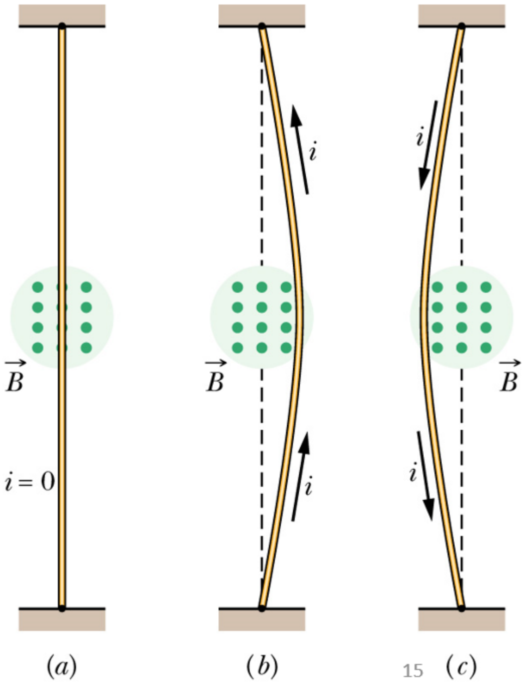
Magnetic Field Line

- magnetic field lines are closed loops from N to S
- electric field lines can go to infinity
- direction of $\vec{B}$ is tangent to field line at that point
- **density** of lines represents the magnitude
- Rounding a Vertical Current, Iron filings (铁屑) are aligned in circles and they show field lines

Torque (P9)

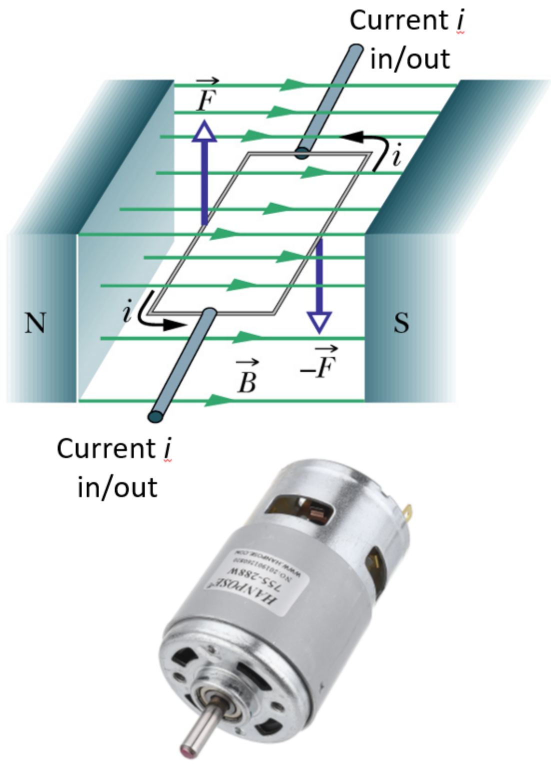
- Magnetic field exerts a torque on a magnet, $\vec{\tau} = \vec{F} \times \vec{d}$
- **N pole towards the direction**
- Example: Compass

Current in the Magnetic Field



> - `x` means the Field is into the paper
> - `·` means the Field is out of the paper
> - In figure(b), $\vec{B}$ is Outing, $\vec{v}$ is $\uparrow$, So $\vec{F} = q\vec{v} \times \vec{B} = \rightarrow$
> - Imagine there is a wire right to the current wire (call it wire0) and its $\vec{v}$ is also $\uparrow$. It creates a $\cdot$ field on its left (= at wire0's place) and these two wires attracted each other (due to the same direction). So wire0 is drawn right.

