

2-03 横波性、光在电 介质表面的反射和折射

光的偏振

- 1 偏振特性
- 2 偏振片
- 3 线偏振光
- 4 自然光
- 5 部分偏振光
- 6 圆偏振光
- 7 椭圆偏振光

1. 光的偏振特性

- 偏振：**振动方向**相对于**传播方向**的不对称性
- 横波： $E \perp k$ ，可能具有偏振的特性

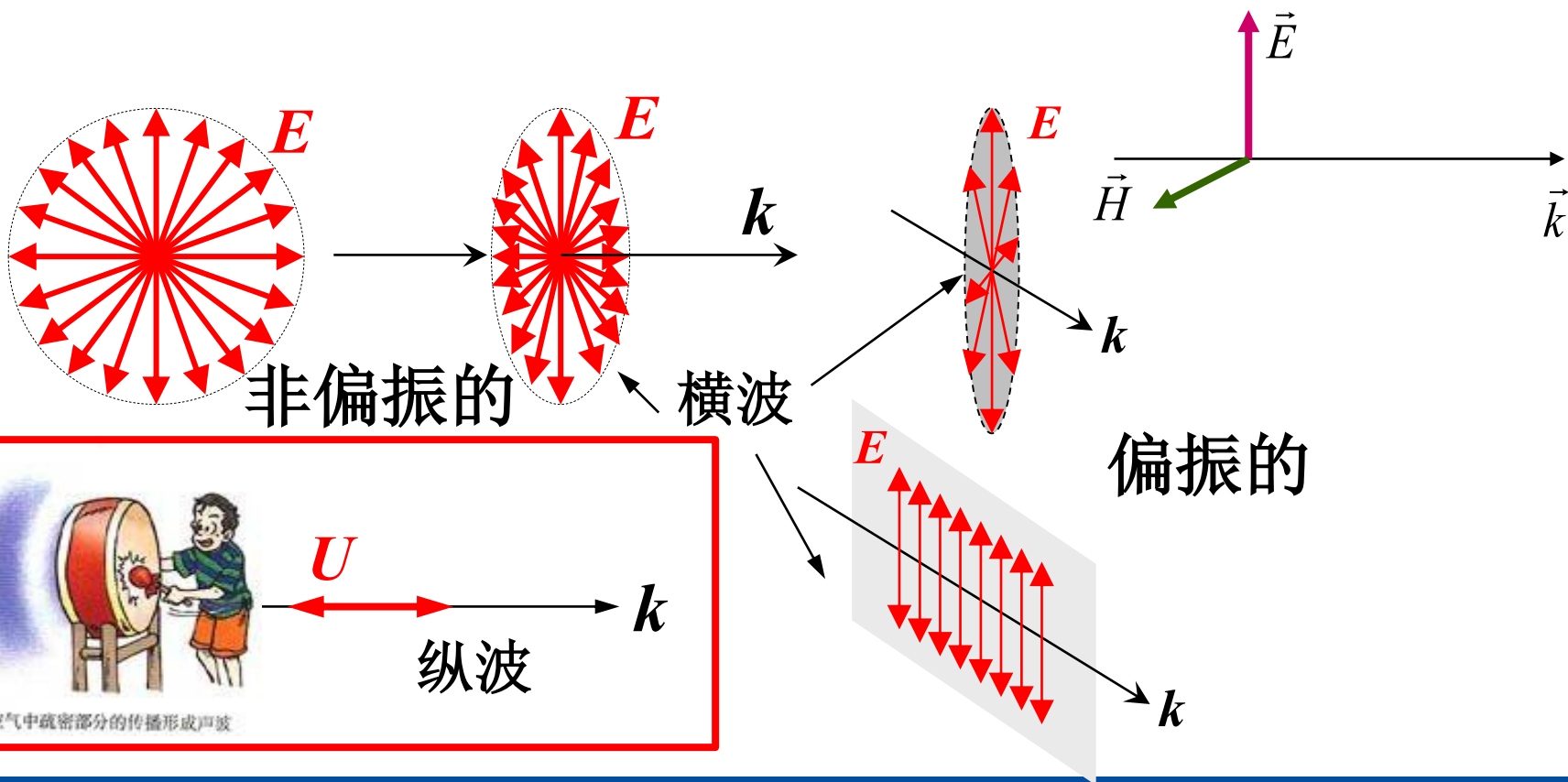
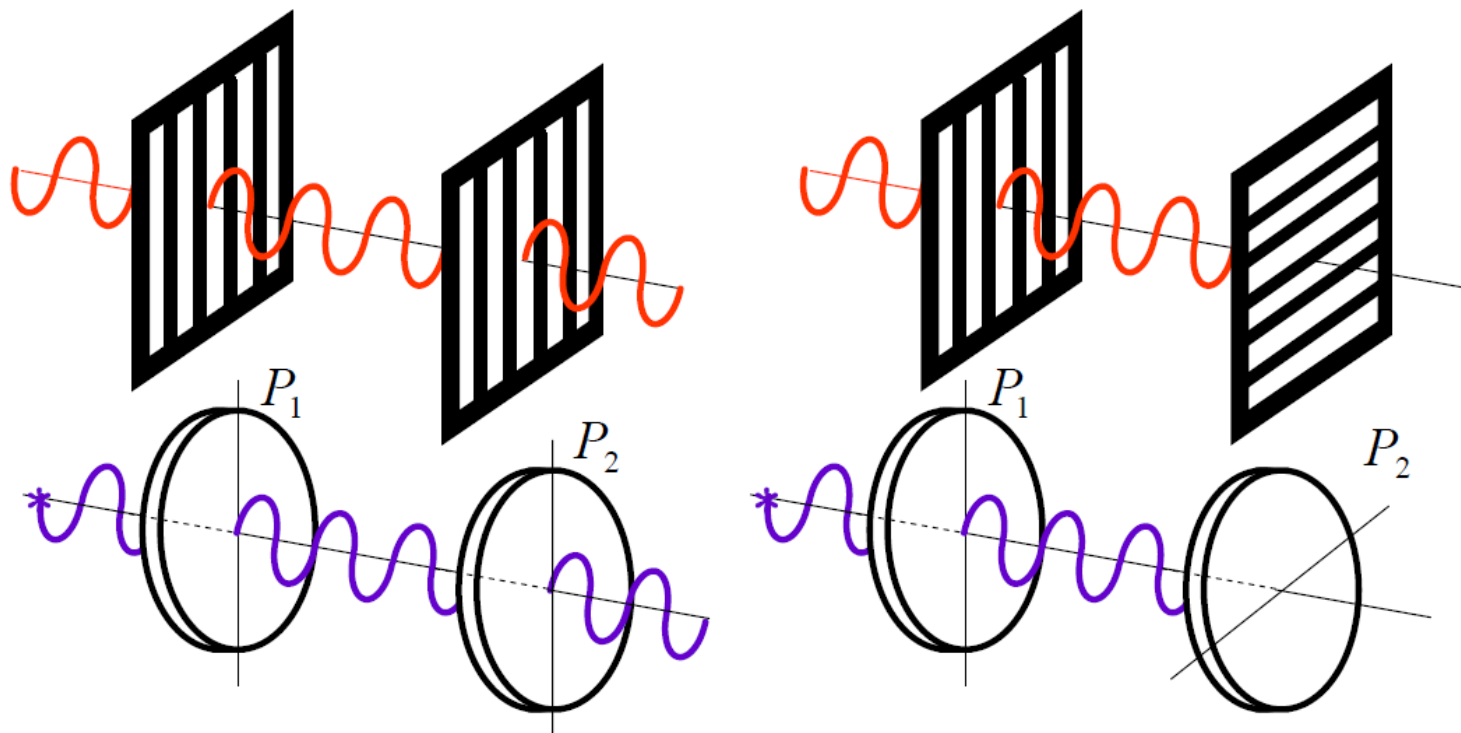


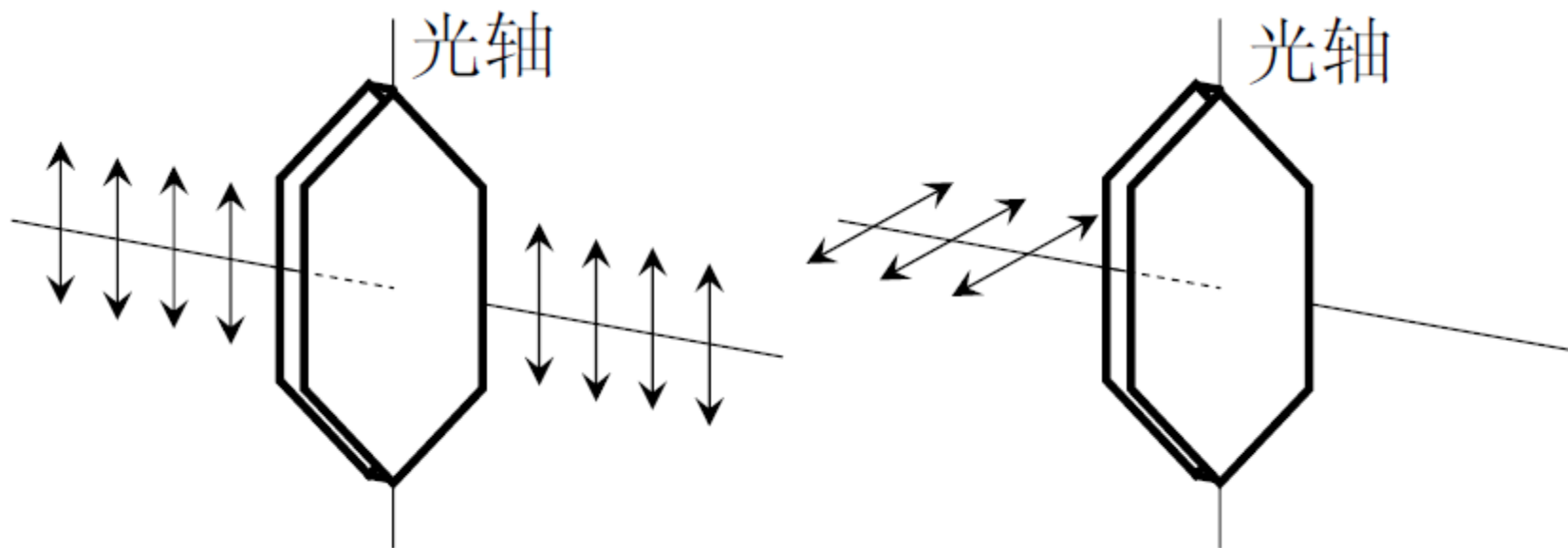
图 1.1-6 空气中疏密部分的传播形成声波

2. 偏振片



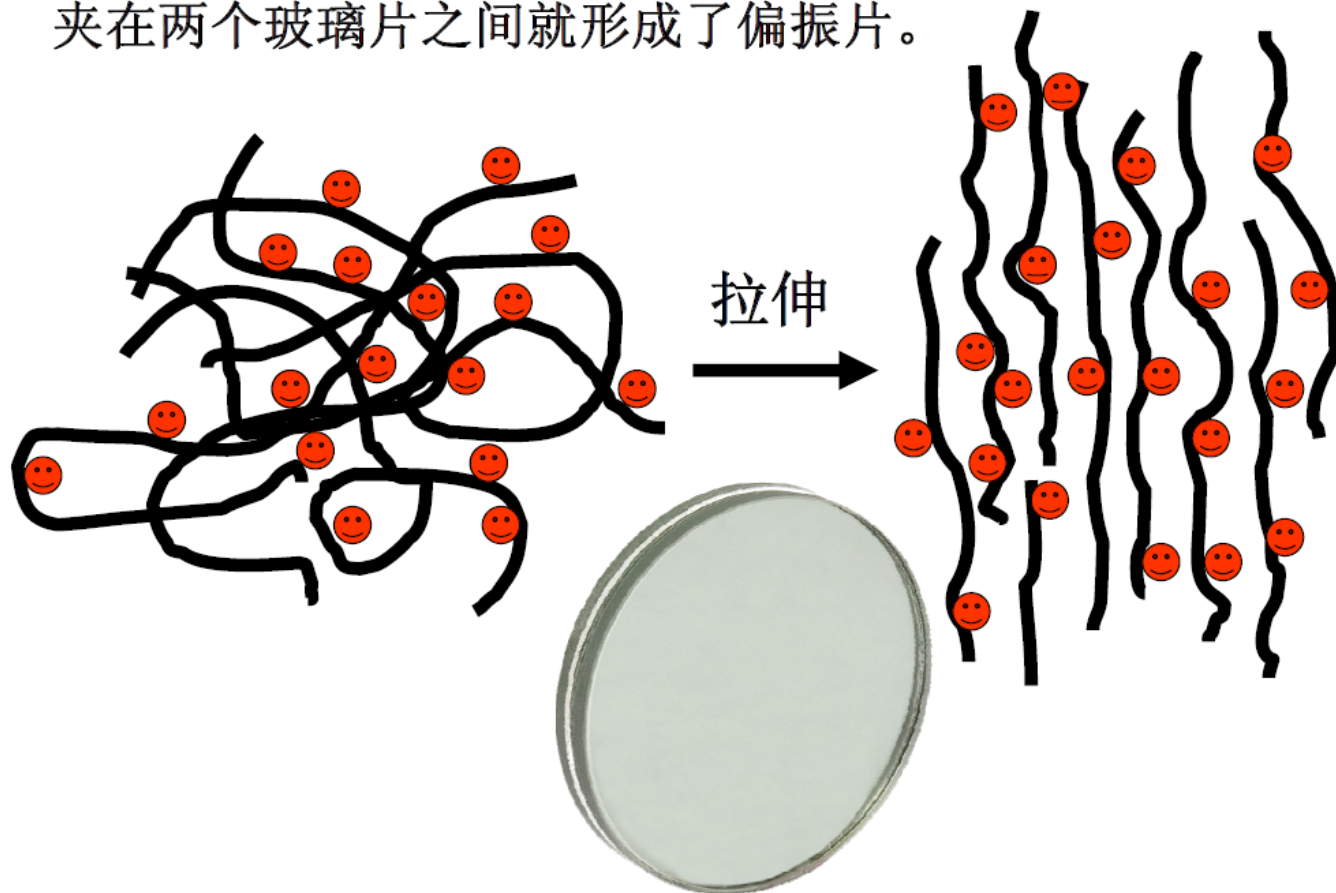
偏振片(Polarizer)：只让某一振动方向光波通过的光学元件称为偏振片。这个方向被称为偏振片的透振方向或偏振方向。

