$p=mv$

$\Sigma F=\frac{\Delta p}{\Delta t}$ $\qquad \Delta p=F\times\Delta t=m\Delta v$

$E_k=\frac{p^2}{2m}$

---

$$\begin{tikzcd}
\theta \arrow[r, "\times r"] \arrow[d, "\frac{d\theta}{dt}"] & l \arrow[d, "\frac{dl}{dt}"] & \vec{s} \arrow[d, "\frac{d\vec{s}}{dt}"] & \\
\omega \arrow[r, "\times r"] \arrow[d, "\frac{d\omega}{dt}"] & v \arrow[d, "\frac{dv}{dt}"] & \vec{v} \arrow[d, "\frac{d\vec{v}}{dt}"] & \\
\cancel{\alpha} \arrow[r, "\times r"] \arrow[d, "\times I"] & \cancel{a_{tan}} \arrow[d, "\times m"] & \vec{a} \arrow[r, equal, "匀速"] \arrow[d, "\times m"] & a_{cen} \arrow[d, "\times m"] \\
\cancel{\Sigma M} & \cancel{\Sigma F_{tan}} & \Sigma\vec{F} \arrow[r, equal] & \Sigma F_{cen}\ (指向圆心)
\end{tikzcd}$$

$v=\omega r.$ $\quad T=\frac{2\pi}{\omega}$ $\quad \omega=2\pi f=\frac{2\pi}{T}$

$\theta=\frac{s}{r}$

$a=\frac{v^2}{r}$

$F_{cen}=\frac{mv^2}{r}=mr\omega^2$

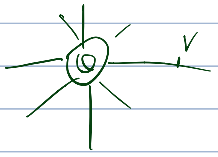
---

所有 $E=\frac{F}{Q}$ $\qquad E_k=W=VQ$ $\qquad a=\frac{EQ}{m}$

↘电势差

匀强 $E=\frac{V}{d}$ $(Vm^{-1})$ $\qquad$ 点 $E=\frac{kQ}{r^2}=\frac{Q}{4\pi\varepsilon_0 r^2}$ $\quad k=\frac{1}{4\pi\varepsilon_0}$

库伦 $F=\frac{kQ_1Q_2}{r^2}$ $\qquad$ 点 $V=\frac{kQ}{r}.$



↓粒子间的静电力

$\phi=BA\sin\theta$ $\quad (Wb=Tm^2)$

$N\phi=NBA\sin\theta$ $\quad (Wb)$

通电导线在B中受力 $F=BIl\sin\theta$

带电粒子在B中受力 $F=Bqv\sin\theta=\frac{mv^2}{r}$ $\qquad r=\frac{mv}{Bq}$

电容 $C=\frac{Q}{V}$ → 一个极的电荷 $\qquad C=\frac{\varepsilon A}{d}$

$W=\frac{1}{2}VQ=\frac{1}{2}CV^2=\frac{Q^2}{2C}$

放电 $V=V_0e^{-\frac{t}{RC}}$ $\qquad I=I_0e^{-\frac{t}{RC}}$

充电 $V=V_0(1-e^{-\frac{t}{RC}})$

$1eV/c^2=1.78\times10^{-36}kg$

$1MeV/c^2=1.78\times10^{-30}kg$

$1kg=5.6\times10^{35}eV/c^2$

法拉第 $\varepsilon=\frac{-d(N\phi)}{dt}=\frac{-\Delta N\phi}{\Delta t}$

further machanics

- collision (def. $\Sigma F_{ext} = 0$)
  - classify ($\Delta KE \to$ elastic/inelastic)
  - 2D: 条件 $m_1 = m_2$, $V_2 = 0$, elastic $\to$ 结论 $\vec{V_1}' \perp \vec{V_2}'$, $\vec{V_1}' + \vec{V_2}' = \vec{V_1}$
- ciraular motion

$$\begin{tikzcd}
\theta \arrow[r, "\times r"] \arrow[d, "求导"] & l \arrow[d, "求导"] & \vec{s} \arrow[d, "求导"] & \\
\omega \arrow[r, "\times r"] \arrow[d, "求导"] & v \arrow[d, "求导"] & \vec{v} \arrow[d, "求导"] & \\
\cancel{\alpha} \arrow[r, "\times r"] \arrow[d, "\times I"] & \cancel{a_{tan}} \arrow[d, "\times m"] & \vec{a} \arrow[r, equal, "匀速"] \arrow[d, "\times m"] & a_{cen} \arrow[d, "\times m"] \\
\cancel{\Sigma M} & \cancel{\Sigma F_{tan}} & \Sigma \vec{F} \arrow[r, equal] & \Sigma F_{cen} \text{ (指向圆心)}
\end{tikzcd}$$

$$F_{cen} = \frac{mv^2}{r} = mr\omega^2$$

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

electric & magnetic field

- electric
  - $E = \frac{F}{q} = \frac{kQ}{r^2}$
  - $V = \frac{E_p}{q} = \frac{kQ}{r}$ (仅球形场)
  - $\Delta V = -\int E\, dr$, $E = -\frac{dV}{dr}$
    - 匀强场
    - 球形场
  - $Q \to E \to F \to W \to \Delta E$; $Q \to \Delta V \to \Delta E$
- capacitor
  - 平衡态 Q, Energy, ⇒C → Q
  - discharge / charge
- magnetic field
  - 产生 & 受力: I → B → magnet / I / moving charge
  - 电磁感应
    - $\phi$ cutting
    - $\phi$ change

particle physics

- structure of atom
  - α-scattering
  - nucleus
    - symbol
    - isotopes
    - nuclear decay
  - electron beam
    - 产生: thermionic equation
    - 应用
      - wave: $\lambda = \frac{h}{p}$ diffraction
      - particle
        - E
        - B
- particle study
  - accelerator
    - linac
    - cynclotron
    - syncrotron
  - detector
    - ionization → image
    - B (分析运动)
  - analyse
    - 凸要点: con. law
    - size of culvature → P
    - direction of culvature → Q
    - no track →
      - no Q
      - no V
- standard model
  - fundamental particle
    - Bosons
    - fermions
      - quark
      - lepton
  - composited particle → Hardron
    - baryon
    - meason
  - reaction
    - 2 con → motion
    - 4 con → matter

# 1.1 一维碰撞 & 二维碰撞

碰撞条件：系统不受外力的作用 ∴两个物体可不接触

momentum

- $\vec{P} = m\vec{v} = Ft$
  - ↓
- $N_2: \Sigma\vec{F} = ma = \frac{\Delta P}{\Delta t} = \frac{mv}{t}$
  - ↓ +N3
- conservation law of momentum $\xrightarrow{\text{应用}}$ collision

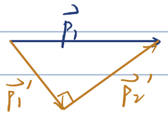
$KE = \frac{1}{2}mv^2 = \frac{p^2}{2m}$ （P有方向. KE无方向）

collision $\xrightarrow{\Sigma KE}$

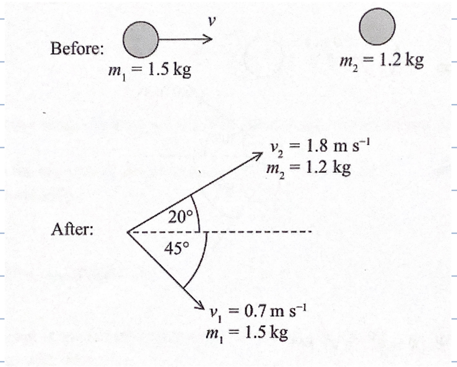
- $KE > KE'$ inelastic
- $KE = KE'$ elastic （↓max：stick：complete elastic）
- $KE < KE'$ superelastic

collision $\xrightarrow{\text{碰撞}}$

- 一维
- 二维 → 条件：$m_1 = m_2$, $V_2 = 0$, elastic → 结论：$\vec{V_1}' \perp \vec{V_2}'$, $\vec{V_1}' + \vec{V_2}' = \vec{V_1}$



$\text{Impulse} = \Delta P = \Sigma\vec{F}\,\Delta t$
$\text{Work} = \Delta E = \Sigma\vec{F} \cdot \vec{S}$

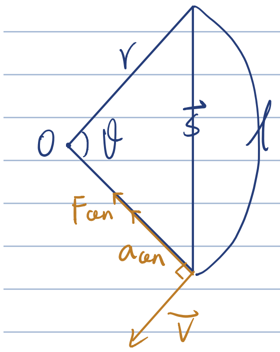


计算

P 要×cos

KE 不要cos

# 1.2 圆周运动



$$\begin{tikzcd}
\theta \arrow[r, "\times r"] \arrow[d, "\frac{d\theta}{dt}"] & l \arrow[d, "\frac{dl}{dt}"] & \vec{s} \arrow[d, "\frac{d\vec{s}}{dt}"] & \\
\omega \arrow[r, "\times r"] \arrow[d, "\frac{d\omega}{dt}"] & v \arrow[d, "\frac{dv}{dt}"] & \vec{v} \arrow[d, "\frac{d\vec{v}}{dt}"] & \\
\cancel{\alpha} \arrow[r, "\times r"] \arrow[d, "\times I"] & \cancel{a_{tan}} \arrow[d, "\times m"] & \vec{a} \arrow[r, equal, "\text{匀速}"] \arrow[d, "\times m"] & a_{cen} \arrow[d, "\times m"] \\
\cancel{\Sigma M} & \cancel{\Sigma f_{tan}} & \Sigma\vec{F} \arrow[r, equal] & \Sigma F_{cen}\ (\text{指向圆心})
\end{tikzcd}$$

计算

角速度 $\omega=\frac{\Delta\theta}{\Delta t}=\frac{2\pi}{T}=2\pi f$

$s=r\theta$

$v=r\omega$

$a_\perp=r\alpha=0$

论述

① tangent

a. $\Sigma F_{cen}=0$

$a_{tan}=0$ $\Updownarrow$ 的V方向

b constant speed

① a → ① b

切线方向 $\Sigma f=0$

↓

$a=0$

↓ v在切线方向上

$a_\perp=0$

↓

constant speed

② centripetal

$\Sigma F_{cen}\neq0$

$a_{cen}\neq0$ $\Updownarrow$ $\perp v$

change direction

② a → ② b

net force 在切线方向

↓

a的方向⊥V的方向

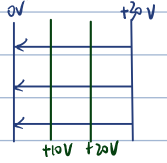
↓

direction change

# 2.1 Electric field 电场

def 电场: a charge particle $\xrightarrow{电场}$ a charge particle

场线.
Field line:



指向场强方向.
势高 → 势低. ⊕ ⟶ ⊖
间距相同

等势线. equipotential lines. (⊥ 场强)

场强
Field strength: $E=\frac{F}{Q}$ $(NC^{-1})$

能量 ↗

⊕: F与E同向
⊖: F与E反向

$F=EQ=ma$ ↙ 场强

$\Delta V=\frac{\Delta E}{q}$ ← 场强

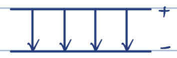
电势
Electric potential: $E=VQ$.

(粒子加速: KE = E)

$$\Delta V=\frac{\Delta E}{Q}=\frac{\vec{F}\vec{d}}{Q}=-\vec{E}\vec{d}$$

匀强场
uniform field

def.