Example: Electric Motor



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> - The left wire: $\vec{B}$ is $\rightarrow$, $\vec{v}$ is Outing, So $\vec{F} = q\vec{v} \times \vec{B} = \uparrow$
> - A Commutator reverse the direction of I every 180° so the torque always act in the same direction (left up right down)

I Generate B (P17)

- $B = \frac{\mu_o I}{2\pi r}$
- B field is a **closed loop** around I
- Use right hand (figure omitted), thumb is I, other fingers are B

Example: Solenoid 螺线管

- A long coil of wire with many turns
- **Inside solenoid, B is nearly uniform**
- **Electromagnet**
- More turns or **a ferromagnetic iron inside** makes B stronger

Example: Between Parallel Currents

- Given: parallel currents i_a, i_b, separated by distance d
- i_b is in B_a created by a
- **parallel currents attract, antiparallel repel**

$$\begin{aligned}
B_a &= \frac{\mu_0 i_a}{2\pi d} \\
\vec{F}_b &= i_b \vec{L} \times \vec{B}_a \\
F_b &= i_b L B_a \sin 90^\circ = \frac{\mu_0 L i_a i_b}{2\pi d}
\end{aligned}$$

Magnetic Properties (P20)

In micro

- electron acts like a small magnet (due to its motion's current)
- If electron are **orderly aligned**, they produce a magnetic field
- a bar ferromagnet is created by application of an external field

Diamagnetism 抗磁性

- repel the external field
- the weakest magnetism
- all materials have
- **not a permanent magnet**

Paramagnetism 顺磁性

- attract the external field

Ferromagnetism 铁磁性

- Strongest, found in Iron Cobalt Nickel
- Used in data storage
- Atom show **magnetic moments**
- In a **magnetic domain** all atoms are aligned in the same direction
- Without external field, different domains randomly aligned
- With external field, **all domains align with the field**
- **hard magnet**: **walls between domains** hard to move -> permanent magnet
- **soft magnet**: easy to move -> electromagnet

More

Earth Magnetic Field (P36)

- Magnetic North Pole = **Magnet South** is near North Pole
- **magnetic declination** (地磁偏角)
- magnetic north pole is changing everyday
- reverse about every million years

Magnetic Induction 电磁感应 (P41)

- **coil creates a current when a magnet moves**
- Magnetic flux (磁通量) = area * magnetic field (**perpndicular to the coil**), $\phi = B \cdot A \cos \theta$
- induced current (感应电流) depends on **the change of flux over time**
- magnetic flux can also be changed by area:
  - moving rod between two parallel lines in a magnetic field converts E_K to E_e
- can generate current from rotation (power generator)

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3. Energy and Power

Chapter 3.1 PDF

Energy Types

Kinetic Energy

- $E_k = \frac{1}{2}mv^2$
- **Stationary** objects have no KE

Electric Potential Energy

- $U = k\frac{q_1q_2}{r}, W = q_1U$

Gravitational Energy

- $E = mg\Delta h$
- Gravitational Energy in Water is used to Generate Electricity

Chemical Energy

- Oil, coal, gas
- Li-ion Battery

Energy in Sound Waves

- Higher vibration Amplitude, Bigger Sound, More Energy

Elastic Energy

- $E = \frac{1}{2}k\Delta x^2$

Heat Energy, Thermal (internal) Energy

- Thermal Energy = $\Sigma(E_p + E_k)$ for all molecules
- The **macroscopic** energy of the material is not considered.
- Nor the macroscopic potential energy
- Thermometer

Temperature

Specific heat 比熱容

- The amount of heat required to change the temperature of a material is proportional to the **mass** and to the temperature change
- $Q = mc\Delta T$, c in $\mathrm{J/kg \cdot C^\circ}$

Nuclear Energy

Nuclear Reaction

- ${}^{12}_{6}C$ = 12 nucleons = 6 protons + $12 - 6$ neutrons
- **nuclear fission**: heavy atom split
  - can use to Generate Electrical Power
  - **chain reaction**: fission produce **neutron** and cause more fission

- $^{235}U + n \rightarrow ^{91}K + ^{142}Ba + 3n + E$
- **nuclear fusion**: light atom form heavy
  - **solar fusion**: $^{2}H + ^{3}H \rightarrow ^{4}He + n + E$

Chapter 3.2 PDF

1 human-day energy $\sim 2000 \text{ kcal} \sim 8 \times 10^6 \text{ J}$

Conservation of Energy

(First Law of Thermodynamics, by James Prescott Joule)

$E_2 - E_1 = Q - W$

- Q: energy transferred in (by heat)
- W: energy transferred out (by work)
- this makes perpetual motion machines impossible

Second Law of Thermodynamics

- Cannot **completely convert heat to work**, Efficiency = Work / Heat < 1
- Cannot **transfer heat from the cooler to the hotter**

