物理学中具有里程碑意义实验

现代物理前沿

散 射

1908年 E.Rutherford，英国物理学家提出了原子的核式模型获得诺贝尔奖

1927康普顿发现康普顿效应获诺贝尔物理学奖

1935年 J.Chadwick，英国物理学家，因发现了中子获得诺贝尔奖。

1938年 E.Fermi，意大利物理学家发明了热中子链式反应堆，获得诺贝尔奖。。

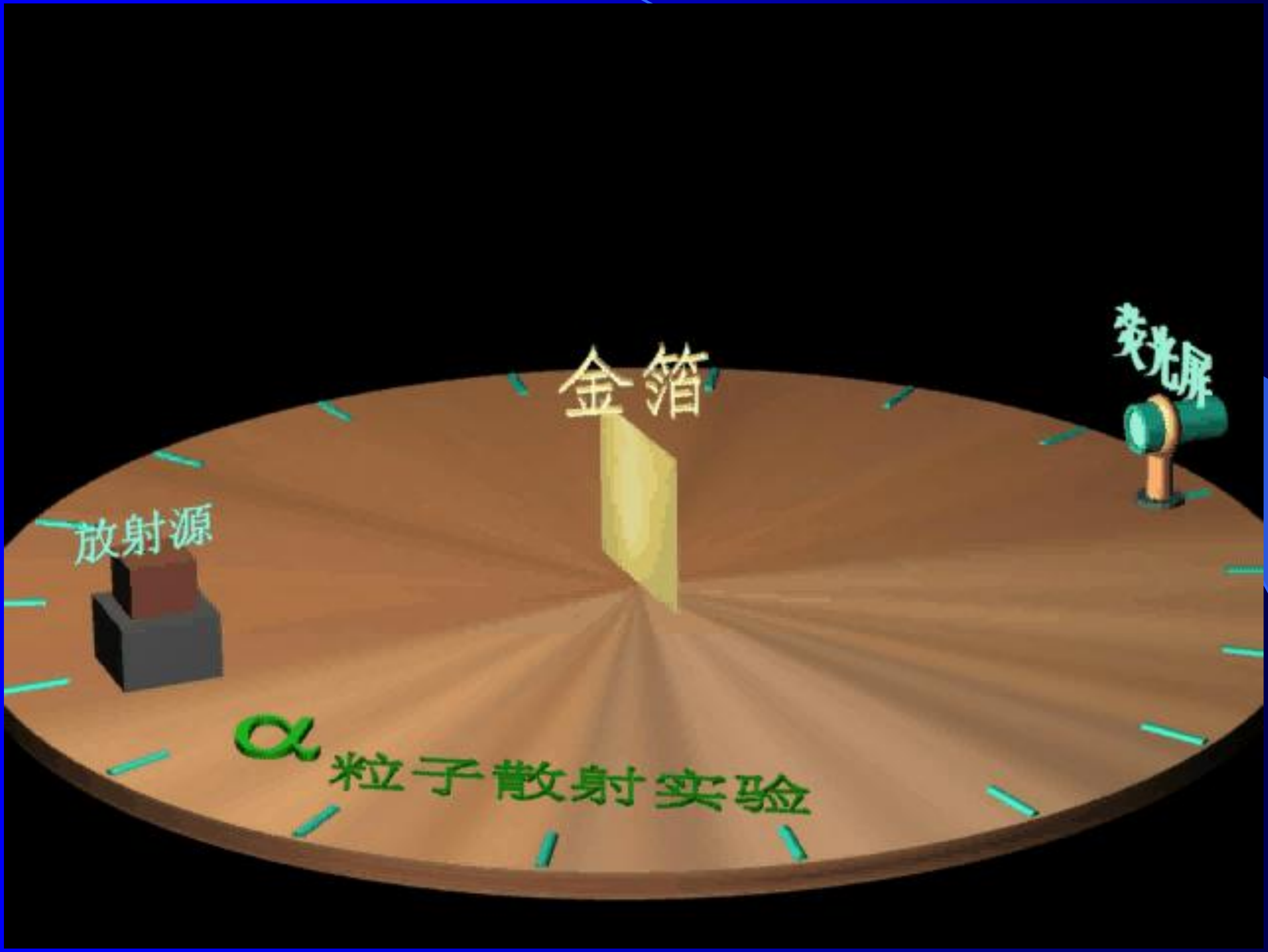
1976丁肇中分别发现J／ψ粒子年获诺贝尔奖。

数万亿个质子以每秒1.1245万次的频率急速穿行，速度接近光速。两束质子束分别以70000亿电子伏特的相向而行，在功率达到140000亿电子伏特时发生碰撞。每秒总共能发生大约6亿次撞击。

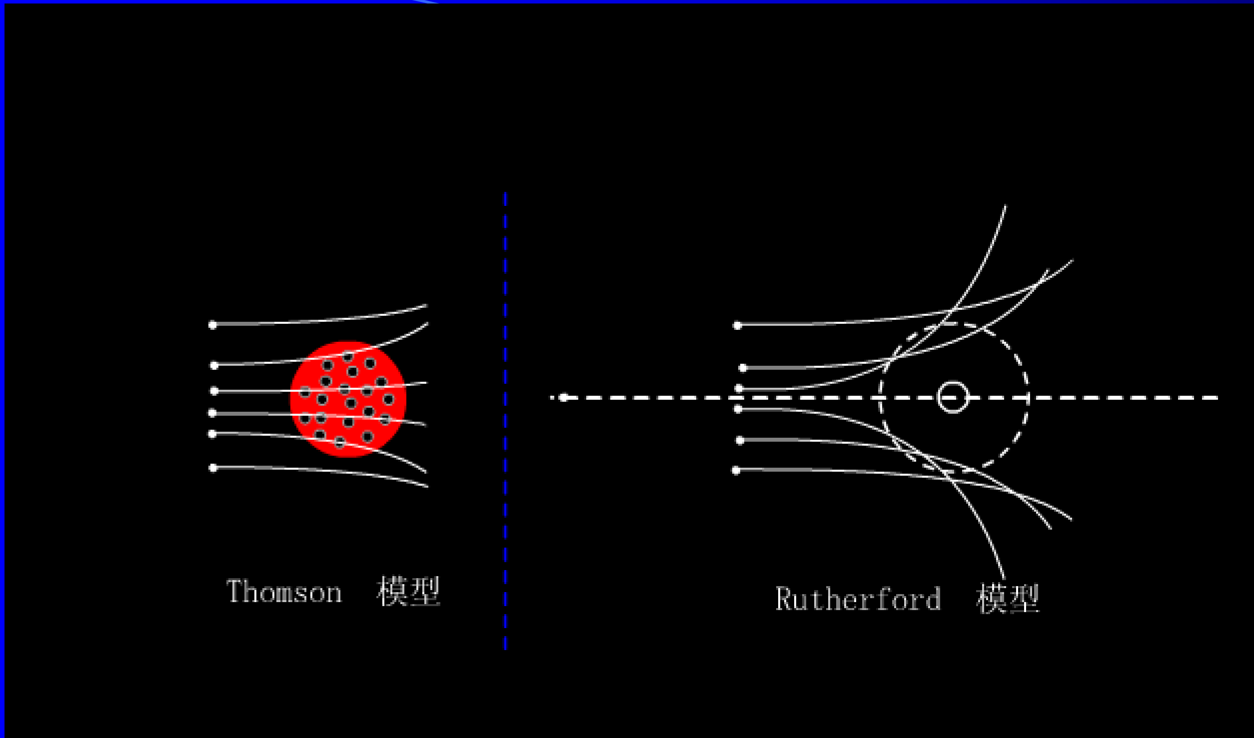
寻找标准模型预言的希格斯粒子

创造夸克-胶子等离子体，
模拟宇宙“大爆炸”

撞击时产生的高温是太阳内部温度的10万倍

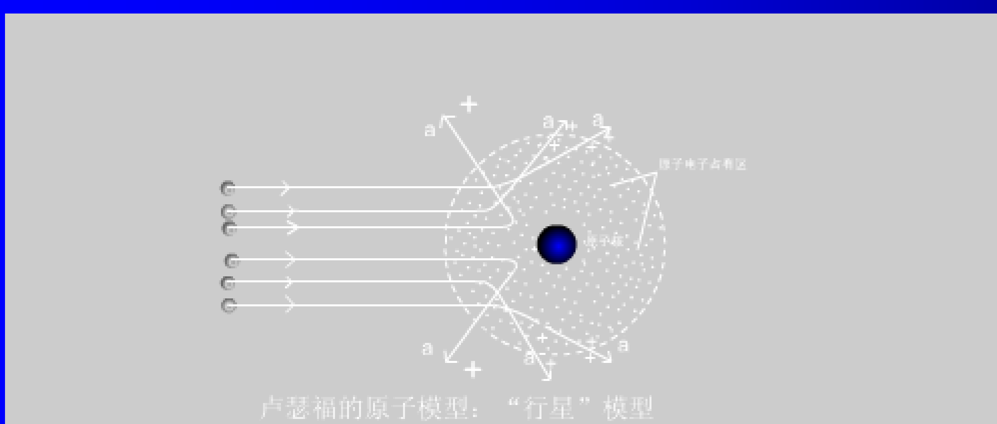


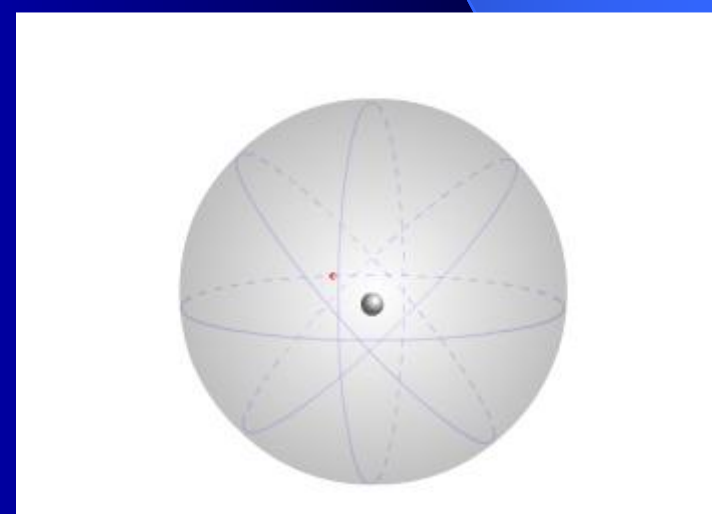
金箔
荧光屏
放射源
α粒子散射实验



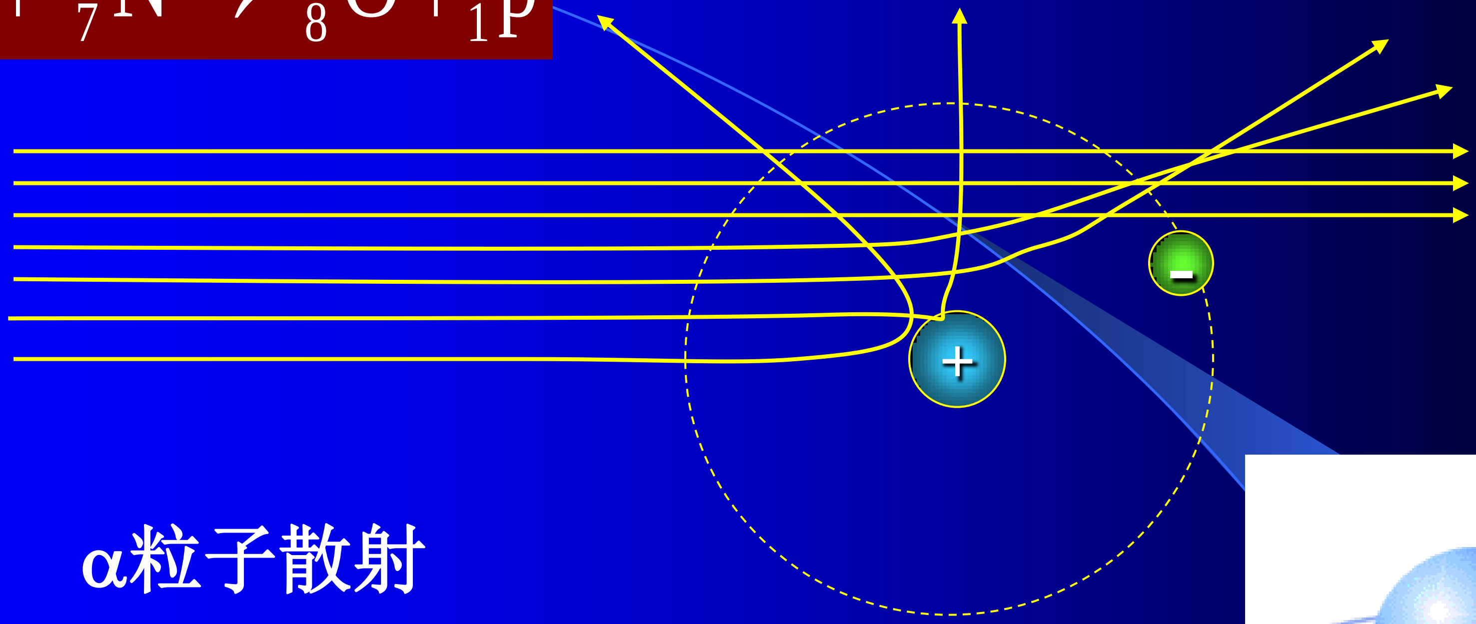
Rutherford模型

原子的核式模型：

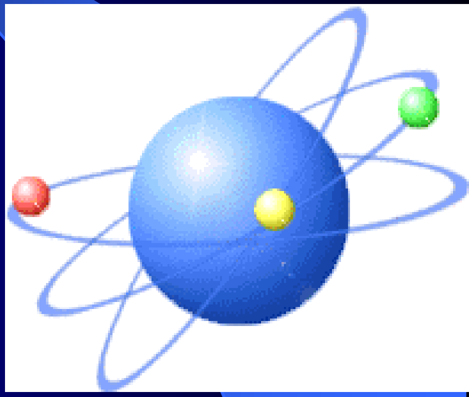




$${}_{2}^{4}He+{}_{7}^{14}N\rightarrow{}_{8}^{17}O+{}_{1}^{1}p$$



α粒子散射



原子的核式模型：

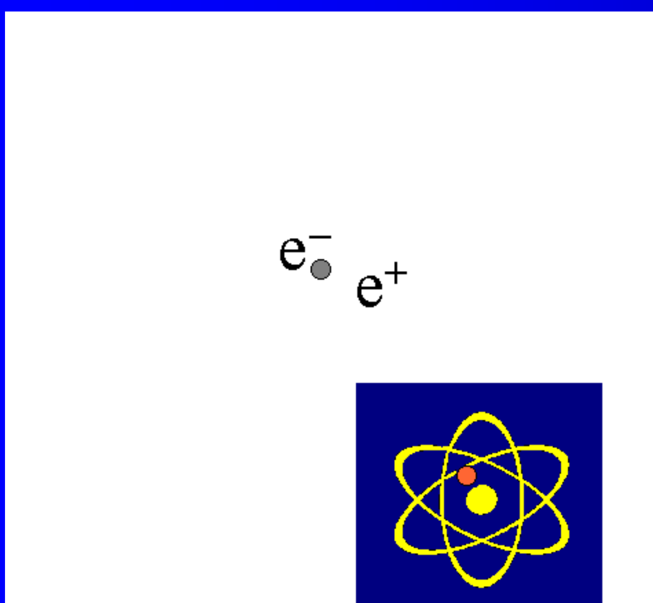
原子由原子核和核外电子构成，原子核带正电荷，占据整个原子的极小一部分空间，而电子带负电，绕着原子核转动，如同行星绕太阳转动一样。

中子发现

1932年，物理学家查德威克发现了其质量同质子相当的中性粒子，这正是1920年卢瑟福猜想原子核内可能存在的一种中性的粒子，即中子。他因此获1935年诺贝尔物理学奖。

$$^{9}_{4}Be+^{4}_{2}He \longrightarrow ^{12}_{6}C+^{1}_{0}n$$

物质	能量密度（焦耳/kg）
TNT	4.7×10^{6}
裂变(100%)	7.1×10^{13}
聚变(100%)	7.5×10^{14}
正电子	1.8×10^{17}