偏振片按其用途（获得偏振光、检验偏振光）分别称为起偏器、检偏器

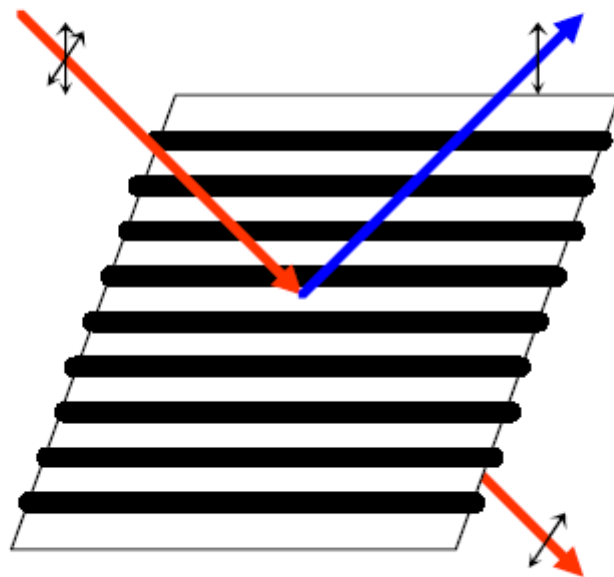


二向色性偏振片：

有机晶体，如硫酸碘奎宁、电气石或聚乙烯醇，薄膜在碘溶液中浸泡后，在高温下拉伸、烘干，然后夹在两个玻璃片之间就形成了偏振片。

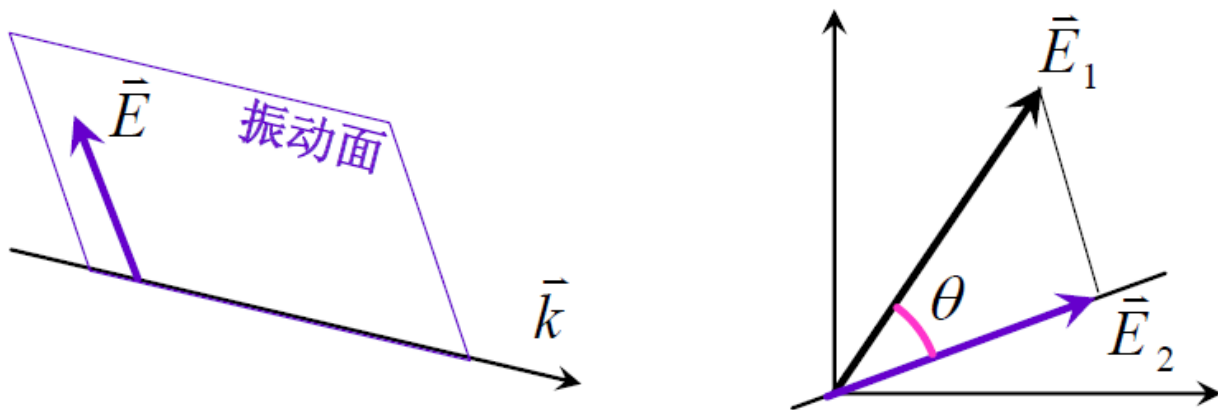


纳米金属光栅 偏振片



3. 线偏振光（平面偏振光）

- 光矢量只在一个固定的平面（振动面）内振动



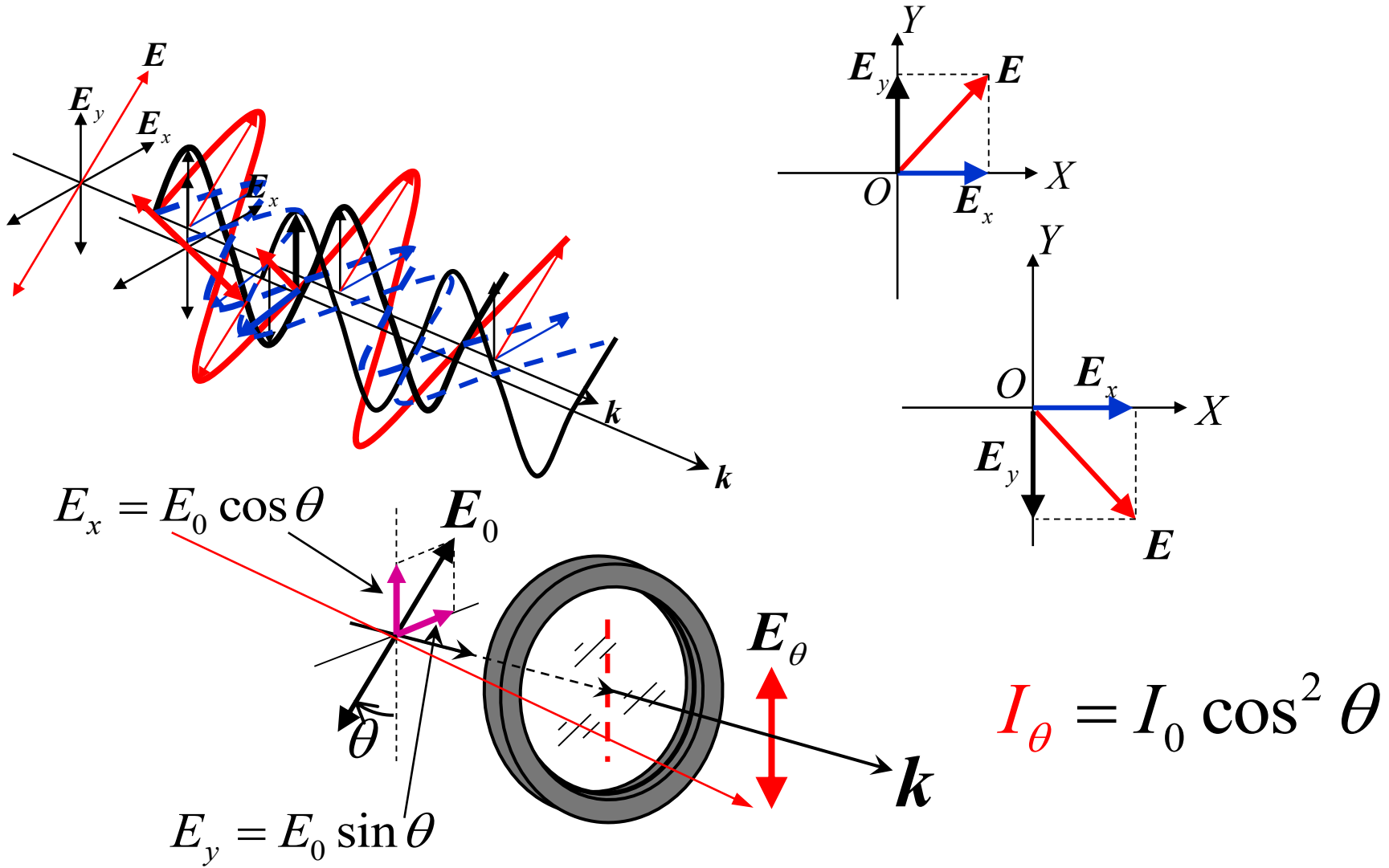
马吕斯（E.L. Malus, 1809）定律：

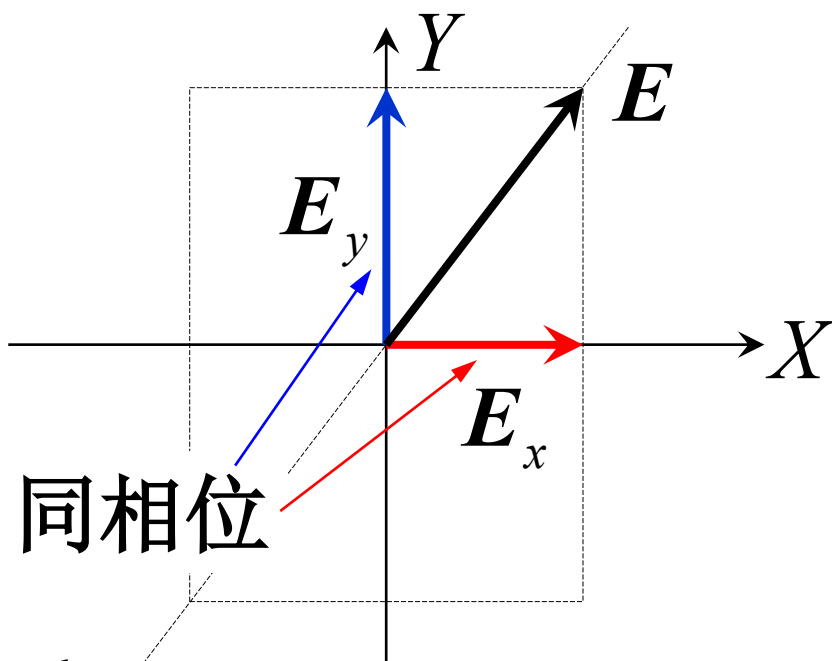
线偏振光在其它方向上的振动分量同其与振动面夹角余弦的平方成正比，即：

$$I_2 = I_1 \cos^2 \theta$$

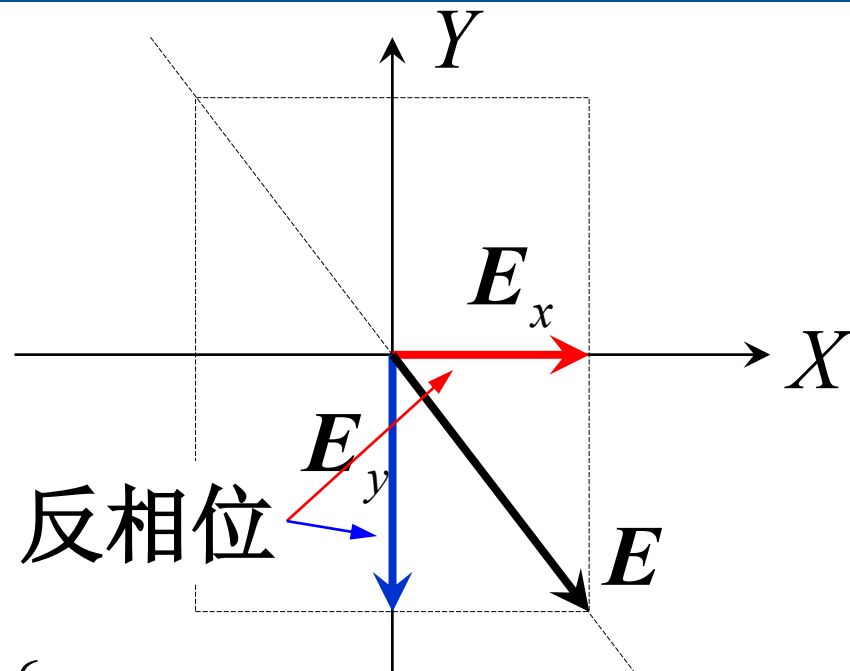
$$E_2 = E_1 \cos \theta$$

- 光矢量的正交分解





$$\begin{cases} E_x(z, t) = A \cos(\omega t - kz) \\ E_y(z, t) = A \cos(\omega t - kz) \end{cases}$$



$$\begin{cases} E_x(z, t) = A \cos(\omega t - kz) \\ E_y(z, t) = A \cos(\omega t - kz + \pi) \end{cases}$$

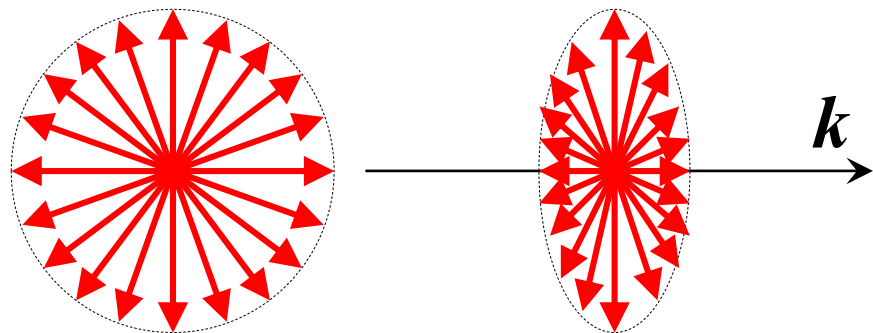
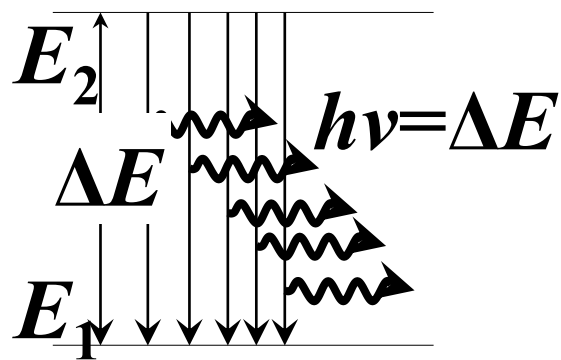
总是在一个固定点观察，可略写空间相位

$$\begin{cases} E_x(t) = A \cos \omega t \\ E_y(t) = A \cos \omega t \end{cases}$$

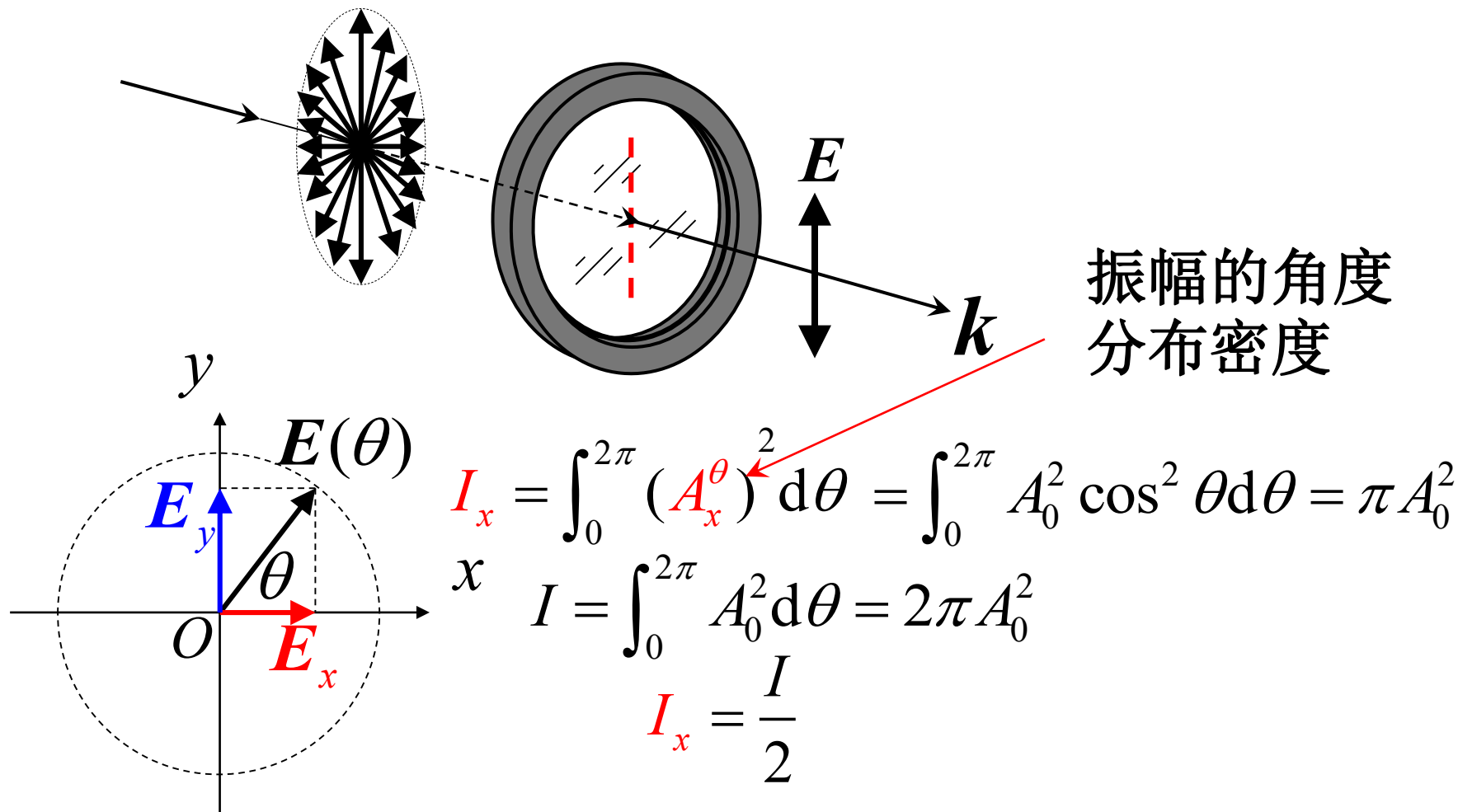
$$\begin{cases} E_x(t) = A \cos \omega t \\ E_y(t) = A \cos(\omega t + \pi) \end{cases}$$