> Renewable forms of energy
>
> - solar (from solar radiation)
> - wind (from atmospheric effects)
> - ocean (from wind, motion of Moon)
> - hydro (from atmospheric effects)
> - biomass, biofuel (from photosynthesis)
> - geothermal (mostly from radioactivity)

> Non-renewable
>
> - mineral oil / petroleum / gasoline
> - gas (methane)
> - coal
> - nuclear

---

4. Wave, Light and Invisible Light

Chapter 4.1 PDF

Oscillations

- A regular periodic motion in time
- Harmonic Oscillation: $y = A\sin(\omega t), \omega = \frac{2\pi}{T}$

Wave

- A periodic motion in both space and time
- Can transport energy without transport matter

Transverse Wave

- Vibration is **perpendicular** to the propagation
- **Crests and Troughs**
- Example: light wave, water wave

Longitudinal Wave

- Vibration is **parallel** to the propagation
- **Compressions (+) and Rarefactions (-)**
- Example: sound wave

Sound Wave

- mechanical wave
- need **a material medium** - air
- sound cannot travel in vacuum, but light can
- <20Hz: Infrasound
- **>20000Hz: Ultrasound**

f, λ, v

- Frequency $f = \frac{1}{T}, T$ is Period
- Wavelength λ : crest-to-crest distance
- Speed $v = \frac{\lambda}{T}$
- Amplitude

Superposition

- Two Identical Wave
  - Constructive Interference (Same Direction)
  - Destructive Interference (Opposite Direction)
- can be from two sources (e.g. water wave)
- Example: **noise-canceling earphones**
  - play signal back **inverted (+180°)**

Standing Wave

- Two Identical Wave in Opposite cause **Standing Wave** (驻波)
- The wave form is kept same all the time
- Have different number of **nodes (zero amplitude point)**:
  - On a $2L$ length begins and ends with nodes
  - 2 node, $\lambda = 2L$
  - 3 node, $\lambda = L$
  - 4 node, $\lambda = \frac{2}{3}L$
- $f = \frac{v}{\lambda}, v = \sqrt{\frac{\tau}{\rho}}, \tau$ is tension force, ρ is linear density
  - wave travels faster under higher tension

Examples

- Guitar (ρ is large, so sound f is low)
- Pipe / Flute (Shorter pipe, shorter wavelength, higher f)
- Beats ($f_{\text{beat}} = f_1 - f_2$), in **Tuning piano**
- **Doppler Effect**
  - source move away from observer, $f' = \frac{v-v_o}{v+v_s} f$
  - source move towards observer, $f' = \frac{v+v_o}{v-v_s} f$
  - closer = higher f
- **Bow waves**: source speed > wave

Sound Intensity

- Sound intensity $\propto$ **square of amplitude**
- Unit: $\mathrm{W/m^2}$
- $\text{Loudness(dB)} = 10 \log \frac{I}{I_0}$

Sound Reflection & Absorption

- Reflective Surfaces in Concert Halls
- Absorbing Walls in Acoustical Quiet Room
- Dolphin: Use the Reflection of Ultrasound
- -> Ultrasound can be applied: **Ultrasonic radar** & Medical Use

Fourier analysis

- Break waves into **Sine Waves**

Light

- **Electromagnetic Wave**
- **No material Medium is required**
- **Visible Light** Wavelength: $380 \sim 750\ \mathrm{nm}$

Color in Human Eye

- **Screen Emit light**
- Cone cells and Rod cells on Retina
  - Rod: low light vision
  - Cone: Color vision and detail
  - R & G & B Cone cells, intake the same color
- White is mixed by equal R & G & B

Printed Color

- **Ink Absorb light**, reflecting the rest
- Cyan = -Red, Magenta = -Green, Yellow = -Blue, Black(K) = -All
- CMYK

Photography

- Evolved From **Hole to Lenses**

Chapter 4.2 PDF

Light Reflection

- Spherical Mirrors
- Parabolic Mirrors
- Will **reflect into the middle**

Antireflective Coating (P18)