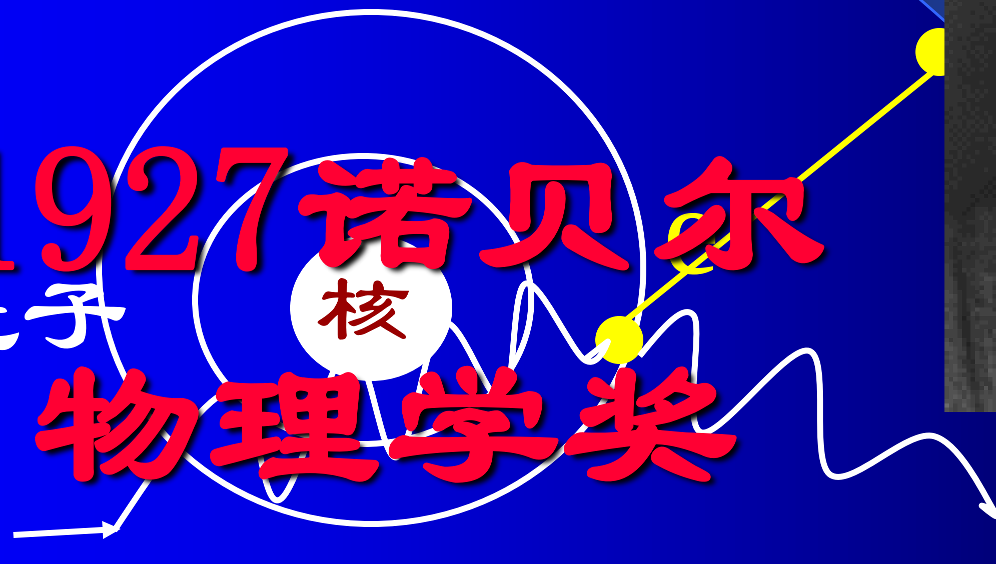
$$e^{+} + e^{-} \Rightarrow 2\gamma$$

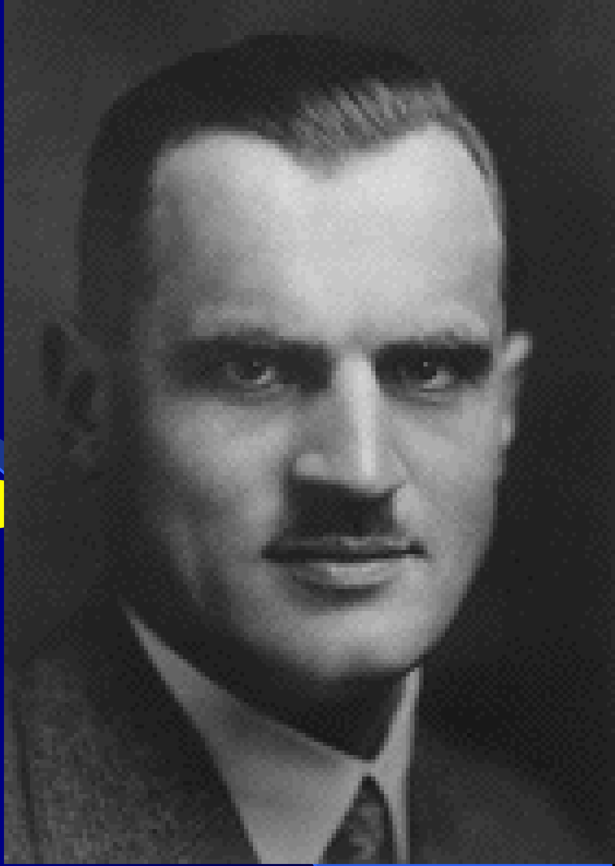
$$\Downarrow$$

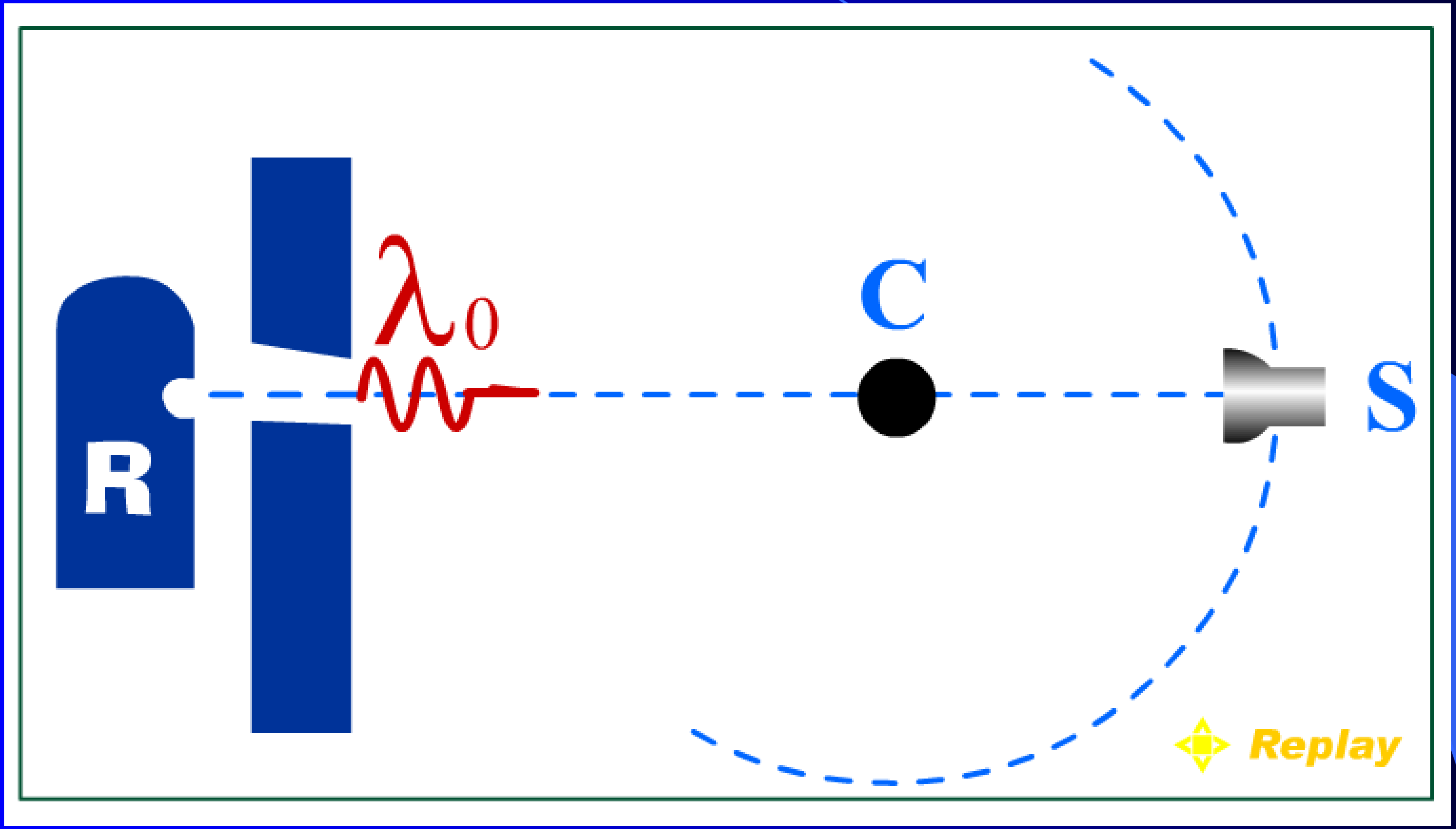
相对论性质能转换过程

康普顿效应

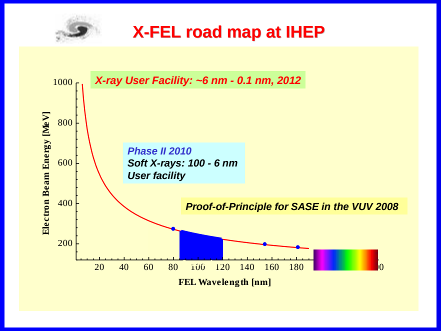
1927诺贝尔物理学奖



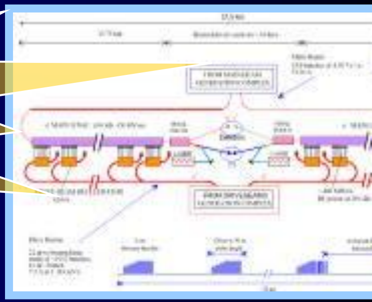



R
λ_0
C
S
Replay

北京正负电子对撞机



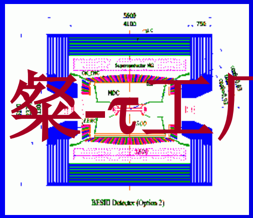
直线对撞机国际合作



XFEL

试验束和慢正电子

高增益自由电子激光装置



粲-τ工厂

散裂中子源和ADS

核技术产业化

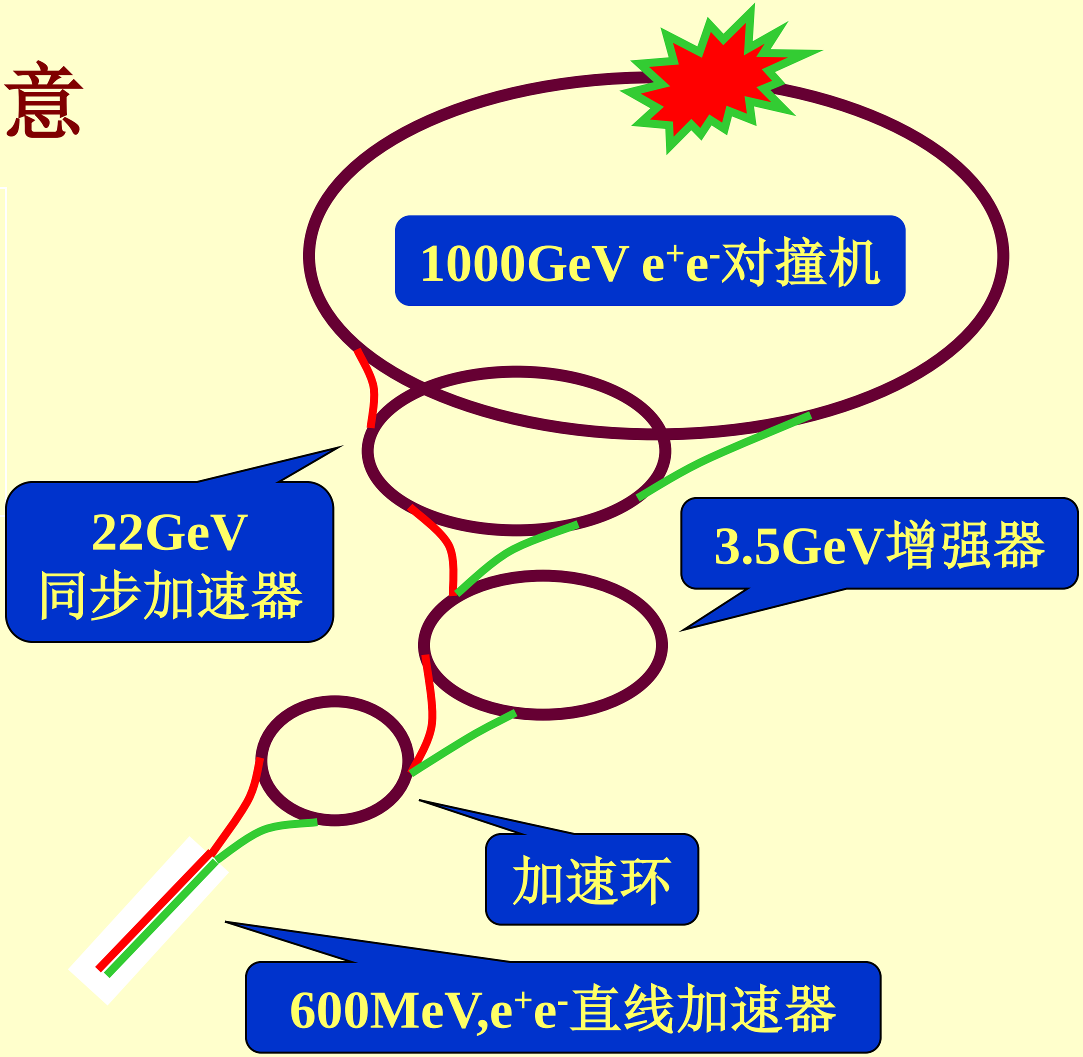
同步辐射工厂

2. 对撞机组成示意

近几十年，加速器的能量每10年提高一个量级，加速器的尺寸由数米增加到数十公里。

美国的LEP加速器是目前能量最高的加速器：

- 最高能量：1000 GeV
- 周长：27 km

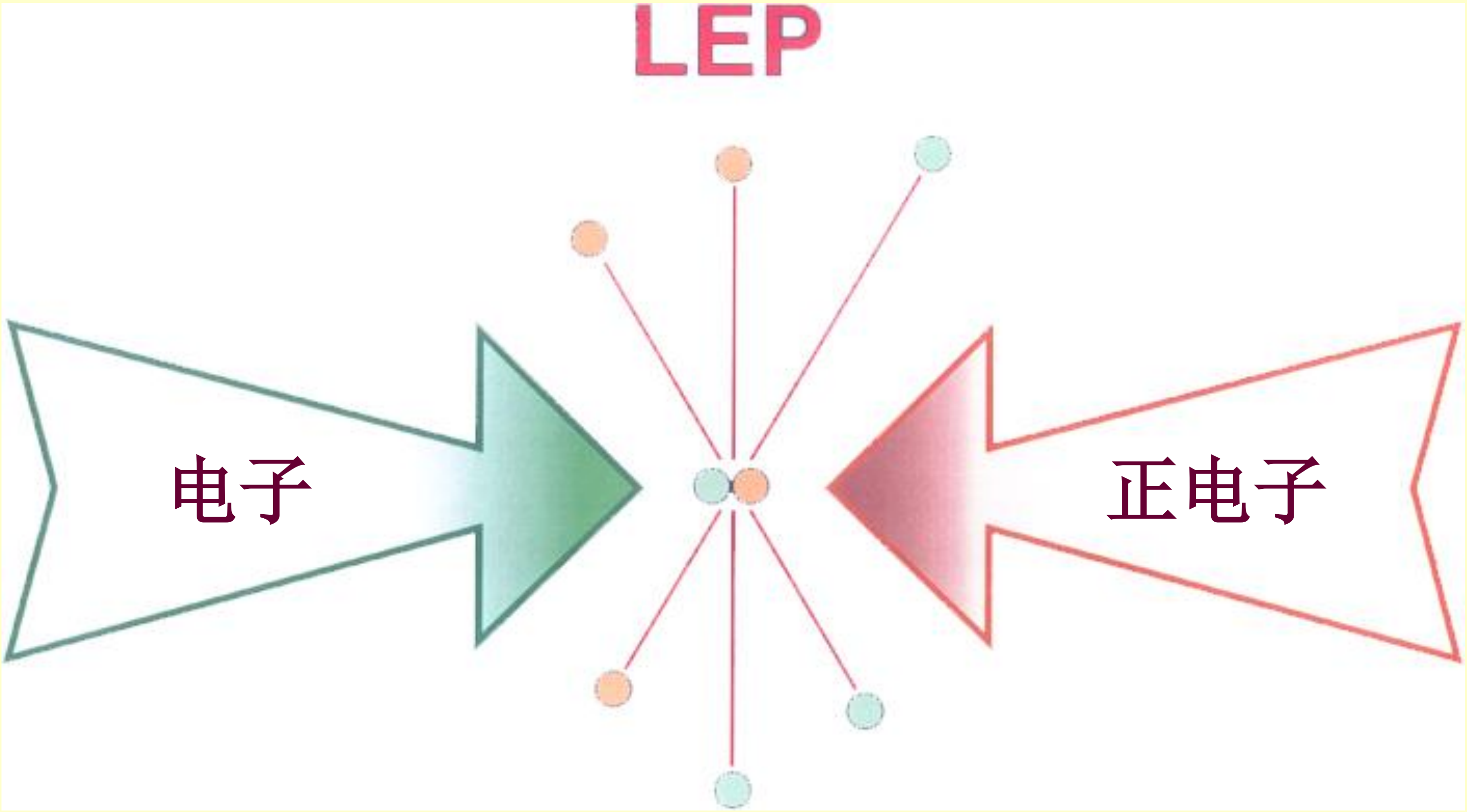


北京正负电子对撞机

正负电子在对撞机里相向高速回旋、对撞，探测对撞产生的“碎片”——次级粒子并加以研究，就能了解物质微观结构的许多奥秘。

图 21-8

对撞机

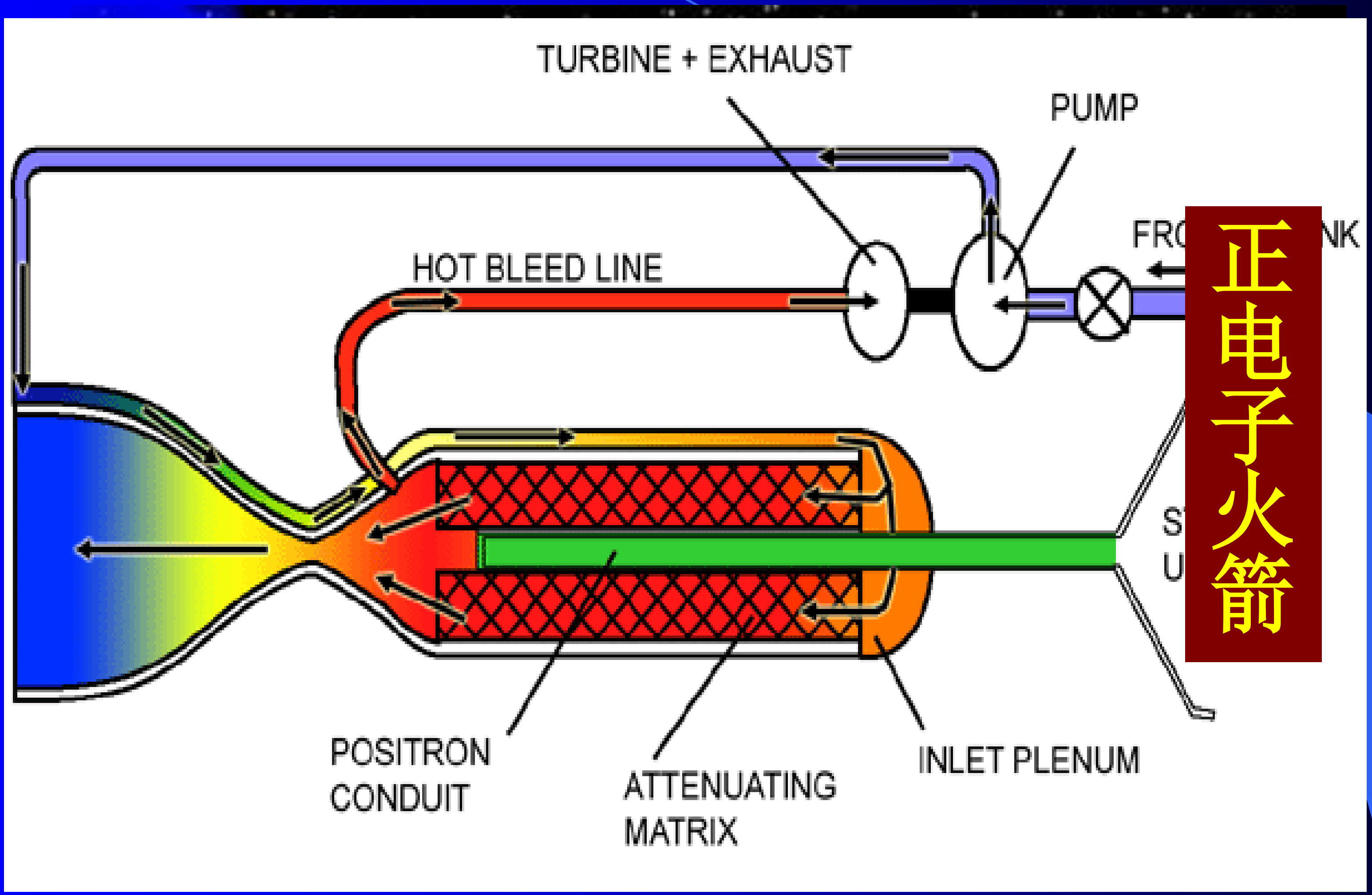


对撞机模拟环境：温度是太阳表面温度的4×10^{11}倍
宇宙诞生的最初的10^{-19}秒

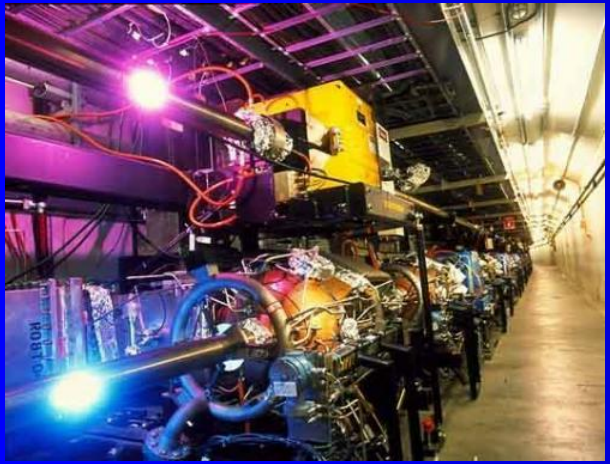
KEK,Japan

Brookhaven Nat’l Lab相對論性重離子碰撞器RHIC利用金原子核形成的光束，以幾近光速的高速相互碰撞，結果碰撞時產生的高熱火球，行為類似黑洞。

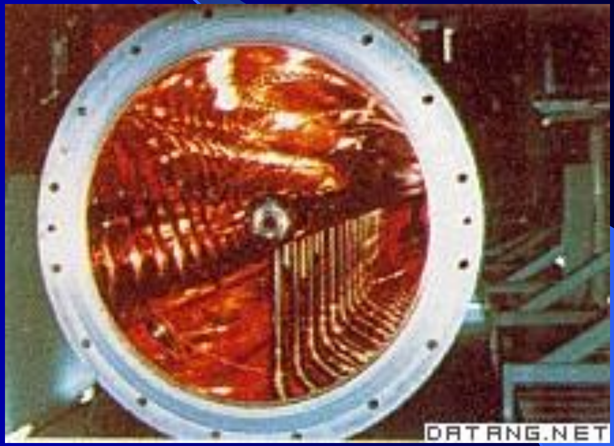
未来新能源


TURBINE + EXHAUST
PUMP
HOT BLEED LINE
正电子火箭
POSITRON
CONDUIT
ATTENUATING
MATRIX
INLET PLENUM

美国斯坦福大学的斯坦福直线加速器中心(Stanford Linear Accelerator Center，简称SLAC)所建造的粒子加速器，用作研究物质与反物质的分别。科学家将电子光束(蓝色)和正电子(粉红色)光束放在不同的圆管，然后观察它们相撞所引致的光束偏差(deflection)和分裂(disruption)。



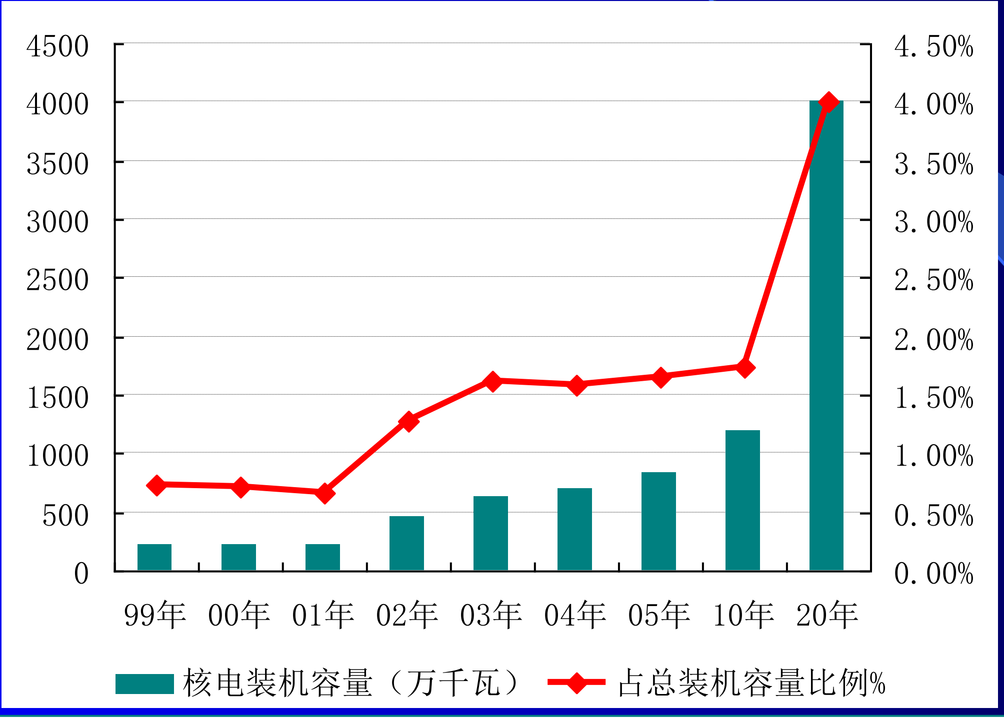
美国斯坦福大学的斯坦福直线加速器中心(Stanford Linear Accelerator Center，简称SLAC)所建造的粒子加速器



中国科学院高能物理研究所35 MeV质子直线加速器的加速腔

核电起步

核电装机容量及占比趋势



资料来源:中电联、中信建投证券研究所整理

核电战略

"十五"
"适当发展核电"

"十一五"
"积极发展核电"

我国已建、在建及拟建核电站

核电站	容量MW	并网日期
秦山一期	300	91.12
大亚湾-1	900	93.8
大亚湾-2	900	94.2
秦山二-1	600	02.2
岭澳-1	984	02.4
岭澳-2	984	02.11
秦山三-1	720	02.12
秦山三-2	720	03.6
秦山二-2	600	04.3
田湾一1	106	06.5

规划项目	容量（万千瓦）
浙江三门健跳	6*100
浙江三门扩塘山	4*100
广东阳江	6*100
广东台山腰古	6*100
大连温垛子	4*100
山东烟台海阳	6*100
山东乳山红石顶	6*100
江苏连云港田湾	8*100
福建惠安	6*100
合计	5200

厂址	容量	预计并网日期
江苏田湾-2	106万千瓦	06年底
秦山二期扩建	2台共130万千瓦	2011年
岭澳扩建	2台共200万千瓦	2010年
浙江三门	2台共200万千瓦	2010年后
广东阳江	2台共200万千瓦	2010年后

目前，我国核电装机容量681.4万千瓦，占总装机容量的1.36%

第四章　　经典散射

§1. 碰撞的特征及分类

动力学特征

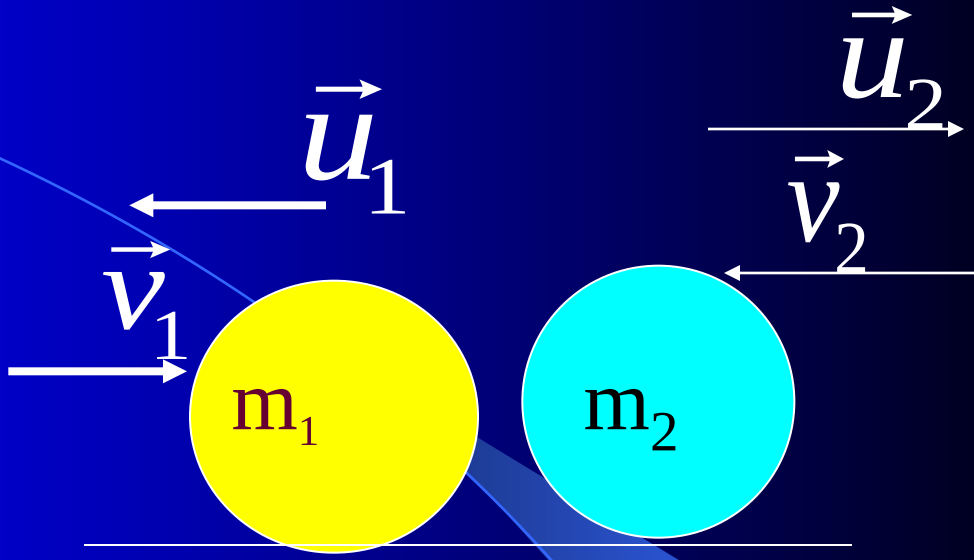
- 时间极短 ⇒ 不考虑位移
- 相互作用冲量很大 ⇒ 动量守恒
- 碰撞前后总能量守恒
  但机械能不一定守恒
- 碰撞前后总质量守恒

碰撞的分类

- 碰撞的后果
  - 弹性碰撞
  - 非弹性碰撞
  - 完全非弹性碰撞
- 相对速度方向
  - 正碰
    相对速度方向与公法线一致
  - 斜碰
    相对速度方向与公法线不一致

正碰

- 碰前：$\vec{v}_1 \quad \vec{v}_2$
- 碰后：$\vec{u}_1 \quad \vec{u}_2$



$$m_1 v_1 + m_2 v_2 = m_1 u_1 + m_2 u_2$$

$$e = \frac{u_2 - u_1}{v_1 - v_2} = \frac{\text{恢复冲量}}{\text{压缩冲量}}$$

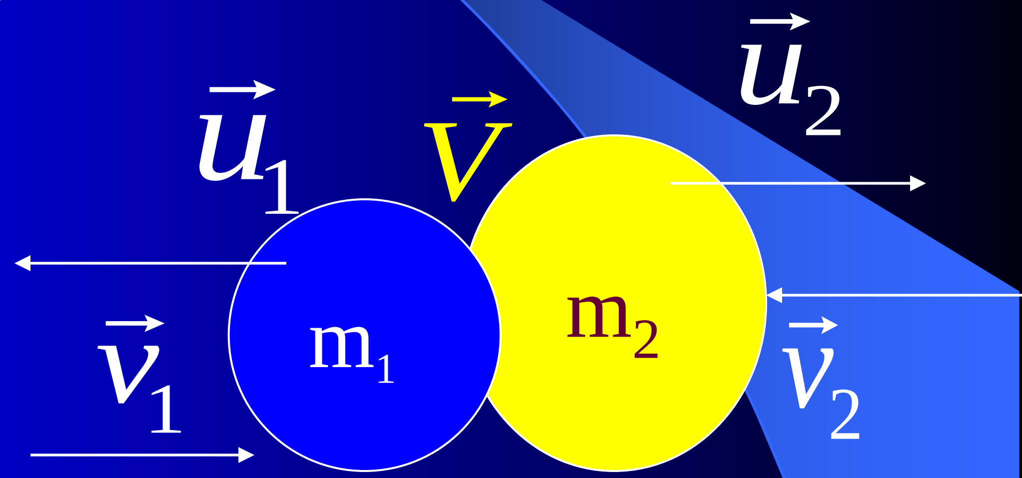
恢复系数

Attention:

公式中的量均为代数量!!!