$E=\frac{V}{d}$ $(Vm^{-1}.\ NC^{-1})$

↑ 场强

球形场

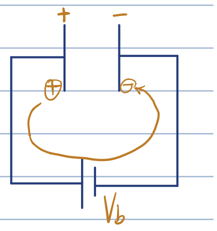
Coulomb's law $F=\frac{kQq}{r^2}$ $k=9\times10^9\ Nm^2C^{-1}$

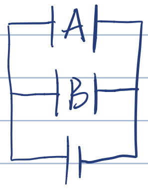
$E=\frac{kQ}{r^2}$ $V=\frac{kQ}{r}$

# 2.2.1 电容

平衡态
- 原理
  - def. plates insulator 用于储存电荷
  - 工作过程 $\Delta V \to E \to$ more of $e^- \to q\uparrow \to V_c\uparrow$
    until $V_c = V_b$，两板达到平衡
- 特性
  - capacity of Q：绝缘能力 → $\frac{\varepsilon A}{d} = C = \frac{Q}{V}$ ← Q：容电量
    (F)
    ↓ 与V大小无关
  - capacity of E：$\int_0^Q dE = \int_0^Q V_c \cdot dq = \frac{Q^2}{2C} = \frac{1}{2}QV = \frac{1}{2}CV^2$
- 串并联
  - series
    $Q_A = Q_B = Q_C$
    $V_A + V_B = V_t$
    $\frac{1}{C_A} + \frac{1}{C_B} = \frac{1}{C_t}$
  - parallel
    $V_A = V_B = V_t$
    $Q_A + Q_B = Q_t$
    $C_A + C_B = C_t$

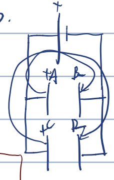
空间储存能量





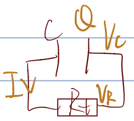
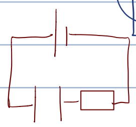
判断两板谁 + 与 −
↑
- con of Q：判断电荷流动方向
- con of E：$\Delta V = 0$ for every loop
  ↓
  过程中V增加量 = V减小量

ep.



$Q_A = Q_B = Q_1$
$Q_C = Q_D = Q_2$
$Q_b = Q_1 + Q_2$

## 充放电

| | RC-circuit | 放电<br>discharge | 充电<br>charge |
|---|---|---|---|
| | |  |  |
| exponential change | 本质 $\frac{dx}{dt} \propto x$ | $V_c = V_R$<br>$\frac{Q}{C} = IR \Rightarrow \frac{dQ}{dt} = -\frac{Q}{CR}$ | $V_0 = V_R + V_c$<br>$V_0 = R\frac{dQ}{dt} + \frac{Q}{C} \Rightarrow \frac{dQ}{dt} = \frac{V_0}{R} - \frac{Q}{CR}$ |
| | time constant<br>$\tau = RC$<br>$\tau \longrightarrow t$<br>判断充/放电时间 | ↓<br>$Q = Q_0 e^{-\frac{\tau}{RC}} \to \ln Q = \ln Q_0 \frac{\tau}{RC}$<br>↓ $Q = CV$<br>$V_c = V_0 e^{-\frac{\tau}{RC}}$<br>↓ $I = \frac{V}{R}$<br>$I = I_0 e^{-\frac{\tau}{RC}}$ | ↓<br>$Q = Q_0(1 - e^{-\frac{t}{RC}}) \to \ln(Q_0 - Q) = \ln Q_0 - \frac{t}{RC}$<br>↓ $Q = CV$<br>$V_c = V_0(1 - e^{-\frac{\tau}{RC}})$<br>↓ $I = \frac{V_0 - V_c}{R}$<br>$I = I_0 e^{-\frac{\tau}{RC}}$ |

充放电过程问答题 p.d → R/C → τ(RC) → t

放电

充电

$$Q \xrightarrow[C=\frac{Q}{V}]{C=\frac{Q}{V}} V_c \xrightarrow[V_R+V_c=V_0]{V_R=V_c} V_R \xrightarrow[V_R=RI]{V_R=RI} I$$

# 2.1 电场

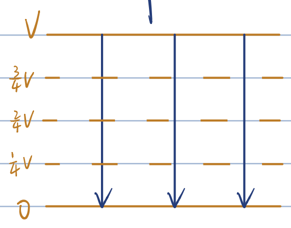
电场 $\vec{E} = \frac{\vec{F}}{q} \longrightarrow$ field line

$\Delta V = \int \vec{E} \cdot \vec{ds}$ $\Big\downarrow\Big\uparrow$ $\vec{E} = \frac{-dv}{\vec{ds}} \longrightarrow$

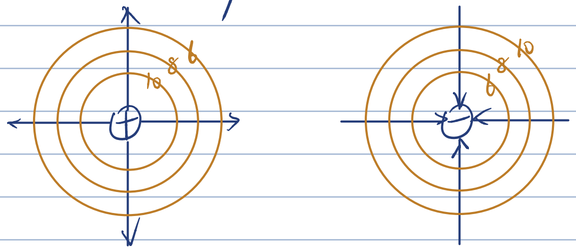
1. $\perp$
2. 方向 $\vec{E}$ $V\downarrow$
3. 大小 场线&等势线 同密同疏

势 $V = Ed/q \longrightarrow$ equipotential lines

uniform 匀强场



radial 球形场



$V$
$\downarrow$
$\vec{E} = \frac{\Delta V}{d}$
$\downarrow$
$\vec{F_q} = \vec{E}q$
$\downarrow$
motion

悬停
$\Sigma F = 0$

加速
$u = 0 / u \parallel \vec{E}$
$\Delta Vq = \Delta KE$

偏转
$u \perp \vec{E}$
$\{$

$Q$
$\downarrow \frac{kQ}{r^2}$
$E \to F \to \Sigma F = 0$
$\downarrow \frac{kQ}{r}$
$V$
$\downarrow q\Delta V$
$\Delta Ed$
$\downarrow$ cons of E
$\Delta KE$

$\frac{kQq}{r^2} = F \longrightarrow \Sigma F = 0$

$\downarrow$ $\vec{E} = \frac{\vec{F}}{d}$

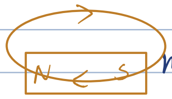
$\frac{kQ}{r^2} = E$

$\downarrow$ $\Delta V_{12} = -\int_1^2 \vec{E}\, \vec{dl}$

$\frac{kQ}{r} = V \longrightarrow$ con of E ( $q \cdot \Delta V_{12} = \Delta KE$)

施力物体 中介 受力物体

magnetic force



magnet 1 → field lines

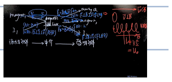
⇓

大小 $B \propto I$
方向 $B \perp I \perp l$ (RHR)
} current 1 → field lines

field lines → current 2 $F = B \times I \times l$ $\begin{cases} F = BIl\sin\theta \\ \vec{F} \perp \vec{B} \perp \vec{I} \text{ (LHR)} \end{cases}$

field lines → magnet 2 极性

field lines → moving charge $\vec{F} = \vec{B} \times (vq)$ $\begin{cases} F = Bvq\sin\theta \\ \vec{F} \perp \vec{B} \perp \vec{v} \text{ (LHR)} \end{cases}$



↓

electromagnetic induction

受力物体 施力物体

metal
coil
bar
......

I (A.C) → $\Delta B$

magnet → $V \begin{cases} V_1 \\ V_2 \end{cases}$

$\Delta B$, $V$ → $\Delta\phi_2 \rightarrow \varepsilon_2$ 发生

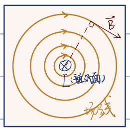
$\Delta\phi \rightarrow \varepsilon_2$ 大小

# 2.3.1 Electromagnetic effect

moving charge

产

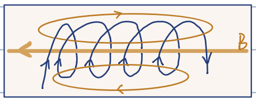
- by current $\vec{B} \perp \vec{I} \perp \vec{r}$
  (I可调节
  B可调节)
  - straight ~

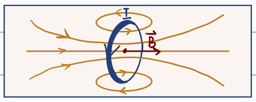


离电流近，场线越密，B大

无数螺线圈叠加

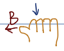
  - loop ~





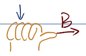
RHR

四指指I



四指&大拇指
↓
闭I中 弯曲&直线

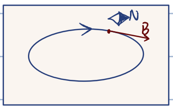
四指指I



- by magnet
  - 磁性 ⟶ moving charge
  - 非磁性 ⟶ 磁性 磁化 magnization

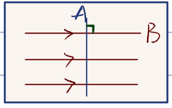
磁场

- magnetic flux density $(\vec{B})$ 磁感应强度
  def. number of lines through perpendicular unit area
  SI unit: tesla (T)  方向：磁感线切线方向 (N极指向)



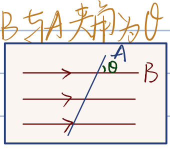
- magnetic flux $(\phi)$ 磁通量 (用于描述磁场)
  def. number of lines through a certain area
  SI unit: Weber (Wb) $= Tm^2$

$B \perp A$



$\phi = B \cdot \vec{A}$
有正负，总标量
↳ 面有正负之分

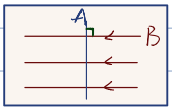
B与A夹角为$\theta$



$\phi = BA\sin\theta$

$B /\!/ A$, $\phi = 0$

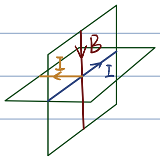
若



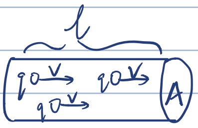
$\phi = -BA$

作用于

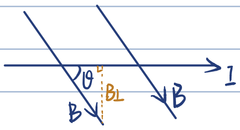
- on current (宏观)
  - 方向：LHR
    磁感线B穿过手心
    四指 → I  拇指 → F



  - 大小
    - $B \perp \vec{l}$  $\vec{F} = \vec{B} \times \vec{I}\vec{l}$
    - B交l  $F = BIl\sin\theta$ ← B与I的夹角
      ↳ 判断方向时仅看$B_\perp l$的方向

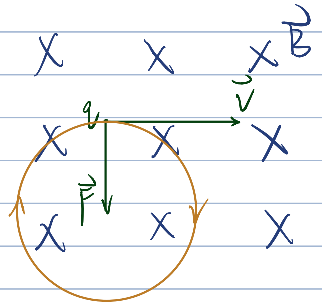


- (运动电荷在磁场中受到的力)
  on moving charge (微观)
  - 方向：$\vec{B} \perp \vec{V} \perp \vec{F_q}$
    q {带+电 四指向v正方向 ← q有正负，影响F方向
       带-电 …… 负 ……
  - 大小
    - $V \perp B$  $F = qvB$
    - V与B不垂直  $F = qvB\sin\theta$ ⟶



moving charge

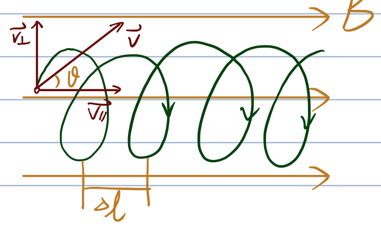
① What motion (解释+圆周运动)



F永远与v垂直 → { F不做功 → v大小不变 → F大小不变 → 匀圆
F改变 v方向 }

{ 动能不变 ($\frac{1}{2}mv^2$). v大小不变
$\vec{a} = \frac{dv}{dt}$ }

② What motion if $\vec{B}$ isn't ⊥ $\vec{v}$

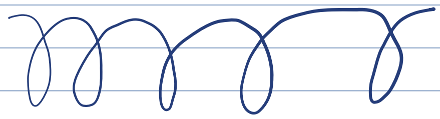


← 电场效

{ //: $F=0$ → constant ⊥ $\vec{v}$
⊥: $\vec{F} \perp \vec{v_\perp}$ → 圆周运动 }

↖ B效

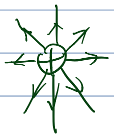
③



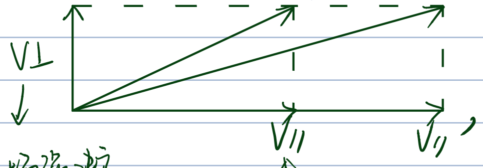
- In what field?