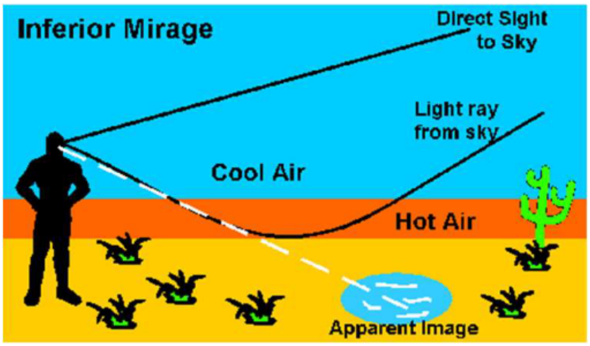
- Apply a coating of thickness $\frac{\lambda}{4}$
- **Reflected light from Top and Bottom of Coating Cancel each other**
- as the two reflected light have a distance of $\frac{\lambda}{2}$

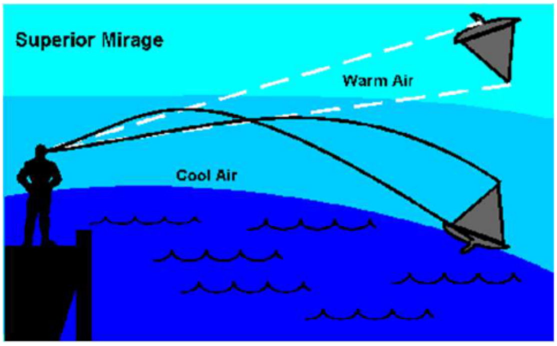
Light Refraction

- $v_{\text{light}} = \frac{c}{n}, c = 3 \times 10^8 \text{ m/s}$
- $n_{\text{water}} = 1.33, n_{\text{glass}} = 1.5$
- **Snell's law**: $n_1 \sin \theta_1 = n_2 \sin \theta_2$

Mirages 海市蜃楼

- $n_{\text{cool air}} > n_{\text{hot air}}$





Total Internal Reflection

- Only when $n_1 > n_2$, θ_2 will reach 90°
- $n_1 \sin \theta_1 = n_2 \sin 90^\circ \Rightarrow \theta_1 = \arcsin \frac{n_2}{n_1}$
- Example: Glass Fibers

Dispersion 色散

- Different colors have different refractive indices in the same material
- Example: Rainbow

Scattering 散射

- **Scatter Likelihood: Violet > ... > Red**
- Scattered by Atoms and Molecules
- **Blue light is scattered most in the sky**
- **Red light is least scattered in the sunset**

Lens

- **Converging Lens** 凸透镜
- **Diverging Lens** 凹透镜
- $\frac{1}{f} = \frac{1}{O} + \frac{1}{I}$
- Magnification (放大倍数) $M = \frac{\text{Image Size}}{\text{Object Size}} = \frac{I}{O} = \frac{f}{f-O}$
- where: I is image coordinate, O is object coordinate, f is focal length
- $I > 0$ Real Image (Opposite, Upside Down)
- $I < 0$ Virtual Image (Same side, Up)

Telescope

- Photo Resolution limited by diffraction (spreading of light)

Microscope

- Make high M lens(like $100\times$) is difficult
- Use multiple lens
- Resolution limited by diffraction

3D Movie

- Early 3D: monochrome images **projected in red and cyan**
- Recent 3D: **Polarization**. Only allow light vibrating in a particular direction

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Invisible Light

Black-body Radiation

- $\lambda_{\max} = \frac{2.90\times10^6}{T}\ \mathrm{nm}\cdot\mathrm{K}$
- **Higher temperature, Lower wavelength where radiation is max**

Color Temperature 色温

- Used in Lightning & Photography
- Only for Red->Orange->Yellow->White->Violet Colors

Solar Spectrum

- Approximately 5778K Blackbody Radiation
- UV + Visible + Infrared

Infrared Light (IR Light)

- **Infrared Bulb Low Efficiency**
- Bulb in Red color, **emit more infrared light than visible light**
- Transcendent -> Fluorescent -> LED
- **Infrared light emitted by T > 0 object**
- **Thermography**: Infrared Camera, Night Vision, Thermometer

Ultraviolet

- Largely on Blackbody > 6000K
- Wavelength: 400mm > UVA > UVB > UVC > 100mm
- UVB help **production of Vitamin-D**
- UVB cause DNA Damage lead to **Sunburn and Skin Cancer**
- can cause polymeric materials / pigment / dye damage