- $e=1$ ⇒ 弹性碰撞
- $e=0$ ⇒ 完全非弹性碰撞
- $e<1$ ⇒ 非弹性碰撞

推导 $e=\dfrac{u_2-u_1}{v_1-v_2}$



压缩阶段

⇓

公共速度V

设压缩冲量I_1

$$I_1 = m_1(V - v_1) = -m_2(V - v_2) \quad \ldots(1)$$

$$I_1 = m_1(V - v_1) = -m_2(V - v_2) \quad \ldots(1)$$

$$v_1 = V - \frac{I_1}{m_1} \qquad v_2 = V + \frac{I_1}{m_2}$$

恢复阶段

设恢复冲量I_2

$$I_2 = m_1(u_1 - V) = -m_2(u_2 - V) \quad \ldots(2)$$

$$u_1 = V + \frac{I_2}{m_1} \qquad u_2 = V - \frac{I_2}{m_2}$$

$$v_1 = V - \frac{I_1}{m_1} \qquad v_2 = V + \frac{I_1}{m_2}$$

$$v_2 - v_1 = I_1\left(\frac{1}{m_1} + \frac{1}{m_2}\right)$$

$$u_1 = V + \frac{I_2}{m_1} \qquad u_2 = V - \frac{I_2}{m_2}$$

$$u_2 - u_1 = -I_2\left(\frac{1}{m_1} + \frac{1}{m_2}\right)$$

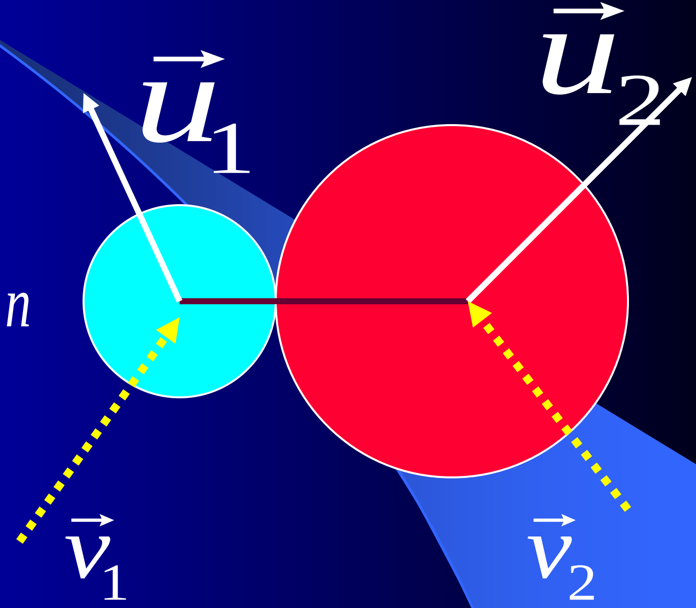
$$e = \frac{I_2}{I_1} = \frac{u_2 - u_1}{v_1 - v_2}$$

斜碰 $\begin{cases} \text{法线方向} \Longrightarrow \text{正碰} \\ \text{切线方向} \end{cases}$

法线方向

$$m_1 v_{1n} + m_2 v_{2n} = m_1 u_{1n} + m_2 u_{2n}$$

$$e = \frac{u_{2n} - u_{1n}}{v_{1n} - v_{2n}}$$



切线方向 $\begin{cases} \text{物体光滑} \Longrightarrow v_{1t} = u_{1t} \quad v_{2t} = u_{2t} \\ \text{物体非光滑} \quad m_1 v_{1t} + m_2 v_{2t} = m_1 u_{1t} + m_2 u_{2t} \end{cases}$

解决碰撞问题的注意点

- 恢复系数e正确应用
- 刚体的碰撞 $\left\{\begin{array}{l}\text{质心的平动} \\ \text{绕质心的转动}\end{array}\right.$
- 质心的平动 ⇒ 质 心 冲 量 定 理

$$\vec{I} = m\Delta\vec{V}_c$$

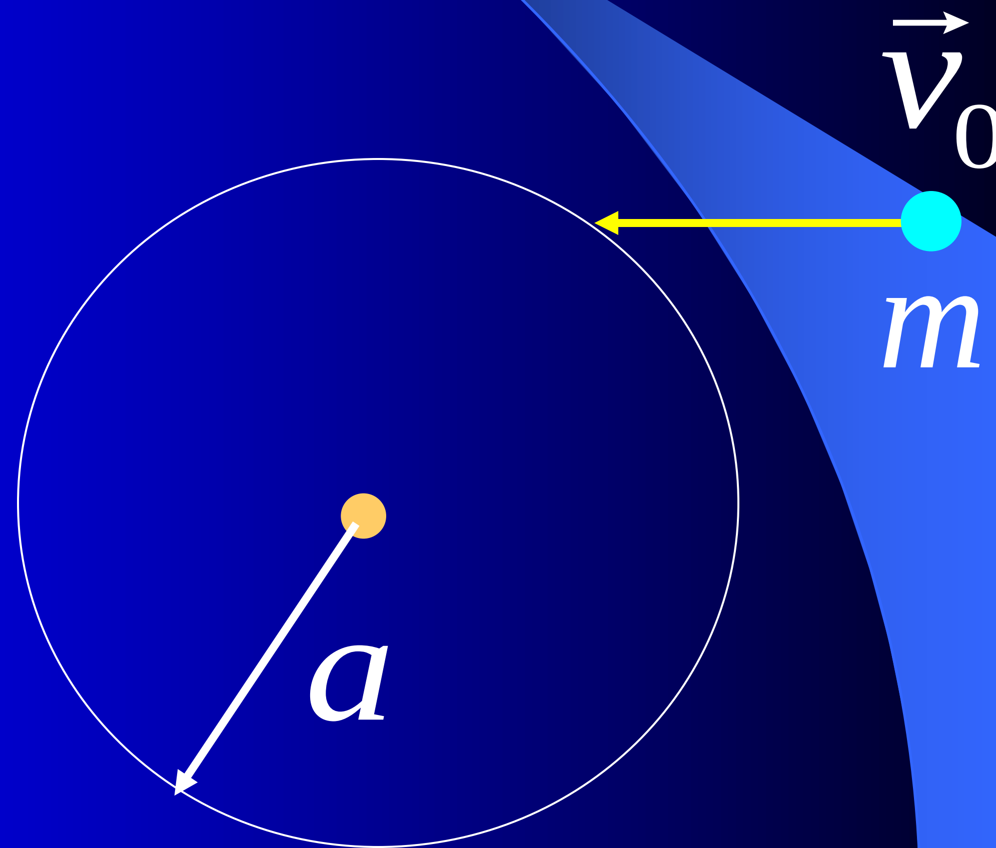
- 绕质心的转动

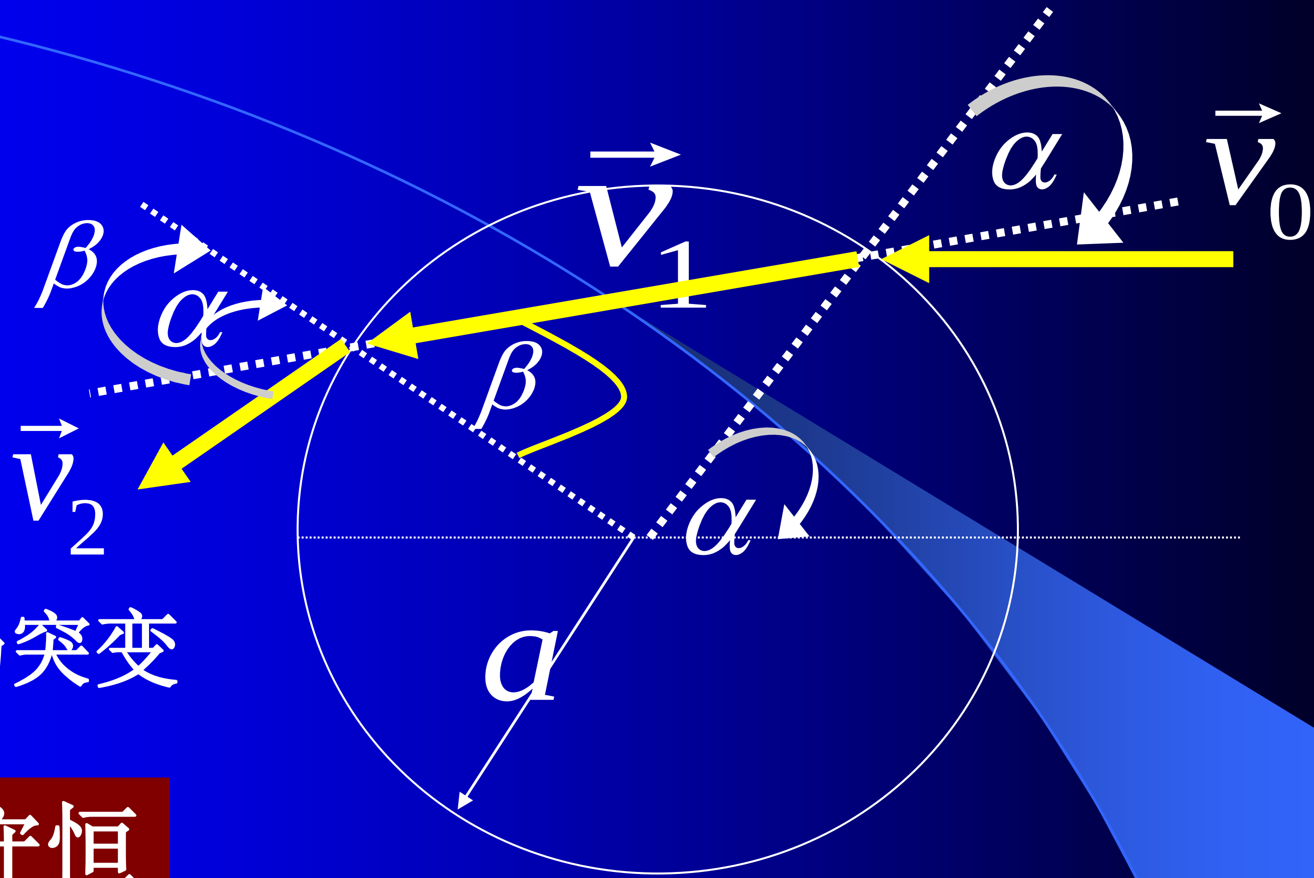
相 对 质 心 冲 量 矩 定 理

$$\vec{M} = \frac{d\vec{J}}{dt} \Rightarrow Mdt = I\Delta\omega$$

例一. 一粒子被球形势阱散射, 画出粒子出射方向

$$
V=\begin{cases} 0 & r > a \\ -V_0 & r \le a \end{cases}
$$





边界处势场突变

动量守恒

切线方向

$$\left.\begin{aligned} m v_0 \sin\alpha &= m v_1 \sin\beta \\ m v_2 \sin\alpha &= m v_1 \sin\beta \end{aligned}\right\} \Rightarrow \frac{\sin\alpha}{\sin\beta} = \frac{v_1}{v_2}$$

$$\frac{1}{2}mv_1^2 - V_0 = \frac{1}{2}mv_2^2 = E$$

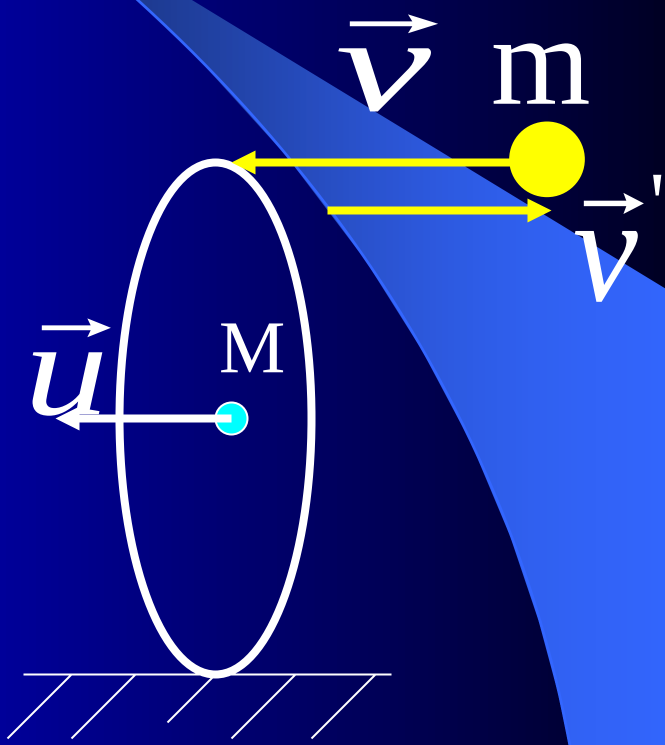
$$v_1 = \sqrt{\frac{2(E+V_0)}{m}} \qquad v_2 = \sqrt{\frac{2E}{m}}$$

$$\frac{\sin\alpha}{\sin\beta} = \frac{v_1}{v_2} = \sqrt{1+\frac{V_0}{E}} = n \Rightarrow$$

等效折射率

例一. 质量为M, 半径为r的匀质圆盘直立在光滑的水平面上, 在与环面垂直方向上受一质量为m速率为v的质点的冲击, 冲击点恰好在最高点, 证明:

$$v = \frac{\pi(3m+M)\sqrt{2gr}}{8m(1+e)}$$



圆盘恰好呈水平状落地

解: 第一阶段 ⇒ 碰撞过程

碰后 { 质心 ⇒ $\vec{u}$; 质点 ⇒ $\vec{v}'$ }

动量守恒

$$mv = Mu - mv' \qquad \ldots(1)$$

相对质心冲量矩定理

$$M\Delta\vec{v}_c = \vec{I} \Rightarrow M(u-0) = I$$

$$Ir = \frac{1}{2}Mr^2\dot{\theta} \qquad \ldots(2)$$

$$e=\frac{(u+r\dot{\theta})-(-v')}{v} \quad \ldots(3)$$

绝对速度和方向!!!

$$Mur=\frac{1}{2}Mr^2\dot{\theta}$$

$$\dot{\theta}=\frac{2u}{r} \quad \ldots(4)$$

$$mv=Mu-mv'$$

下一阶段的初始条件

$$u=\frac{mv(1+e)}{M+3m} \quad \ldots(5)$$

$$\dot{\theta}=\frac{2mv(1+e)}{(M+3m)r} \quad \ldots(6)$$

第二阶段 $\Rightarrow$ 圆环质心作平抛运动

圆环绕质心匀速转动

落地时间

$$\boxed{t = \frac{\pi/2}{\dot{\theta}}} \Leftarrow \dot{\theta} = \frac{2mv(1+e)}{(M+3m)r} \quad \ldots(6)$$

$$= \frac{\pi(3m+M)r}{4mv(1+e)} \quad \ldots(7)$$

$$v_{cy} = gt = \frac{\pi(3m+M)gr}{4mv(1+e)} \quad \ldots(8)$$

$$\frac{1}{2}Mu^2 + \frac{1}{2}I_c\dot{\theta}^2 = \cancel{\frac{1}{2}Mu^2} + \frac{1}{2}Mv_{cy}^2 + \frac{1}{2}I_c\dot{\theta}^2 - Mgr$$

$$t = \frac{\pi(3m+M)r}{4mv(1+e)}$$

$$v_{cy} = gt = \frac{\pi(3m+M)gr}{4mv(1+e)} \quad \ldots(8)$$

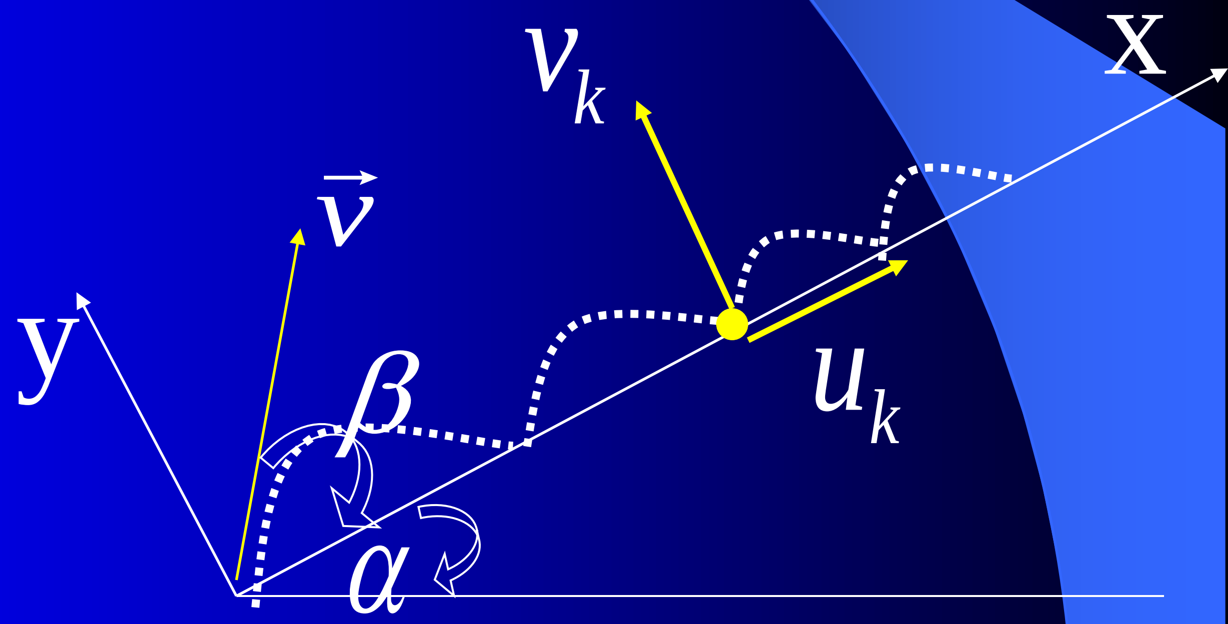
$$v = \frac{\pi(3m+M)\sqrt{2gr}}{8m(1+e)}$$

例三. 质量为m的质点在一倾角为α的斜面底部以一定初速且与斜面成β角方向发射, 如果经n次碰撞后回到原点, 证明:

demonstration

$$(1-e)ctg\alpha ctg\beta = 1-e^{n}$$

恢复系数



设第K次碰撞在A_k点,速度分别为$(\vec{u}_k, \vec{v}_k)$

$k \Rightarrow k+1 \Rightarrow$ 历经时间为t_{k+1}

$$v_k t_{K+1} - \frac{1}{2} g \cos\alpha \, t_{K+1}^2 = 0$$

$$t_{K+1} = \frac{2v_k}{g\cos\alpha} \quad \cdots\cdots(1)$$

从原点O到A_k所需时间T_k

$$T_k = t_1 + t_2 + t_3 + \cdots\cdots + t_k \quad \cdots\cdots(2)$$

$$= \frac{2(v_0 + v_1 + v_2 + \cdots\cdots v_{k-1})}{g\cos\alpha} \quad \cdots\cdots(2)$$

$$v_0, v_1, v_2, \ldots\ldots v_{k-1}$$

分别表示第一次第二次,........第k次碰撞前y方向的速度

第一次 ⇨ $v_0 = v\sin\beta$

$$e = \frac{v_1 - 0}{0 - (-v\sin\beta)} \Rightarrow v_1 = ev\sin\beta$$

第二次

$$e = \frac{v_2 - 0}{0 - (-v_1)} \Rightarrow v_2 = e^2 v\sin\beta$$

....