4. 自然光

- 普通光源发出非偏振光
- 大量原子**热运动**或**跃迁**发光：固体材料中原子的体积密度 $\sim 10^{23}/\text{cm}^3$
- 发光是**自发辐射**过程
- 发光原子间无关联
- 称为**自然光**
- **相位**、**光矢量**方向任意

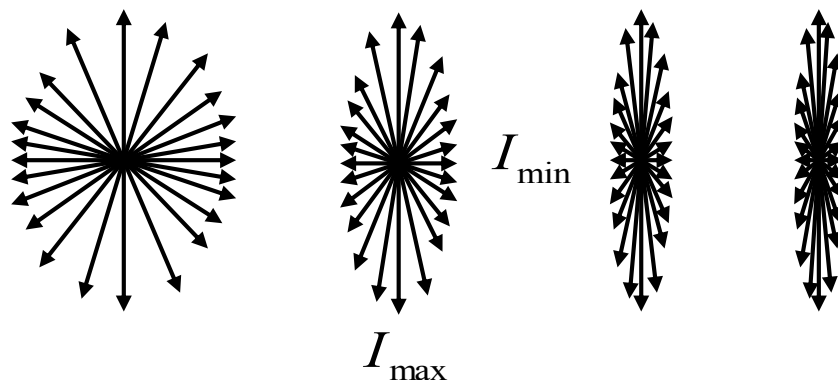


- 旋转起偏器，出射光强不变，强度变为1/2
- 自然光经起偏器，变为偏振光

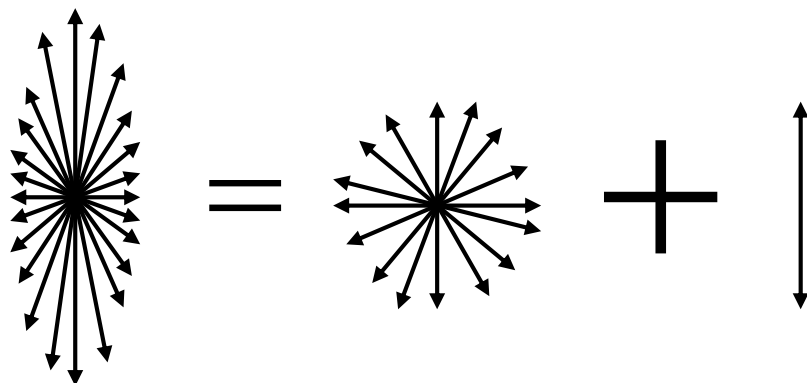


5. 部分偏振光

- 介于自然光和线偏振光之间



可看作是自然光和线偏振光的叠加



偏振度

$$P = \frac{I_{\max} - I_{\min}}{I_{\max} + I_{\min}}$$

P=0 自然光 (或非偏振光)

P=1 线偏光 (或全偏振光)

偏振光的图示标记方法：

线偏振光



振动方向垂直纸面

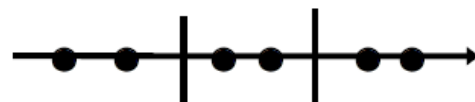


振动方向平行纸面

部分偏振光



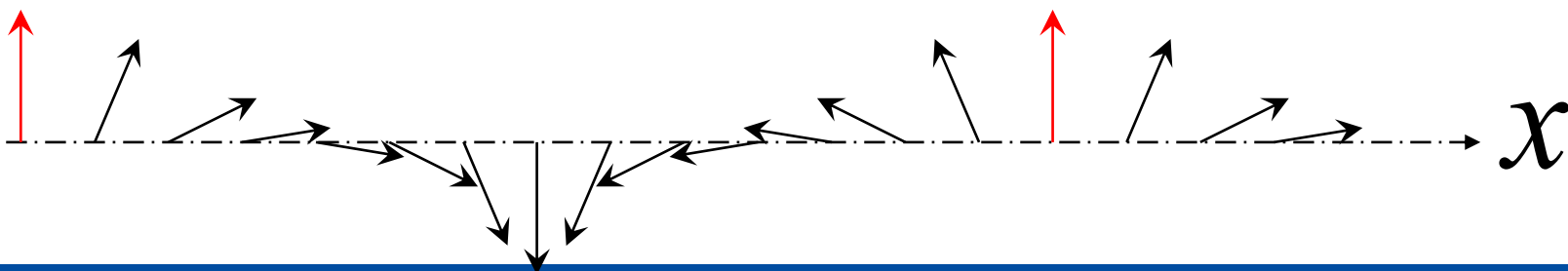
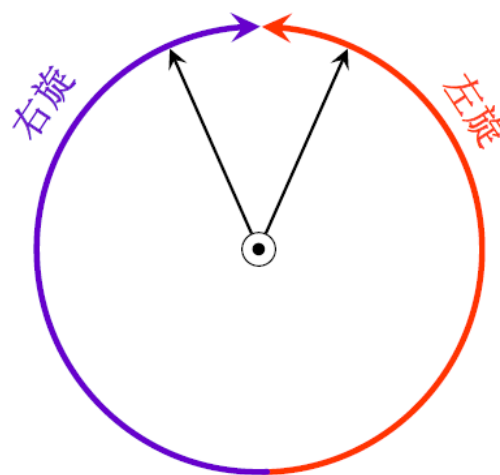
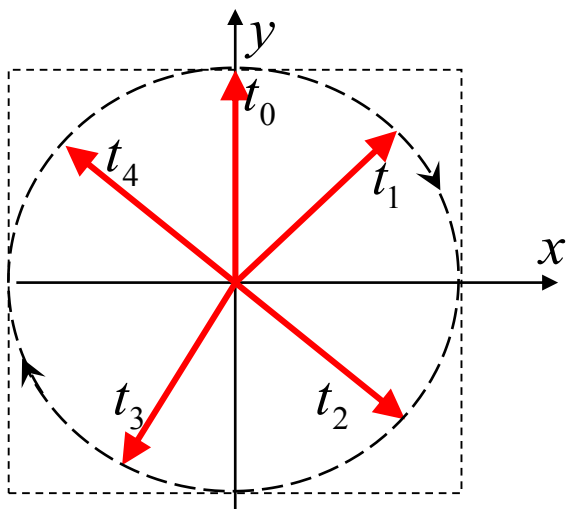
纸面内的振动较强



垂直纸面的振动较强

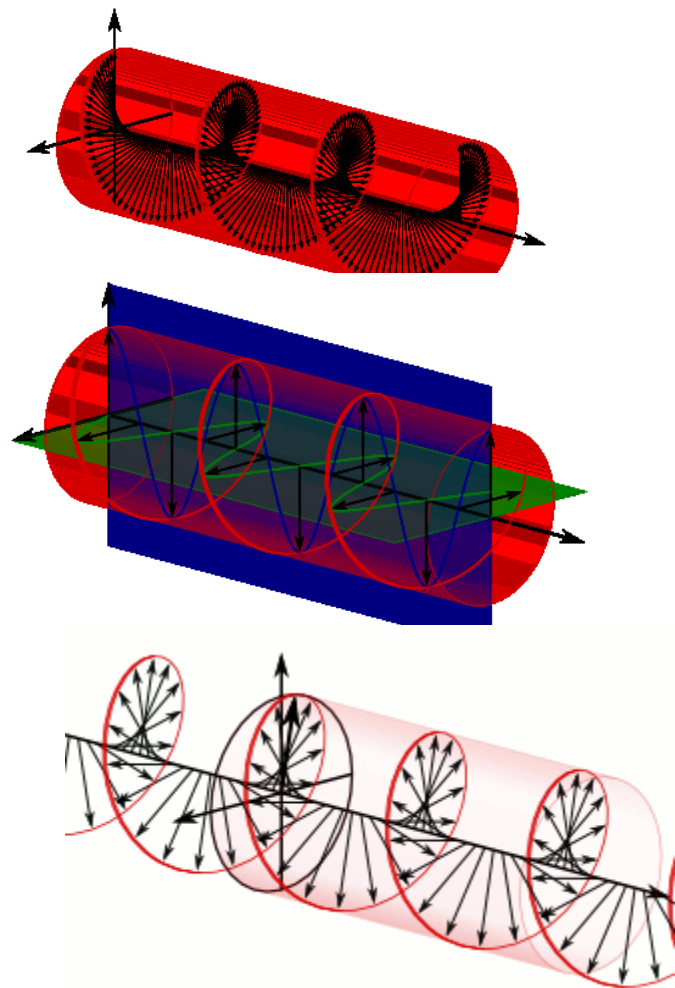
6. 圆偏振光

- 在一个垂直于波矢的**固定平面**内观察，光矢量旋转，大小不变，端点轨迹是圆



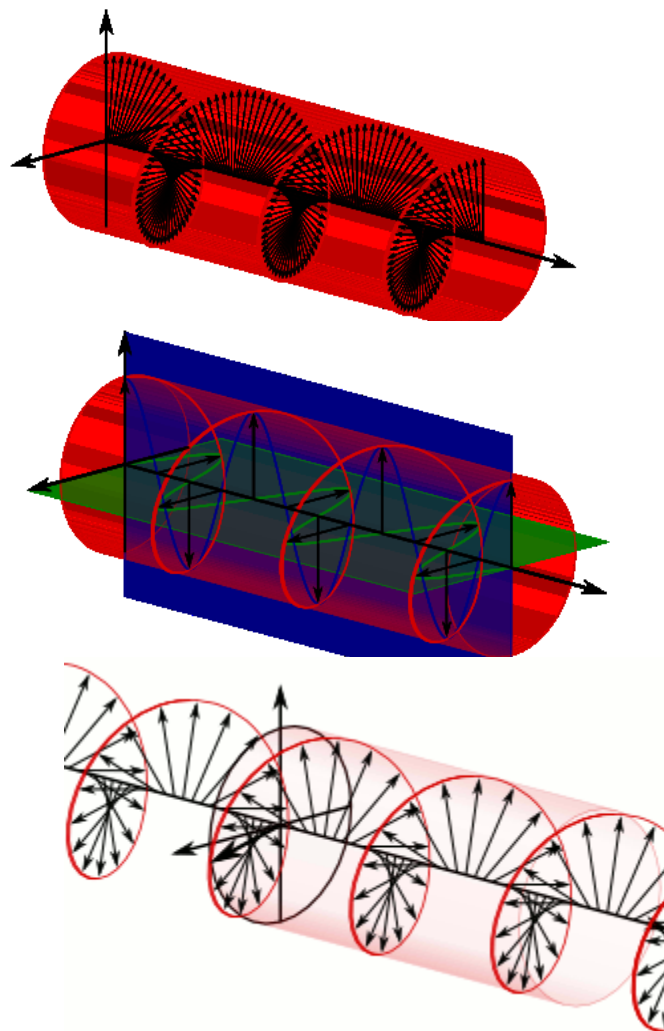
圆偏振光

Right-handed/clockwise circularly polarized light

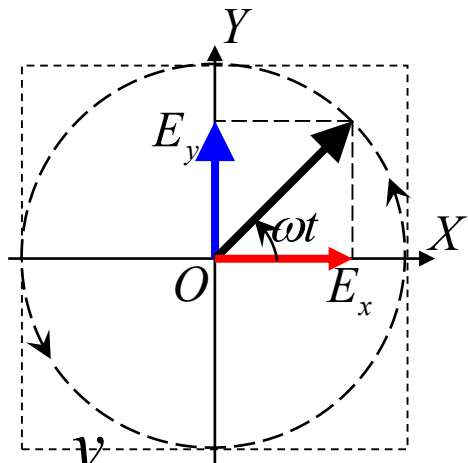


point of view of the receiver

Left-handed/counter-clockwise circularly polarized light

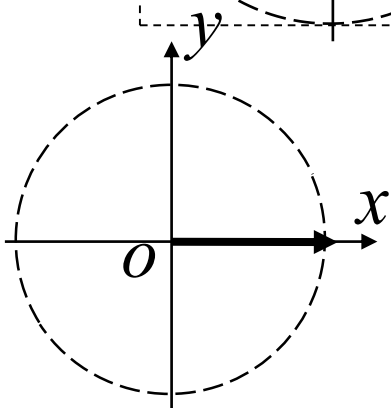


- 圆偏光可看作是两相位差为的 $\pi/2$ 的正交分量的叠加

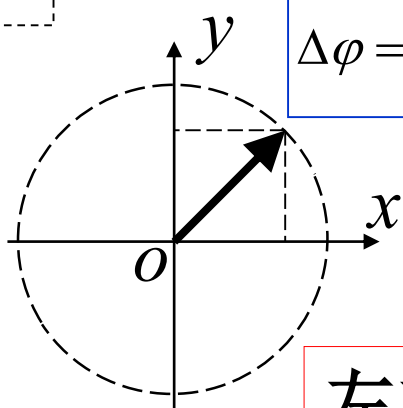


$$\begin{cases} E_x(t) = A \cos \omega t \\ E_y(t) = A \cos(\omega t \pm \frac{\pi}{2}) \end{cases}$$