Application of UV

- Bacteria Killing
- **Water Purification**
- Banknotes & Passport Authentication
- UV fluorescent dyes as Bio-markers

Radio Waves (<Infrared)

- $f = 3\ \mathrm{kHz}(3 \times 10^3) \sim 300\ \mathrm{GHz}(3 \times 10^{11})$
- $\lambda = 10^5\ \mathrm{m} \sim 10^{-3}\ \mathrm{m}$
- Frequency: AM < FM < TV
- Wavelength & Distance: AM > FM

Microwaves

- $f = 300\ \mathrm{MHz}(3 \times 10^8) \sim 300\ \mathrm{GHz}$
- $\lambda = 1\ \mathrm{m} \sim 10^{-3}\ \mathrm{m}$

X-ray, γ-ray (>Ultarviolet)

Light Energy

- $E = hf = \frac{hc}{\lambda}, h = 6.63 \times 10^{-34}\ \mathrm{m^2 kgs^{-1}}$

Tutorial

- **Bluish Water due to scattering of IR**

5. Atoms, Radioactivity and Nuclear Reactions

Chapter 5 PDF

Atom

- Atom radius $\sim 10^{-10}\ \mathrm{m} = 0.1\ \mathrm{nm}$
- Atom nucleus radius $10^{-15}\ \mathrm{m}$

Atom Model

- Dalton "Billiard Ball" 实心球
- Thompson "Plum Pudding" 面包葡萄干
  - Uniform distribution of charge & mass
- **Rutherford** 原子核带正电
- **Bohr** 电子轨道
- Schrodinger "Electron Cloud" 电子云

Rutherford's Discovery

- **Mass concentrated at a tiny core**
- Proved by Rutherford **Scattering** Experiment
  - almost all $\alpha-$particles went through the gold foil
  - some $\alpha-$particles were deflected slightly
  - few $\alpha-$particles were turned through $90^\circ+$

Structure of the Nucleus

- Atom = Nucleus + Electrons
- Nucleus = Protons + Neutrons
- Neutron has a similar mass as proton and 0 charge
- Mass of a proton = 1 AMU
- **Z = Proton number**

Isotopes

- Same Protons, Different Neutrons
- Isotopes of Hydrogen
  - Deuterium (D), Tritium (T)
  - **used to make hydrogen bombs**
  - Heavy Water D_2O
- Isotopes of Uranium
  - $U-238$ is more stable than $U-235$

Fundamental Particles: Standard Model

- Proton= Up+Up+Down
- Neutron=Up+Down+Down
- Up Quark=$+\frac{2}{3}e$, Down Quark=$-\frac{1}{3}e$

Radioactive

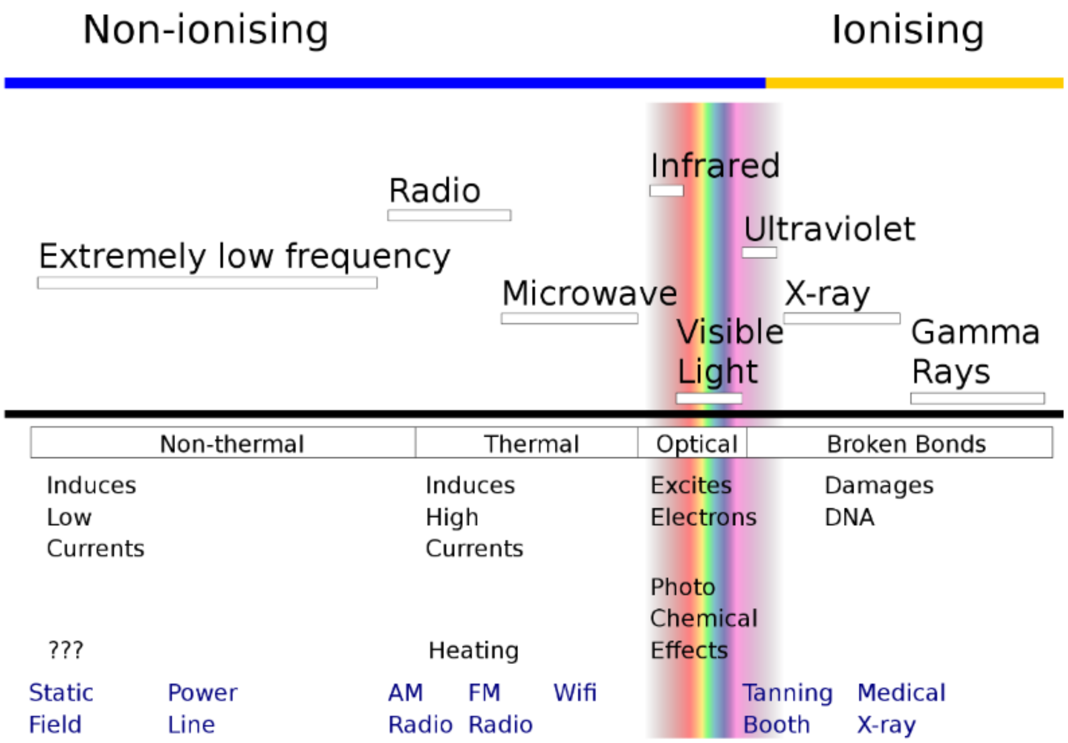
- Proton & Neutrons are held together by **Strong Nuclear Force**, one of foru basic forces
- Radioactive because of Unstable Nuclear