$V_\perp \to \Sigma F \to F \to E$

$V_\parallel \to \Sigma F \to F \to E$

匀a → 电场 → 

- will v change?



$V_\perp$ ↓ B场张效

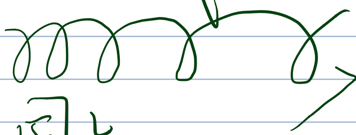
↑ E电场效

- will $V_0$ change

$V_0=0$ 匀加速直线

$V//B$ 匀加速直线

> v不受B影响

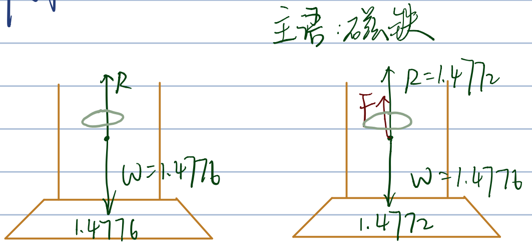
$V \perp B$ 

→ 条件: V不平行于B

$V \times B$ 同上

# 实验 ( determine B of U-magnet )

## 一 步骤

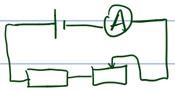


① 公式
- I : $\vec{F}=\vec{B}I\ell$
- q :
  - $\vec{F}=\vec{B}q\vec{v}_{速}$
  - $r=\frac{mv}{Bq}$

② measurements

F(因变)  I(自变)  $\ell$ (constant)

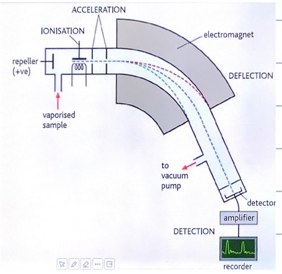
③ set up



④ apparatus
- F : scale
- I : Ⓐ
- $\ell$ : ruler

⑤ repeat read F from scale for variable I

| n | I | m (g) |
|---|---|---|
| 1 | 1.2 | 0.45 |
| 2 | 2.5 | 0.9 |
| 3 | 3.4 | 1.25 |
| 4 | 4.2 | 1.50 |
| 5 | 5.0 | 1.85 |
| 6 | 5.8 | 2.20 |

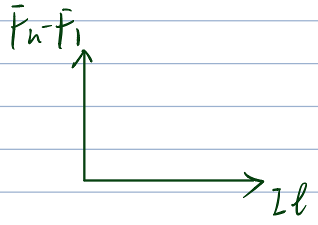


⑥ $F_n-F_1=BI\ell$

$B=\frac{F_n-F_1}{I\ell}$

⑦ plot $(F_n-F_1)-I\ell$ graph

gradient : B.



## 一 Attention.

① What's effective e?

无法测量，仅可测U形磁铁的长

② What's the force the scale show?

R of magnet　去皮：$F_B$

③ What's the direction of magnetic force?

- magnetic : 通过看称的示数，若I↑，m↑，则方向向下
  - ↓N3
- current

④ Sign of the polarity of magnet

⑤ What if current is opposited

magnet与current 从排斥变为吸引

- Application
  - PC electric motion
    - 原理：$$\begin{tikzcd}\text{电} \arrow[rr] \arrow[dr, "B"'] & & \text{动} \\ & F \arrow[ur] & \end{tikzcd}$$
  - Hall effect

## 2.3.2 Electromagnetic induction 电磁感应

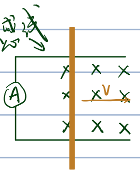
### def.

**magnetic force**: ~ on e⁻ in metal can drive them in a direction
so that current occurs

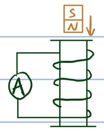
$\phi = \vec{B} \cdot \vec{A}$

电磁感应条件
有感应电流

A 变
stationary magnetic field $\xrightarrow{F}$ moving charges



B 变
moving magnetic field $\xrightarrow{F}$ stationary charges



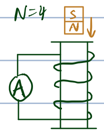
**moving charge**: charge in a metal is free to move under magntic force

### Induced emf. 感应电压

number of coils
空间内磁感线条数
magnetic flux

**magnitude (Faraday's law)**

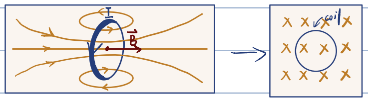
$$\mathcal{E}_{in} = \frac{-d(N\phi)}{dt} = -N\frac{d\phi}{dt}$$



law: the induced emf. is equal in size
to the rate of change of flux linkage

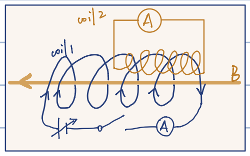
closed metal coil

change in B



$B\uparrow = kt\uparrow$, Why there is current in coil?

$t\uparrow \xrightarrow{B=kt} B\uparrow \xrightarrow{\phi=\vec{B}\cdot\vec{A}} \text{flux}\uparrow \xrightarrow{\text{Fara law}} \varepsilon_{in} \neq 0$



$\overset{\text{coil 1}}{I}$ alternative change $\longrightarrow \overset{\text{coil 1}}{B} \longrightarrow \overset{\text{coil 2}}{\phi} \longrightarrow \overset{\text{coil 2}}{\varepsilon_{in}}$

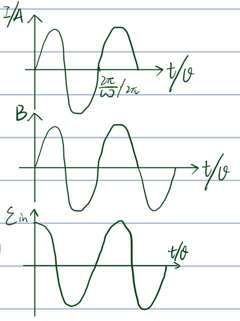
$I = A\sin(\omega t)$

$\downarrow B \propto I$

$B = A's(\omega t)$

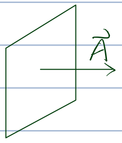
$\downarrow \sin = \dfrac{d(N\phi)}{dt}$

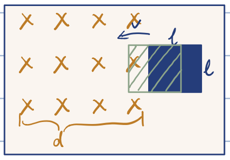
$\varepsilon_{in} = A''\cos(\omega t)$



change in $A_\perp$

change $\vec{A}$ → 有效面积（磁感线以B为密度有效穿过的面积）





① $[0, l]$ $A\uparrow \rightarrow \phi\uparrow \rightarrow \varepsilon_{in} \neq 0$

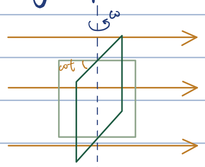
$\varepsilon_{in} = N\dfrac{d\phi}{dt} = NBl\dfrac{ds}{dt} = NBlv$

② $[l, d]$ $A - \rightarrow \phi - \rightarrow \varepsilon_{in} = 0$

③ $[d, d+l]$ $A\downarrow \rightarrow \phi\downarrow \rightarrow \varepsilon_{in} \neq 0$

$\varepsilon_{in} = \dfrac{d(N\phi)}{dt} = NB\cdot\dfrac{dA}{dt} = NBlv$

change effective $A_{\parallel}$

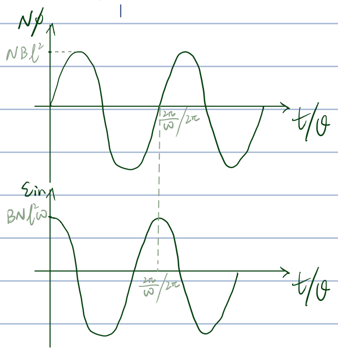


$A \rightarrow \phi \rightarrow \varepsilon_{in}$

$\varepsilon_{in} = \dfrac{dN\phi}{dt} = NB\dfrac{dA}{dt} = BNl\dfrac{dl\sin\omega t}{dt}$

$= BNl^2\omega\cos(\underset{\sim}{\omega t})$

（面与场线的夹角）

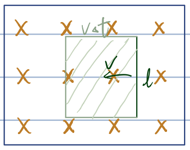


change in flux

induced ε

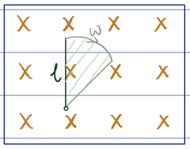
open metal → V → flux cutting → change in flux

v → flux cutting → $\varepsilon_{in}$



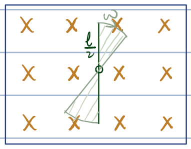
$\Delta\phi = BA = Blv\Delta t$

$\varepsilon_{in} = BlV$



$\Delta\phi = \omega\Delta t l^2 B$

$\varepsilon_{in} = \dfrac{\Delta\phi}{\Delta t} = \dfrac{1}{2}\omega l^2 B$

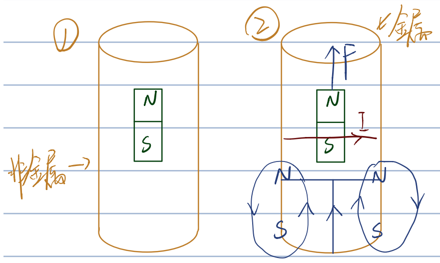


$\Delta\phi = \omega\Delta t\left(\dfrac{l}{2}\right)^2 B\times 2$

$\varepsilon_{in} = \dfrac{\Delta\phi}{\Delta t} = \omega\dfrac{l^2}{4}B$

# direction

## – Lead in



判断哪个v慢.