第k次 $e = \frac{v_k - 0}{0 - (-v_{k-1})}$ ⟹ $v_k = e^{k-1} v \sin\beta$

$$T_k = \frac{2v\sin\beta(1 + e + e^2 + e^3 + \ldots\ldots e^{k-1})}{g\cos\alpha} \quad \ldots\ldots(3)$$

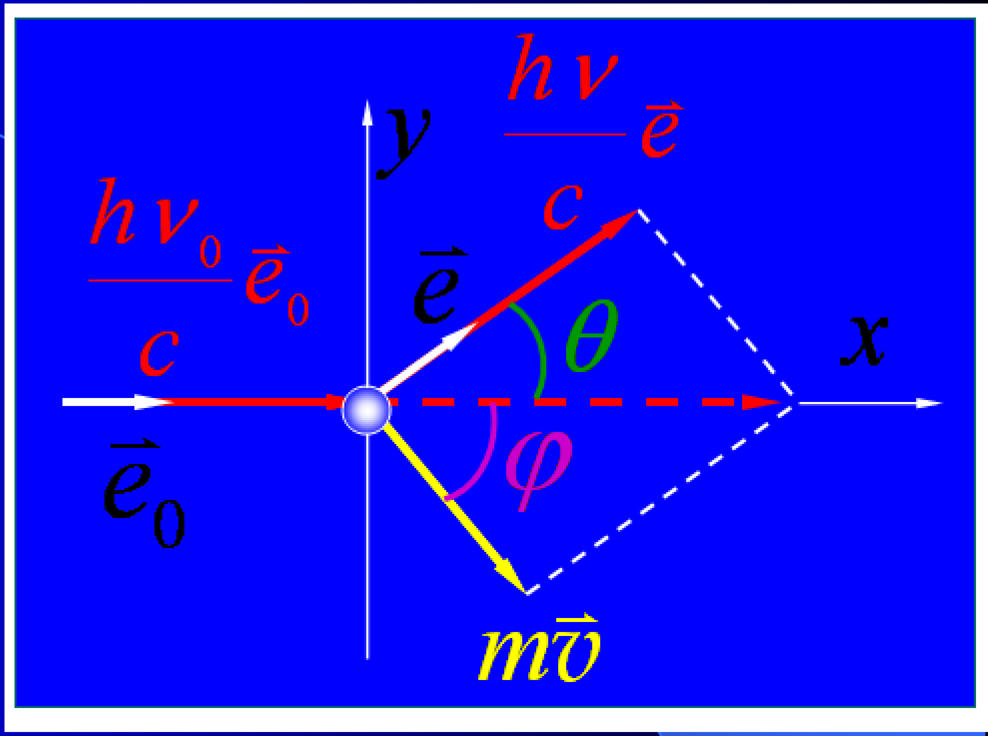
$$T_k = \frac{2v\sin\beta(1 - e^k)}{(1-e)g\cos\alpha} \quad \ldots\ldots(4)$$

令k=n

$$\overline{oA_n} = vT_n\cos\beta - \frac{1}{2}g\sin\alpha T_n^2 = 0$$

$$(1-e)ctg\alpha ctg\beta = 1 - e^n$$

康普顿效应



能量守恒

$$h\nu_0 + m_0c^2 = h\nu + mc^2$$

动量守恒

$$\frac{h\nu_0}{c}\vec{e}_0 = \frac{h\nu}{c}\vec{e} + m\vec{v}$$

$$m^2v^2 = \frac{h^2\nu_0^2}{c^2} + \frac{h^2\nu^2}{c^2} - 2\frac{h^2\nu_0\nu}{c^2}\cos\theta$$

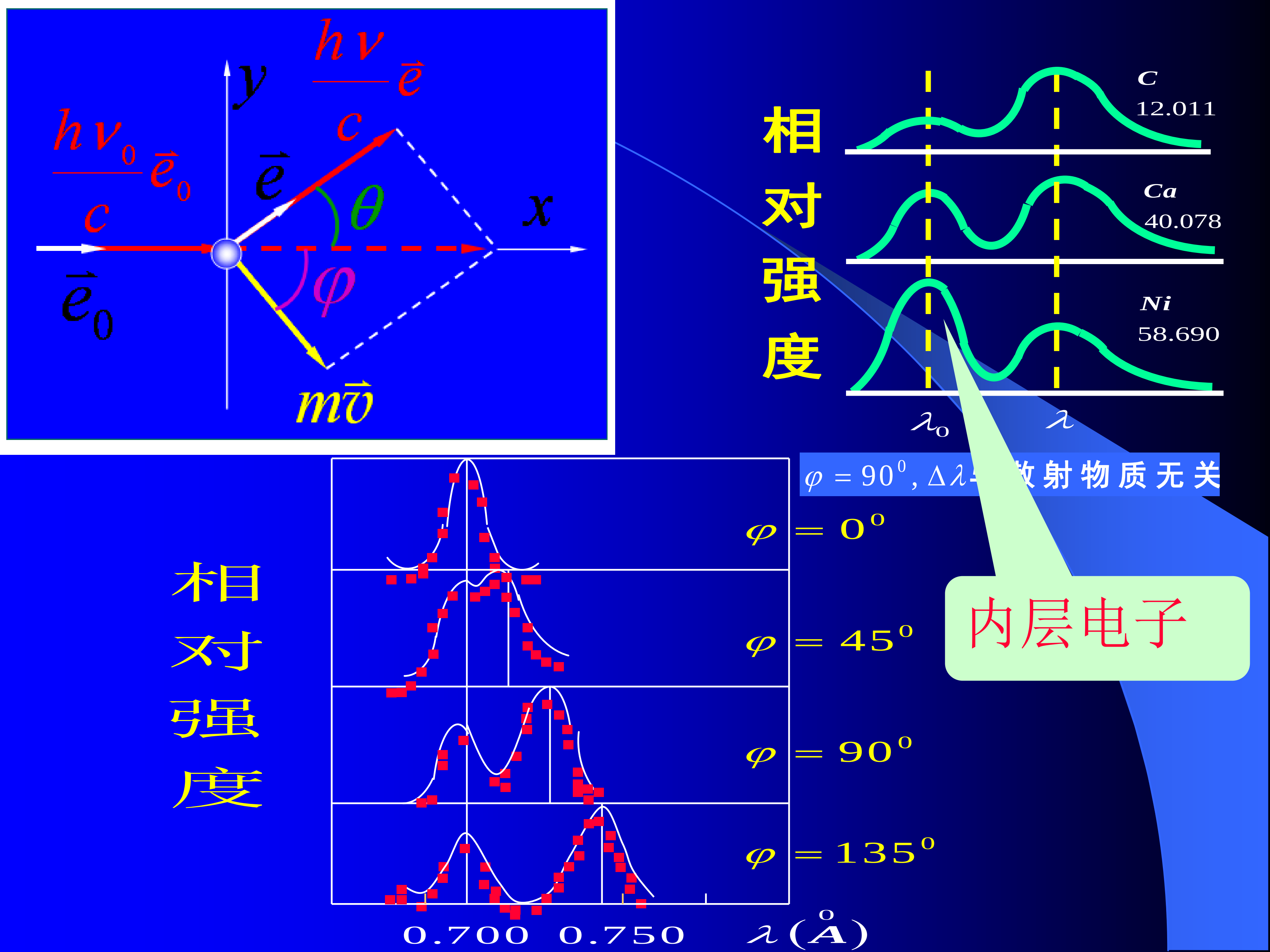
$$m^2c^4(1 - \frac{v^2}{c^2}) = m_0^2c^4 - 2h^2\nu_0\nu(1 - \cos\theta) + 2m_0c^2h(\nu_0 - \nu)$$

$$m^2c^4(1-\frac{v^2}{c^2}) = m_0^2c^4 - 2h^2\nu_0\nu(1-\cos\theta) + 2m_0c^2h(\nu_0-\nu)$$

$$m = m_0(1-v^2/c^2)^{-1/2}$$

$$\frac{c}{\nu} - \frac{c}{\nu_0} = \frac{h}{m_0c}(1-\cos\theta) = \lambda - \lambda_0 = \Delta\lambda$$

- **康普顿公式** $$\boxed{\Delta\lambda = \frac{h}{m_0c}(1-\cos\theta) = \frac{2h}{m_0c}\sin^2\frac{\theta}{2}}$$
- 康普顿波长 $$\lambda_c = \frac{h}{m_0C} = 2.41\times10^{-12}m = 2.41\times10^{-3}nm$$



$\frac{h\nu_0}{c}\vec{e}_0$
$\frac{h\nu}{c}\vec{e}$
y
x
$\vec{e}_0$
$\vec{e}$
θ
φ
$m\vec{v}$
相对强度
C 12.011
Ca 40.078
Ni 58.690
λ_0
λ
$\varphi = 90^0, \Delta\lambda$ 散射物质无关
内层电子
相对强度
$\varphi = 0^o$
$\varphi = 45^o$
$\varphi = 90^o$
$\varphi = 135^o$
0.700
0.750
λ (Å)

Summary:

代数量

- 刚体碰撞点的绝对速度 ← $e=\frac{u_2-u_1}{v_1-v_2}$
- 冲量大小应由质心动量改变量计算

$$\vec{I}=m\Delta\vec{V}_c$$

- 冲量矩应对质心而言

$$\vec{M}=\frac{d\vec{J}}{dt} \Longrightarrow Mdt=I_c\Delta\omega$$

- 冲量对刚体作用的效果

定量讨论

碰撞前

$m_1 \Rightarrow \vec{v}_1 \qquad m_2 \Rightarrow \vec{v}_2$ 绝对速度

$$\vec{v}_c = \frac{m_1\vec{v}_1 + m_2\vec{v}_2}{m_1 + m_2}$$

$m_1 \to \vec{u}_1 \qquad m_2 \to \vec{u}_2$(相对质心速度)

$\vec{u} = \vec{v}_1 - \vec{v}_2 = \vec{u}_1 - \vec{u}_2$ (相对速度)

$$\vec{u}_1 = \vec{v}_1 - \vec{v}_c = \frac{m_2\vec{u}}{m_1 + m_2}$$

$$\vec{u}_2 = \vec{v}_2 - \vec{v}_c = \frac{-m_1\vec{u}}{m_1 + m_2}$$

碰撞后

$m_1' \Rightarrow \vec{v}_1' \qquad m_2' \Rightarrow \vec{v}_2'$ 绝对速度

$$\vec{v}_c' = \frac{m_1'\vec{v}_1' + m_2'\vec{v}_2'}{m_1' + m_2'}$$

$m_1' \rightarrow \vec{u}_1' \quad m_2' \rightarrow \vec{u}_2'$(相对质心速度)

$\vec{u}' = \vec{v}_1' - \vec{v}_2' = \vec{u}_1' - \vec{u}_2'$ (相对速度)

$$\vec{u}_1' = \vec{v}_1' - \vec{v}_c' = \frac{m_2'\vec{u}'}{m_1' + m_2'}$$

$$\vec{u}_2' = \vec{v}_2' - \vec{v}_c' = \frac{-m_1'\vec{u}'}{m_1' + m_2'}$$

质量守恒 $\Rightarrow$ $m_1+m_2=m_1'+m_2'$

动量守恒 $\Rightarrow$ $(m_1+m_2)\vec{v}_c=(m_1'+m_2')\vec{v}_c'$

碰撞过程中动能损失 $\Downarrow$

$\Downarrow$ $\vec{v}_c=\vec{v}_c'$

$$\Delta T=[\cancel{\tfrac{1}{2}(m_1+m_2)\vec{v}_c^{\,2}}+\tfrac{1}{2}m_1u_1^2+\tfrac{1}{2}m_2u_2^2]-$$

$$[\cancel{\tfrac{1}{2}(m_1'+m_2')\vec{v}_c^{\,2}}+\tfrac{1}{2}m_1'u_1'^2+\tfrac{1}{2}m_2u_2'^2]$$

$$\Delta T=[\tfrac{1}{2}m_1u_1^2+\tfrac{1}{2}m_2u_2^2]-[\tfrac{1}{2}m_1'u_1'^2+\tfrac{1}{2}m_2u_2'^2]$$

$$\Delta T=[\tfrac{1}{2}m_1u_1^2+\tfrac{1}{2}m_2u_2^2]-[\tfrac{1}{2}m_1'u_1'^2+\tfrac{1}{2}m_2u_2'^2]$$

$$\Downarrow$$

$$\Delta T=[\tfrac{1}{2}\mu u^2-\tfrac{1}{2}\mu' u'^2]$$

$$\mu=\frac{m_1m_2}{m_1+m_2}\qquad \mu'=\frac{m_1'm_2'}{m_1'+m_2'}$$ (折合质量)

Conclusion

碰前

$$\vec{u}_1=\frac{m_2\vec{u}}{m_1+m_2}$$

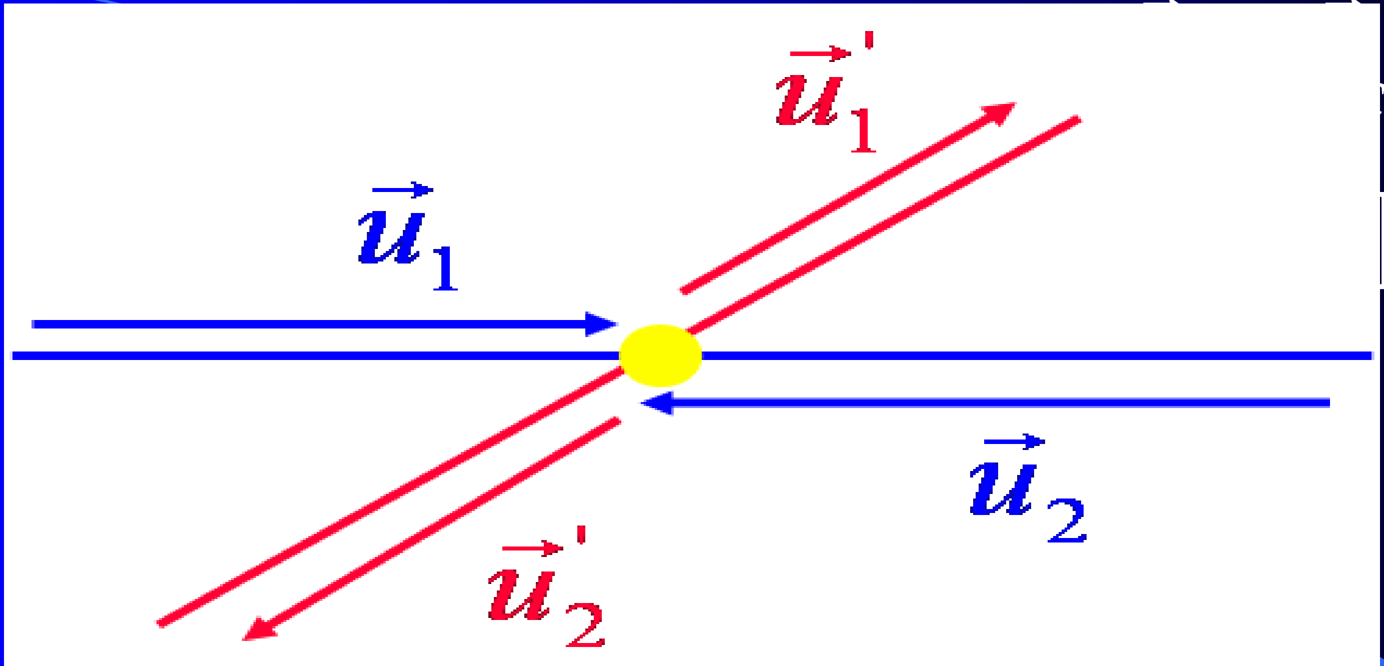
$$\vec{u}_2=\frac{-m_1\vec{u}}{m_1+m_2}$$

碰后

$$\vec{u}_1'=\frac{m_2'\vec{u}'}{m_1'+m_2'}$$

$$\vec{u}_2'=\frac{-m_1'\vec{u}'}{m_1'+m_2'}$$

弹性碰撞



质心系中

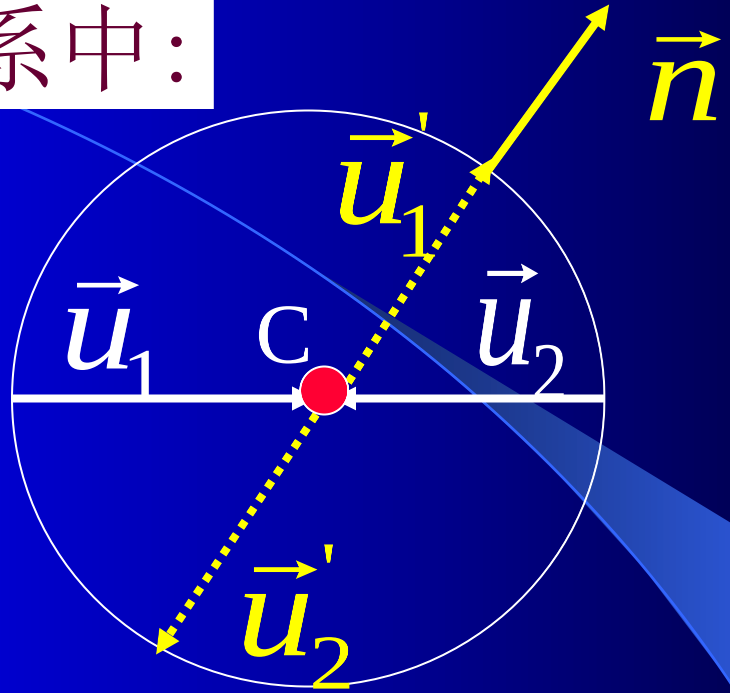
$$[\tfrac{1}{2}m_1u_1^2+\tfrac{1}{2}m_2u_2^2]=[\tfrac{1}{2}m_1u_1'^2+\tfrac{1}{2}m_2u_2'^2]$$

$$m_1u_1+m_2u_2=m_1u_1'+m_2u_2'=0$$

$$u=u' \quad u_1=u_1' \quad u_2=u_2'$$

弹性碰撞

设在C系中：



$$\vec{u}_1 = \frac{m_2\vec{u}}{m_1+m_2}$$

$$\vec{u}_2 = \frac{-m_1\vec{u}}{m_1+m_2}$$

$\vec{n}$ 为 碰 后 相 对 速 度 方 向 单位 矢 量

$$\vec{u}_1' = \frac{m_2'\vec{u}'}{m_1'+m_2'}$$

$$\vec{u}_2' = \frac{-m_1'\vec{u}'}{m_1'+m_2'}$$

$$\begin{cases} \vec{u}_1' = \dfrac{m_2}{m_1+m_2}u\vec{n} \\ \vec{u}_2' = \dfrac{-m_1}{m_1+m_2}u\vec{n} \end{cases}$$

在L系中：

$$\begin{cases} \vec{v}_1^{\,'} = \vec{v}_c^{\,'} + \vec{u}_1^{\,'} = \dfrac{m_1\vec{v}_1 + m_2\vec{v}_2}{m_1+m_2} + \dfrac{m_2 u}{m_1+m_2}\vec{n} \\ \vec{v}_2^{\,'} = \vec{v}_c^{\,'} + \vec{u}_2^{\,'} = \dfrac{m_1\vec{v}_1 + m_2\vec{v}_2}{m_1+m_2} - \dfrac{m_1 u}{m_1+m_2}\vec{n} \end{cases}$$

$$\begin{cases} \vec{u}_1^{\,'} = \dfrac{m_2}{m_1+m_2} u\vec{n} \\ \vec{u}_2^{\,'} = \dfrac{-m_1}{m_1+m_2} u\vec{n} \end{cases}$$

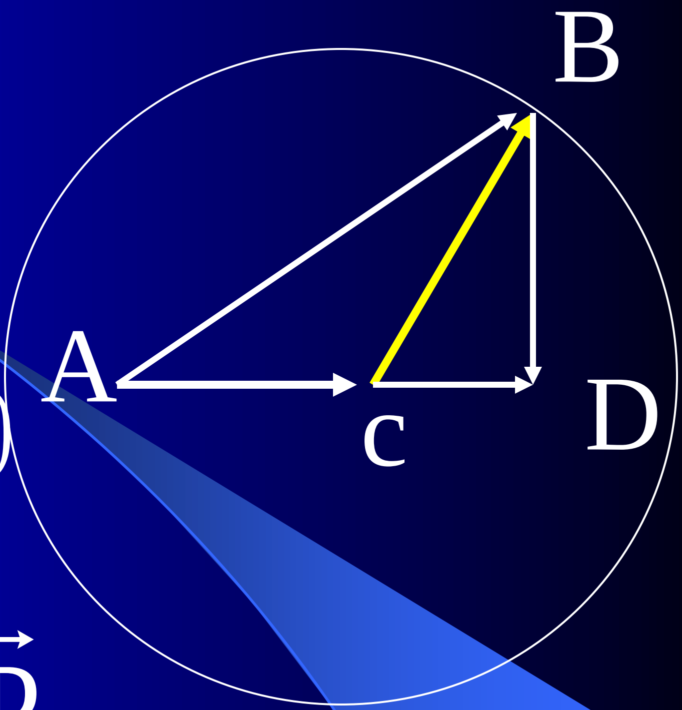
$$\vec{P}_1^{\,'} = m_1\vec{v}_1^{\,'} = \ \ldots\ \mu u\vec{n} \quad \ldots(A)$$

$$\vec{P}_2^{\,'} = m_2\vec{v}_2^{\,'} = \frac{m_2}{m_1+m_2}(\vec{P}_1 + \vec{P}_2) - \mu u\vec{n} \quad \ldots(B)$$

$$\vec{CB} = \mu u \vec{n} \qquad \vec{AC} = \frac{m_1}{m_1 + m_2}(\vec{P}_1 + \vec{P}_2)$$

$$\vec{AB} = \vec{P}_1' \qquad \vec{CD} = \frac{m_2}{m_1 + m_2}(\vec{P}_1 + \vec{P}_2)$$

$$\vec{BD} = \vec{P}_2' \qquad \vec{AD} = \vec{P}_1 + \vec{P}_2$$



入射粒子速度已知时 ⇒ A和D两点位置固定

B点可在圆周上任意变动

散射中靶粒子初始静止 $\Rightarrow$ $\vec{P}_2 = 0$

$$\vec{u} = \vec{v}_1 - \vec{v}_2 = \vec{v}_1$$

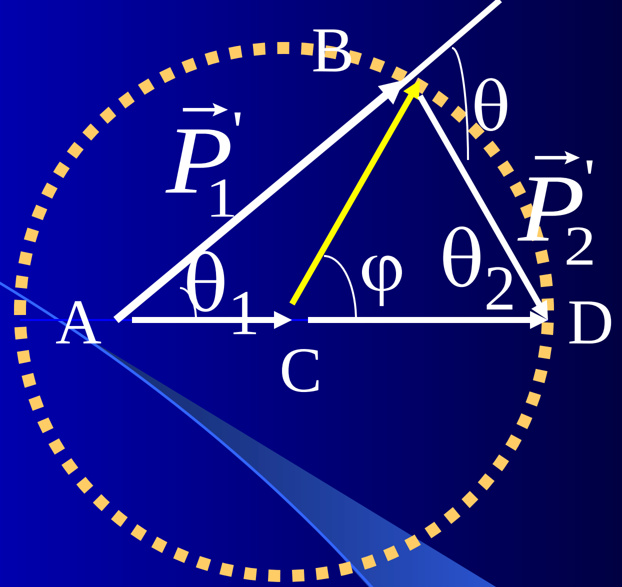
$$\vec{CB} = \mu u \vec{n} = \frac{m_1 m_2}{m_1 + m_2} v_1 \vec{n} \qquad \vec{AC} = \frac{m_1 \vec{P}_1}{m_1 + m_2} = \frac{m_1 m_1}{m_1 + m_2} \vec{v}_1$$

$$\vec{CD} = \frac{m_2 \vec{P}_1}{m_1 + m_2} = \frac{m_2 m_1}{m_1 + m_2} \vec{v}_1$$

$$\vec{P}_1' = m_1 \vec{v}_1' = \frac{m_1}{m_1 + m_2}(\vec{P}_1 + \vec{P}_2) + \mu u \vec{n} \quad \ldots(A)$$

$$\vec{P}_2' = m_2 \vec{v}_2' = \frac{m_2}{m_1 + m_2}(\vec{P}_1 + \vec{P}_2) - \mu u \vec{n} \quad \ldots(B)$$