Raditaion

- Discovered by Antoine Henri Becquerel
- Definition: **Electromagnetic Waves or Energetic Particles**

Types

- Particle: α, β, neutron decay
- Electromagnetic (EM Wave): From radio waves, microwaves, infrared, **visible light**, UV, X-, to $\gamma-$ray
  - **Ionizing**: Part of UV, X-ray and up
  - Non-ionizing: UV and down



Natural Radiations

- Salt and Body contain $K-40$
- Air contain $Rn-86$

Radiation Unites

- **Rad** (radiation absorbed dose)
- **Rem** (Roentgen equivalent man)
- 1 Rem = 1 rad $\times$ Q, Q = Quality Factor
- 1 rem = 0.01 Sv = 10 mSv
- Dental X-ray: 0.005mSv

Radiation Penetration

- $\alpha-$particles can be blocked by paper
- $\beta-$particles can be blocked by thin Al
- $\gamma-$ and $X-$ray can be weakened by thick Pb or Fe
- Neutron beams can be weakened by water (contain H)

Radiation Application

- Therpay
- **Energy Source: Nuclear Fission** (Atomic Bomb)

Decay: Half-Life

- C-14 for dating ancient animals (Carbon Dating)

Nuclear Reaction

Chain Reaction

- $n +^{235}_{92} U \rightarrow^{93}_{36} Kr +^{141}_{56} Ba + 2n + \text{Energy}$
- **Output: 2 neutrons > Input: 1 neutron**
- Application: Nuclear Power Plants + Nuclear Weapons

Energy from Nuclear Reaction

- $E = mc^2$, **Energy come from mass loss**
- $\text{mass}\left(n +^{235}_{92} U\right) > \text{mass}\left(^{93}_{36}Kr +^{141}_{56} Ba + 2n\right)$

Nuclear Fusion

- $^2H +^3H \rightarrow^4 He + n + \text{Energy}$
- **Energy from Fusion >> Fission**
- Application: Hydrogen Bomb
- Sun's energy come from nuclear fusion

6. Modern Physics

[Chapter 6 PDF]