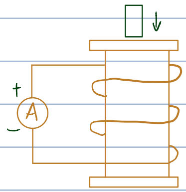
① GPE → KE

② 金属管切割磁感线 → 产生 $\varepsilon_{in}$

GPE → KE + Ed

$$\text{con of E} \xrightarrow{} F\uparrow \xrightarrow[\text{右手} \to \text{current}]{\text{极性} \to \text{magnet}} B\uparrow \xrightarrow{\text{右手}} I_{in}$$

## – Lenz's law



| | 原磁场 | | 感应电流 | |
|---|---|---|---|---|
| | (S→N) 方向 | 大小 | (RHR) 磁场方向 | Ⓐ |
| N 入 | ↓ | 增大 | ↑ | + |
| N 出 | ↓ | 减小 | ↓ | – |
| S 入 | ↑ | 增大 | ↓ | – |
| S 出 | ↑ | 减小 | ↑ | + |

Lenz's law: the direction of induced ε has an effect to opposite the change creating it

$$\text{感应电流的磁场} \xrightarrow[\text{Lenz's law (增反减同)}]{\text{阻碍}} \text{引起感应电流的}\ \phi\ \text{变化}$$

## – 答题

$$\underset{\text{cause}}{\text{(已知条件)}} \xrightarrow{\text{Fa law}} \varepsilon_{in} \xrightarrow{} \text{effect}$$

$$\text{cause} \xleftarrow[\text{Lenz's oppose}]{} \text{effect}$$

$I \to \Delta B$, $\Delta A$ } → flux change

$\Delta\phi$

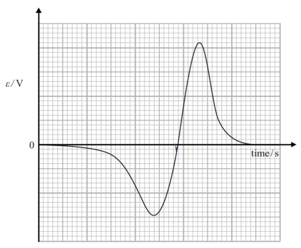
$v$ → flux cutting

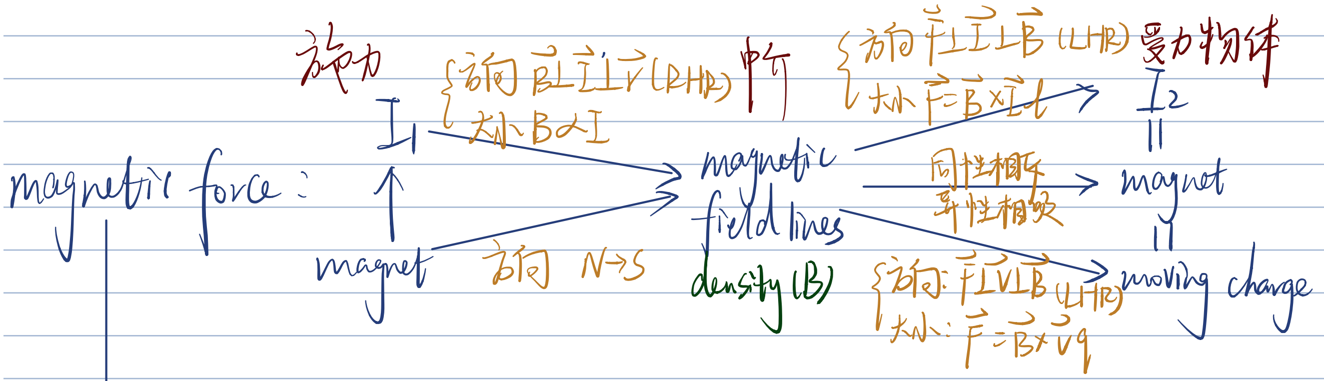
} $\xrightarrow{\text{Fa law}} \varepsilon_{in} \to I_{in} \to B_{new} \to F_{\text{origin } I/\text{magnet}}$

$I_{in} \downarrow F_{\text{induce } I}$

解释图像

- x轴 $t_- > t_+$ → motion
- y轴
  - ε 先负后正
  - $\varepsilon_{+max} > \varepsilon_{-max}$
  - } Fara rate of $\Delta\phi\uparrow$ ↓ $\varepsilon_{in}\uparrow$
- slope/area $A_+ = A_-$

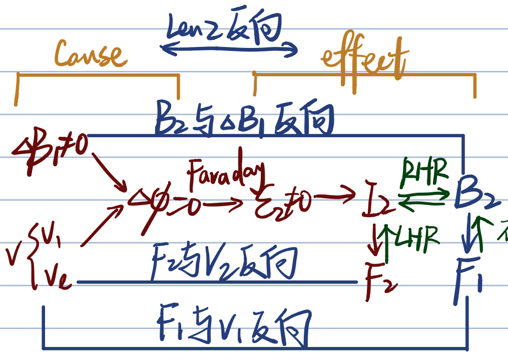




Electromagnetic induction

| Object 2 (受力物体) | Object 1 (施力物体) |
|---|---|
| metal { coils<br>bar<br>tube<br>... | coils (A.C) |
| | magnet |

↑ 接电源



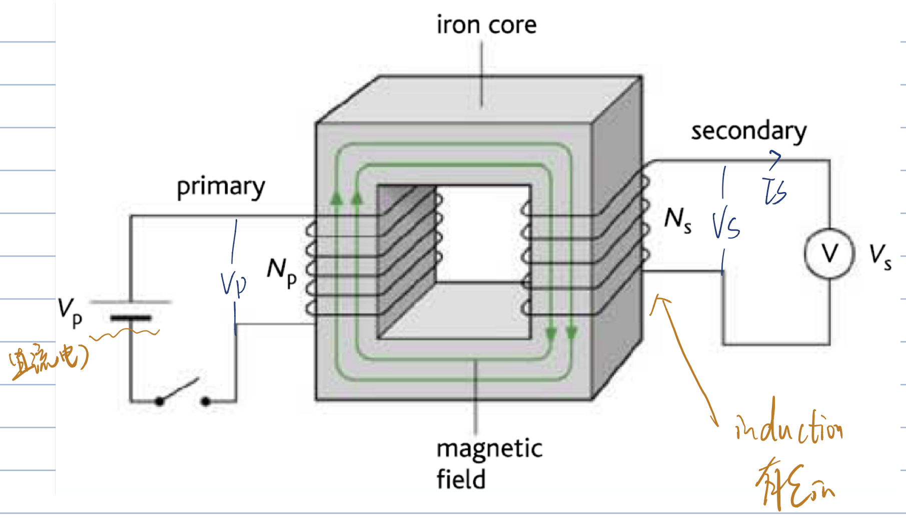
Step1. Cause & effect
Step2 Lenz's 反向
Step3 结论

大小: $\left.\begin{matrix}\Delta B\uparrow \\ V\uparrow\end{matrix}\right\} \rightarrow \frac{\Delta\phi_2}{\Delta t} \longrightarrow \varepsilon_2\uparrow$

方向: $\left.\begin{matrix}\Delta B反 \\ V反\end{matrix}\right\} \rightarrow \Delta\phi$反向 $\rightarrow \varepsilon_2$反向

① 磁化：加强磁场.

② 不会漏磁：no linkage of magnetic flux



Q: If D.C in primary, $I_p \rightarrow B_p \rightarrow \Delta\phi_s \xrightarrow{Fa} \varepsilon_s \neq 0$

if A C in primary. $\underset{\text{alternative change}}{I_p} \rightarrow \underset{\text{alternative change}}{B_p} \rightarrow \underset{\text{alternative}}{\Delta\phi_s} \xrightarrow{Fa} \underset{\text{alternative}}{\varepsilon_s \neq 0}$

Q₂. $220\,kV \underset{?}{\nrightarrow} 220\,V$

$\phi_p = \phi_s$ (理想状态假设)

$$\frac{d\phi_p}{dt} = \frac{d\phi_s}{dt}$$

$$\varepsilon_s = N_s \frac{d\phi_s}{dt}$$

$$\varepsilon_p = N_p \frac{d\phi_p}{dt}$$

$$\frac{\varepsilon_s}{\varepsilon_p} = \frac{N_s}{N_p}$$

$$\Big\downarrow r=0$$

$$\frac{V_s}{V_p} = \frac{\varepsilon_s}{\varepsilon_p} = \frac{N_s}{N_p}$$

Q3: 电压不断改变，为何依然能达平衡

$P_p = P_s \leftarrow V_p I_p = V_s I_s$

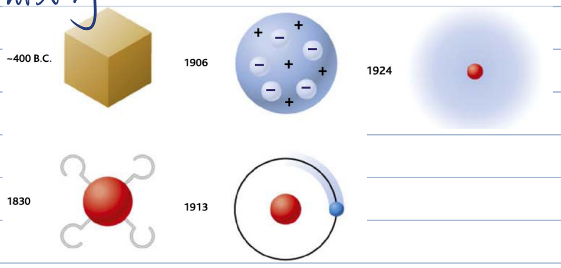
coil 上有阻值

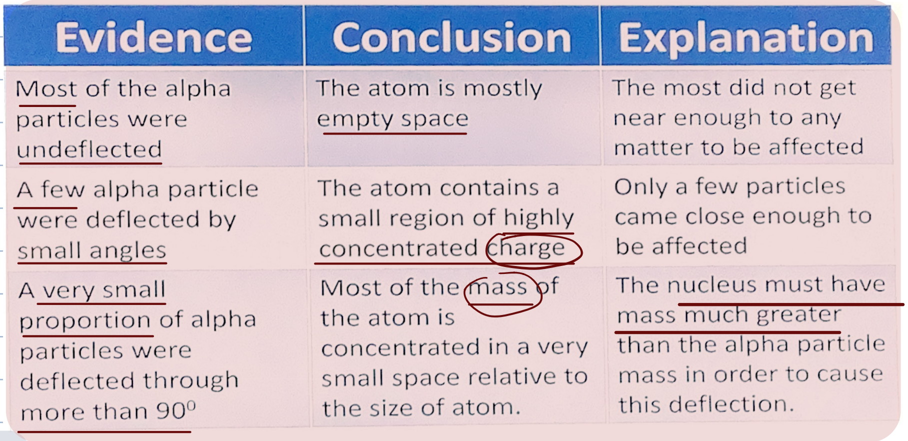
iron coil 有电流.会 induction (eddy current)

3.1
- α scattering experiment
- nucleus
- electron beam
  - 产生 → electron gun
    - 电子产生
    - 加速
    - 方向种
  - 应用
    - wave B
    - particle E

# 3.1.1 Structure of atom

## 1. history

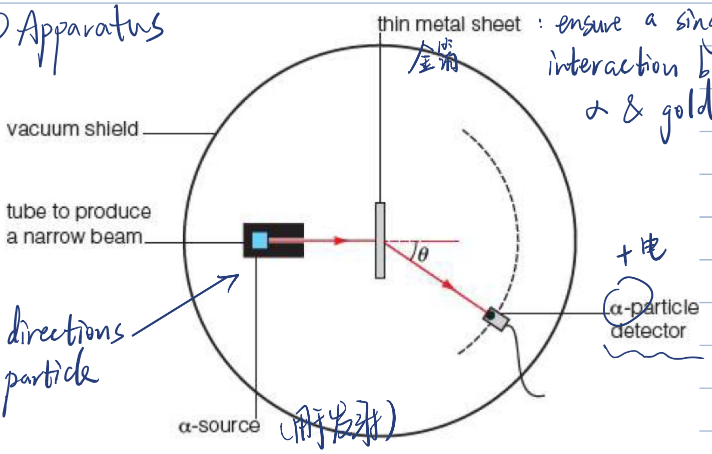




| Evidence | Conclusion | Explanation |
|---|---|---|
| Most of the alpha particles were undeflected | The atom is mostly empty space | The most did not get near enough to any matter to be affected |
| A few alpha particle were deflected by small angles | The atom contains a small region of highly concentrated charge | Only a few particles came close enough to be affected |
| A very small proportion of alpha particles were deflected through more than 90⁰ | Most of the mass of the atom is concentrated in a very small space relative to the size of atom. | The nucleus must have mass much greater than the alpha particle mass in order to cause this deflection. |