+ : 右旋
 - : 左旋

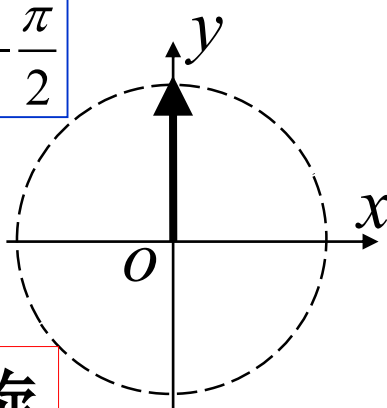


$t = 0$

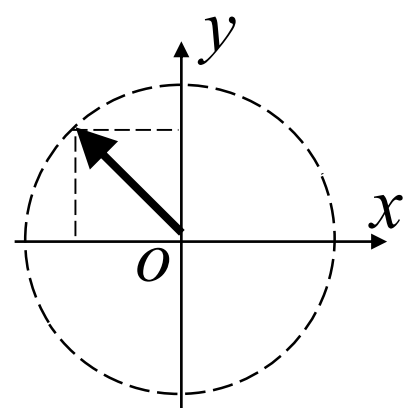


$t = \frac{\pi}{4\omega}$

左旋



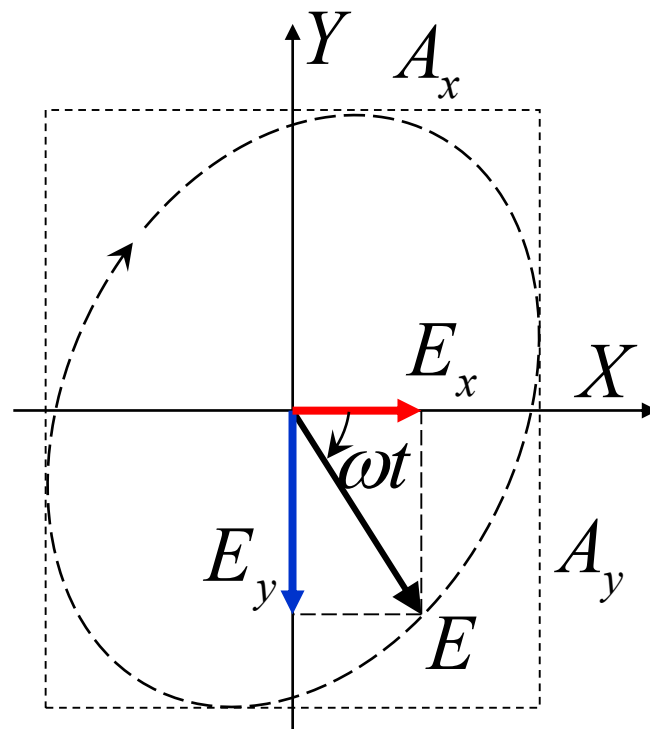
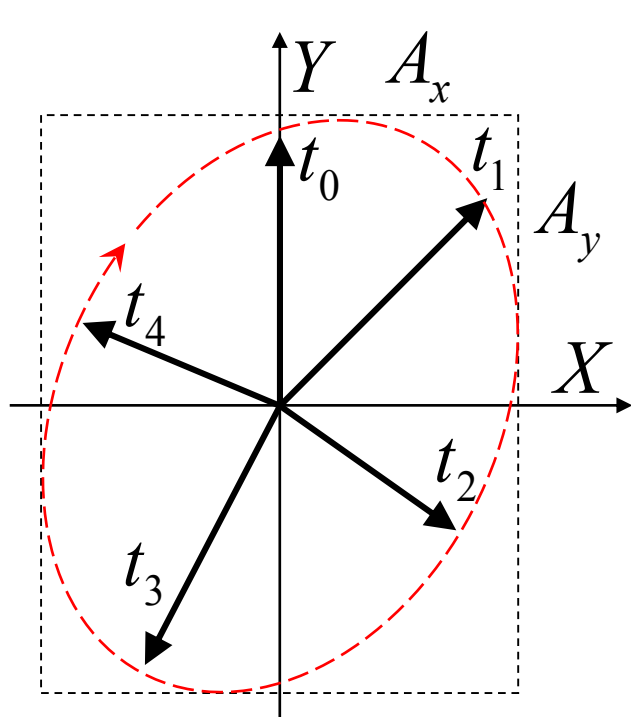
$t = \frac{\pi}{2\omega}$

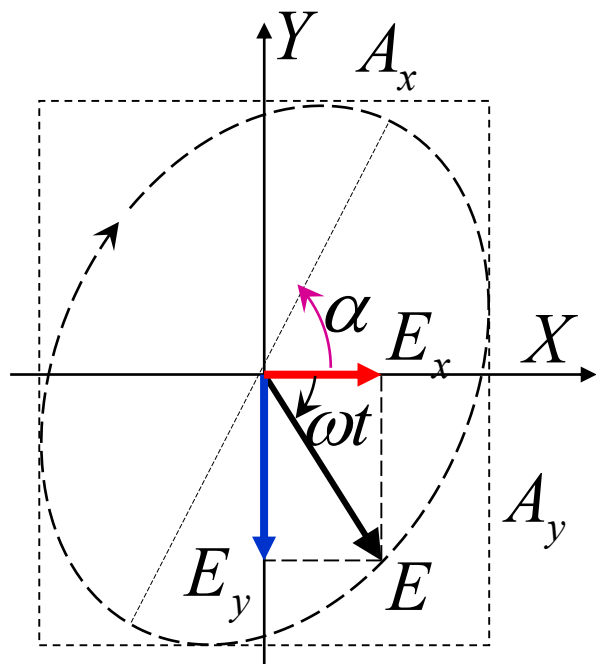


$t = \frac{3\pi}{4\omega}$

7. 椭圆偏振光

- 在一个垂直于波矢的固定平面内，光矢量旋转，大小作周期性改变，端点轨迹是椭圆



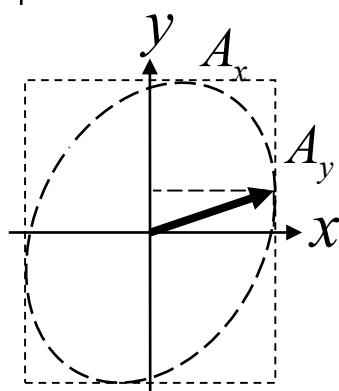


$$\begin{cases} E_x = A_x \cos(\omega t) \\ E_y = A_y \cos(\omega t + \Delta\varphi) \end{cases}$$

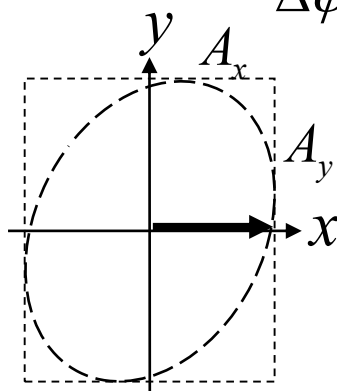
$$\frac{E_x^2}{A_x^2} + \frac{E_y^2}{A_y^2} - \frac{2E_x E_y}{A_x A_y} \cos \Delta\varphi = \sin^2 \Delta\varphi$$

$$\tan 2\alpha = \frac{2A_x A_y}{A_x^2 - A_y^2} \cos \Delta\varphi$$

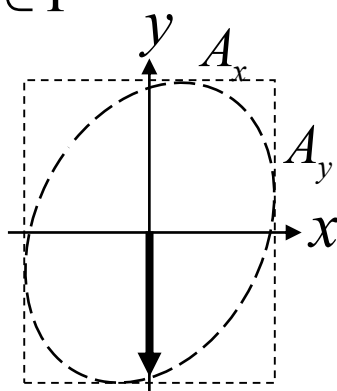
右旋



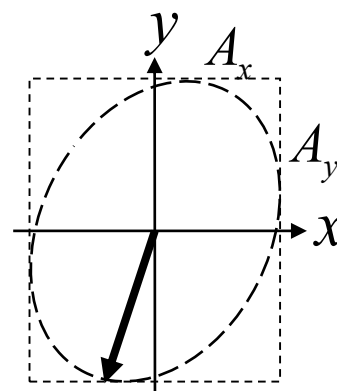
$$\omega t = 0$$



$$\omega t = \frac{\pi}{2} - \Delta\varphi$$



$$\omega t = \frac{\pi}{2}$$

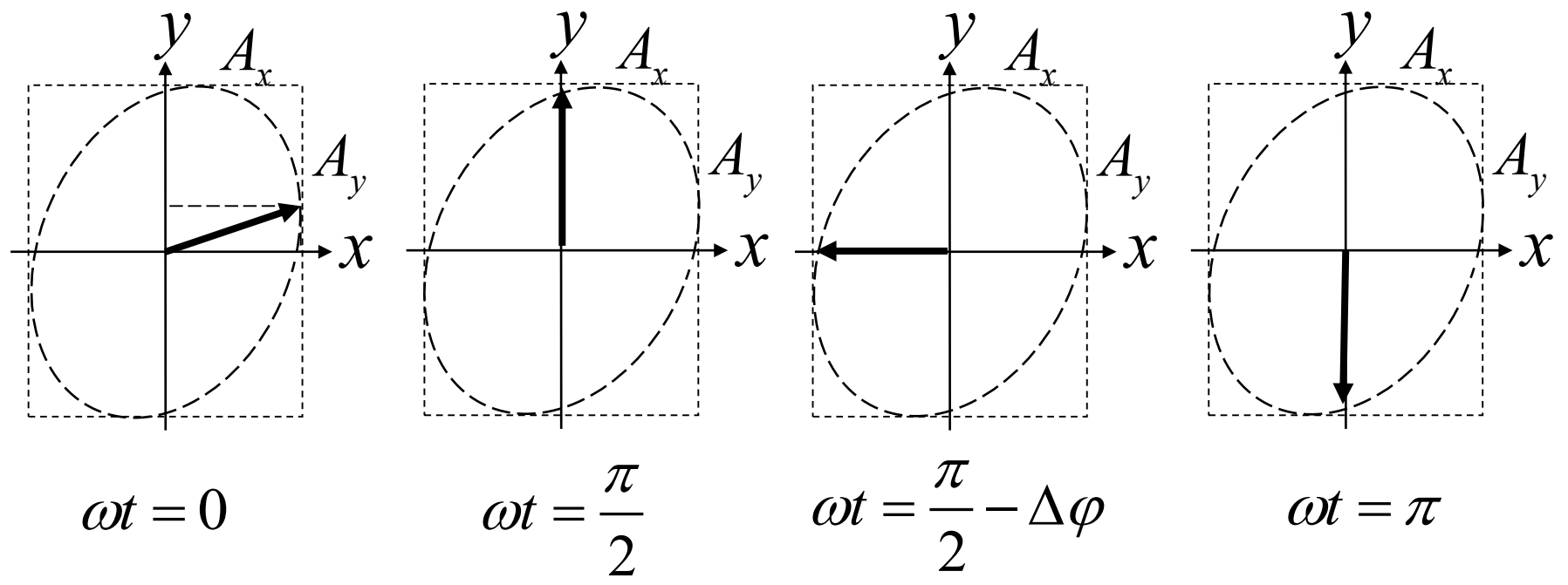


$$\omega t = \pi - \Delta\varphi$$

$\Delta\varphi \in I$

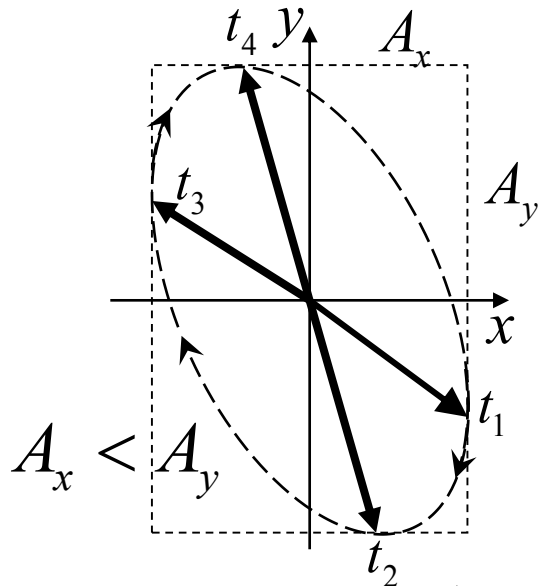
$$\begin{cases} E_x = A_x \cos(\omega t) \\ E_y = A_y \cos(\omega t + \Delta\varphi) \end{cases}$$

$\Delta\varphi \in \text{IV}$ 左旋



$\Delta\varphi \in \text{II}$

椭圆的取向只取决于相位差

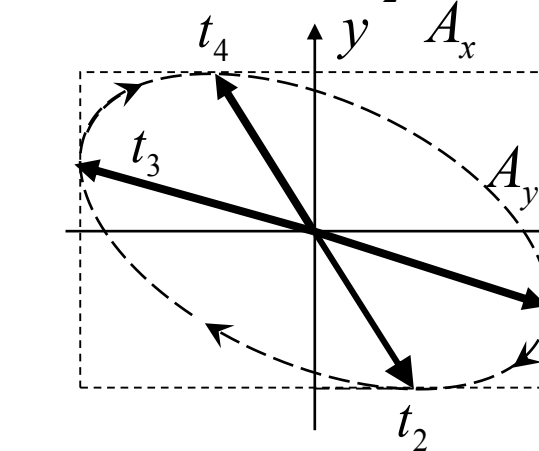


$$\begin{cases} E_x = A_x > 0 \\ E_y = A_y \cos \Delta\varphi < 0 \end{cases}$$

切点在第IV象限

$$\begin{cases} E_x = A_x \cos(\pi - \Delta\varphi) > 0 \\ E_y = -A < 0_y \end{cases}$$

切点在第IV象限



$$\begin{cases} E_x = -A_x < 0 \\ E_y = A_y \cos(\pi + \Delta\varphi) > 0 \end{cases}$$

切点在第II象限

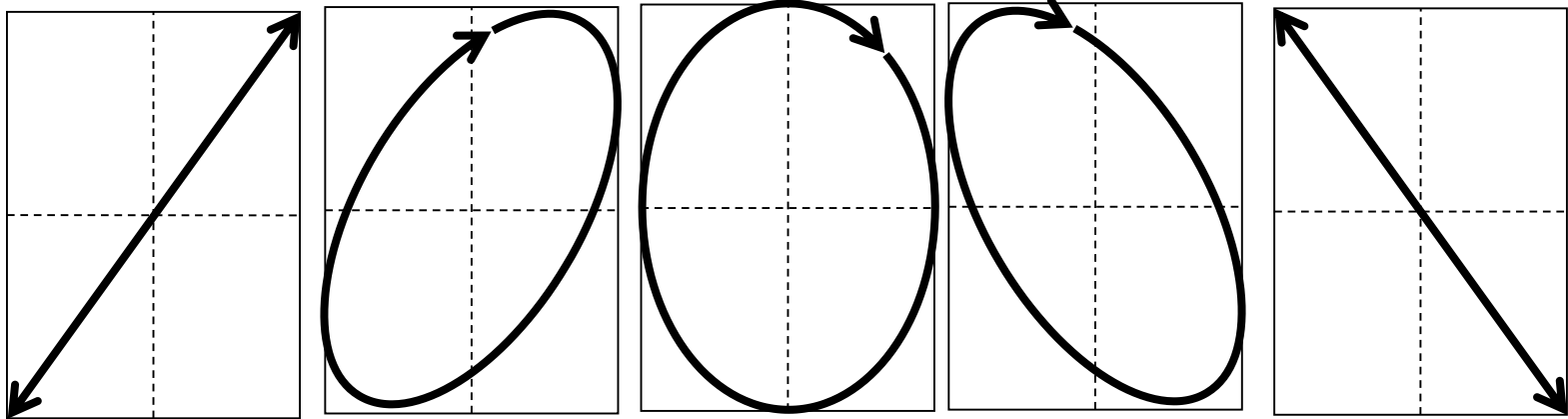
$$\begin{cases} E_x = A_x \cos \Delta\varphi < 0 \\ E_y = A_y > 0 \end{cases}$$