Discussion:



$$\frac{AC}{CD}=\frac{m_1}{m_2},\quad CB=CD$$

- $m_1 < m_2$ ⇒ AC<CD

φ为c系中入射粒子偏转角

θ_1为入射粒子出射方向对入射方向偏离

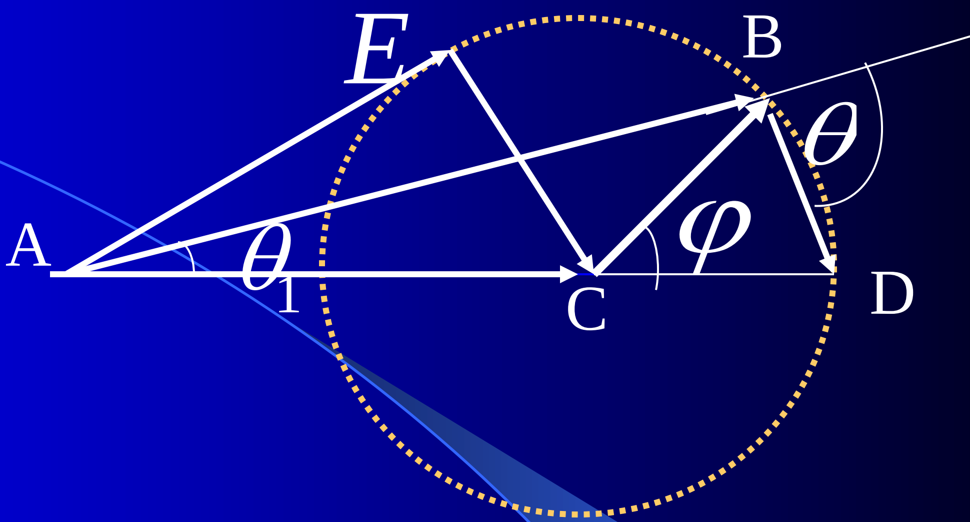
θ_2为靶粒子在L系中反冲角

$$\theta_2=\frac{\pi-\varphi}{2}$$

$0 \le \theta_1 \le \pi$ ⇒ B点变化范围

- $m_1 > m_2$

A点在圆外

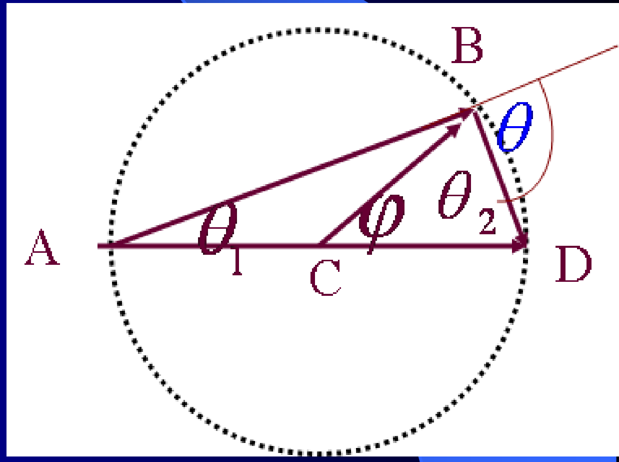


$$0 \le \theta_1 \le \theta_{1\max}$$

$$\sin\theta_{1\max} = \frac{EC}{AC} = \frac{m_2}{m_1} \quad (\because EC = CD)$$

- $m_1 = m_2$

A点在圆上



$$\theta_2 = \frac{\pi - \varphi}{2} \qquad \theta_1 = \frac{\varphi}{2}$$

$$\theta = \theta_1 + \theta_2 = \frac{\pi}{2} \qquad 0 \le \theta_1 \le \frac{\pi}{2}$$

§2. 有心排斥力场中粒子的散射

一.基本概念

- 总截面
- 瞄准距离
- 入射粒子散射
- 微分散射截面

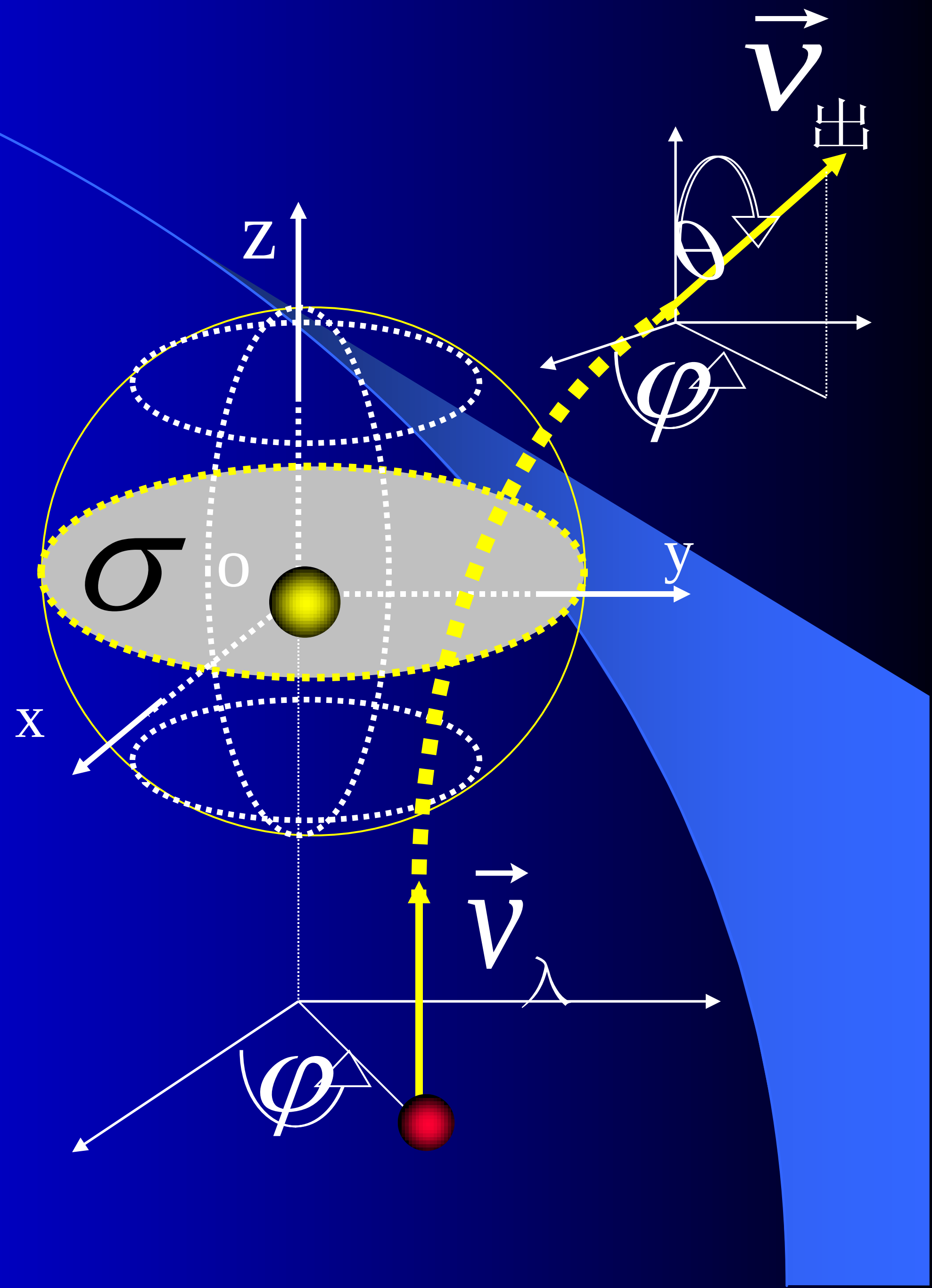
一.基本概念

- 总截面

入射粒子　靶粒子

相互作用区域在xy平面的投影

总截面 σ

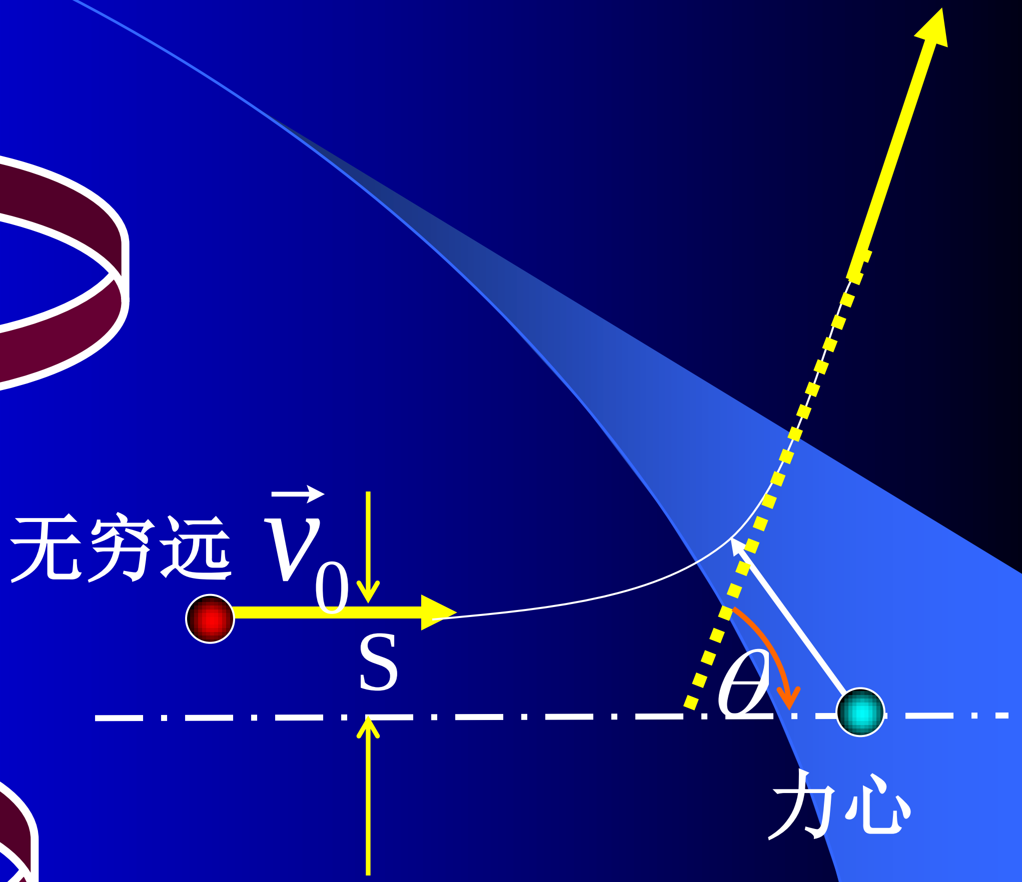


一.基本概念

- 瞄准距离s

s ↑ 相互作用越弱

s ↓ 相互作用越强



一.基本概念

- 入射粒子散射

入射粒子流强度为I:

粒子数/单位时间x入射方向垂直的单位面积

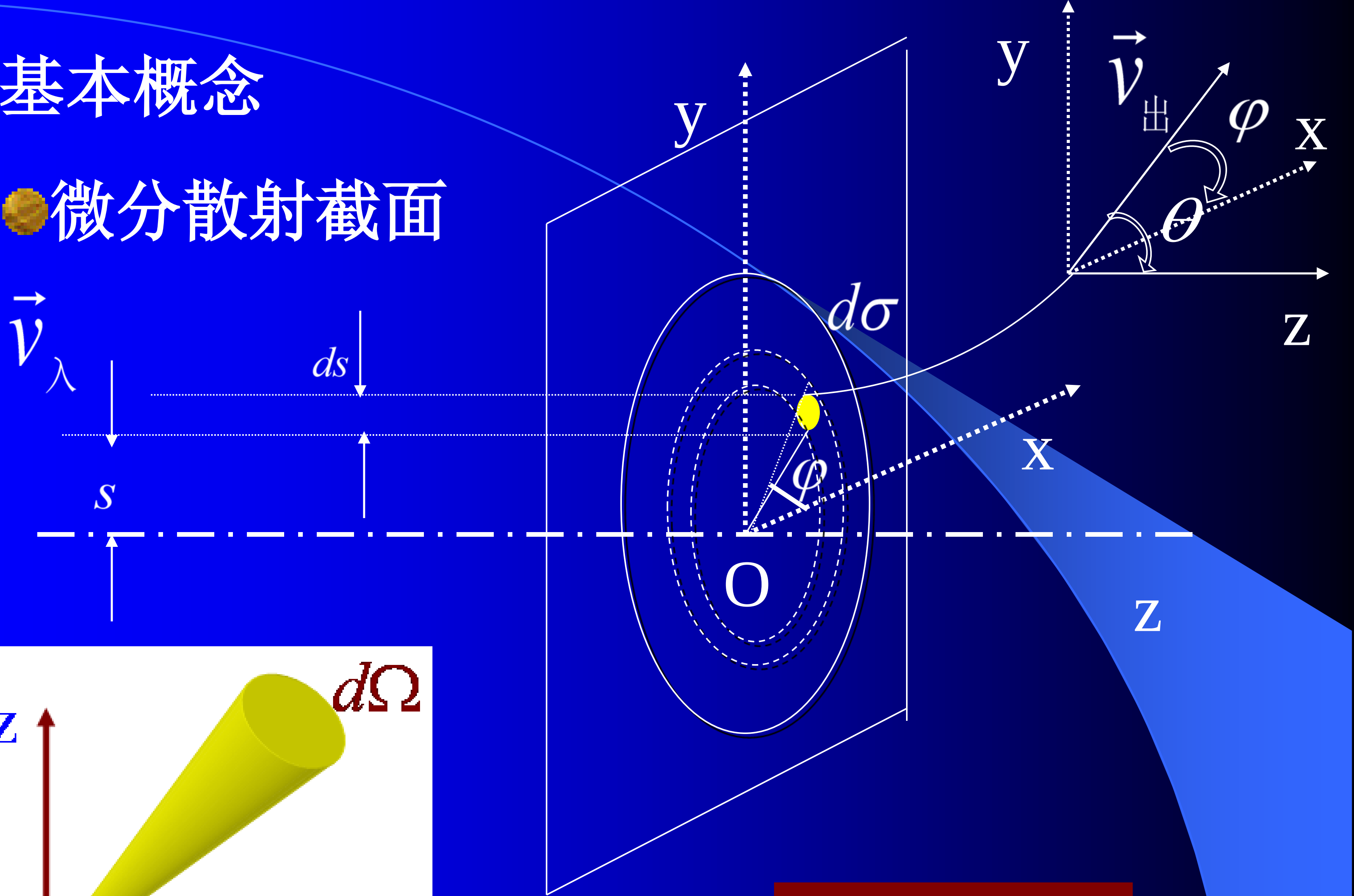
设入射粒子束横截面为A

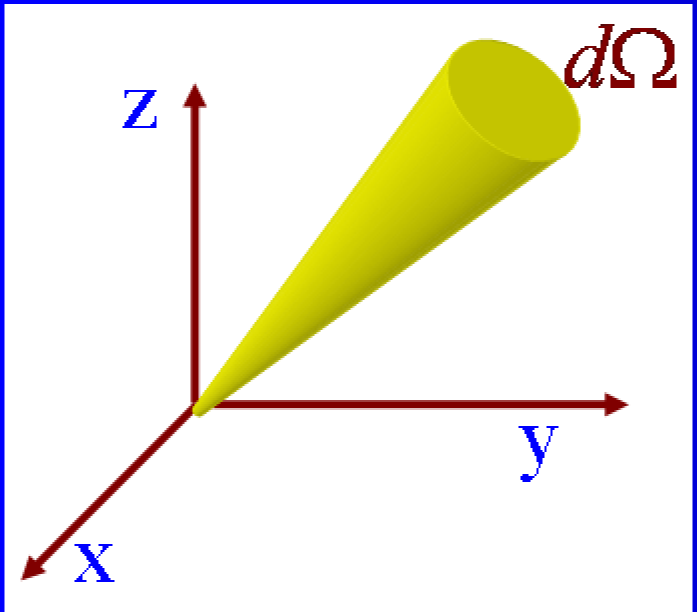
- $\sigma > A$ ⇒ 入射粒子全部被散射
- $\sigma < A$ ⇒ 入射粒子部分被散射

$$\frac{\sigma I}{AI} = \frac{\sigma}{A}$$ ⇒ 入射粒子散射几率

一.基本概念

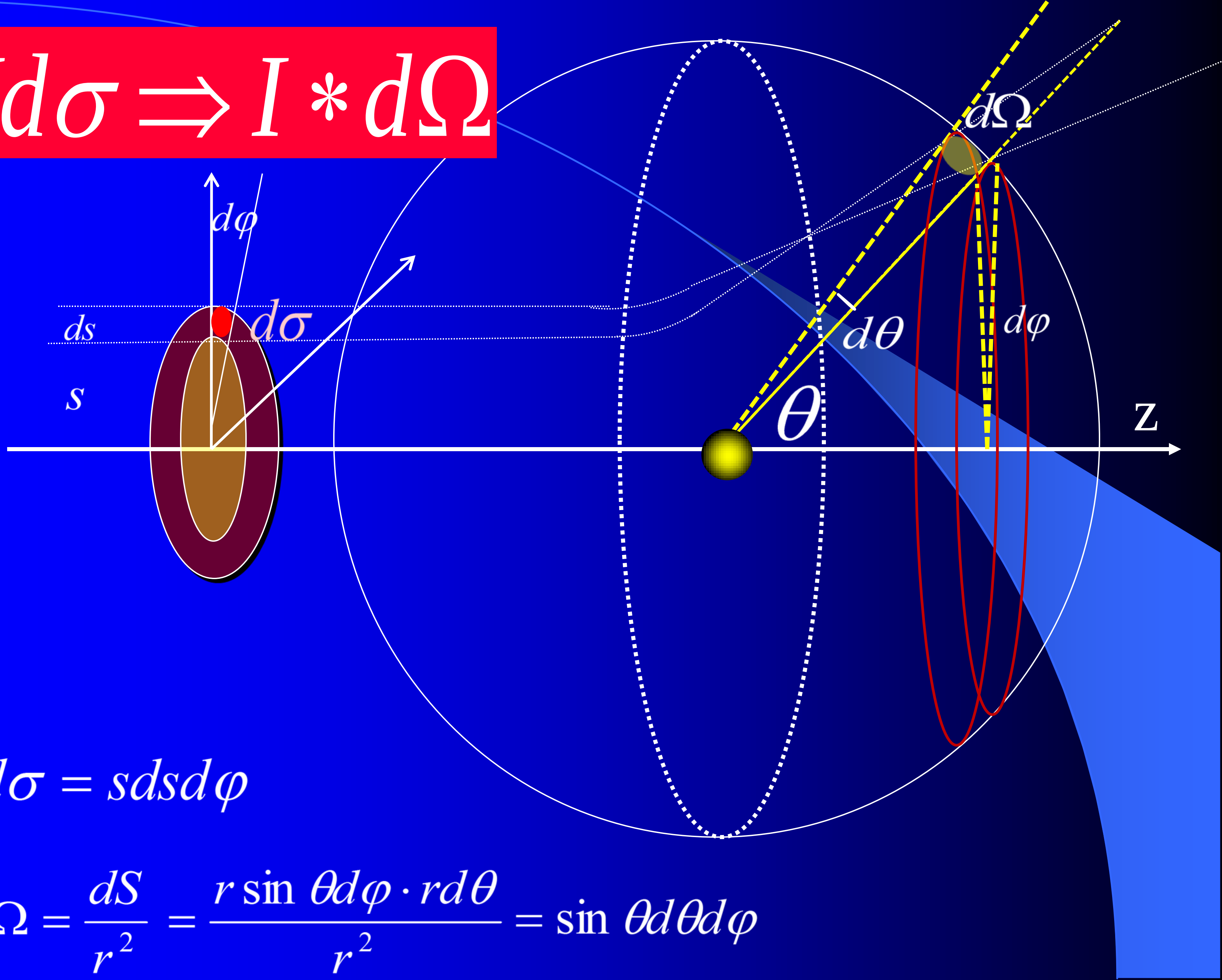
微分散射截面





$$d\sigma = s\,ds\,d\varphi$$

$$Id\sigma \Rightarrow I * d\Omega$$



$$d\sigma = s ds d\varphi$$

$$d\Omega = \frac{dS}{r^2} = \frac{r \sin\theta d\varphi \cdot r d\theta}{r^2} = \sin\theta d\theta d\varphi$$

$$d\sigma = s\,ds\,d\varphi \qquad d\Omega = \sin\theta\, d\theta\, d\varphi$$

$$d\sigma = \sigma(\theta\ \varphi)\, d\Omega$$

$\sigma(\theta\ \varphi)$ ⇒ 微分散射截面

$d\sigma$ ⇒ 部分散射截面

$\sigma(\theta\ \varphi) = \sigma(\theta\ )$ ⇒ 相互作用与φ角无关

$\sigma(\theta)$的物理意义

设单位时间散射到dΩ内的粒子数为dN

$$dN = Id\sigma = I\sigma(\theta)d\Omega$$

$$\sigma(\theta) = \frac{dN}{Id\Omega} = \frac{dN/d\Omega}{I}$$

$$\frac{\text{单位时间散射到单位立体角粒子数}}{\text{单位时间通过垂直入射方向单位面积粒子数}}$$

$$d\sigma = \sigma(\theta\ \varphi)d\Omega \qquad d\Omega = \sin\theta d\theta d\varphi$$