## 2. Rutherfold α scattering → 研究原子内部

### ① Apparatus



thin metal sheet: ensure a single interaction between α & gold atom

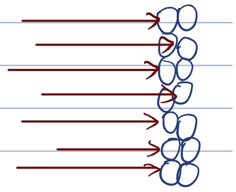
金箔

+电

(用于发射)

lead: absorb α particle in other directions ensure a fine beam of α particle

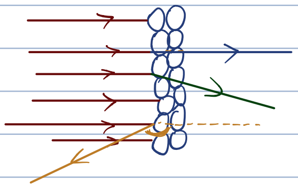
$^{2}_{4}He=2p+2n$



真空！：空气会改变α粒子轨迹 to avoid α particle collide with air molecules otherwise α particle path changes, can't reach the screen/gold foil

### ② Results

| angle of deflection (°) | describe | distribution |
|---|---|---|
| 0-10 | no deflection. go straight through | most |
| 10-90 | deflection take place | few |
| 90-180 | deflect with large angle >90° | very few |



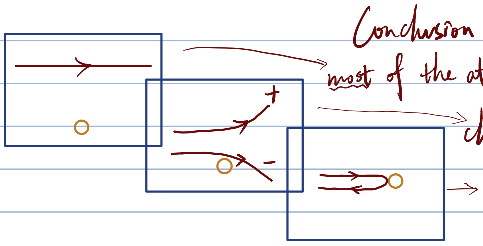
### ③ Analyse

$$= \frac{kqQ}{r^2}$$

α粒子

原子内电荷

| motion ← | Force | → r |
|---|---|---|
| 0°-10° | no force | far away |
| 10°-90° | electrostatic force | close |
| 90°-180° | large repulsive force/collision | very close |



Conclusion

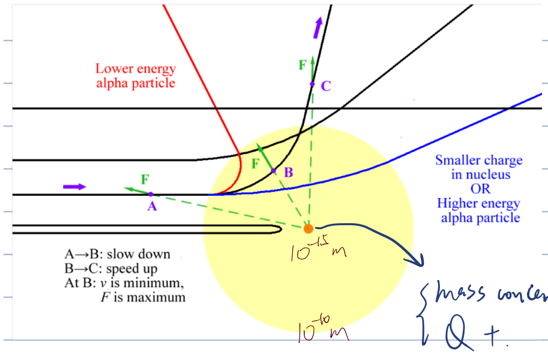
most of the atom are empty space with no mass & no charge

charge is concentrated in a very small region

positive charge

mass is concentrated in a very small region

### ④ Conclusion



most of the atom are empty space with no mass & no charge

charge is concentrated in a very small region

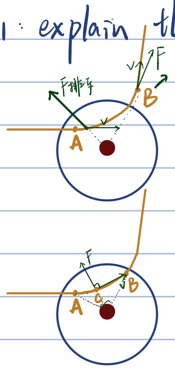
positive charge:

mass is concentrated in a very small region

{ mass concentrate
{ Q + } → neucleus

⑤ Reverse (Construction → 分析现象)

Q1: explain the motion of α when it pass atom



before A . after B : no force → constant $\bar{v}$

A点~C点: F与v反向 → v↓

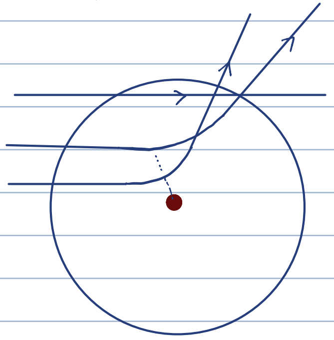
C点 : Vmin.

C点~B点: F与v同向 → v↑

Q2: What factors can effect θ

α粒子初速度. 距离 (越近, 偏转越大). charge of nucleus

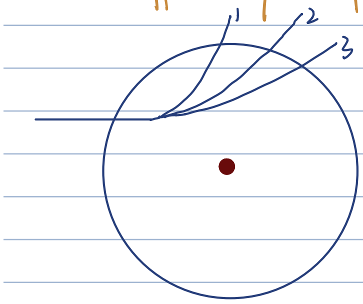
a. different distance



$r \rightarrow F \neq 0 \rightarrow \Delta V \neq 0 \rightarrow \Delta\theta$

$r\uparrow \rightarrow F \approx 0 \rightarrow \theta \approx 0$

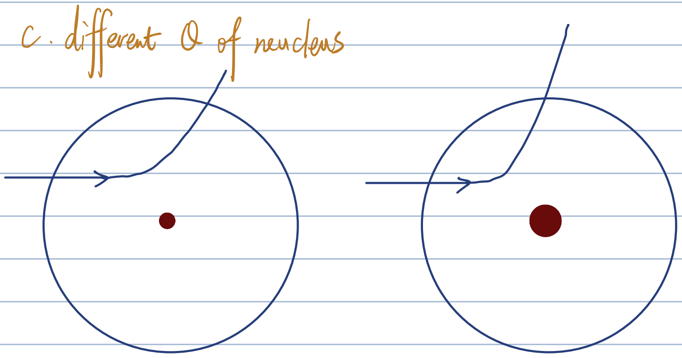
b. different speed of α



$V_1 < V_2 < V_3$

$$V\uparrow \rightarrow \underbrace{t\downarrow}_{\text{在F作用下的时间变短}} \rightarrow \Delta P\downarrow \rightarrow \theta\downarrow$$

c. different Q of nucleus



$$Q\uparrow \xrightarrow{F=\frac{kQq}{r^2}} F_{ele}\uparrow \xrightarrow{\Delta P=F\Delta t} \Delta P\uparrow \rightarrow \theta\uparrow$$

3. Nuclear structure

① Standard symbol of nucleus

mass / nucleon number → A

proton number → Z

X → symbol of element

Z: proton number = atomic number (determine element) 质子数 = 电子数

N: neutron number

A: nucleon = mass number

中子数: Z − A

| | ${}^{197}_{79}Au$ | $Au^{+}$ |
|---|---|---|
| $n_{proton}$ | 79 | $n_{electron}$: 78 |
| $n_{neutron}$ | 197−79 | |
| charge | 79e | |
| mass | 197u | |

③ Isotopes

1. neucleus . Same Z . different N  ep. ${}^{12}_{6}C$ & ${}^{14}_{6}C$
2. Unstable isotope . will decay . by emitting α-particle . β- particle . γ-particle

$\alpha\text{-particle} = {}^{4}_{2}He$, $\beta\text{-particle} = e$, $\gamma\text{-particle} = \text{photon}$

α decay: $${}^{220}_{86}Rn \rightarrow {}^{216}_{84}X + \underbrace{{}^{4}_{2}He}_{\alpha} + \underbrace{\text{energy (photon)}}_{\gamma}$$

β decay: $${}^{131}_{53}I \rightarrow {}^{131}_{54}X + {}^{0}_{-1}e$$

核: ${}^{1}_{0}n \rightarrow {}^{1}_{1}p + {}^{0}_{-1}e$ + energy

${}^{4}_{2}\alpha$  ${}^{0}_{-1}\beta$  ${}^{0}_{1}\beta$  ${}^{2}_{1}H$

hydrogeon neuclears

${}^{1}_{0}n$  ${}^{1}_{1}p$

neutron  proton

④ The distribution of mass in atom

1. p. n. e

| | |
|---|---|
| mass of proton | $m_p = 1.67262 \times 10^{-27}$ kg |
| mass of neutron | $m_n = 1.67493 \times 10^{-27}$ kg |
| mass of e | $m_e = 9.1 \times 10^{-31}$ kg |

$$\begin{cases} m_p \approx m_n \gg m_e \\ m_n > m_p + m_e \end{cases}$$

${}^{1}_{0}n \rightarrow {}^{1}_{1}p + {}^{0}_{-1}e$ + (energy)  n 不稳定

2. 近似法

atomic mass unit (u)

$$\frac{m({}^{12}C\ \text{atom})}{12} = 1.66 \times 10^{-27}\,\text{kg}$$

α-particle = 4.032u

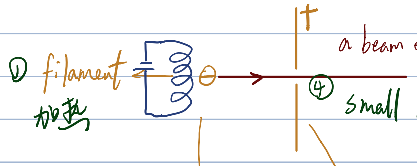
${}^{1}_{1}H$ = 1.007825u

${}^{17}_{8}O$ = 16.999132u

# 3.1.2 Electron beam (cathod ray)

## I. Generation of electron beam —— electron gun 电子枪

② 因热溢出产生电子 (thermionic emission)



④ small hole restrict the direct of electron beam

cathode 阴极　anode 阳极

$\underbrace{\text{cathode 阴极 \quad anode 阳极}}$

③ e accelerate
匀强场

步骤 ① thermionic emission : release of electrons from metal surface due to negative
② electrons are accelerated between cathode and anode

free electron in metal will escape by obsorbing energy by obsorbing energy by

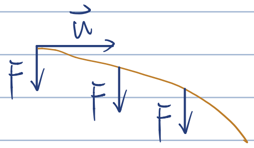
{ photon —— photoelectric effect
{ thermal energy —— thermionic emission

## II. handle the electron beam

1. electron as particle

a. electric field

$\vec{F_E} \perp \vec{u}$
$\downarrow$
$\begin{cases} S_\perp = ut \\ S_{/\!/} = \frac{1}{2}at^2 \end{cases}$



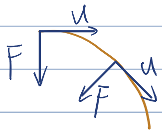
强核力 → 强相互作用　质子与中子间的相互作用

① 短程　0 $\underset{\text{排斥}}{\text{———}}$ $0.8\times10^{-15}$ m $\underset{\text{吸引}}{\text{———}}$ $1.5\times10^{-15}$ m
$\downarrow$
② 饱和性

③ 与电荷无关

b. magnetic field

$\vec{F_B} \perp \vec{u}$ (初速度)　$\vec{F_B} = \vec{B}\times(e\vec{v}) \perp \vec{v}$
$\downarrow$
circular motion



2. electron as wave

light { wave : diffraction . interference
light { particle : 光电效应

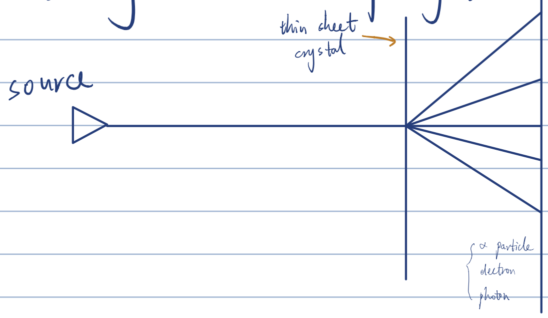
① particle - wave duality

$E \xleftarrow{E=hf} f$
$p \xrightarrow{\lambda=\frac{h}{p}} \lambda$

只限光子用 $p=\frac{E}{c}$
photon

momentum of photon $p=\frac{h}{\lambda}=\frac{h}{\frac{c}{f}}=\frac{hf}{c}=\frac{E}{c}$

② Study structure of crystal



wave matter electron { particle : ionization
wave matter electron { wave : electron diffraction

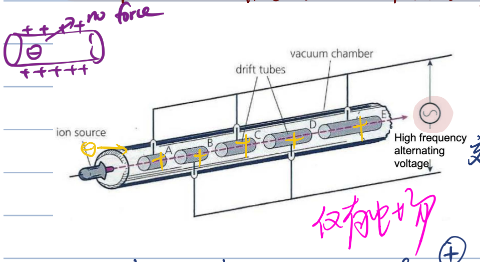
electron bean $V\uparrow \rightarrow d\uparrow \rightarrow$ diffraction $\downarrow \rightarrow \lambda\downarrow$