切点在第II象限

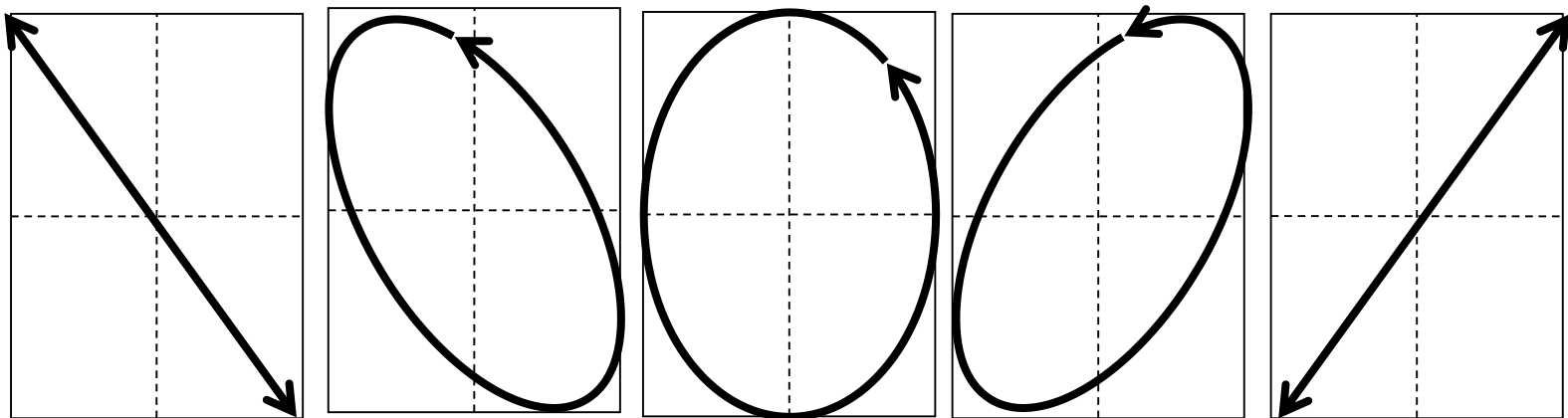
长轴总是在II、IV象限

与 A_x 、 A_y 的相对大小无关

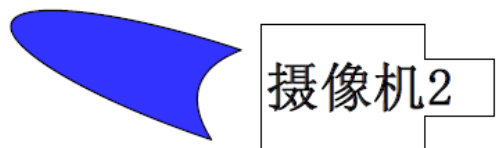
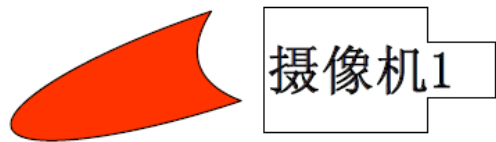
$$\Delta\varphi = 0 \quad \Delta\varphi \in (0, \frac{\pi}{2}) \quad \Delta\varphi = \frac{\pi}{2} \quad \Delta\varphi \in (\frac{\pi}{2}, \pi) \quad \Delta\varphi = \pi$$



$$\Delta\varphi = \pi \quad \Delta\varphi \in (\pi, \frac{3\pi}{2}) \quad \Delta\varphi = \frac{3\pi}{2} \quad \Delta\varphi \in (\frac{3\pi}{2}, 2\pi) \quad \Delta\varphi = 2\pi$$

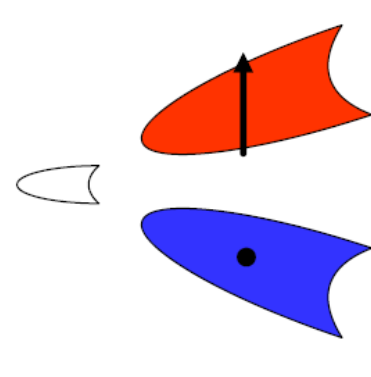
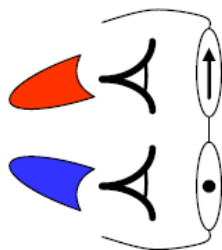
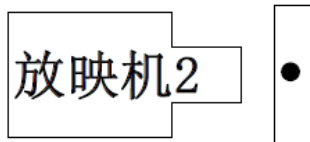


§ 补充：立体电影



拍摄

放映



§ 补充：偏光显微镜(polarizing microscope)

在显微镜的样品的前后加两块偏振方向相互垂直的偏振片，无样品或样品无双折射时，视野是暗的。当样品有双折射或旋光效应时，有相应的图像出现。

双折射：纤维、染色体、淀粉粒、细胞壁
旋光：生物糖、常细胞（左旋）、肿瘤细
（右旋）。



常规显微镜图像



偏光显微镜图像

偏光滤镜



未使用偏光滤镜

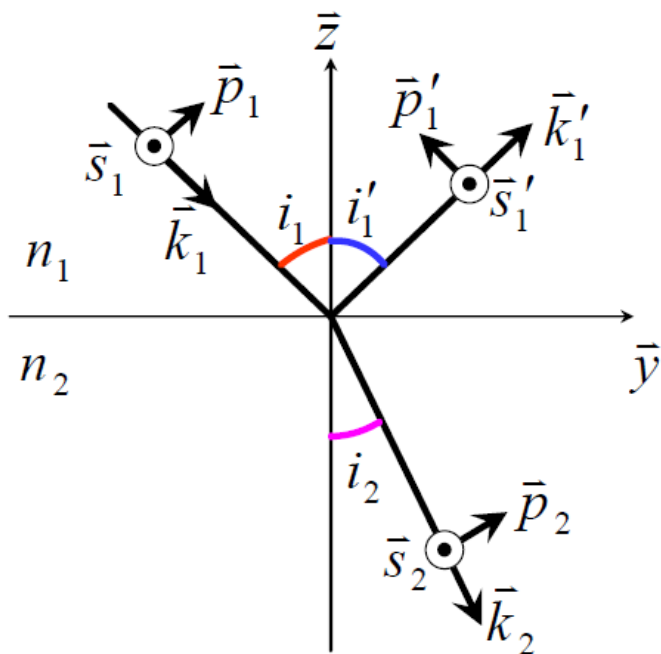
使用偏光滤镜

作业：P245，2,3

光在电介质表面的反射和折射

1. 菲涅尔(A.J. Fresnel, 1823)反射与折射公式
2. 反射率与透射率
3. 斯托克斯倒逆关系
4. 相位关系和半波损失
5. 发射与折射光的偏振

1. 菲涅尔反射与折射公式



$$\begin{cases} \vec{E}_1 = \vec{A}_1 e^{i(\vec{k}_1 \cdot \vec{r} - \omega_1 t)} & \text{入射波} \\ \vec{E}_2 = \vec{A}_2 e^{i(\vec{k}_2 \cdot \vec{r} - \omega_2 t)} & \text{折射波} \\ \vec{E}'_1 = \vec{A}'_1 e^{i(\vec{k}'_1 \cdot \vec{r} - \omega'_1 t)} & \text{反射波} \end{cases}$$

$$k = \frac{2\pi}{\lambda}$$

$$\frac{\omega}{k} = v = \frac{c}{n}$$

$$\frac{k}{n} = \frac{2\pi}{n\lambda} = \frac{2\pi}{\lambda_0} = k_0$$

$$k_2 = \frac{n_2}{n_1} k_1$$

麦克斯韦方程组:

微分形式:	积分形式:
$\left\{ \begin{array}{l} \nabla \cdot \bar{D} = \rho \\ \nabla \cdot \bar{B} = 0 \\ \nabla \times \bar{E} = -\frac{\partial \bar{B}}{\partial t} \\ \nabla \times \bar{H} = \bar{J} + \frac{\partial \bar{D}}{\partial t} \end{array} \right.$	$\left\{ \begin{array}{l} \oiint \bar{D} \cdot d\bar{s} = Q \\ \oint \bar{E} \cdot d\bar{l} = 0 \\ \oiint \bar{E} \cdot d\bar{s} = -\iint \frac{\partial \bar{B}}{\partial t} \cdot d\bar{s} \\ \oint \bar{H} \cdot d\bar{l} = I + \iint \frac{\partial \bar{D}}{\partial t} \cdot d\bar{s} \end{array} \right.$

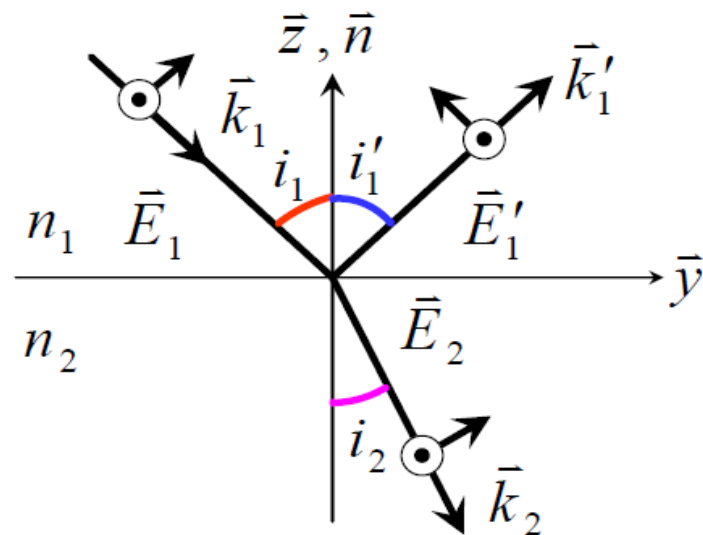
物质方程:

$$\left\{ \begin{array}{l} \bar{D} = \varepsilon \bar{E} \\ \bar{B} = \mu \bar{H} = \sqrt{\varepsilon \mu} \bar{k} \times \bar{E} \\ n = \sqrt{\varepsilon \mu} \\ S = n \sqrt{\frac{\varepsilon_0}{\mu_0}} E^2 \end{array} \right.$$

边界条件:

$$\left\{ \begin{array}{l} \bar{n} \cdot (\bar{D}_1 - \bar{D}_2) = 0 \\ \bar{n} \cdot (\bar{B}_1 - \bar{B}_2) = 0 \\ \bar{n} \times (\bar{E}_1 - \bar{E}_2) = 0 \\ \bar{n} \times (\bar{H}_1 - \bar{H}_2) = 0 \end{array} \right.$$

$$\begin{cases} \vec{n} \times (\vec{E}_1 + \vec{E}'_1) = \vec{n} \times \vec{E}_2 \\ \vec{n} \times (\vec{H}_1 + \vec{H}'_1) = \vec{n} \times \vec{H}_2 \end{cases}$$



i) 反射、折射定律:

$$\vec{n} \times \vec{A}_1 e^{i(\vec{k}_1 \cdot \vec{r} - \omega_1 t)} + \vec{n} \times \vec{A}'_1 e^{i(\vec{k}'_1 \cdot \vec{r} - \omega'_1 t)} = \vec{n} \times \vec{A}_2 e^{i(\vec{k}_2 \cdot \vec{r} - \omega_2 t)}$$

$$\omega_1 = \omega'_1 = \omega_2$$

反射、折射波与入射波同频

$$\vec{k}_1 \cdot \vec{r} = \vec{k}'_1 \cdot \vec{r} = \vec{k}_2 \cdot \vec{r}$$

(波矢切向分量连续)

$$k'_{1y} = k_{1y} = k_{2y}$$

共面

$$\begin{cases} (\vec{k}'_1 - \vec{k}_1) \cdot \vec{r} = 0 \\ (\vec{k}_2 - \vec{k}_1) \cdot \vec{r} = 0 \end{cases}$$



$$\begin{cases} i'_1 = i_1 \\ n_1 \sin i_1 = n_2 \sin i_2 \end{cases}$$

反射

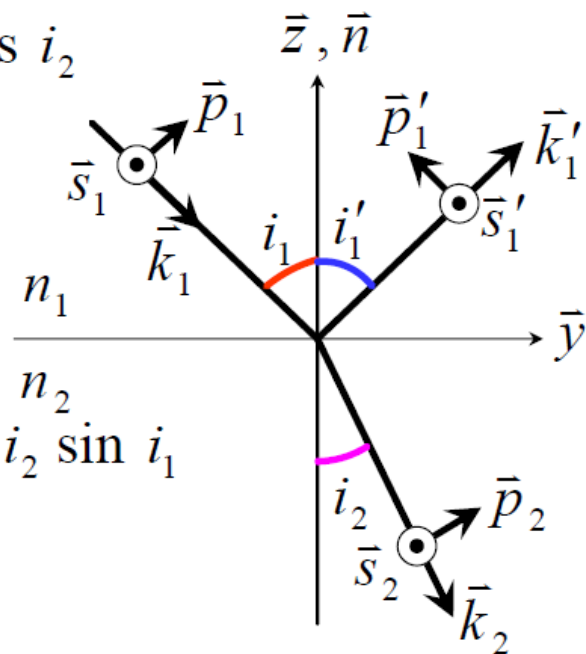
折射

ii) s波的振幅反射系数和透射系数:

$$\begin{cases} E_{1s} + E'_{1s} = E_{2s} \\ H_{1p} \cos i_1 + H'_{1p} \cos i_1 = H_{2p} \cos i_2 \end{cases}$$

$$\begin{cases} A_{1s} + A'_{1s} = A_{2s} \\ \cos i_1 \sin i_2 (A_{1s} - A'_{1s}) = A_{2p} \cos i_2 \sin i_1 \end{cases}$$

$$\begin{cases} r_s = \frac{A'_{1s}}{A_{1s}} = -\frac{\sin(i_1 - i_2)}{\sin(i_1 + i_2)} \\ t_s = \frac{A_{2s}}{A_{1s}} = \frac{2 \sin i_2 \cos i_1}{\sin(i_1 + i_2)} \end{cases}$$

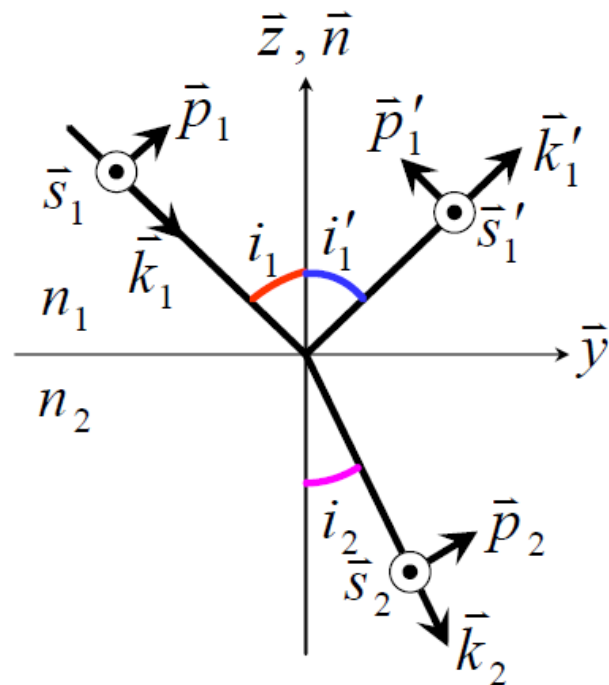


ii) p波的振幅反射系数和透射系数:

$$\begin{cases} E_{1p} \cos i_1 - E'_{1p} \cos i_1 = E_{2p} \cos i_2 \\ H_{1s} + H'_{1s} = H_{2s} \end{cases}$$

$$\begin{cases} \cos i_1 (A_{1p} - A'_{1p}) = A_{2p} \cos i_2 \\ \sin i_2 (A_{1p} - A'_{1p}) = A_{2p} \sin i_1 \end{cases}$$

$$\begin{cases} r_p = \frac{A'_{1p}}{A_{1p}} = \frac{\tan(i_1 - i_2)}{\tan(i_1 + i_2)} \\ t_p = \frac{A_{2p}}{A_{1p}} = \frac{2 \sin i_2 \cos i_1}{\sin(i_1 + i_2) \cos(i_1 - i_2)} \end{cases}$$