$\sigma(\theta)$ ⇨ 量纲为面积

$$dN = Id\sigma = I\sigma(\theta)d\Omega \qquad \sigma(\theta) = \frac{dN}{Id\Omega} = \frac{dN / d\Omega}{I}$$

$$\frac{\text{单位时间散射到单位立体角粒子数}}{\text{单位时间通过垂直入射方向单位面积粒子数}}$$

粒子被散射到θ方向单位立体角中的几率（占总入射粒子数）

$$dN = Id\sigma \Rightarrow I\sigma(\theta)d\Omega$$

$$\text{几率}\rho = \frac{\mathrm{I}d\sigma}{IA} = \frac{I\sigma(\theta)\mathrm{d}\Omega}{IA} = \frac{\sigma(\theta)\mathrm{d}\Omega}{A}$$

σ(θ)

量纲为面积

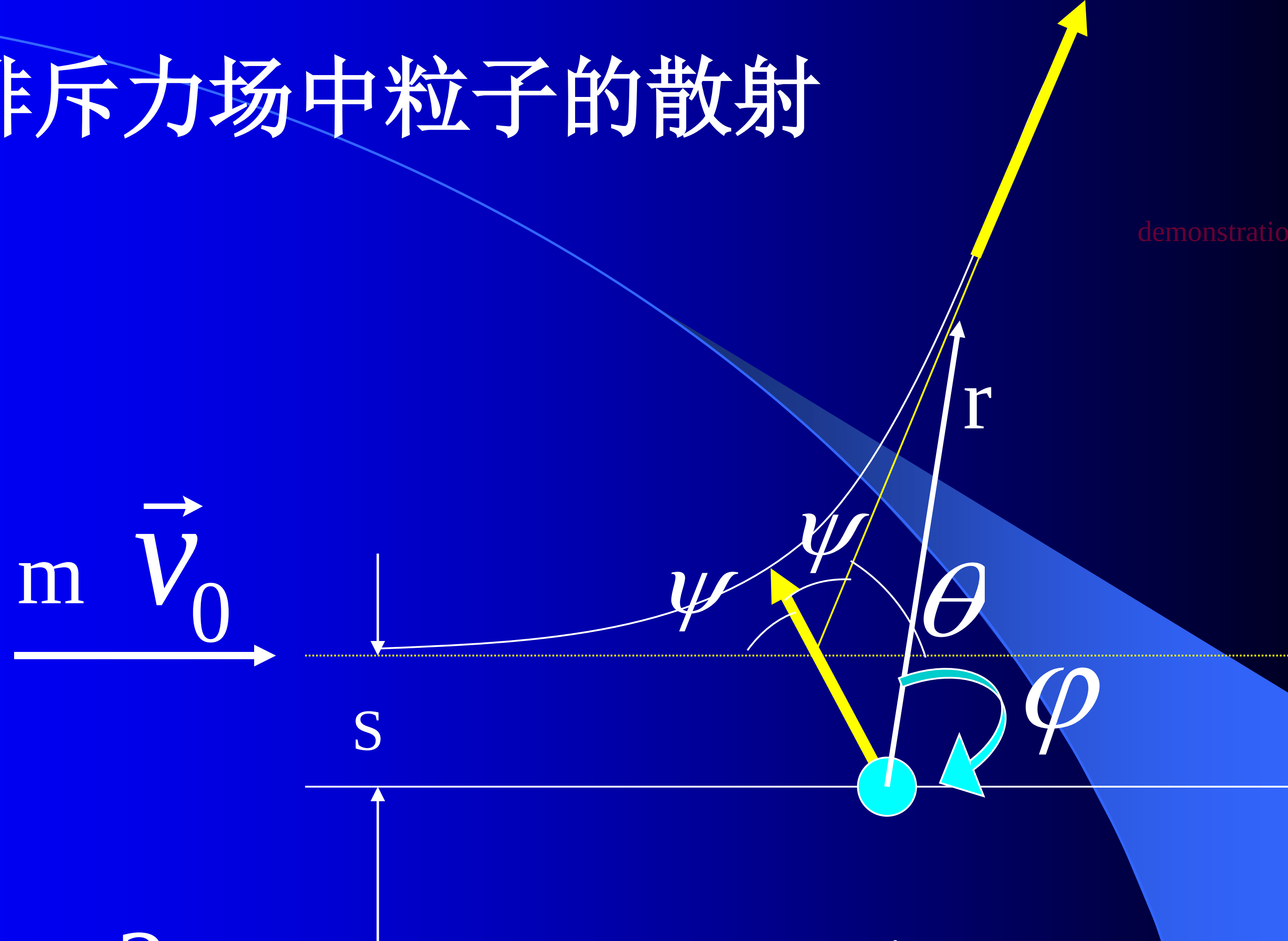
$$d\sigma = \sigma(\theta)d\Omega$$

$$sdsd\varphi = \sigma(\theta)\sin\theta d\theta d\varphi$$

$$\sigma(\theta) = \frac{s}{\sin\theta}\left|\frac{ds}{d\theta}\right|$$

微分散射截面计算

二. 有心排斥力场中粒子的散射



$$\theta = \pi - 2\psi$$

$$E = \frac{1}{2} m v_0^2$$

$$m r^2 \dot{\varphi} = J_0 = m v_0 s$$

demonstration

$$mr^2\dot{\varphi} = J_0 = mv_0 s \qquad E = \frac{1}{2}mv_0^2$$

$$J_0^2 = m^2 v_0^2 s^2 = 2mEs^2$$

$$E = \tfrac{1}{2}(\dot{r}^2 + r^2\dot{\varphi}^2) + V(r)$$

$$E = \frac{1}{2}m\dot{r}^2 + \frac{J_0^2}{2mr^2} + V(r)$$

$$\dot{r} = \frac{dr}{dt} = \frac{dr}{d\varphi}\frac{d\varphi}{dt}$$

$$E=\frac{1}{2}m\dot{r}^2+\frac{J_0^2}{2mr^2}+V(r)$$

$$mr^2\dot{\varphi}=J_0=mv_0s$$

$$\dot{r}=\sqrt{\frac{2}{m}\left[E-V-\frac{J_0^2}{2mr^2}\right]}$$

$$E=\frac{1}{2}mv_0^2$$

$$\dot{r}=\frac{dr}{dt}=\frac{dr}{d\varphi}\frac{d\varphi}{dt}\quad+\quad\dot{\varphi}=\frac{v_0s}{r^2}=\frac{s}{r^2}\sqrt{\frac{2E}{m}}$$

$$\theta=\pi-2\psi$$

$$J_0^2=2mES^2$$

$$\psi=\int_0^{\psi}d\varphi=\int_{r_{\min}}^{\infty}\frac{s}{r^2}\frac{dr}{\sqrt{1-\frac{V}{E}-\frac{s^2}{r^2}}}$$

$r_{\min}$的确定

近日点: $\Rightarrow$ $\dot{r}=0$

$$E=\frac{J_0^2}{2mr_{\min}^2}+V(r_{\min})$$

$$J_0^2=m^2v_0^2s^2=2mEs^2$$

$$E=\frac{2mEs^2}{2mr_{\min}^2}+V(r_{\min})$$

$$r_{\min}=s\sqrt{\frac{E}{E-V(r_{\min})}}$$

变量变换

$$z = \frac{s}{r} \quad \begin{cases} r = \infty & z = 0 \\ r = r_{\min} & z = z_0 \end{cases}$$

$$r_{\min} = s\sqrt{\frac{E}{E - V(r_{\min})}}$$

$$dr = -\frac{r^2}{s}dz$$

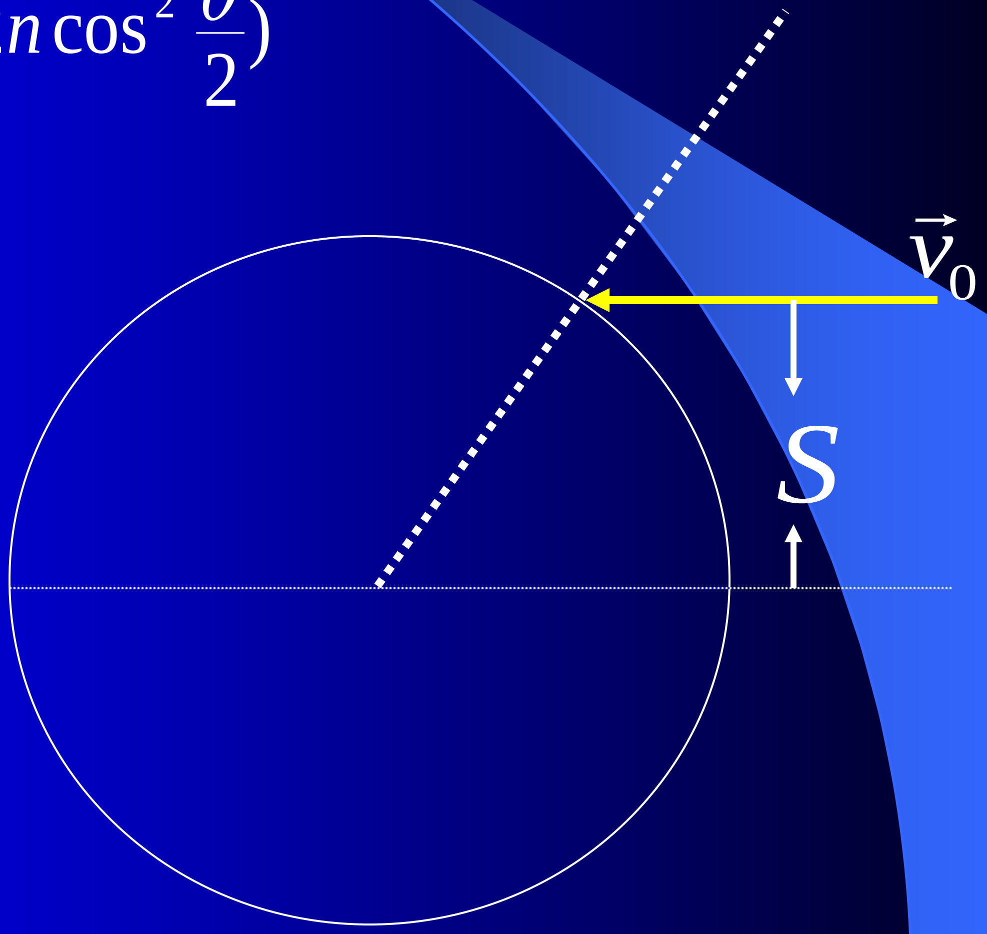
$$1 - \frac{V(z_0)}{E} - z_0^2 = 0$$

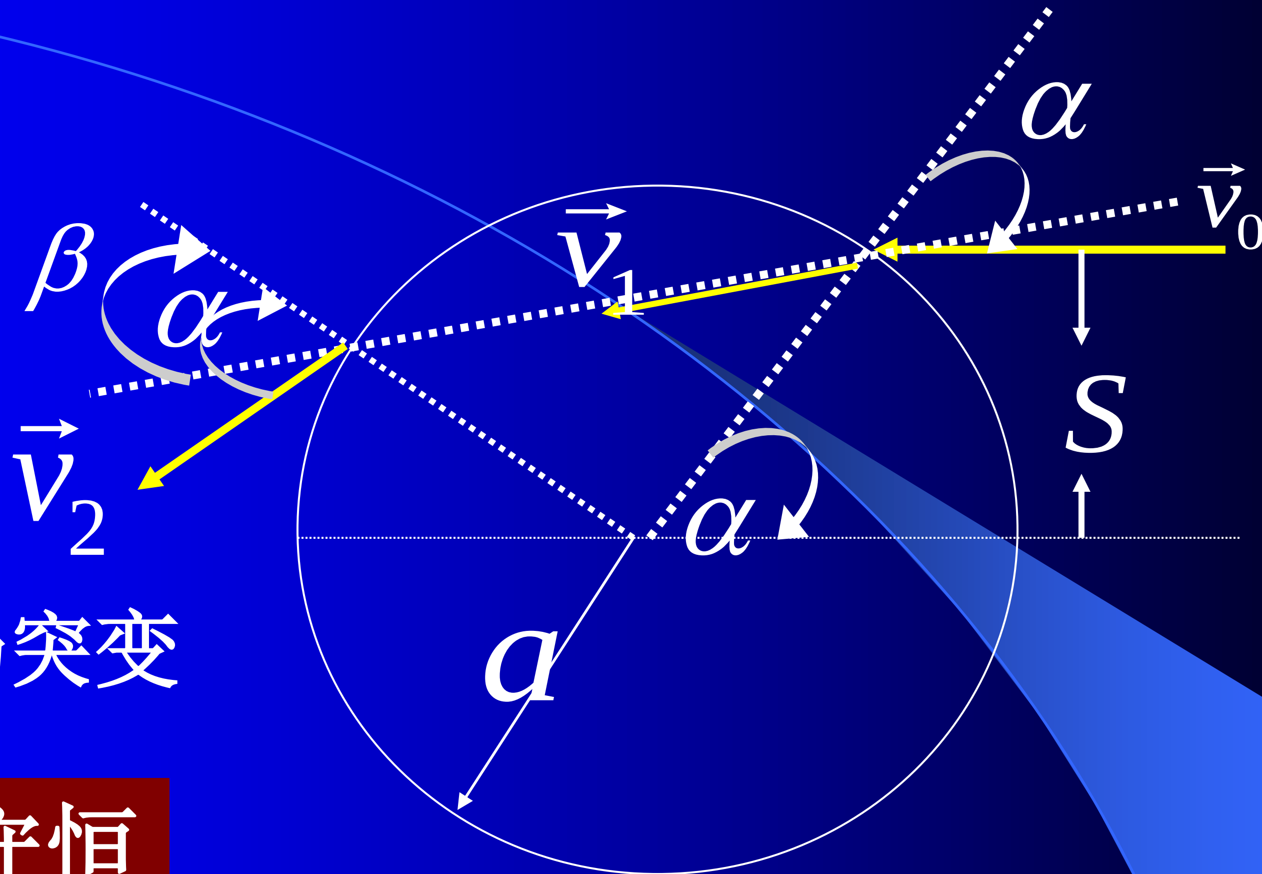
$$\psi = \int_0^{\psi} d\varphi = \int_0^{z_0} \frac{dz}{\sqrt{1 - \frac{V(z)}{E} - z^2}}$$

一粒子被球形势阱散射,证明:

$$\sigma(\theta)=\frac{n^2a^2(n\cos\frac{\theta}{2}-1)(n-\cos\frac{\theta}{2})}{4\cos\frac{\theta}{2}(1+n^2-2n\cos^2\frac{\theta}{2})}$$

$$V=\begin{cases}0 & r>a\\ -V_0 & r<a\end{cases}$$





边界处势场突变

动量守恒

切线方向

$$mv_0 \sin\alpha = mv_1 \sin\beta$$

$$mv_2 \sin\alpha = mv_1 \sin\beta$$

$$\Rightarrow \frac{\sin\alpha}{\sin\beta} = \frac{v_1}{v_2}$$

$$\frac{1}{2}mv_1^2 - V_0 = \frac{1}{2}mv_2^2 = E$$

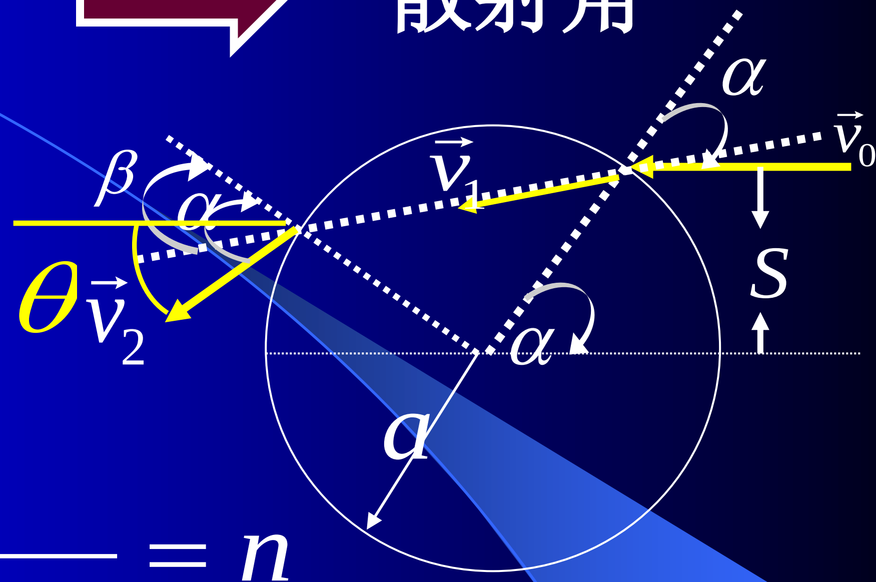
$$v_1 = \sqrt{\frac{2(E+V_0)}{m}} \qquad v_2 = \sqrt{\frac{2E}{m}}$$

$$\boxed{\frac{\sin\alpha}{\sin\beta} = \frac{v_1}{v_2} = \sqrt{1+\frac{V_0}{E}} = n}$$

$\vec{v}_2$对$\vec{v}_0$为 $\theta = 2(\alpha - \beta)$ ⇒ 散射角

$$\beta = \alpha - \frac{\theta}{2}$$

$$\because\ s = a\sin\alpha$$



$$\frac{\sin\alpha}{\sin\beta} = \frac{\sin\alpha}{\sin(\alpha - \frac{\theta}{2})} = n$$

$$s^2 = a^2 n^2 \sin^2\frac{\theta}{2} / (1 + n^2 - 2n\cos^2\frac{\theta}{2})$$

$$\frac{ds}{d\theta} = \frac{\cos\frac{\theta}{2}(1+n^2-2n\cos\frac{\theta}{2}) - n\sin^2\frac{\theta}{2}}{2(1+n^2-2n\cos\frac{\theta}{2})\sin^2\frac{\theta}{2}}$$

$$\sigma(\theta)=\frac{s}{\sin\theta}\left|\frac{ds}{d\theta}\right|$$

$$\sigma(\theta)=\frac{a^2n^2}{4\cos\frac{\theta}{2}}\frac{(n\cos\frac{\theta}{2}-1)(n-\cos\frac{\theta}{2})}{(1+n^2-2n\cos\frac{\theta}{2})^2}$$

Discussion:

- 当$n=\cos\frac{\theta}{2}$　$\sigma(\theta)=0$

  散射发生在　$0<\theta<2\cos^{-1}n$

- 当S > a散射不能发生

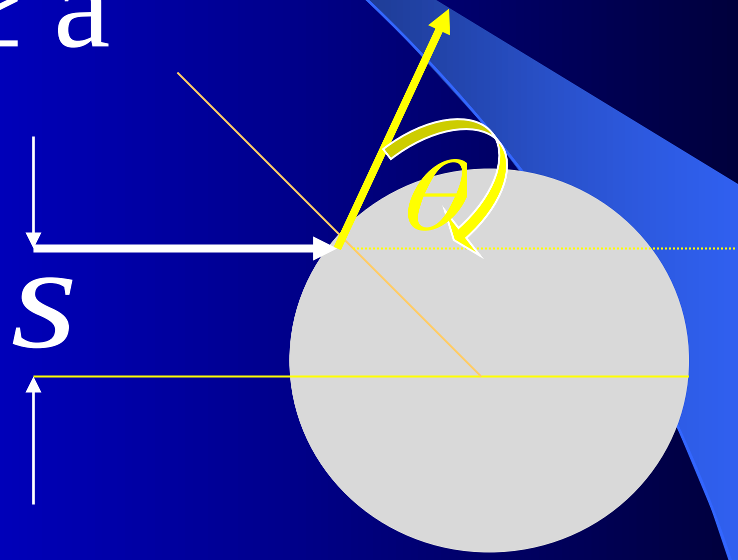
求一质点与半径为a的钢球碰撞的散射截面

$$V(r)=\begin{cases}\infty & r<a\\ 0 & r\ge a\end{cases}$$

$$\psi=\int_0^{\psi}d\varphi=\int_{r_{\min}}^{z_0}\frac{dz}{\sqrt{1-\frac{V(z)}{E}-z^2}}$$

解：

$$\theta=\pi-2\int_a^{\infty}\frac{s}{r^2}\frac{1}{\sqrt{1-\frac{s^2}{r^2}}}$$



$$=\pi+2\int_a^{\infty}\frac{d(\frac{s}{r})}{\sqrt{1-\frac{s^2}{r^2}}}$$

$$\int\frac{dx}{\sqrt{1-x^2}}=\sin^{-1}x$$

$$\theta = \pi + 2\sin^{-1}\frac{s}{r}\Big|_a^{\infty} \Rightarrow \theta = \pi - 2\sin^{-1}\frac{s}{a}$$

$$S = a\sin\frac{\pi-\theta}{2} = a\cos\frac{\theta}{2}$$

$$\sigma(\theta) = \frac{s}{\sin\theta}\left|\frac{ds}{d\theta}\right| = \frac{a^2}{4}$$