$\lambda = \frac{h}{p} = \frac{h}{mv}$

# 3.2 Particle study

## 3.2.1 accelerator 加速器

### I. linac (linear + accelerator) 线性加速器



① particles accelerated between tubes $W = VQ$ $W_{total} = \overset{\text{经过 gap 数}}{n} VQ$

② constant velocity of particle in the tube $E=0 \rightarrow F_{electric}=0 \rightarrow V=0$

交流电源：① 产生电势差 → 提供电场 → 粒子在gap中可加速

② 改变磁场方向 → 使粒子不停地加速

Explain the motion of ⊕ ion in linac

#### 1. the motion in tube 匀速直线运动

$\Delta V = 0$ (metal is equal potential object)

$E = \frac{\Delta V}{\Delta d}$

↓

没有电场 $E=0$

↓

$F_E = 0$

↓

move with constant velocity

电场中加速度公式

$\Delta V q = \Delta KE$

∴与tube间距无关

#### 2. the motion in gap between 2 tube 加速运动

A.B之间有势差 $\Delta V \neq 0$

↓

$E \neq 0$

↓

$F_E \neq 0$

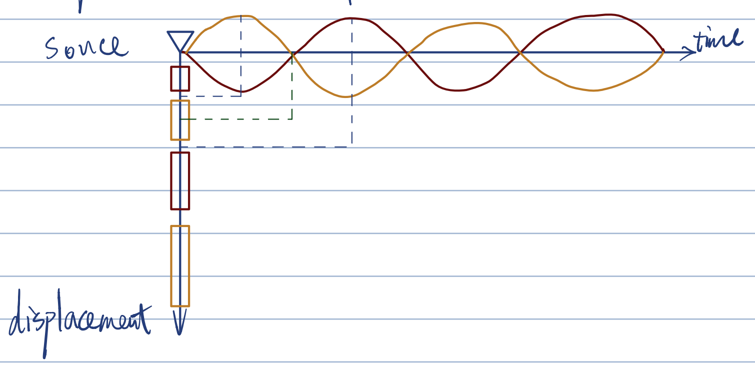
$V \uparrow \leftarrow F_E$ 与 $V$ 同向 ← next tube opposite polarity (back tube same polarity)

↑

E/V reverse when particle in tube ($t_{tube\ motion} = t_{p.d\ reverse}$)

#### 3. how to insure ion accelerate in each gap not decelerate

cooperate of motion of ion and switch of A.C



① 大小

gap: p.d two tubes max

tube: p.d two tubes =0

② 方向

accelerate in the gap

↓

tube ahead is positive (if ⊖)

↓

time for one tube = T of p.d reverse = $\frac{1}{2}$ A.C

#### 4. why tube length increases?

$t_{in\ each\ tube}$ is the same

↓

$V_{particle} \uparrow$

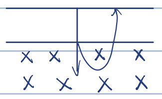
$l = vt$ ↓ (在tube中做匀速运动)

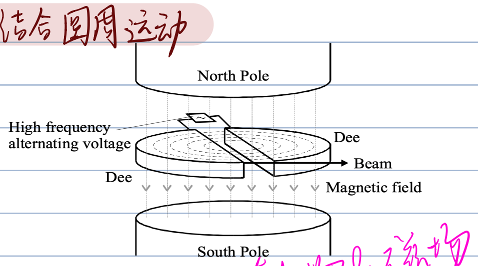
$tube\ length \uparrow$

#### 5. 为什么最后管子长度不变

$V_{particle} \approx V_{light} \xrightarrow{\Delta E = \Delta mc^2} E_{gain}$ convert into $M_{particle}$

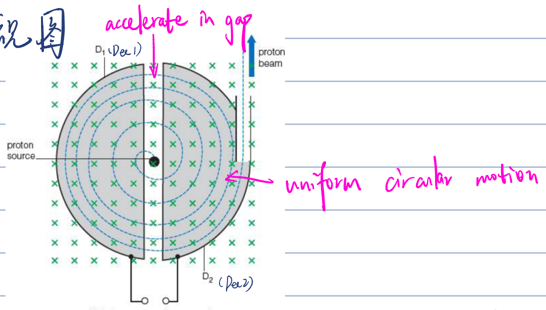
## Ⅱ. Cyclotron →结合圆周运动





有电场&磁场

俯视图



∵粒子速度快

explain the motion proton in cyclotron

改变大小：电场
改变方向：磁场

### 1. In dees with magnetic field 圆周运动

$\vec{F} = \vec{B} \times (q\vec{v})$

$B \perp \vec{v}$
↓
$F \perp \vec{v}$
↓
circular motion

$r = \frac{mv}{Bq}$ $F_c = F_B = \frac{mv^2}{r} = Bqv$ $r = \frac{mv}{Bq}$ $f = \frac{1}{T} = \frac{Bq}{2\pi m}$ (频率) $T = \frac{2\pi r}{v} = \frac{2\pi \frac{mv}{Bq}}{r}$

time spent in dee $\frac{T}{2} = \frac{\pi m}{Bq}$

**role of magnetic field:** moving charge experience a magnetic force
- force perpendicular to direction of v motion
- force provides centripal force
- cause the particle deflected into a circular path

所有金属都是等势体，场强处处为0

### 2. In gap with Electric Field 加速

E
↓
F
↓
a
↓
v

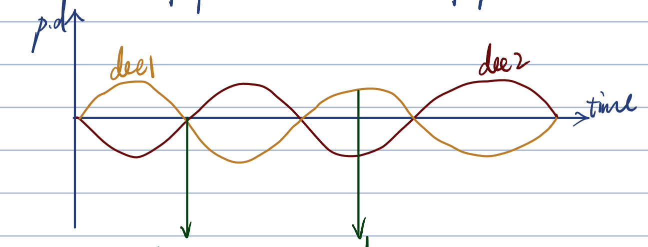
$Vq = \Delta KE$

$v\uparrow$ ← $F_E$与v同向 $\xleftarrow[\text{after passing a dee}]{\text{v方向 reverse (half a circle)}}$ E/ V reverse when particle in dee
($t_{\text{dee motion}} = t_{\text{p.d reverse}}$)

**role of electric field:** there is a "electric field" between 2 dees
charged particle experience a force in the electric field
charged particle accelerates

### 3. How to ensure particle accelerate each time when it comes into gap

① motion of particle & switch of p.d



p.d=0
proton在(Dee2)dees中间

p.d>0
positive in gap

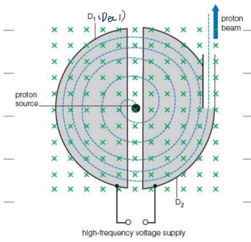
②方向

accelerate everytime when particle in gap
↓ direction of v reverses every half circle

p.d reverse　half a circle

$T_{A.C} = T_{circle}$

$f_{A.C} = f_{circle}$



解释路径 { accelerate { E ② In gap, E → F → a
A.C not D.E proton在dees中间 → p.d reverse → $T_{pd} = T_{circular\ motion}$
spiral { circular motion ① In dee, B⊥v → $F_B \perp v$ → circular motion
$r\uparrow$　$v\uparrow \xrightarrow{r=\frac{mv}{Bq}} r\uparrow$

# Ⅲ. Sychrotron

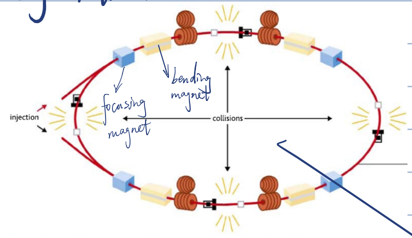


fig. 3.2.6 The Large-Electron-Positron Collider at CERN, near Geneva, is a 27 km synchrotron.

~~1. $v\uparrow \to B\uparrow \xrightarrow{r=\frac{mv}{Bq}} r$ constant~~

~~2. $\Delta KE$ Vs $v$~~
~~无上限 有限 ($3\times10^8$)~~
~~$\frac{1}{2}mv^2$ (当v达到极限. $E\uparrow \xrightarrow{E=\frac{1}{2}mc^2} m\uparrow$)~~
~~When speed close to speed of light.~~
~~Energy increased, transfer to mass increased.~~

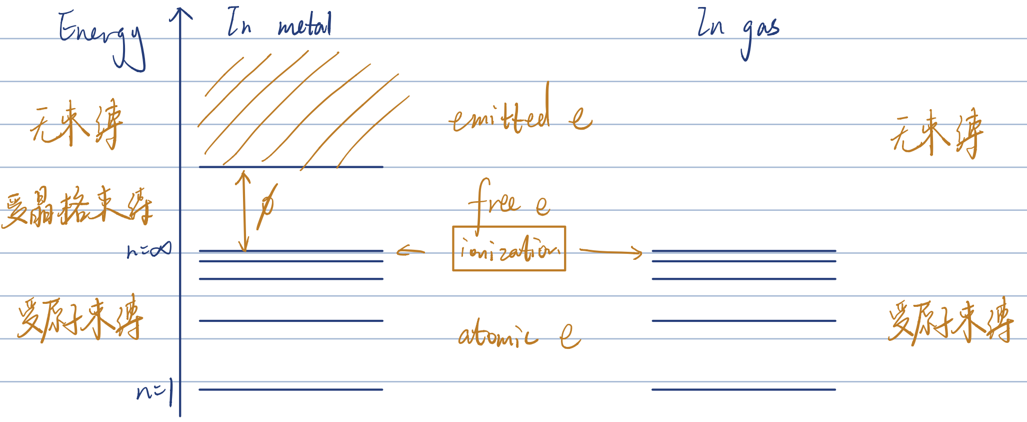
~~3. $m\uparrow$, B? E?~~
~~fixed r. $m\uparrow \longrightarrow$ { $B\uparrow \Leftarrow F_c\uparrow$~~
~~E稜 $f\downarrow$~~

3.2 particle study
- accelerator
  - linac
  - syclotron
  - syncrotron
- detector
  - ionization — imaging
  - B
- analyse
  - ___ → ___
  - ___ →
  - ___ → ___
  - ___ → ___

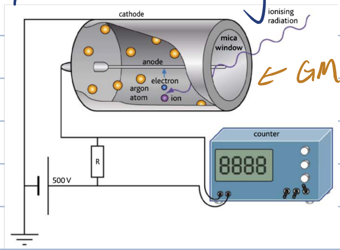
# 3.2.2 Particle detector and Particle analysis

## I. Principle of detection

Ionization



## II. Particle-counting detector



↓

仅显示通过的粒子数

count rate $= \frac{\Delta N}{\Delta t}$

① high energy particle will ionize argon atom in tube

② E

↓

e accelerate to anode

& ionized to cathod

越高 辐射越强 reflect light be photoed

## III. Tracing detector

1. Ionization → visible 观测电子

the created particle after collision

ionization of …

① Clould Chamber

ionization of air atoms

↓

tiny liquid water droped

② bubble chamber

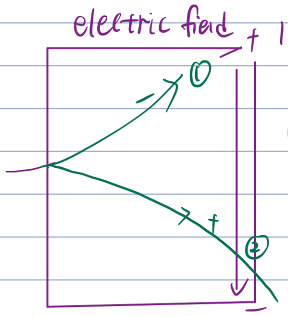
ionization of $H_2$ (in liquid)

↓

tiny gas bubble produced → only charged particle can leave track

because charged particle can cause ionisation → 产生path

∴仅可探测不带电的粒子



liquid hydrogen

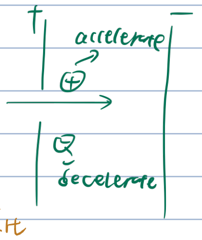
path: { ① sign of charge.