2. 反射率和透射率

$$I \propto S \propto n|E|^2$$

i) s波:

$$\text{反射} \left\{ \begin{array}{l} \text{光强} \\ \text{能流} \end{array} \right. \quad R_s = \frac{I'_{1s}}{I_{1s}} = r_s^2 = \frac{\sin^2(i_1 - i_2)}{\sin^2(i_1 + i_2)}$$
$$\mathfrak{R}_s = \frac{W'_{1s}}{W_{1s}} = R_s$$

$$\text{透射} \left\{ \begin{array}{l} \text{光强} \\ \text{能流} \end{array} \right. \quad T_s = \frac{I_{2s}}{I_{1s}} = \frac{n_2}{n_1} t_s^2 = \frac{n_2}{n_1} \frac{4 \sin^2 i_2 \cos^2 i_1}{\sin^2(i_1 + i_2)}$$
$$\mathfrak{T}_s = \frac{W_{2s}}{W_{1s}} = \frac{\cos i_2}{\cos i_1} T_s = \frac{n_2 \cos i_2}{n_1 \cos i_1} \frac{4 \sin^2 i_2 \cos^2 i_1}{\sin^2(i_1 + i_2)}$$

ii) p波:

$$R_p = \frac{I'_{1p}}{I_{1p}} = r_p^2 = \frac{\tan^2(i_1 - i_2)}{\tan^2(i_1 + i_2)}$$

$$\mathfrak{R}_p = \frac{W'_{1p}}{W_{1p}} = R_p$$

$$T_p = \frac{I_{2p}}{I_{1p}} = \frac{n_2}{n_1} t_p^2 = \frac{n_2}{n_1} \frac{4 \sin^2 i_2 \cos^2 i_1}{\sin^2(i_1 + i_2) \cos^2(i_1 - i_2)}$$

$$\mathfrak{T}_s = \frac{W_{2s}}{W_{1s}} = \frac{\cos i_2}{\cos i_1} T_s = \frac{n_2 \cos i_2}{n_1 \cos i_1} \frac{4 \sin^2 i_2 \cos^2 i_1}{\sin^2(i_1 + i_2) \cos^2(i_1 - i_2)}$$

$$W'_{1s} + W_{2s} = W_{1s}, \quad W'_{1p} + W_{2p} = W_{1p}$$

$$\mathfrak{R}_s + \mathfrak{T}_s = 1, \quad \mathfrak{R}_p + \mathfrak{T}_p = 1$$

一般说来, 反射光和折射光都是部分偏振光

特例：i) 正入射 $i_1 = i_2 = 0$

$$r_p = -r_s = \frac{n_2 - n_1}{n_2 + n_1}$$

$$t_p = t_s = \frac{2n_1}{n_2 + n_1}$$

$$R_p = R_s = \mathfrak{R}_p = \mathfrak{R}_s = \left(\frac{n_2 - n_1}{n_2 + n_1} \right)^2$$

$$T_p = T_s = \mathfrak{T}_p = \mathfrak{T}_s = \frac{4n_2n_1}{(n_2 + n_1)^2}$$

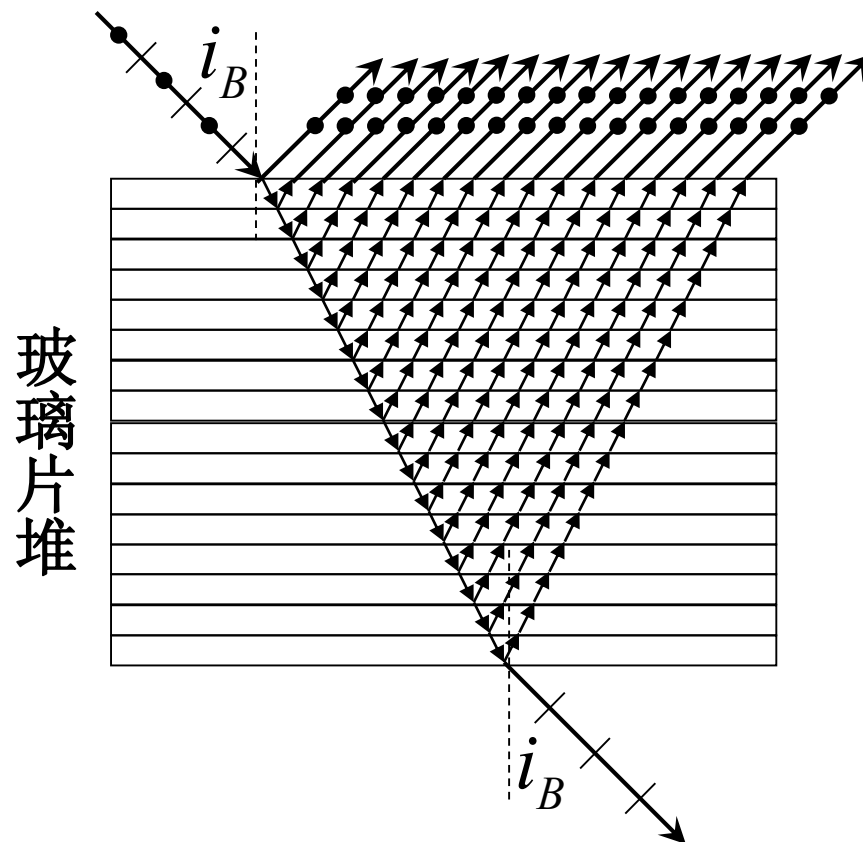
ii) 布儒斯特 (D.Brewster, 1815) 角

$$i_B = \tan^{-1} \frac{n_2}{n_1}$$

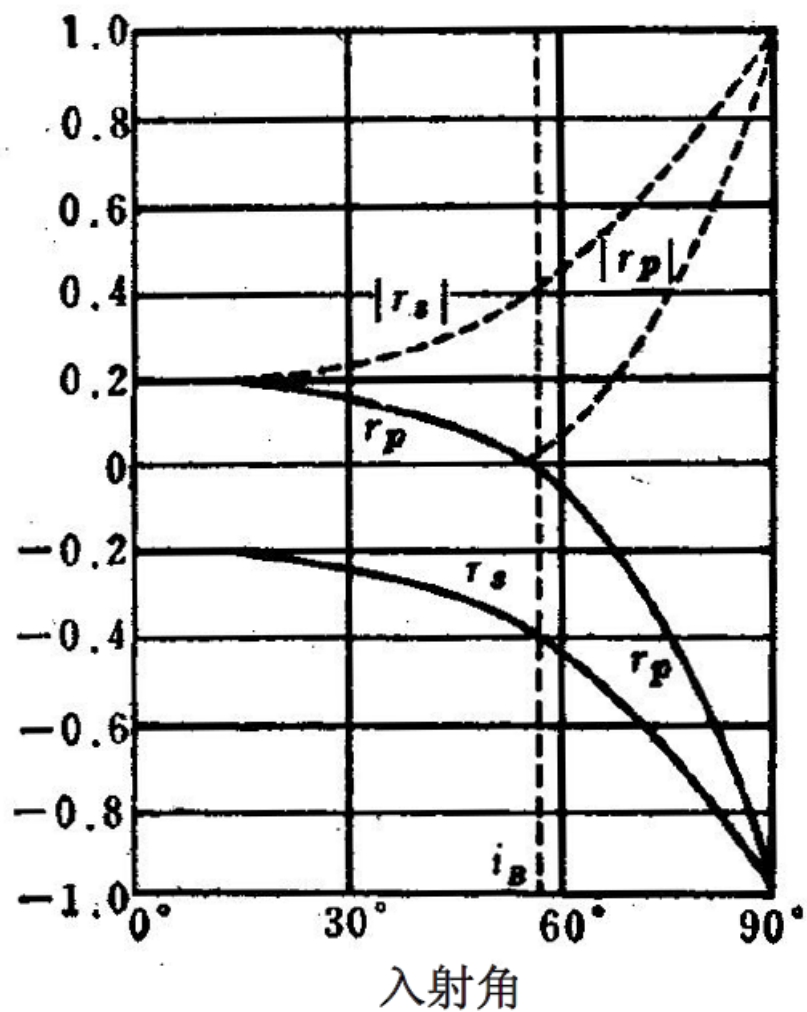
当 $i_1 = i_B$ 时, $i_1 + i_2 = \pi/2$

此时, $R_p = \mathfrak{R}_p = 0$ 反射光中只有s分量, 为线偏振光。

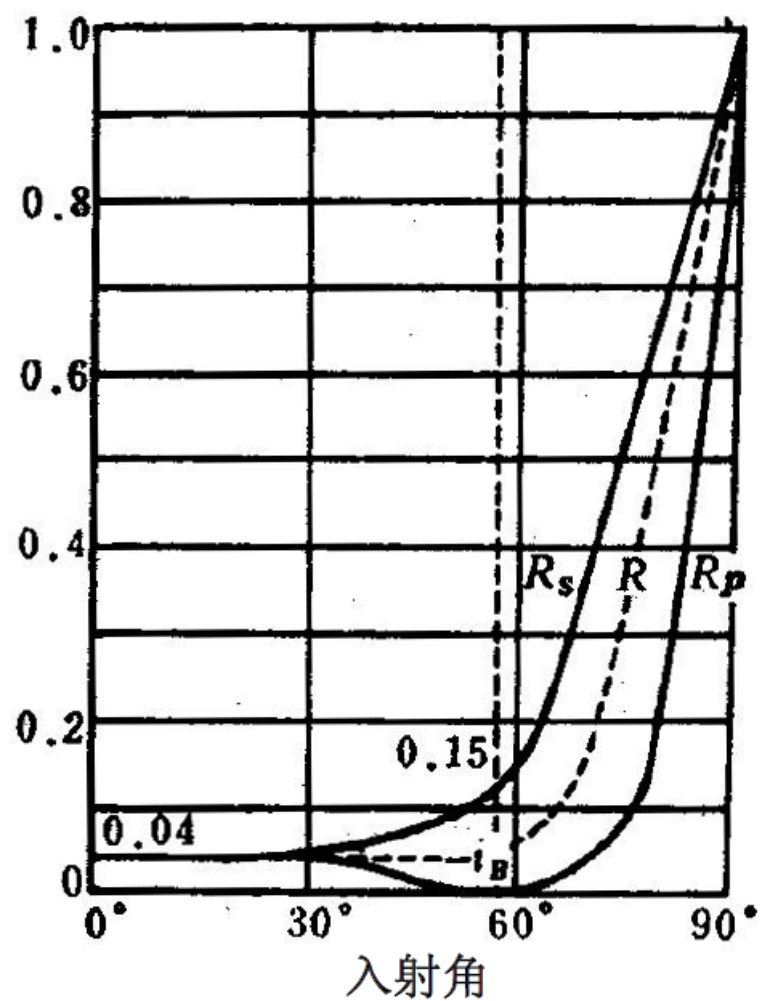
以布儒斯特角入射获得线偏振光



空气→玻璃 ($n=1.5$):

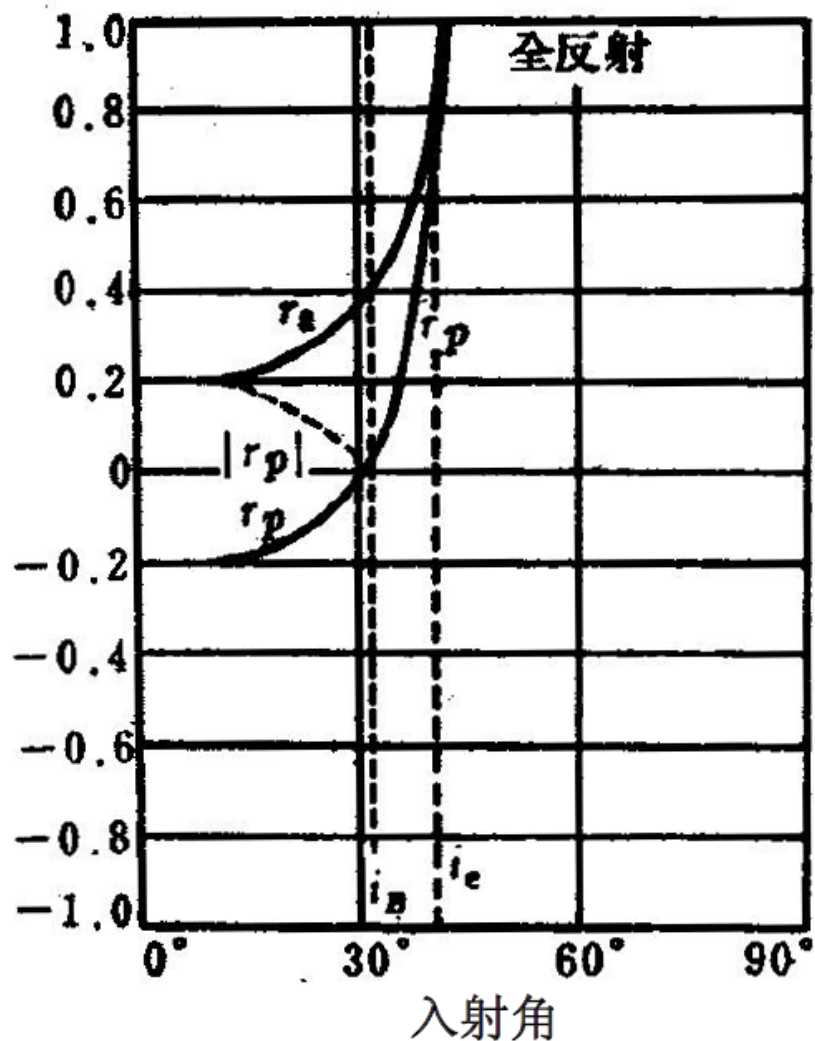


振幅反射率

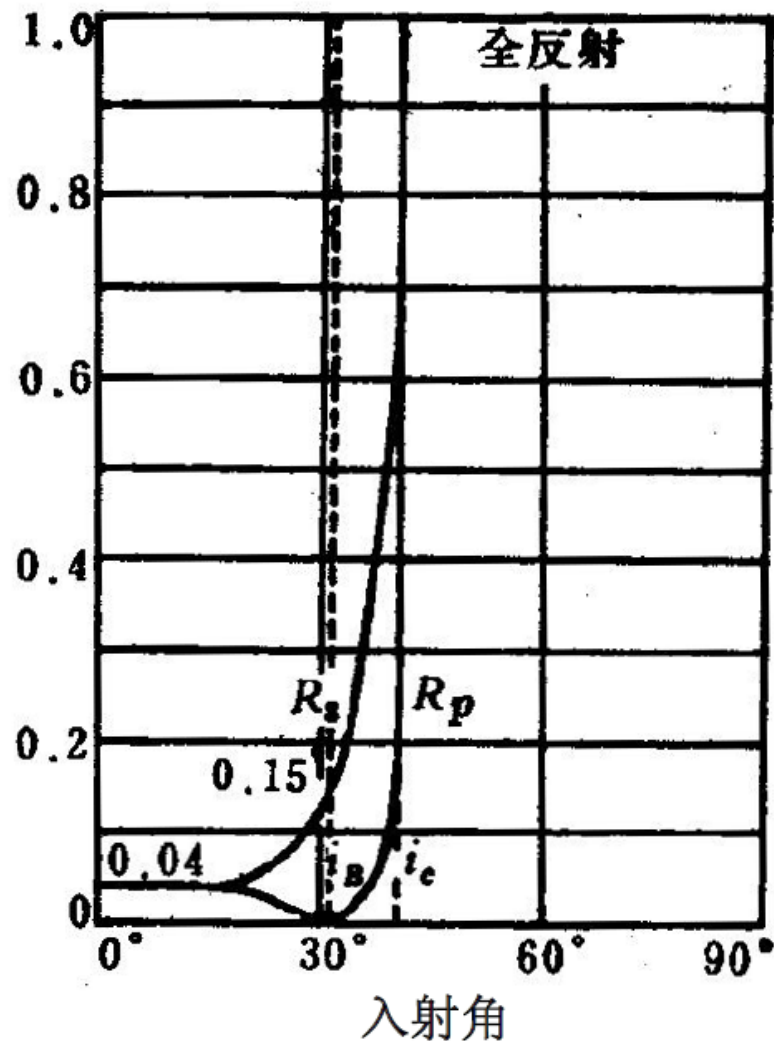


光强反射率

玻璃 ($n=1.5$) \rightarrow 空气:



振幅反射率



光强反射率

全反射和消逝波

$$k = \frac{2\pi}{\lambda}$$

$$\frac{\omega}{k} = v = \frac{c}{n}$$

$$\frac{k}{n} = \frac{2\pi}{n\lambda} = \frac{2\pi}{\lambda_0} = k_0$$

$$k_2 = \frac{n_2}{n_1} k_1$$

$$k_{2z} = \sqrt{k_2^2 - k_{2y}^2}$$

$$= \sqrt{\left(\frac{n_2}{n_1}\right)^2 k_1^2 - k_1^2 \sin^2 i_1}$$

$$= k_1 \sqrt{\left(\frac{n_2}{n_1}\right)^2 - \sin^2 i_1}$$

$$= k_2 \cos i_2$$

全反射时： $i_c = \arcsin \left(\frac{n_2}{n_1} \right)$

当 $n_1 < n_2$, $i_1 > i_c$ 时, k_{2z} 和 i_2 无实数解:

$$k_{2z} = i \frac{2\pi}{\lambda_1} \sqrt{\sin^2 i_1 - \sin^2 i_c} = i\kappa$$

$$\vec{E}_2 = \vec{A}_2 e^{i(\vec{k}_2 \cdot \vec{r} - \omega_2 t)} = \vec{A}_2 e^{-\kappa z} e^{i(k_{2y}y - \omega_2 t)}$$

即媒质2内的折射波沿深度方向按指数衰减, 称为衰
失波 (evanescent wave), 其穿透深度定义为:

$$d_z = \frac{1}{\kappa} = \frac{\lambda_1}{2\pi} \frac{1}{\sqrt{\sin^2 i_1 - \sin^2 i_c}}$$

d_z 与波长同一量级

衰失波波矢的定义、横波性都成问题!