Quantum Physics

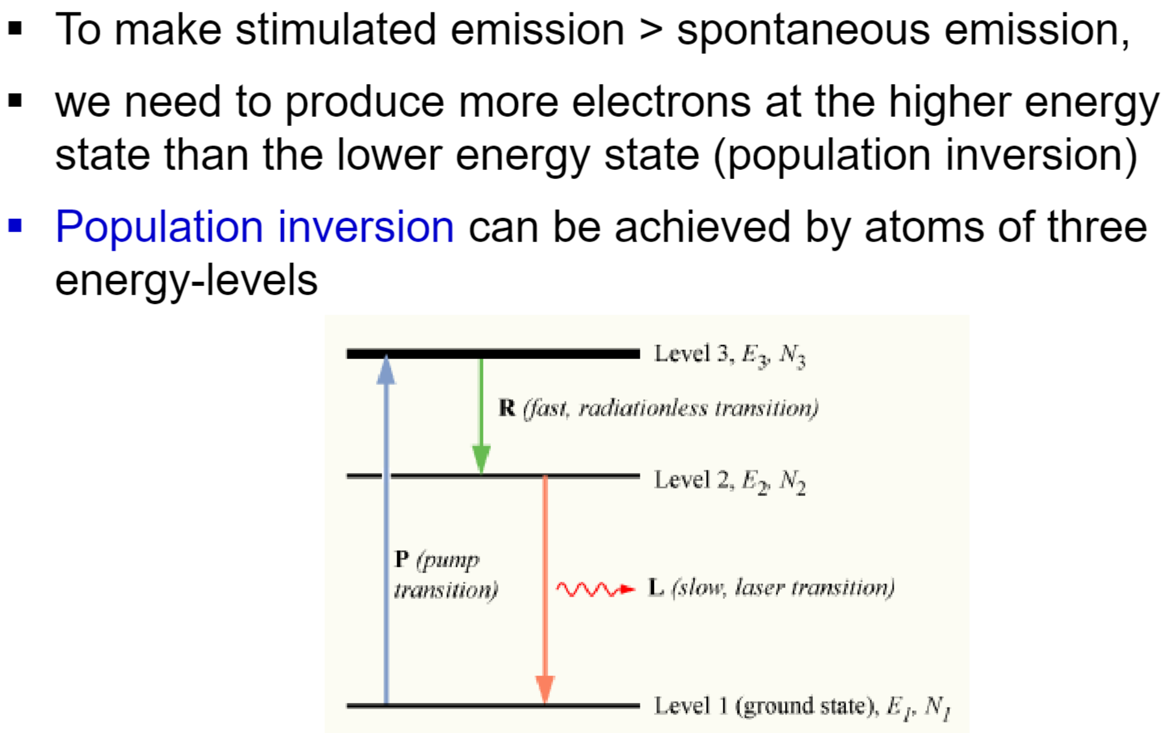
- **Energy Quantization** 能量量子化
- **Wave-Particle Duality** 波粒二象性
- **Uncertainty Principle** 不确定性原理

Energy Quantization

- Hydrogen atom energy level $KE = \frac{13.6}{n^2} eV$
- Energies of **free electrons** are not quantized

Application: Laser

- Stimulated Emission of Radiation
  - $E_2 - E_1 = \Delta E = hv$
  - Input one Photon
  - Output two **identical photons** with exactly same hv
- Light Amplification (**Population Inversion**)



- Advantages: **Identical color/wavelength, Coherent (same phase), Single Direction**, Highly focused, High energy intensity
- Application: Compact Discs (**Shorter Wavelength, Higher Capacity**: Blu-ray > DVD > CD)

Photoelectric Effect 光电效应 (Particle Properties of Light)

- Light **give energy to electron in the unit of photon** (= in a **discrete** manner)
- Light energy is in individual photons
- Energy of 1 Photon $= hf$, $h =$ Planck Constant, $f =$ frequency of light
- Electron can escape when **frequency > threshold** (hf > well energy)

Wave Properties of Electrons

- **Double-slit interference experiment**
- $\lambda = \frac{h}{mv}$
- h is Planck constant $6.626 \times 10^{-34} \mathrm{J/s}$
- After Accelerating Voltage, Electron Energy $E(eV) = \frac{1}{2} m_0 v^2 \Rightarrow \lambda = \frac{h}{\sqrt{2m_o eV}}$
- with **relativistic correction**, wavelength is shorter
- Higher Voltage, Higher Velocity, Shorter Wavelength

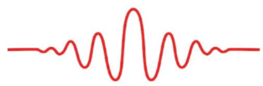
Application: Electron Microscope

- Optical Microscope: Visible Light $\sim \mu m$
- Visible Light wavelength: $380 \sim 740nm$
- Electron Microscope: Electron $\sim nm$
- Electron wavelength $< 0.01nm$

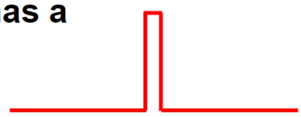
Heisenberg Uncertainty Principle

- $\Delta(mv) \cdot \Delta x \geq \frac{h}{2\pi}$ (**position & momentum**)
- Wave Function

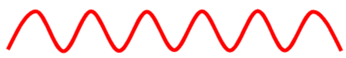
- **Each electron has a wavefunction which tells you the position and velocity of the electron. Wavefunction describes a wave.**