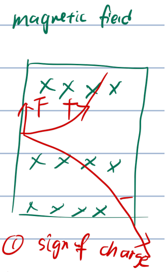
② $F = EQ = ma.$

$\frac{m}{Q} = \frac{E}{a}.$

↑

通过偏转程度判断(q)核质比





① sign of charge

② $r = \frac{mv}{Bq}$

$= \frac{p}{Bq}.$

2. magnetic field - Analyse

$B \perp v$

↓

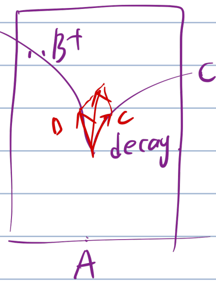
$F \perp v$

↓

move in curve/spirial/arc ☆需予证明Q相等

direction of curvature ↙ ↘ $r = \frac{P}{Bq}$ size of curvature

polarity of charge momentum



$A^0 = B^+ + c^-$

① no track

② charge conservation

momentum conservation

$\vec{P_A} = \vec{P_B} + \vec{P_C}$

mass-energy conservation.

# IV. Analysing

1. momentum 的变化

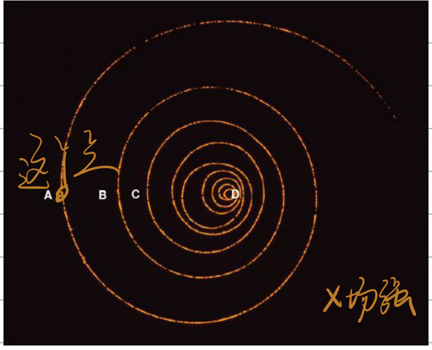
ionization 电离

↓

ΔKE↓

↓

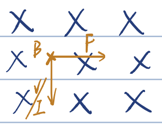
P↓



粒子运动从A→B→C→D

2. Direction of motion  半径变小

3. Polarity of charge



V与I相同为⊕

V与I相反为⊖

## 1. Conclusion : what can you get from pictures

① direction of motion

ionize $H_2$

↓

lose E↓

$E_k = \frac{P^2}{2m}$ ↓

P↓

$r = \frac{P}{Bq}$ ↓

r↓/ size of curvature ↑

② Charge of curvature

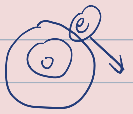
- no track

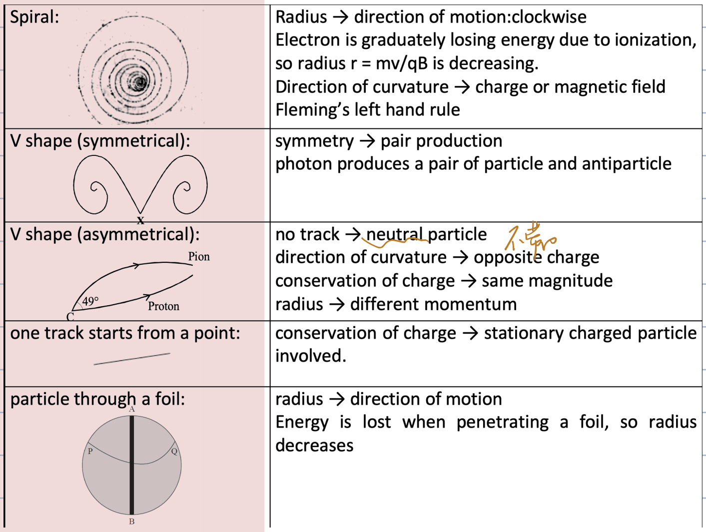
no speed / no charge

- Direction of curvature

↓LHR

Sign of charge





| | |
|---|---|
| Spiral: | Radius → direction of motion:clockwise<br>Electron is graduately losing energy due to ionization, so radius r = mv/qB is decreasing.<br>Direction of curvature → charge or magnetic field<br>Fleming's left hand rule |
| V shape (symmetrical): | symmetry → pair production<br>photon produces a pair of particle and antiparticle |
| V shape (asymmetrical): | no track → neutral particle 不带<br>direction of curvature → opposite charge<br>conservation of charge → same magnitude<br>radius → different momentum |
| one track starts from a point: | conservation of charge → stationary charged particle involved. |
| particle through a foil: | radius → direction of motion<br>Energy is lost when penetrating a foil, so radius decreases |

动量大小. 方向
charge
运动

→ 运动信息. 本质属性

③ Momentum

size of curvature ↓/ r↑

↓ $r = \frac{P}{Bq}$ . same q

P↑

④ Use of conservation law (at shape change points)

con of P
con of Q (电荷)
con of E

## ☆2. What information should pay attention

① Size of curvature { with time
with another particle

$$r \xrightarrow[\text{same size of } q]{r=\frac{P}{Bq}} P$$

{ ionization
speed

② track (no track / has track)

charged, high energy particle ionize □ atom as it pass

↓

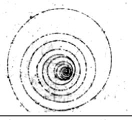
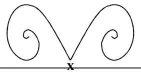
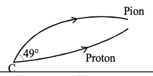
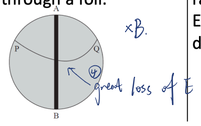
gather as □ gas

↓

reflect light

③ direction of curvature

④ Sharp changed point: 粒子相互作用ing { con of Q
con of P

| | |
|---|---|
| Spiral:  | Radius → direction of motion:clockwise<br>Electron is graduately losing energy due to ionization, so radius r = mv/qB is decreasing.<br>Direction of curvature → charge or magnetic field<br>Fleming's left hand rule |
| V shape (symmetrical):  | symmetry → pair production<br>photon produces a pair of particle and antiparticle |
| V shape (asymmetrical):  | no track → neutral particle 不带电<br>direction of curvature → opposite charge<br>conservation of charge → same magnitude<br>radius → different momentum |
| one track starts from a point:  | conservation of charge → stationary charged particle involved. ← ④ ☆ |
| particle through a foil:  | radius → direction of motion<br>Energy is lost when penetrating a foil, so radius decreases |

①small ① 有轨迹 无轨迹 ③ ☆④

# 3.3 Particle physics

## 3.3.1 mass-energy equation

1. 宇宙最初状态 充满巨大能量的一个点

2. Energy 与mass 的互换

3.

Energy → matter. (made of atoms)

$$E = mc^2$$

J ↙ ↓ kg ↘ $ms^{-1}$

### I. Creation and annihilation

Creation : pair production $\gamma \rightarrow e^- + e^+$ $hf = 2mc^2 + KE$

$$(\text{pure energy})\ \Delta E \underset{\text{annihilation}}{\overset{\text{Creation}}{\rightleftharpoons}} c^2 \Delta m\ (\text{mass of matter})$$

Creation ↙ $E \rightarrow m$

annihilation ↘ $m \rightarrow E$

annihilation : particle meets its antiparticle. they will immediately vanish and convert equivalent energy $e^- + e^+ \rightarrow 2\gamma$ $2mc^2 + KE = 2hf$

歼灭

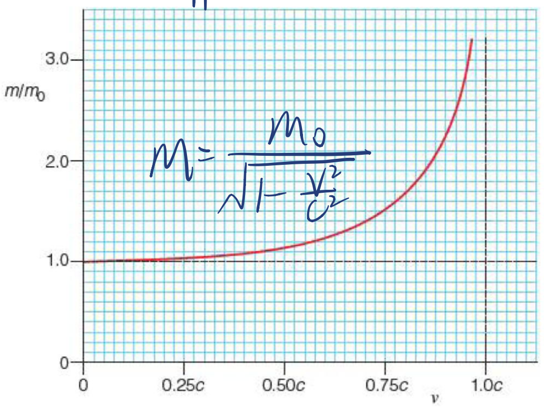
antiparticle : all properties expect mass are opposite 除了mass 其它性能相反

反粒子

ep. $p \rightarrow \bar{p}$ $n \rightarrow \bar{n}$ $e^- \rightarrow e^+$

antiphoton position

### II. Relativistic effect : when $v \rightarrow c$. $m > m_0$ (rest mass)



$$M = \frac{m_0}{\sqrt{1 - \frac{v^2}{c^2}}}$$

粒子 v 接近 $v_{light}$ 时，速度不变，m 增加

$$E\uparrow \rightarrow \begin{cases} v\uparrow \\ m\uparrow \end{cases}$$

### III Conservation law

1. everyday world $\begin{cases} \text{con of } E \\ \text{con of } m \end{cases}$

2. sub-atomic world : con of m-E

3. new unit of mass : $MeV/c^2$
   $E = mc^2$

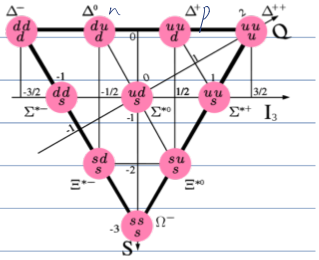
$$\begin{cases} \text{KE守恒} & KE = \frac{1}{2}mv^2 \\ \text{photoenergy} & E = hf \\ \text{质量守恒} & E = mc^2 \end{cases}$$

mass unit: kg u $MeV/c^2$

| | 1kg | 1u | $1MeV/c^2$ |
|---|---|---|---|
| 1kg | 1 | | |
| 1u | $= 1.66 \times 10^{-27}kg$ | 1 | |
| $1MeV/c^2$ | $= \frac{1.6 \times 10^{-13}}{(3 \times 10^8)^2}$<br>$= 1.78 \times 10^{-30}$ | | 1 |

$$1MeV/c^2 = 1.78 \times 10^{-30} kg$$

- fundamental particle (no internal structure)
  - ferminions
    - quark 6个 (strong nuclear force 强合力) 无法独立存在
      - [illegible]
      - I. $u < d$
      - II. $c > s$
      - III. $t > b$
      - $+\frac{2}{3}e$  $-\frac{1}{3}e$
      - →
        - $\bar{u}$  $\bar{d}$
        - $\bar{c}$  $\bar{s}$
        - $\bar{t}$  $\bar{b}$
        - $-\frac{2}{3}e$  $+\frac{1}{3}e$
    - lepton 6个 (no strong nuclear force) 无法独立存在
      - I. $e^-$  $\nu_e$ nutrino
      - II. $\mu$  $\nu_\mu$
      - III. $\tau$  $\nu_\tau$ Tau nutrino
      - $e^-$  0
      - →
        - position $e^+$  $\bar{\nu}_e$ antinutrino
        - $\bar{\mu}$  $\bar{\nu}_\mu$
        - $\bar{\tau}$  $\bar{\nu}_\tau$
        - $e^+$  0
  - bosons
    - $\gamma$
    - Gauge boson –
      - strong
      - week
      - magnetic
- composited (Hadron) quark 的复合物
  - baryon
    - $\Delta$ (S=0) (p) uud (n) udd
    - $\Sigma$ (S=1) uds
    - $\Xi$ (S=2)
    - $\Omega$
  - meason
    - Pion (0S): $u\bar{u}$ ($\pi^0$)  $d\bar{d}$ ($\pi^0$)  $u\bar{d}$ ($\pi^+$)  $\bar{u}d$ ($\pi^-$)
    - Koan (1S): $u\bar{s}$ ($k^+$)  $\bar{u}s$ ($k^-$)  $d\bar{s}$ ($k^0$)  $\bar{d}s$ ($k^0$)
    - Eta (2S): $s\bar{s}$ ($\eta^0$)
  - ...