反射波:

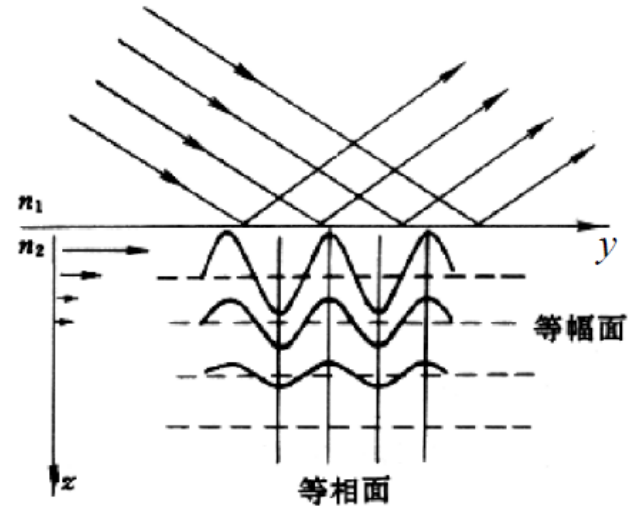
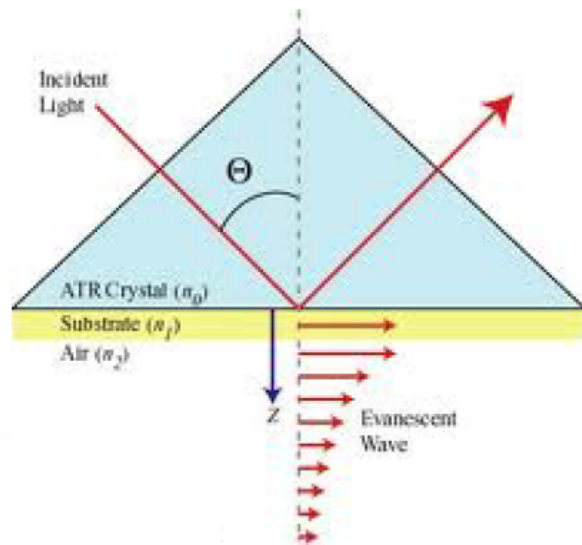
$$\left\{ \begin{aligned} r_s &= \frac{\cos i_1 - i\sqrt{\sin^2 i_1 - \sin^2 i_c}}{\cos i_1 + i\sqrt{\sin^2 i_1 - \sin^2 i_c}} \\ r_p &= \frac{n_2^2 \cos i_1 - in_1^2 \sqrt{\sin^2 i_1 - \sin^2 i_c}}{n_2^2 \cos i_1 + in_1^2 \sqrt{\sin^2 i_1 - \sin^2 i_c}} \end{aligned} \right.$$

$$\left\{ \begin{aligned} \delta_s &= -2 \arctan \frac{\sqrt{\sin^2 i_1 - \sin^2 i_c}}{\cos i_1} \\ \delta_p &= -2 \arctan \frac{n_1 \sqrt{\sin^2 i_1 - \sin^2 i_c}}{n_2 \cos i_1} \end{aligned} \right.$$

此时, 媒质2内的平均能流为零, 发生全反射:

$$|r_s| = |r_p| = 1$$

衰逝波、隱失波(evanescent wave): $\vec{E} = \vec{E}_0 e^{-\kappa z} e^{i(k_y y - \omega t)}$



沿界面深度方向指数衰減，不能传播到远场。

- y方向：行波，z方向：非波；
- 等幅面与等相面不一致：等幅面平行于界面，等相面垂直于界面；
- 非单纯横波。

衰减波不是单纯的横波：

$$\vec{E} = \vec{E}_0 e^{-\kappa z} e^{i(k_y y - \omega t)}$$

从麦克斯韦方程组：

$$\nabla \cdot \vec{E} = 0$$

得：

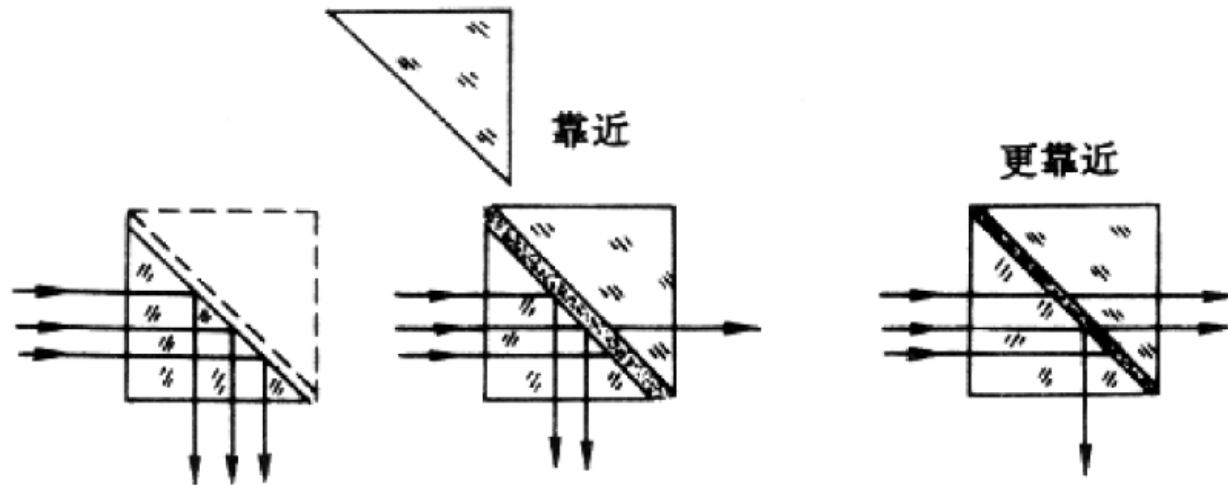
$$(ik_y E_{0y} - \kappa E_{0z}) e^{-\kappa z} e^{i(k_y y - \omega t)} = 0$$

$$\frac{E_{0y}}{E_{0z}} = -i \frac{\kappa}{k_y} = -i \frac{\sqrt{\sin^2 i_1 - \sin^2 i_c}}{\sin i_1}$$

无论沿等幅面还是等相面的法线方向，都既有纵波、也有横波成分，而且两者位相差 $\pi/2$ 。

消逝波实的应用

一、光学隧道效应



通过消逝波场的耦合可改变行波的能量分配。

二、光波导输入耦合

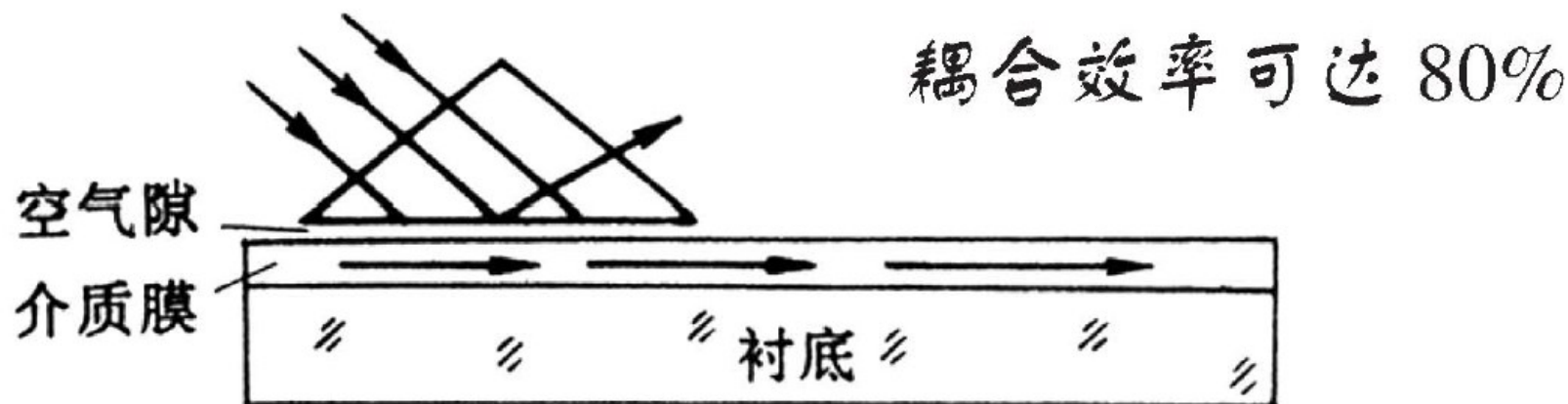
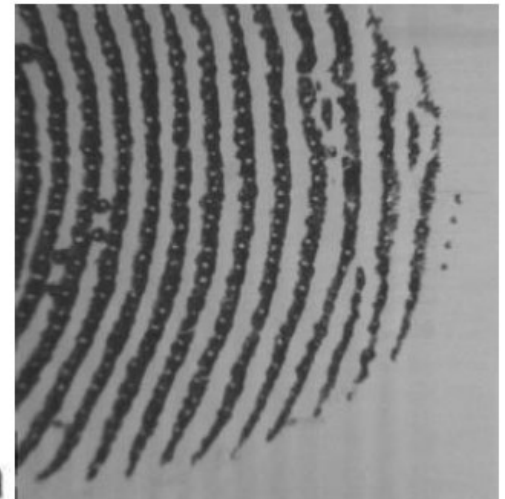
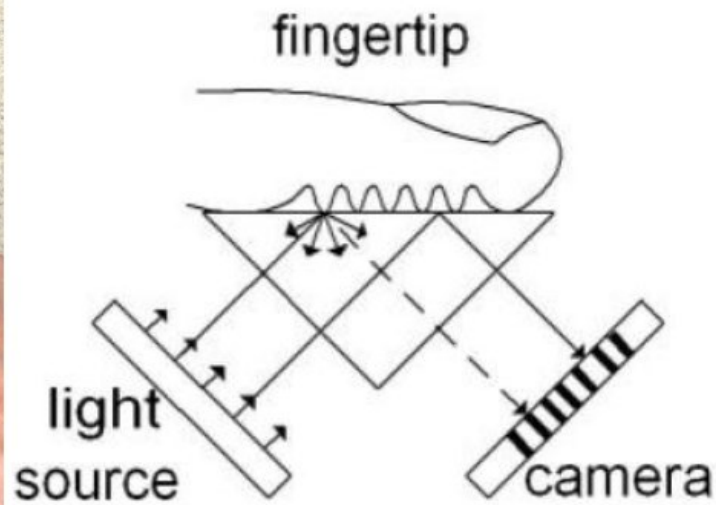


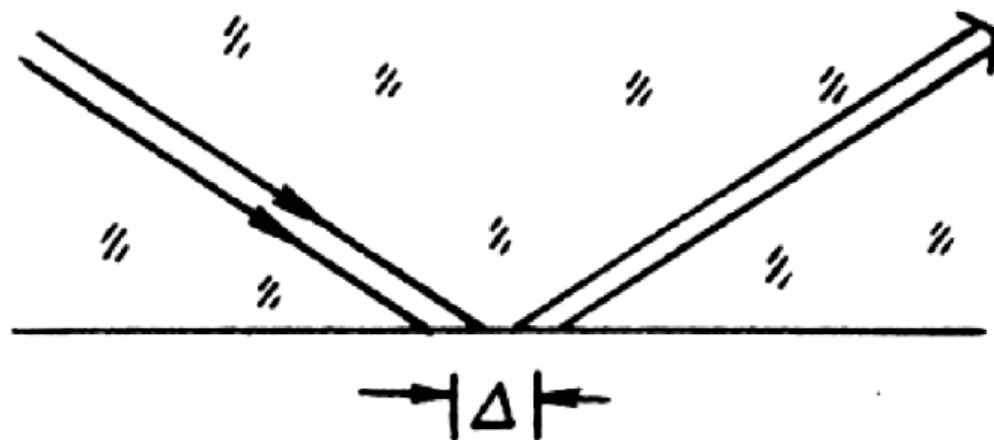
图 3.22 利用隐失波耦合而实现光波导

利用全反射透射区域中衰减波场的耦合，实现平面光导波的输入耦合。

三、指纹采集



古斯-哈恩森位移的物理解释

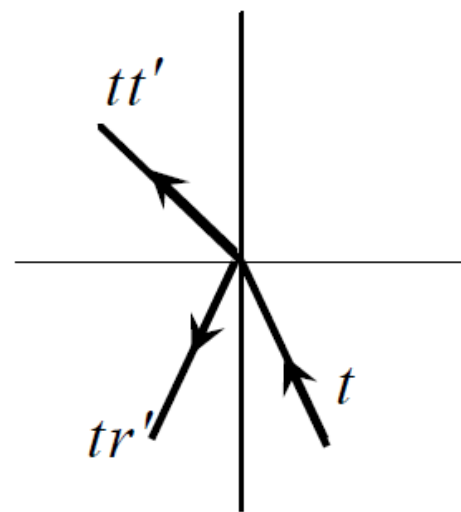
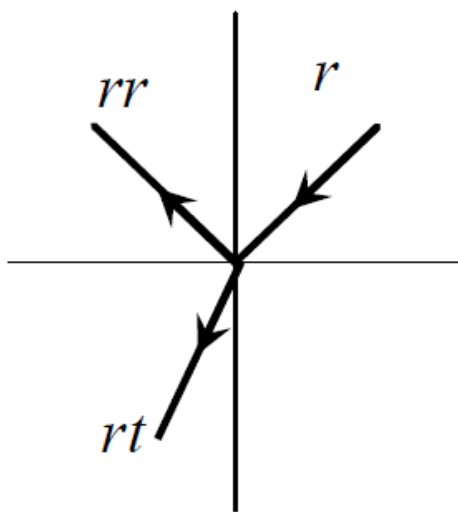
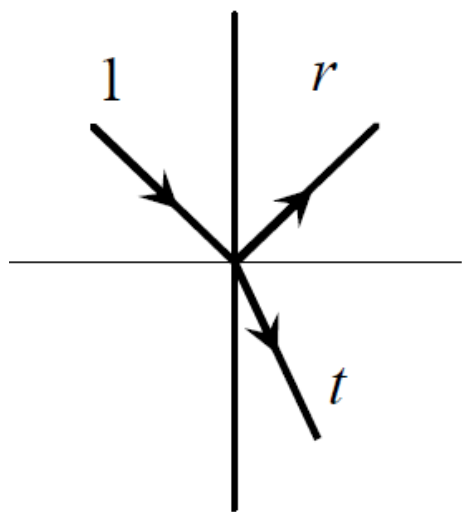