总截面 $\sigma = \iint \sigma(\theta)\sin\theta \mathrm{d}\theta \mathrm{d}\varphi$

$$= \int_0^{2\pi} d\varphi \int_0^{\pi} \frac{a^2}{4}\sin\theta d\theta$$

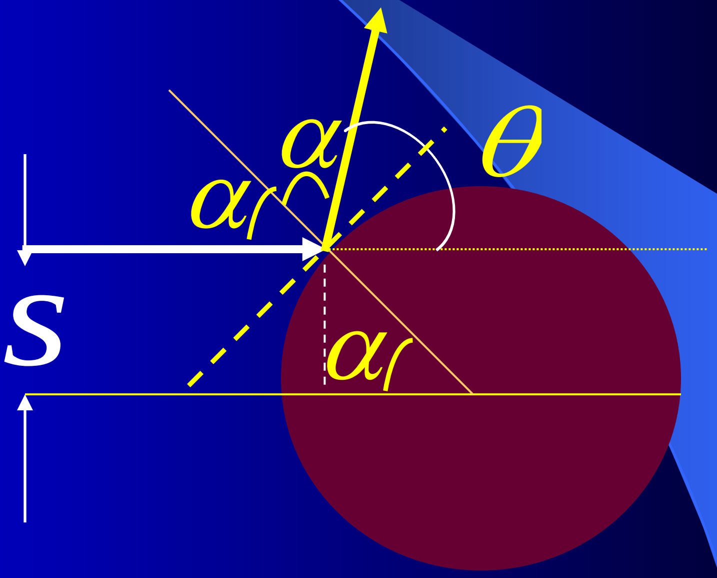
$$\boxed{\sigma = \pi a^2}$$

Simple Solution:

$$\alpha = \frac{\pi - \theta}{2}$$

$$S = a \sin \frac{\pi - \theta}{2} = a \cos \frac{\theta}{2}$$

$$\sigma(\theta) = \frac{s}{\sin\theta} \left| \frac{ds}{d\theta} \right| = \frac{a^2}{4}$$



平方反比有心斥力场 $V=\frac{k}{r}$ 散射的散射截面

解：

$$\psi=\int_0^{z_0}\frac{dz}{\sqrt{1-z^2-\frac{V(z)}{E}}} \qquad \ldots\ldots(1)$$

z_0由下式确定：

$$1-Z_0^2-\frac{V(z_0)}{E}=0 \Leftarrow V(z_0)=\frac{k}{r}\frac{s}{s}=\frac{k}{s}z_0$$

$$z_0=\frac{-\frac{k}{sE}\pm\sqrt{(\frac{k}{sE})^2+4}}{2} \qquad z_0=\frac{-\frac{k}{sE}+\sqrt{(\frac{k}{sE})^2+4}}{2}$$

$$\theta = \pi - 2\int_0^{z_0} \frac{dz}{\sqrt{1 - z^2 - \frac{V(z)}{E}}}$$

$$V(z) = \frac{k}{r}\frac{s}{s} = \frac{k}{s} z$$

$$\theta = \pi - 2\int_0^{z_0} \frac{dz}{\sqrt{1 + \frac{k^2}{4E^2 s^2} - \left(z + \frac{k}{2Es}\right)^2}}$$

$$\theta = \pi - 2\int_0^{z_0} \frac{2dz}{\sqrt{4 + \frac{k^2}{E^2 s^2}}\sqrt{1 - \left(\frac{2z + \frac{k}{SE}}{\sqrt{4 + \frac{K^2}{(SE)^2}}}\right)}}$$

$$\theta = \pi - 2\int_0^{z_0} \frac{-1}{\sqrt{1-\left(\dfrac{2z+\dfrac{k}{SE}}{\sqrt{4+\dfrac{k^2}{(ES)^2}}}\right)^2}}\, d\left(\frac{2z+\dfrac{k}{SE}}{\sqrt{4+\dfrac{K^2}{(SE)^2}}}\right)$$

$$\theta = \pi - 2\int_0^{z_0} \frac{-1}{\sqrt{1 - \left(\dfrac{-2z - \dfrac{k}{SE}}{\sqrt{4 + \dfrac{k^2}{(ES)^2}}} \right)^2}} \, d\left(\frac{-2z - \dfrac{k}{SE}}{\sqrt{4 + \dfrac{K^2}{(SE)^2}}} \right)$$

$$\int \frac{dx}{\sqrt{1 - x^2}} = \sin^{-1} x$$

$$\theta = \pi - 2\left(-\sin^{-1} \frac{-2z - \frac{k}{SE}}{\sqrt{4 + \frac{K^2}{(SE)^2}}} \right)_0^{z_0}$$

$$z_0 = \frac{-\frac{k}{sE} + \sqrt{\left(\frac{k}{sE}\right)^2 + 4}}{2}$$

$$\boxed{\theta = 2\sin^{-1}\left(\frac{\frac{k}{SE}}{\sqrt{4 + \frac{k^2}{(SE)^2}}} \right)}$$

$$-\sin x = \sin(-x)$$

$$\theta = 2\sin^{-1}\left(\frac{\frac{k}{SE}}{\sqrt{4+\frac{k^2}{(SE)^2}}}\right)$$

$$E = \frac{1}{2}mv^2$$

$$S = \frac{kctg\frac{\theta}{2}}{mv^2}$$

$$\sigma(\theta) = \frac{s}{\sin\theta}\left|\frac{ds}{d\theta}\right|$$

$$\sigma(\theta) = [k/2mv^2\sin^2\frac{\theta}{2}]^2$$

对卢瑟福散射

$$F = \frac{1}{4\pi\varepsilon}\frac{2zq^2}{r^2}$$

$$k = \frac{zq^2}{2\pi\varepsilon}$$

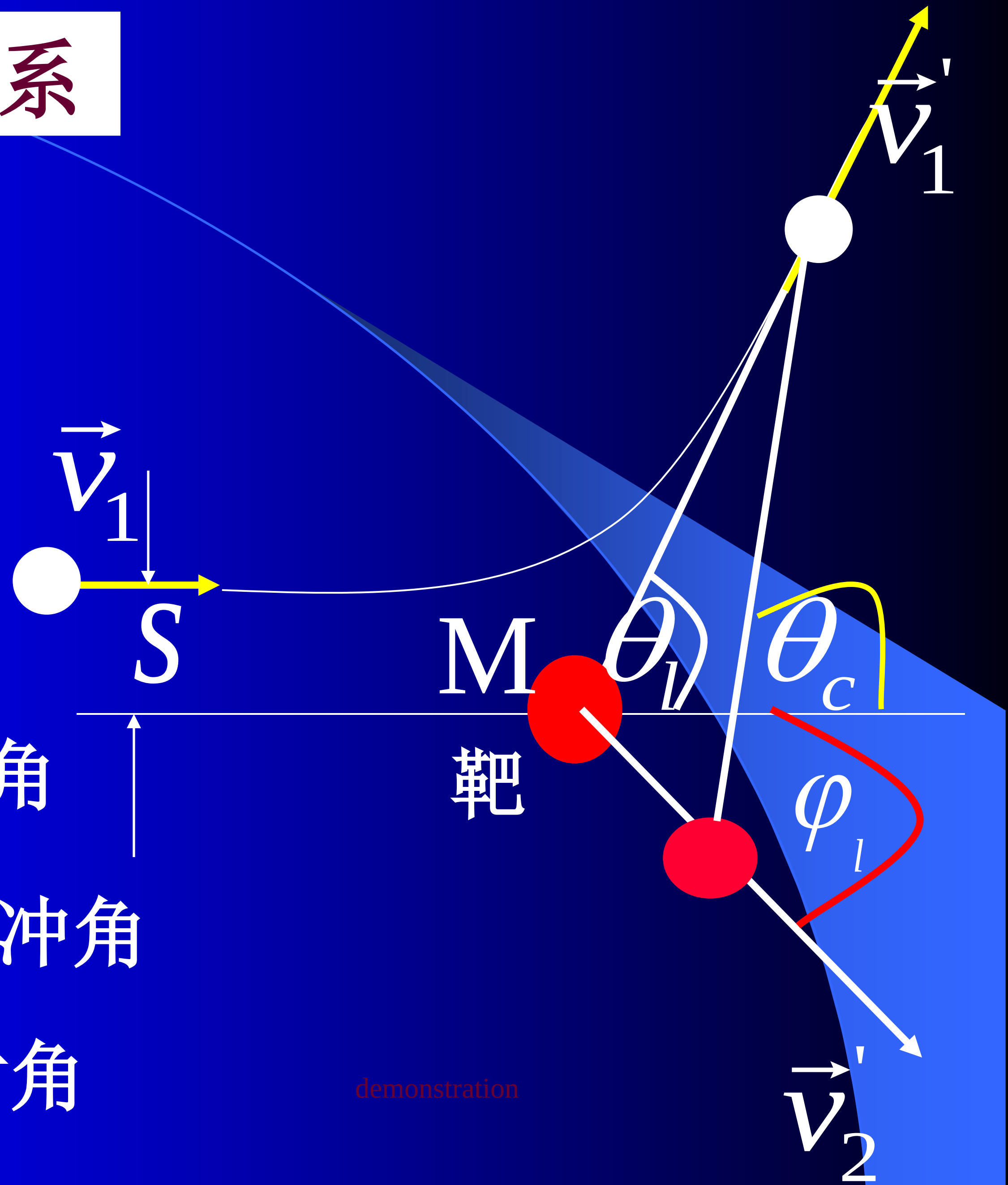
$$\sigma(\theta) = \left(\frac{zq}{4\pi\varepsilon}\right)^2 \csc^4\frac{\theta}{2}$$

§ 3. L系C系的关系

一. 散射角的关系

L系

散射前靶静止 m

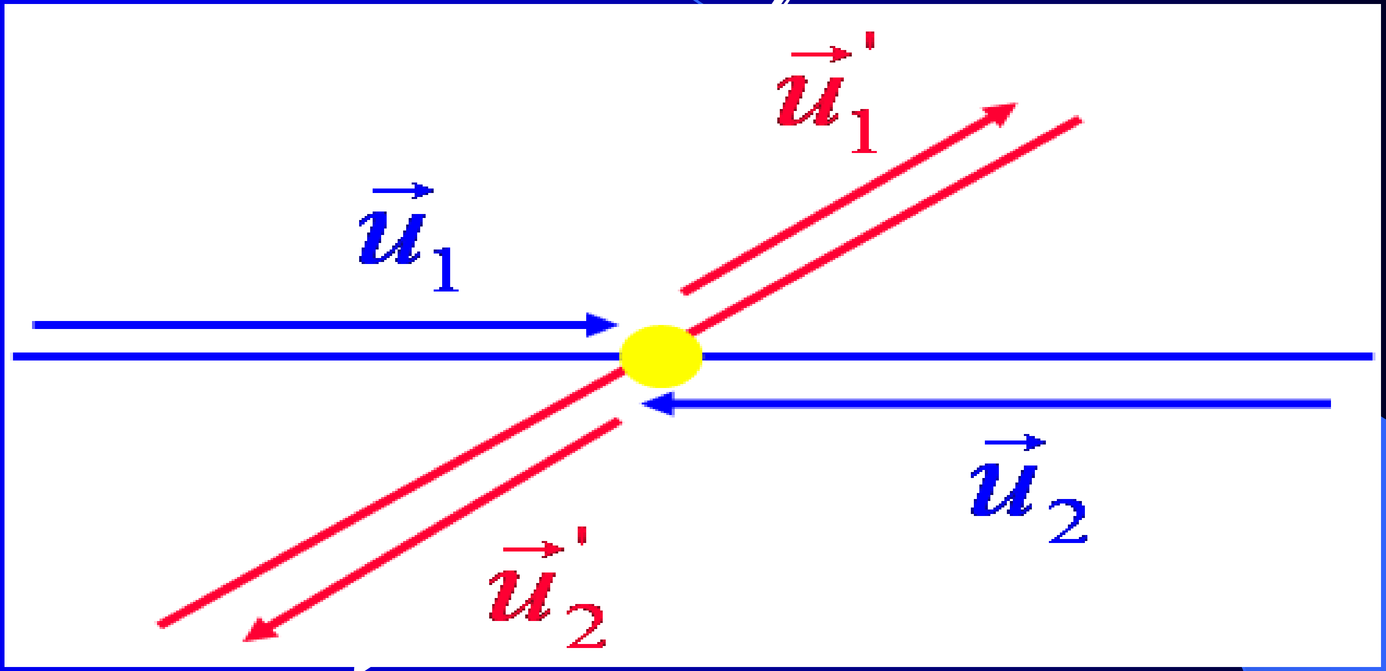


θ_l ⇨ L系中散射角

φ_l ⇨ L系中靶反冲角

θ_c ⇨ C系中散射角

C系中的图象



demonstration

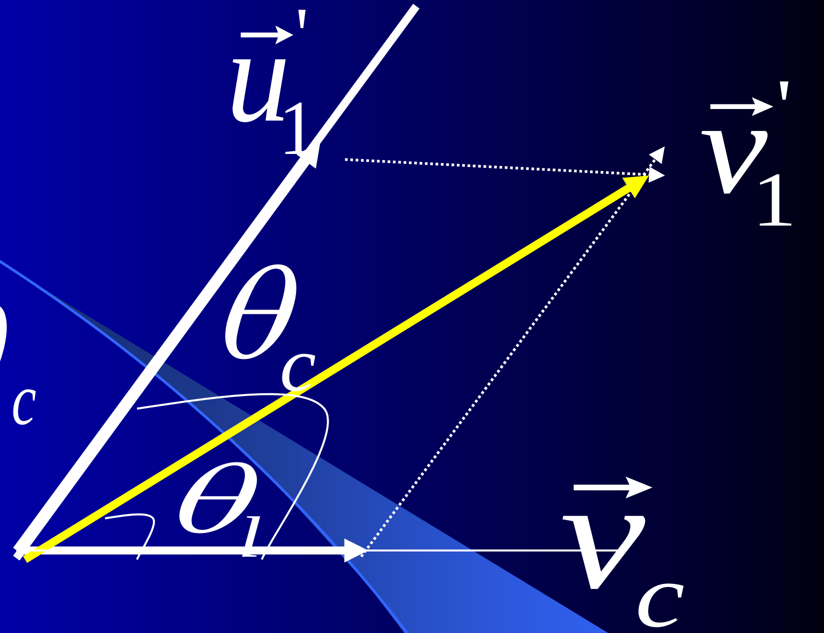
散射前

- 入射粒子
  - 绝对速度 $\Rightarrow$ $\vec{v}_1$
  - 相对质心速度 $\Rightarrow$ $\vec{u}_1$
- 靶粒子
  - 绝对速度 $\Rightarrow$ $\vec{v}_2 = 0$
  - 相对质心速度 $\Rightarrow$ $-\vec{v}_c$

散射后

- 入射粒子出射
  - 绝对速度 $\Rightarrow$ $\vec{v}_1'$
  - 相对质心速度 $\Rightarrow$ $\vec{u}_1'$
- 靶粒子反冲:
  - 绝对速度 $\Rightarrow$ $\vec{v}_2'$
  - 相对质心速度 $\Rightarrow$ $\vec{u}_2'$

$$\vec{v}_1' = \vec{v}_c + \vec{u}_1'$$



$$\begin{cases} v_1'\cos\theta_l = v_c + u_1'\cos\theta_c \\ v_1'\sin\theta_l = u_1'\sin\theta_c \end{cases}$$

$$tg\theta_l = \frac{\sin\theta_c}{\frac{v_c}{u_1'} + \cos\theta_c}$$

$$\gamma \equiv \frac{v_c}{u_1'}$$

$$tg\theta_l = \frac{\sin\theta_c}{\gamma + \cos\theta_c}$$

$$v_1'^2 = v_c^2 + u_1'^2 - 2v_c u_1' \cos(\pi - \theta_c)$$

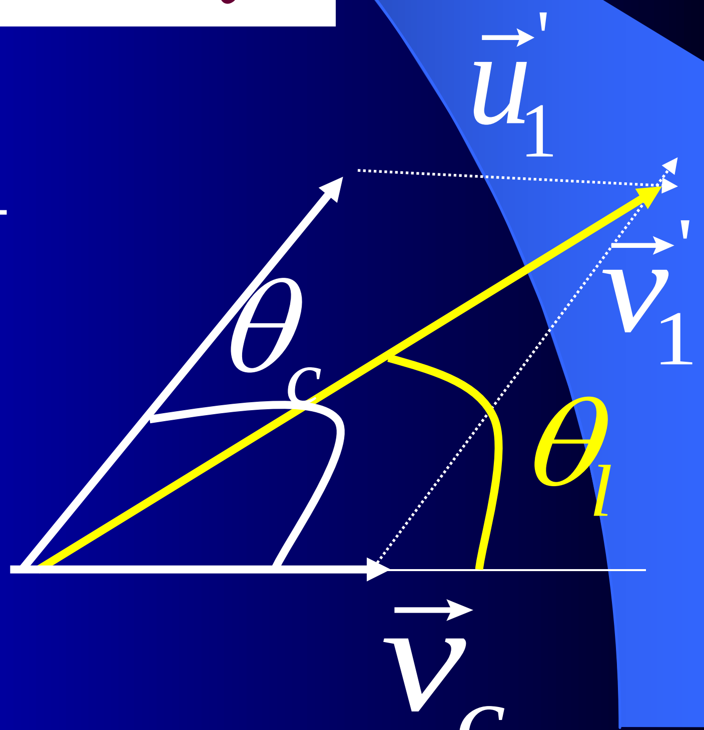
$$\boxed{v_1'^2 = v_c^2 + u_1'^2 + 2v_c u_1' \cos\theta_c}$$

$$v_1' \cos\theta_l = v_c + u_1' \cos\theta_c$$

$$\boxed{v_1'^2 \cos^2\theta_l = u_1'^2 (1 + \gamma\cos\theta_c)^2}$$

$$\cos^2\theta_l = \frac{u_1'^2 (\gamma + \cos\theta_c)^2}{v_c^2 + u_1'^2 + 2v_c u_1' \cos\theta_c}$$

$$\boxed{\cos\theta_l = \frac{\gamma + \cos\theta_c}{\sqrt{1 + \gamma^2 + 2\gamma\cos\theta_c}}}$$



In fact, from $tg\theta_l = \dfrac{\sin\theta_c}{\gamma + \cos\theta_c}$ we can have,

$$\frac{1}{\cos^2\theta_l} = 1 + tg^2\theta_l = 1 + \left(\frac{\sin\theta_c}{\gamma + \cos\theta_c}\right)^2$$

$$= \frac{1 + 2\gamma\cos\theta_c + \gamma^2}{(\gamma + \cos\theta_c)^2}$$

i.e.,

$$\cos\theta_l = \frac{\gamma + \cos\theta_c}{\sqrt{1 + \gamma^2 + 2\gamma\cos\theta_c}}$$

对弹性碰撞设靶M散射前静止

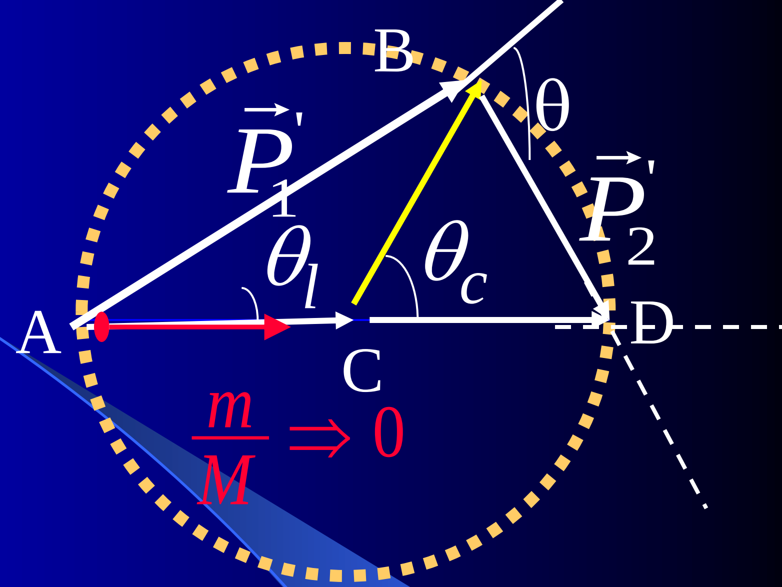
$$\vec{v}_c = \frac{m\vec{v}_1}{m+M} \Rightarrow v_c = \frac{mv_1}{m+M}$$

$$\vec{u}_1{}' = \vec{v}_1 - \vec{v}_c = \frac{(m+M)\vec{v}_1 - m\vec{v}_1}{M+m} = \frac{M\vec{v}_1}{M+m}$$

$$u_1{}' = \frac{Mv_1}{M+m} \Rightarrow \gamma \equiv \frac{v_c}{u_1{}'} = \frac{m}{M}$$

$$tg\theta_l = \frac{\sin\theta_c}{\frac{m}{M} + \cos\theta_c}$$

$$tg\theta_l = \frac{\sin\theta_c}{\frac{m}{M} + \cos\theta_c}$$



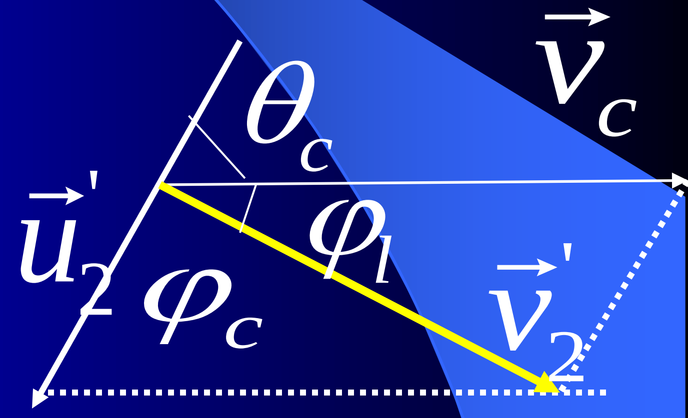
Discussion:

- 当 $m << M$, $\frac{m}{M} = 0$ $\Rightarrow$ $\theta_l = \theta_c$
- 当 $m = M$ $tg\theta_l = \dfrac{\sin\theta_c}{\frac{m}{M} + \cos\theta_c}$

$$tg\theta_l = \frac{\sin\theta_c}{1+\cos\theta_c} = tg\frac{\theta_c}{2} \Rightarrow \theta_l = \frac{\theta_c}{2}$$

$$\begin{cases} v_2^{'}\cos\varphi_l = v_c + u_2^{'}\cos(\pi - \varphi_c) \\ v_2^{'}\sin\varphi_l = u_2^{'}\sin\varphi_c \end{cases}$$

$$tg\varphi_l = \frac{u_2^{'}\sin\varphi_c}{v_c + u_2^{'}\cos\varphi_c}$$



对弹性碰撞设靶M散射前静止

$$u = u^{'} = v_1 \qquad u_2^{'} = \frac{mu^{'}}{m+M}$$

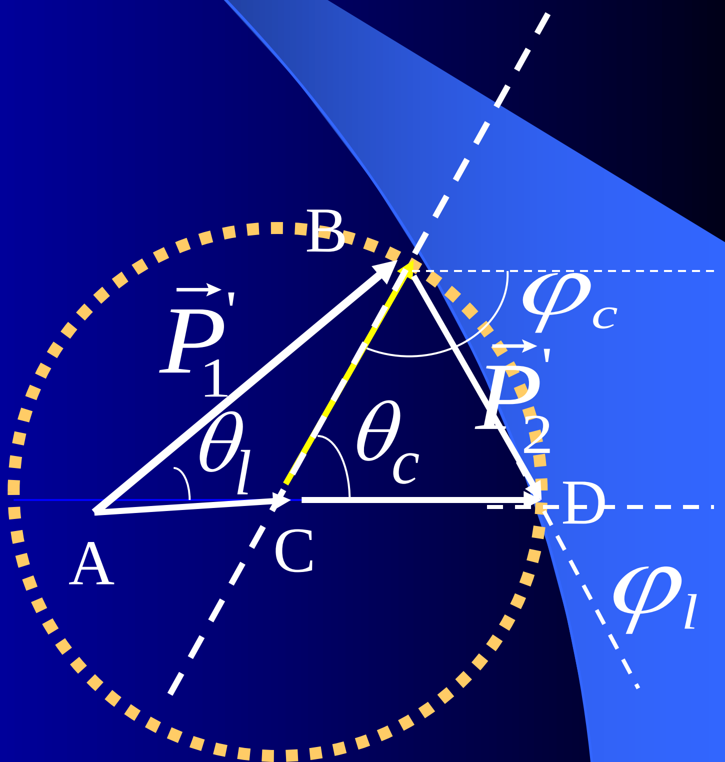
$$v_c = \frac{mv_1}{m+M} = \frac{mu}{m+M} = \frac{mu^{'}}{m+M}$$

$$tg\varphi_l = \frac{u_2' \sin\varphi_c}{v_c + u_2' \cos\varphi_c}$$

$$\begin{cases} u_2' = \dfrac{mu'}{m+M} \\ v_c = \dfrac{mu'}{m+M} \end{cases}$$

$$tg\varphi_l = \frac{\sin\varphi_c}{1+\cos\varphi_c} = tg\frac{\varphi_c}{2}$$

$$\varphi_l = \frac{\varphi_c}{2} \qquad \varphi_l = \frac{\pi-\theta_c}{2}$$



$$tg\varphi_l = \frac{\sin\varphi_c}{1+\cos\varphi_c} = tg\frac{\varphi_c}{2}$$

$$\varphi_l = \frac{\varphi_c}{2}$$

二. 能量关系

L系 $\Rightarrow$ $$E_l = \frac{1}{2}mv_1^2$$

C系 $\Rightarrow$ $$E_c = \frac{1}{2}mu_1^2 + \frac{1}{2}Mu_2^2$$

$$= \frac{1}{2}\frac{mM}{m+M}v_1^2$$

$$\frac{E_l}{E_c}=\frac{m+M}{M}$$

对弹性散射 ⇒ m=M ⇒ $E_l=2E_c$

入射粒子动能损失

散射前 ⇒ $E_0=\frac{1}{2}mv_1^2$，靶粒子静止

散射后 ⇒ $E_1=\frac{1}{2}m(\vec{v}_c+\vec{u}_1')^2$

$$E_1=\frac{1}{2}m(v_c^2+u_1'^2+2\vec{v}_c\vec{u}_1')$$

$$E_1=\frac{1}{2}mu_1'^2(1+\gamma^2+2\gamma\cos\theta_c)$$

$$\vec{u}_1' = \vec{v}_1 - \vec{v}_c = \frac{M\vec{v}_1}{M+m} \Rightarrow u_1' = \frac{Mv_1}{M+m} = \frac{Mu}{M+m}$$

$$E_1 = \frac{1}{2} m \left(\frac{Mu}{M+m}\right)^2 (1 + \gamma^2 + 2\gamma \cos\theta_c)$$

$$= \frac{1}{2} m v_1^2 \left(\frac{1}{1+\gamma}\right)^2 (1 + \gamma^2 + 2\gamma\, c$$

$$\gamma \equiv \frac{v_c}{u_1'} = \frac{m}{M}$$

$$\mathrm{E}_0 \qquad E_1 = \frac{1}{2} m u_1'^2 (1 + \gamma^2 + 2\gamma \cos\theta_c)$$

$$\frac{E_1}{E_0} = \left(\frac{1}{1+\gamma}\right)^2 (1 + \gamma^2 + 2\gamma \cos\theta_c)$$

$$\frac{E_1}{E_0} = \left(\frac{1}{1+\gamma}\right)^2 (1+\gamma^2+2\gamma\cos\theta_c)$$

Discussion: $m = M \Rightarrow \gamma = 1$

$$\frac{E_1}{E_0} = \frac{2+2\cos\theta_C}{4} = \frac{1+\cos\theta_c}{2}$$

$$\cos\theta_l = \frac{\gamma + \cos\theta_c}{\sqrt{1+\gamma^2+2\gamma\cos\theta_c}} \Rightarrow \cos\theta_l = \sqrt{\frac{1+\cos\theta_C}{2}}$$

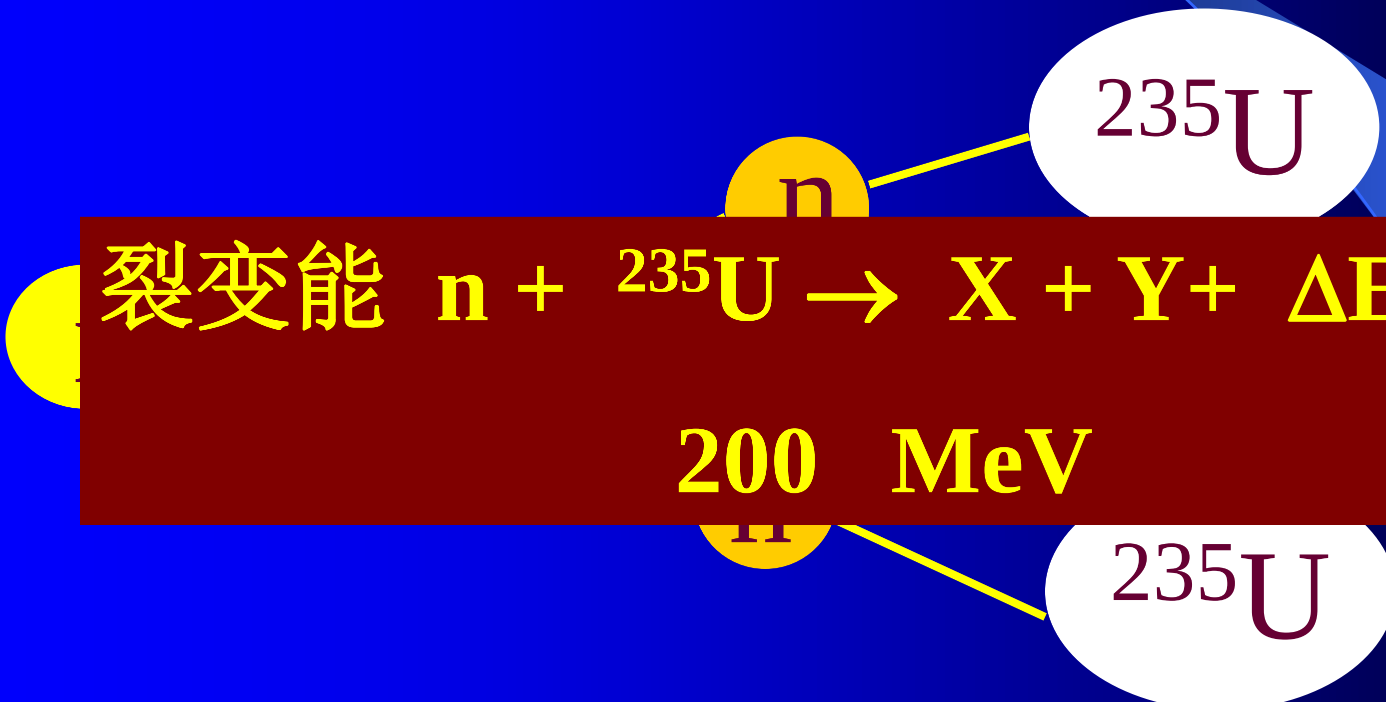
$$\Downarrow$$

$$\cos\frac{\theta_C}{2}$$

$$\frac{E_1}{E_0} = \cos^2\theta_l$$

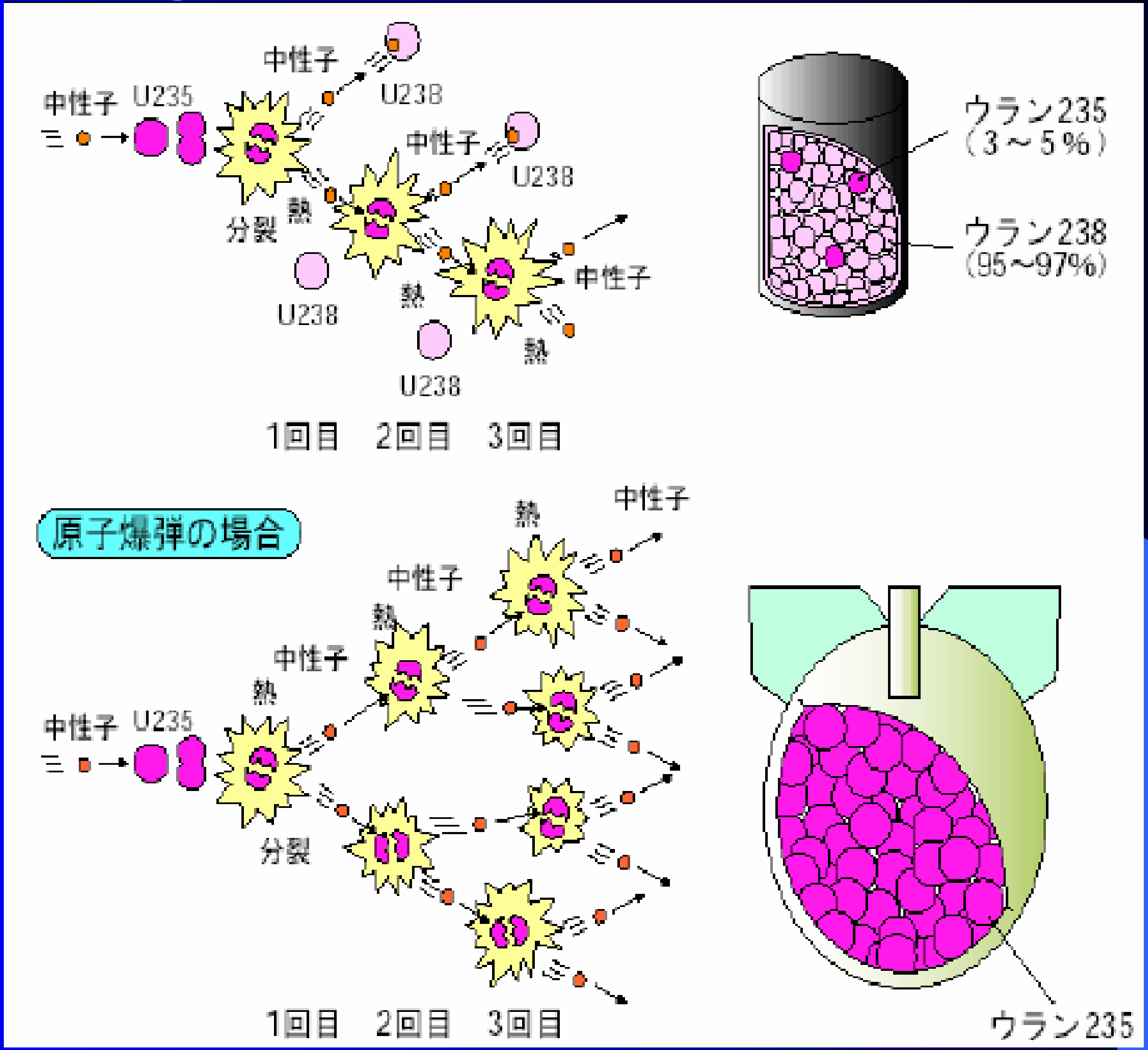
当 $\theta_l = \dfrac{\pi}{2} \Longrightarrow \theta_c = \pi$ ？ 正碰

入射粒子能量全部传给靶粒子



裂变能 $n + {}^{235}U \rightarrow X + Y + \Delta E$

200 MeV



中性子
U235
中性子
U238
中性子
U238
分裂
熱
熱
熱
中性子
U238
U238
1回目　2回目　3回目
ウラン235
（3～5％）
ウラン238
（95～97％）
原子爆弾の場合
中性子
熱
中性子
熱
中性子
熱
中性子
U235
分裂
1回目　2回目　3回目
ウラン235

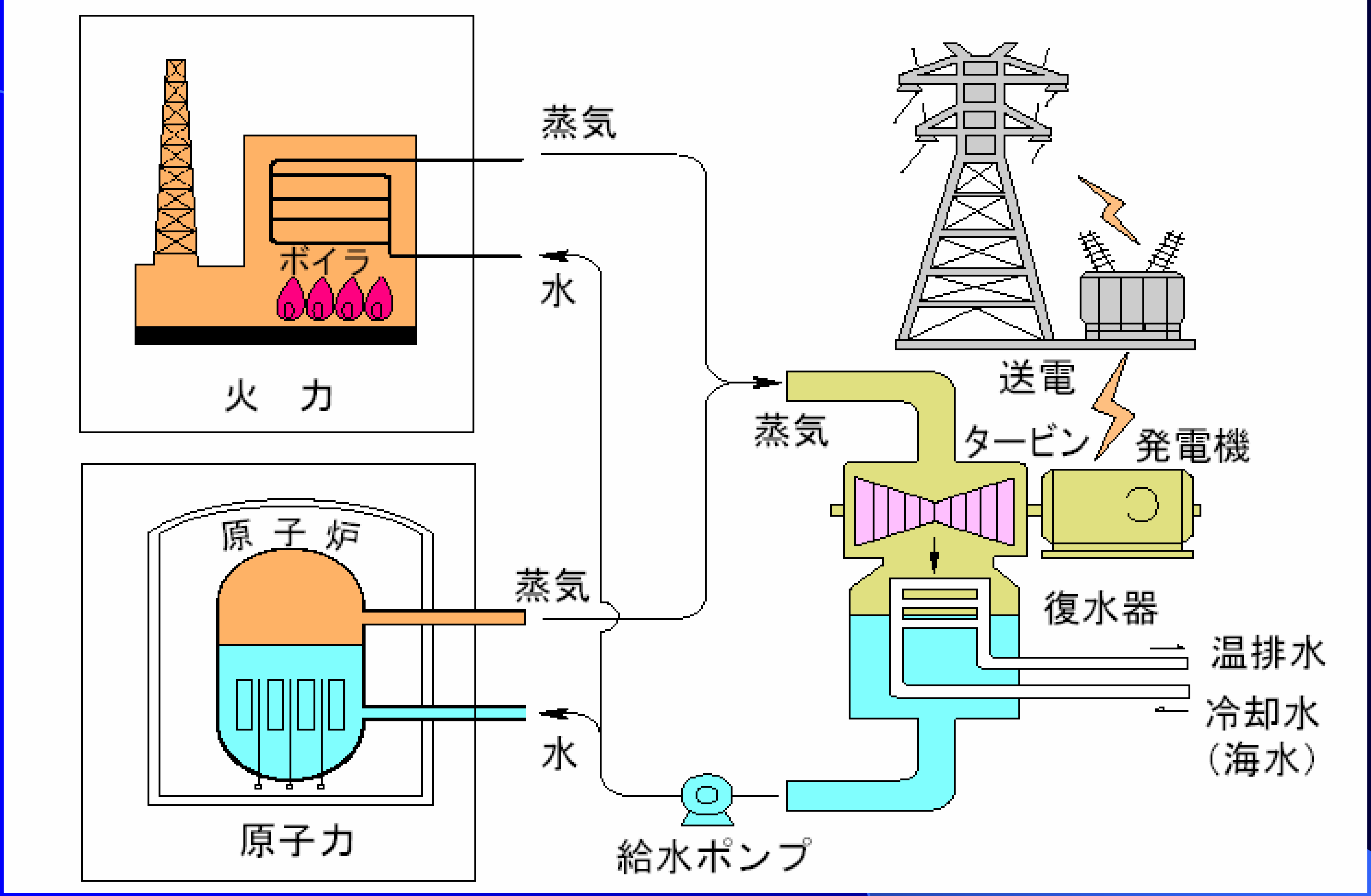
核能从何而来

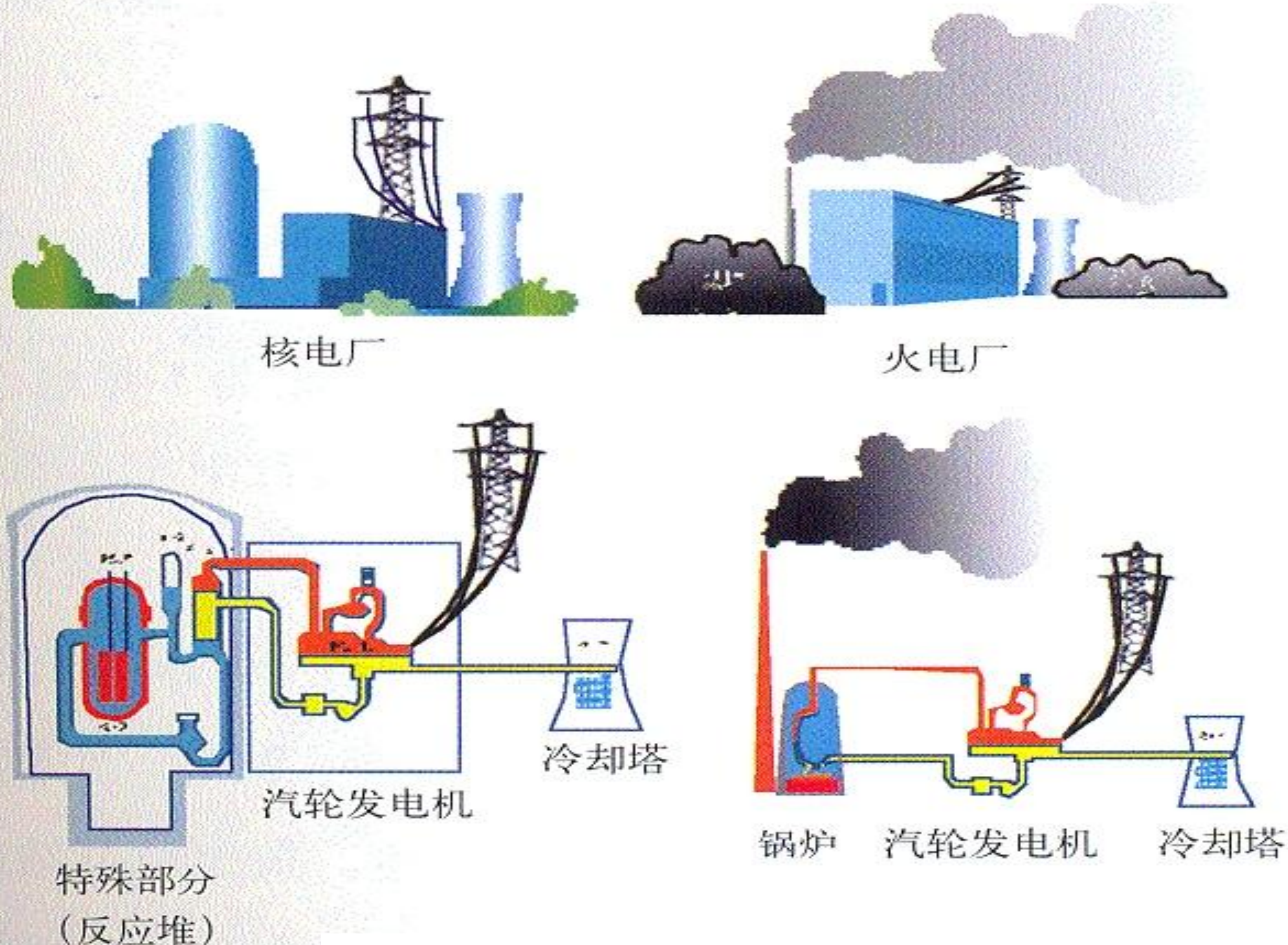
- 爱因斯坦质能关系式：　　**E＝mc²**
- 裂变反应：

$$^{235}U + n \Rightarrow X + Y + 2.5n + 200Mev$$

- 燃烧1千克铀-235相当于2700吨标准煤大270万倍

核电站





核电厂与火电厂比较

三. 散射截面关系

总截面 $\sigma_l = \sigma_c$ 与坐标系无关

$$\because \sigma_l = \iint \sigma(\theta_l) \sin\theta_l d\theta_l d\varphi$$

$$= 2\pi \int \sigma(\theta_l) \sin\theta_l d\theta_c$$

$$\because \sigma_c = \iint \sigma(\theta_c) \sin\theta_c d\theta_c d\varphi$$

$$= 2\pi \int \sigma(\theta_c) \sin\theta_c d\theta_c$$

$$\int \sigma(\theta_l) \sin\theta_l d\theta_l = \int \sigma(\theta_c) \sin\theta_c d\theta c$$

$$d\sigma = s\,ds\,d\varphi = \sigma(\theta)\sin\theta\,d\theta\,d\varphi$$

$$\int \sigma(\theta_l)\sin\theta_l\,d\theta_l = \int \sigma(\theta_c)\sin\theta_c\,d\theta c$$

$$= \int \sigma(\theta_c)\sin\theta_c\left|\frac{d\theta_C}{d\theta_l}\right|d\theta_l$$

$$\sigma(\theta_l)\sin\theta_l = \sin\theta_c\,\sigma(\theta_c)\left|\frac{d\theta_C}{d\theta_l}\right|$$

$$\frac{\sigma(\theta_l)}{\sigma(\theta_C)} = \frac{\sin\theta_C}{\sin\theta_l}\left|\frac{d\theta_C}{d\theta_l}\right|$$

$$\cos\theta_l = \frac{\gamma+\cos\theta_c}{\sqrt{1+\gamma^2+2\gamma\cos\theta_c}}$$

$$\sigma(\theta_c) = \left|\frac{\gamma+\cos\theta_c}{(1+\gamma^2+2\gamma\cos\theta_c)^{\frac{3}{2}}}\right|\sigma(\theta_l(\theta_c))$$