## 3.3.2 The standard model

### I. Standard model

a. theory concerning the electromagnetic, weak, and nuclear interaction, as well as classifying all the subatomic particle known.

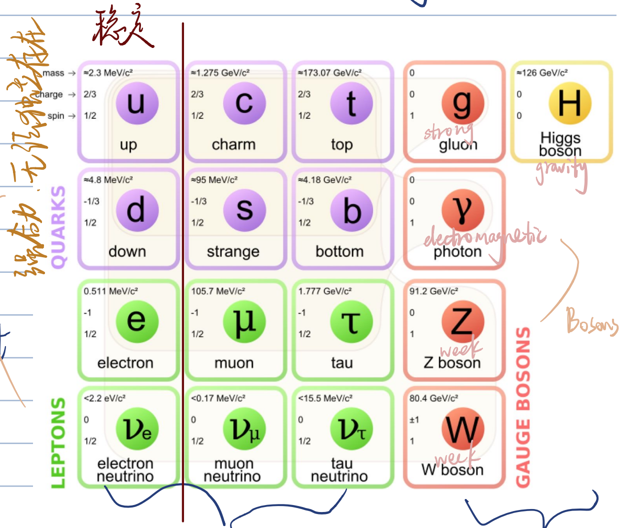
① Fundamental interaction 基本相互作用

- gravitational ~
- electromagnetic ~
- strong ~
- weak ~

② Fundamental particles: 17 particles can not be split

a. Fermions: matter particles (构成物质)

- 6个 quarks: undergo strong nuclear force
- 6个 leptons: Not feel the strong force, can occur singly



matter carries

force carrier

12 fundamental particle (no internal structure)

(fermions)

quark 6个 (strong nuclear force 强合力)
无法独立存在

| | | | | | |
|---|---|---|---|---|---|
| I. | u | d | → | $\bar{u}$ | $\bar{d}$ |
| II. | c | s | | $\bar{c}$ | $\bar{s}$ |
| III. | t | b | | $\bar{t}$ | $\bar{b}$ |
| | $+\frac{2}{3}e$ | $-\frac{1}{3}e$ | | $-\frac{2}{3}e$ | $+\frac{1}{3}e$ |

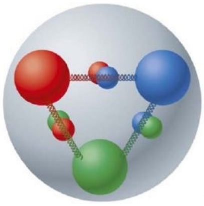
lepton 6个 (no strong nuclear force)
无法独立存在

| | | | | | |
|---|---|---|---|---|---|
| I. | $e^-$ | $\nu_e$ | | $e^+$ | $\bar{\nu}_e$ |
| II. | $\mu$ | $\nu_\mu$ | → | $\bar{\mu}$ | $\bar{\nu}_\mu$ |
| III. | $\tau$ | $\nu_\tau$ | | $\bar{\tau}$ | $\bar{\nu}_\tau$ |
| | $e^-$ | 0 | | $e^+$ | 0 |

↑ position

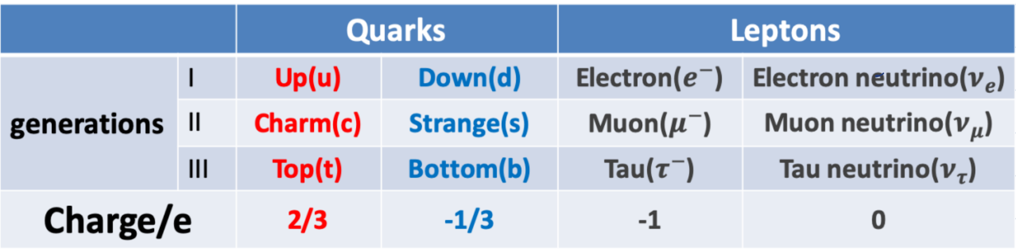
b. Bosons: force carries (力的载体)

- 1个 Higgs boson — gravity
- 4个 Gauge boson —
  - strong
  - week
  - magnetic

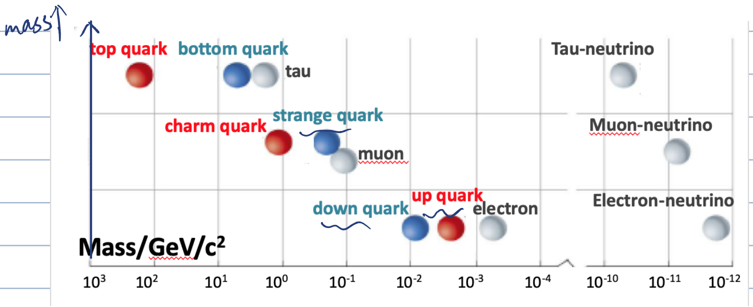


← 通过粒子间的转换产生力

### II. 12 individual femions: group (charges) & generation (mass)



| | | Quarks | | Leptons | |
|---|---|---|---|---|---|
| generations | I | Up(u) | Down(d) | Electron($e^-$) | Electron neutrino($\nu_e$) |
| | II | Charm(c) | Strange(s) | Muon($\mu^-$) | Muon neutrino($\nu_\mu$) |
| | III | Top(t) | Bottom(b) | Tau($\tau^-$) | Tau neutrino($\nu_\tau$) |
| Charge/e | | 2/3 | -1/3 | -1 | 0 |



generation 1

generation 2

generation 3

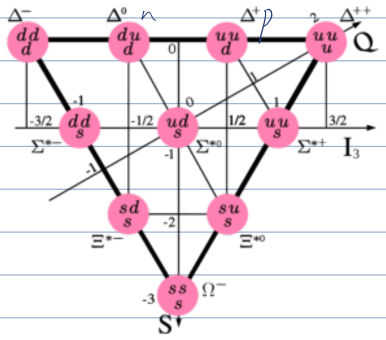
## Ⅲ. Composite particles (combine of quarks)

Hadrons : composite particles made of quarks held together by strong force

* always based on lightest 3 : U. D. S
( particle 越重越不稳定 )

1. Baryons : composite particles made of 3 quarks or antiquarks
重子

Different groups based on the number of S
ep. neutrons (udd) protons (uud)



| | |
|---|---|
| 0S | Δ |
| 1S | Σ |
| 2S | Ξ |
| 3s | Ω |

* all baryons has its 反粒子 ep. antineutron $(\bar{u}\bar{d}\bar{d})$

2. Mesons : made by a quark & an anti-quark

| | | | | |
|---|---|---|---|---|
| Pion (0S): | $u\bar{u}$ ($\pi^0$) | $d\bar{d}$ ($\pi^0$) | $u\bar{d}$ ($\pi^+$) | $\bar{u}d$ ($\pi^-$) |
| Koan (1S): | $u\bar{s}$ ($k^+$) | $\bar{u}s$ ($k^-$) | $d\bar{s}$ ($k^0$) | $\bar{d}s$ ($k^0$) |
| Eta (2S): | $s\bar{s}$ ($\eta^0$) | | | |

## 3.3.3 Conserved properties in nucear reactions

### I. Nuclear reaction at different level

1. recombination of baryons

ep: α-decay: $^{235}_{92}U \longrightarrow ^{231}_{90}Th + ^{4}_{2}\alpha$

2. recombination of quarks

ep. β-decay: $^{14}_{6}C \longrightarrow ^{14}_{7}N + ^{0}_{-1}\beta + ^{0}_{0}\bar{V}e$

Q₁: How nuclear reaction in lower base levels?

| | $\beta^-$-decay | $\beta^+$-decay |
|---|---|---|
| nuclear level: | $^{14}_{6}C \longrightarrow ^{14}_{7}N + ^{0}_{-1}\beta + ^{0}_{0}\bar{V}e$ | $^{13}_{7}N \rightarrow ^{13}_{6}C + ^{0}_{+1}e + ^{0}_{0}Ve$ |
| baryon level: | $\underset{(udd)}{^{1}_{0}n} \rightarrow ^{1}_{1}p + ^{0}_{-1}e + ^{0}_{0}\bar{V}e$ | $^{1}_{1}p \rightarrow ^{1}_{0}n + ^{0}_{+1}e + ^{0}_{0}Ve$ |
| quark level: | $d \longrightarrow u + ^{0}_{-1}e + ^{0}_{0}\bar{V}e$ | |

Q₂: Why $\underset{\downarrow}{\text{must}}$ be these? What restrict the reaction?

### II. Conservation laws restrict reaction

1. Restrict the motion

$$\begin{cases} \text{con of mass-energy} \rightarrow \text{大小} \\ \text{con of } P \rightarrow \text{方向} \end{cases}$$

2. Restrict the matter (反应物)

- con of Q
- con of baryon (B) → each baryon: B = +1
  - each quark: B = $+\frac{1}{3}$  $B_{anti} = -\frac{1}{3}$
  - each meson: B = 0
- con of lepton number: L
- con of strangeness: S  each strange quark: S = -1 (一般不用)

↘ $^{A}_{Z}X$

* each antiparticle has opposite properties (Q. B. L. S)

$e^+$: -1

| | symbol | Q | B | L | | symbol | Q | B | L |
|---|---|---|---|---|---|---|---|---|---|
| proton | $\Delta^+$ | +1e | +1 | 0 | Electron | $e^-$ | -1e | 0 | +1 |
| neutron | $\Delta^0$ | 0 | +1 | 0 | Electron nutrino | $V_e$ | 0 | 0 | +1 |
| neutral pion | $\pi^0$ | 0 | 0 | 0 | Muon | $\mu$ | -1e | 0 | +1 |
| pi-plus | $\pi^+$ | +1e | 0 | 0 | Muon nutrino | $V_\mu$ | 0 | 0 | +1 |
| down quarks | d | $-\frac{1}{3}e$ | $+\frac{1}{3}$ | 0 | Tau | $\tau$ | -1e | 0 | +1 |
| Xi-minus | $\Xi^-$ | -1e | +1 | 0 | Tau nutrino | $V_\tau$ | 0 | 0 | +1 |

ep

$$d \longrightarrow u + ^{0}_{+1}\beta + ^{0}_{0}\bar{V}_e$$

| | | | | | | |
|---|---|---|---|---|---|---|
| Q | $-\frac{1}{3}$ | $\neq$ | $\frac{2}{3} + 1 + 0$ | | Q isn't conserved |
| B | $\frac{1}{3}$ | $=$ | $\frac{1}{3} + 0 + 0$ | | B is conserved |
| L | 0 | $\neq$ | $0 - 1 - 1$ | | L isn't conserved |

$E = \frac{2hc}{\lambda}$