- **The spread of the wavefunction tells you the possible positions of the electron.**
- **The wavelengths of the wave tell you the possible velocities of the electron.**
- **If the wavefunction has a small spread in space, it has a and the velocity (large spread in wavelengths) momentum's accuracy decreases**



- **If the wavefunction has a small spread in velocity(momentum), it has a large spread in space, accuracy of the position decreases and accuracy of velocity increases.**



Application

Semiconductor

- Semiconductor has a medium **band gap between Conduction Band & Valence Band**
- Computer Chips
- Junction Diodes
- Solar Cells

Relativity

- **speed of light in vacuum is the same** in all inertial reference frames (Maxwell Theory)
- Lorentz transformation

$$\begin{cases} x' &= \frac{x - vt}{\sqrt{1 - \frac{v^2}{c^2}}} \\ y' &= y \\ z' &= z \\ t' &= \frac{t - \frac{v}{c^2} x}{\sqrt{1 - \frac{v^2}{c^2}}} \end{cases}$$

Time Dilation

- $\gamma = \frac{1}{\sqrt{1 - \frac{u^2}{c^2}}} > 1$ **Lorentz Factor**
- $\Delta t =$ Duration measured on the train
- $\Delta t' = \gamma \Delta t = \frac{\Delta t}{\sqrt{1 - \frac{u^2}{c^2}}} =$ Duration measured from the ground
- $\Delta t' > \Delta t$

Length Contraction

- $L_0 =$ Length measured on the train
- $L = \frac{L_0}{\gamma} = L_0 \sqrt{1 - \frac{u^2}{c^2}} =$ Length Measured from the ground
- $L < L_0$

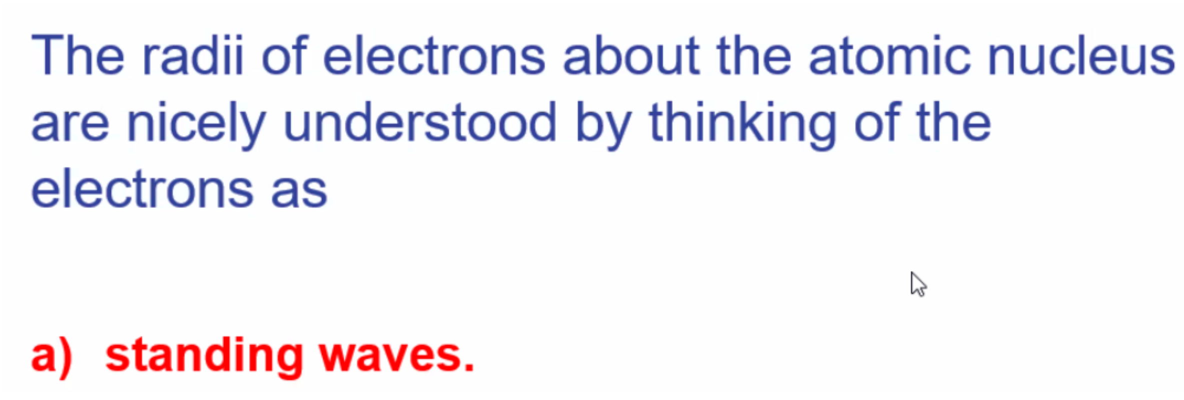
Mass Loss

- $m_u = \frac{m_0}{\sqrt{1 - \frac{u^2}{c^2}}}$
- m_0 is rest speed
- $m_u \approx m_0 \left[1 + \frac{1}{2} \left(\frac{u}{c}\right)^2\right] \Rightarrow m_u c^2 = m_0 c^2 + \frac{1}{2} m_0 u^2$
- **Total Energy = Kinetic Energy +** $m_0 c^2$
- Mass Loss in Nuclear Reactions $\Rightarrow$ Huge Energy

Application: GPS

Important Experiment

- Michelson-Morley experiment: Special Relativity
- Stern-Gerlach experiment: angular momentum is quantized



Orbital electrons don't spiral into the atomic nucleus because of

a) angular momentum conservation.
b) energy conservation.
c) the wave nature of electrons.
d) All of the above.

Comment:
The wave nature prevents spiraling, not the conservation principles stated.