有限截面的光束从光密介质1进入光疏介质2、且入射角大于临界角时，光束在界面将发生全反射。反射光束相对于入射光束沿界面将产生一位置移动 Δ ，称为**Goos-Hänchen**位移。

F. Goos and H. Hänchen, Ann. Phys. Lpz. (6) 1 (1947) 333.

F. Goos and H. Lindberg-Hänchen, Ann. Phys. Lpz. (6) 5 (1949) 251.

3. 斯托克斯倒逆关系



$$\begin{cases} r^2 + tt' = 1 \\ r' = -r \end{cases}$$

4. 相位关系和半波损失

$$\left\{ \begin{array}{l} t_s = \frac{2 \sin i_2 \cos i_1}{\sin(i_1 + i_2)} \\ t_p = \frac{2 \sin i_2 \cos i_1}{\sin(i_1 + i_2) \cos(i_1 - i_2)} \end{array} \right. \quad \left\{ \begin{array}{l} r_s = -\frac{\sin(i_1 - i_2)}{\sin(i_1 + i_2)} \\ r_p = \frac{\tan(i_1 - i_2)}{\tan(i_1 + i_2)} \end{array} \right.$$

$$\left\{ \begin{array}{l} r_s = \frac{\cos i_1 - i \sqrt{\sin^2 i_1 - \sin^2 i_c}}{\cos i_1 + i \sqrt{\sin^2 i_1 - \sin^2 i_c}} \\ r_p = \frac{n_2^2 \cos i_1 - i n_1^2 \sqrt{\sin^2 i_1 - \sin^2 i_c}}{n_2^2 \cos i_1 + i n_1^2 \sqrt{\sin^2 i_1 - \sin^2 i_c}} \end{array} \right.$$

$$\text{位相关系} \begin{cases} E_{2(s,p)} = |t_{(s,p)}| e^{i \arg t_{(s,p)}} A_{1(s,p)} e^{i(\bar{k}_2 \cdot \bar{r} - \omega t)} \\ E'_{1(s,p)} = |r_{(s,p)}| e^{i \arg r_{(s,p)}} A_{1(s,p)} e^{i(\bar{k}'_1 \cdot \bar{r} - \omega t)} \end{cases}$$

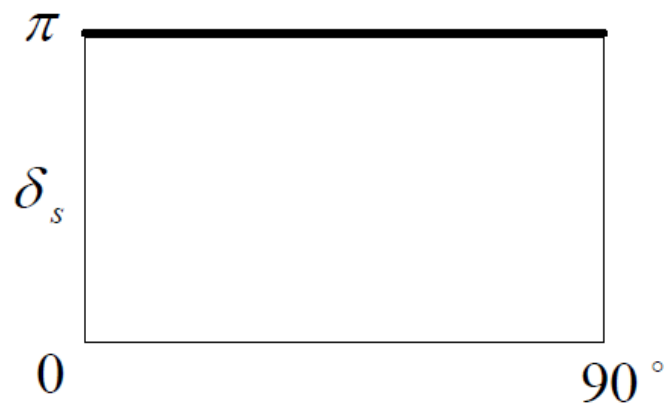
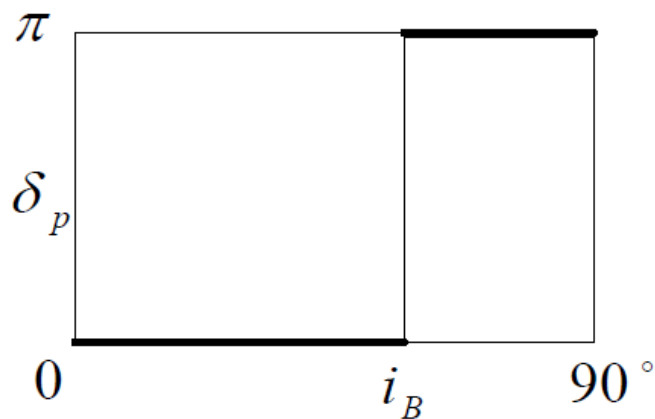
$$\text{透射波: } \delta_t = -\arg t \equiv 0$$

$$\text{反射波: } \delta_r = -\arg r = 0, \quad \text{或 } \pi$$

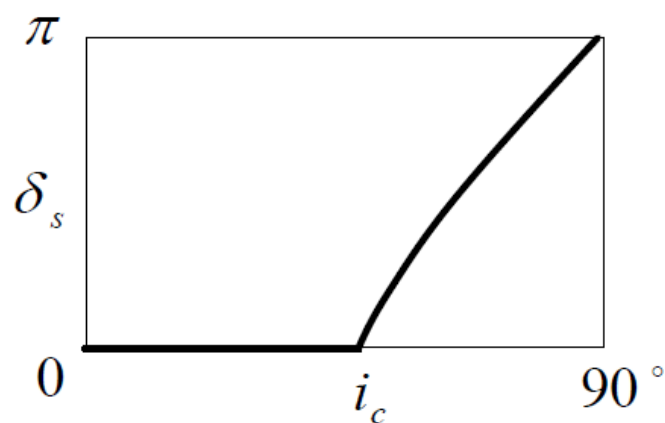
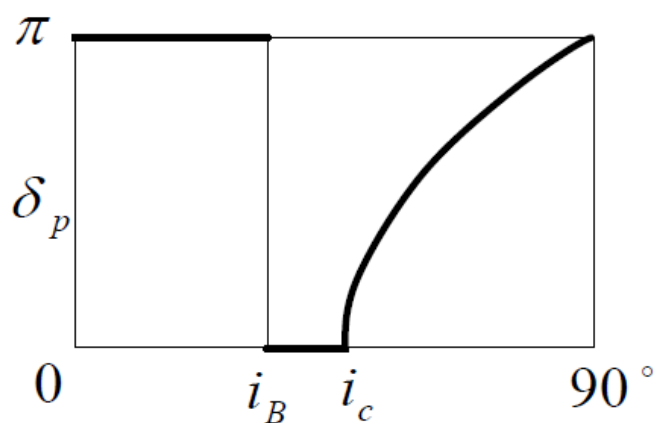
$$\begin{cases} r_s = -\frac{\sin(i_1 - i_2)}{\sin(i_1 + i_2)} & n_1 < n_2 (i_1 > i_2) & i_1 < i_B: \delta_{rp} = 0 & \delta_{rs} \equiv \pi \\ & & i_1 > i_B: \delta_{rp} = \pi & \\ r_p = \frac{\tan(i_1 - i_2)}{\tan(i_1 + i_2)} & n_1 > n_2 (i_1 < i_2, i_1 < i_c) & i_1 < i_B: \delta_{rp} = \pi & \delta_{rs} \equiv 0 \\ & & i_1 > i_B: \delta_{rp} = 0 & \end{cases}$$

反射波的位相差：

$$n_1 < n_2$$



$$n_1 > n_2$$

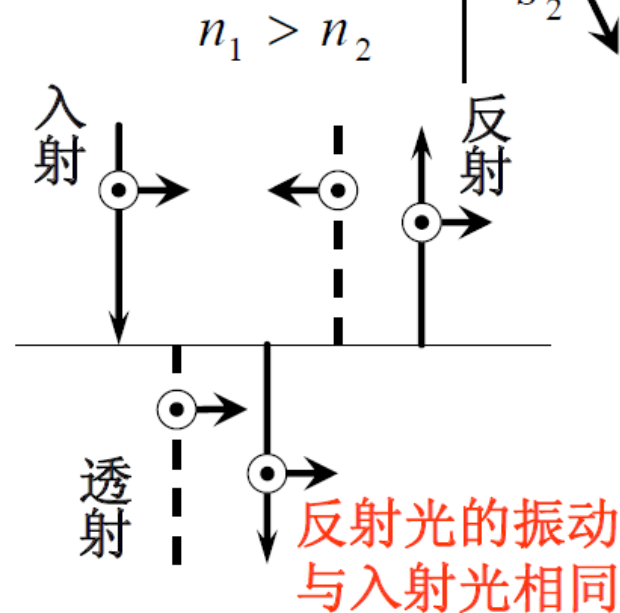
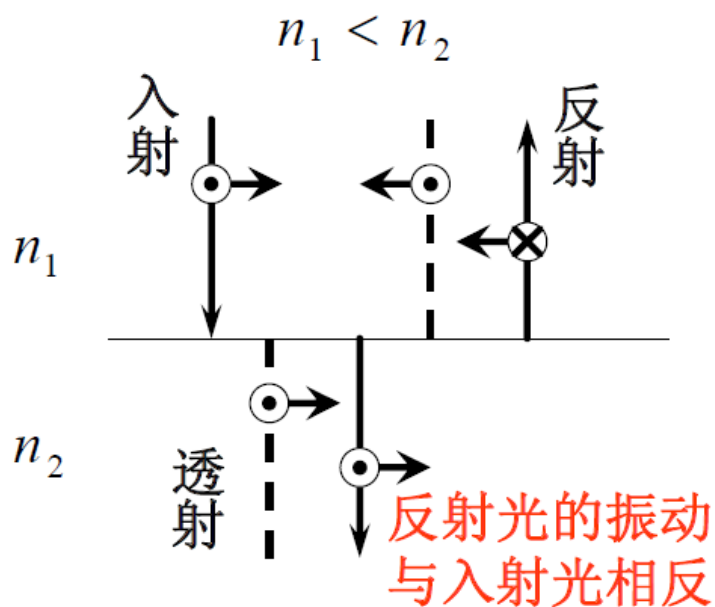
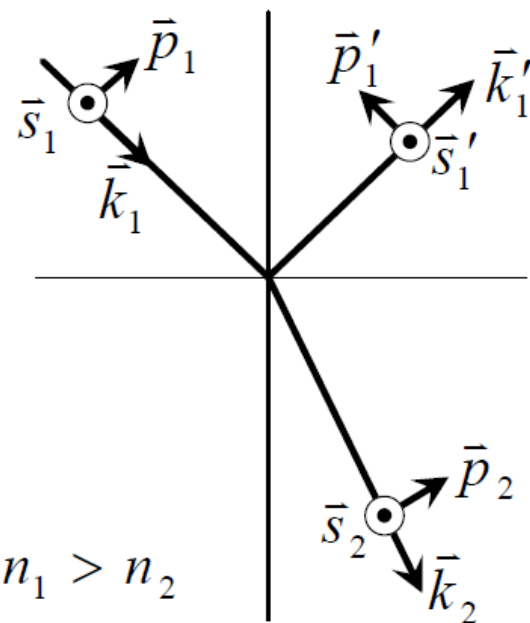


此处的位相（正负）是相对所取坐标系定义的，并不意味着实际的反方向，仅在少数情况有实际意义。

例

正入射时，反射光p、s分量的位相改变

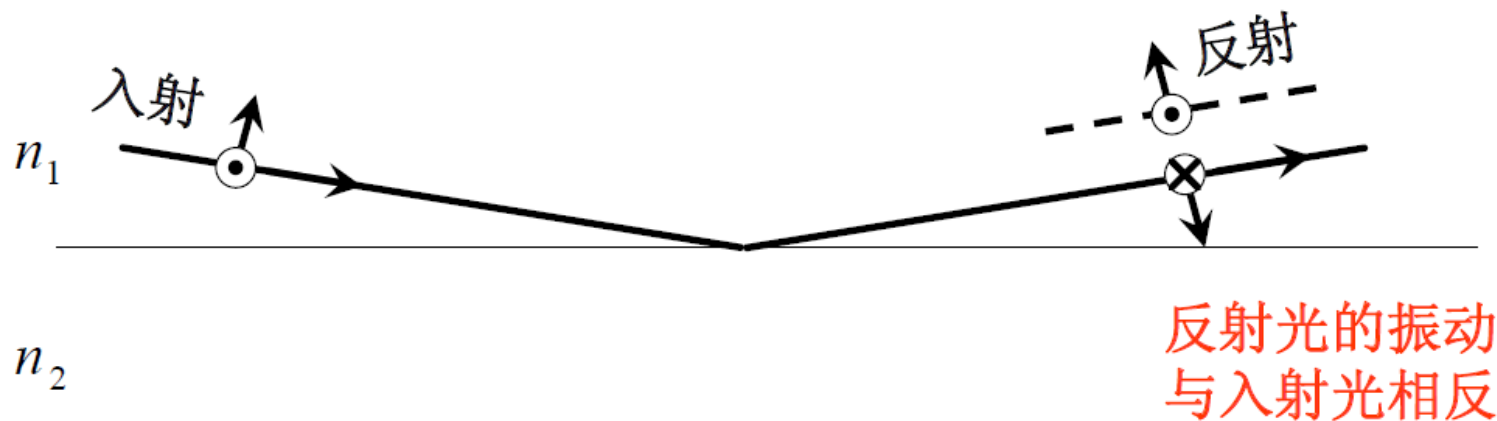
	$n_1 < n_2$	$n_1 > n_2$
r_p	+	-
r_s	-	+
t_p	+	+
t_s	+	+



例

$n_1 < n_2$, 掠入射时, 反射光p、s分量的位相改变

	$n_1 < n_2$
r_p	-
r_s	-

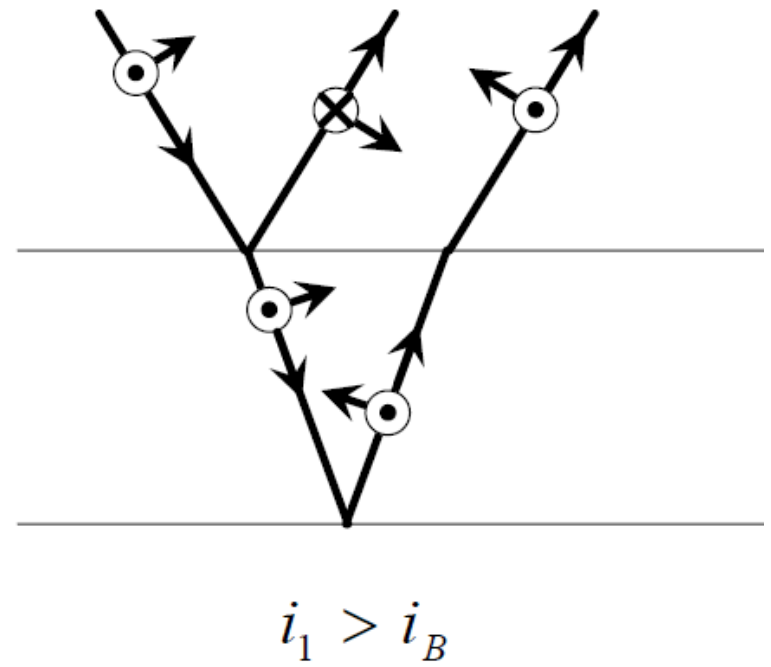
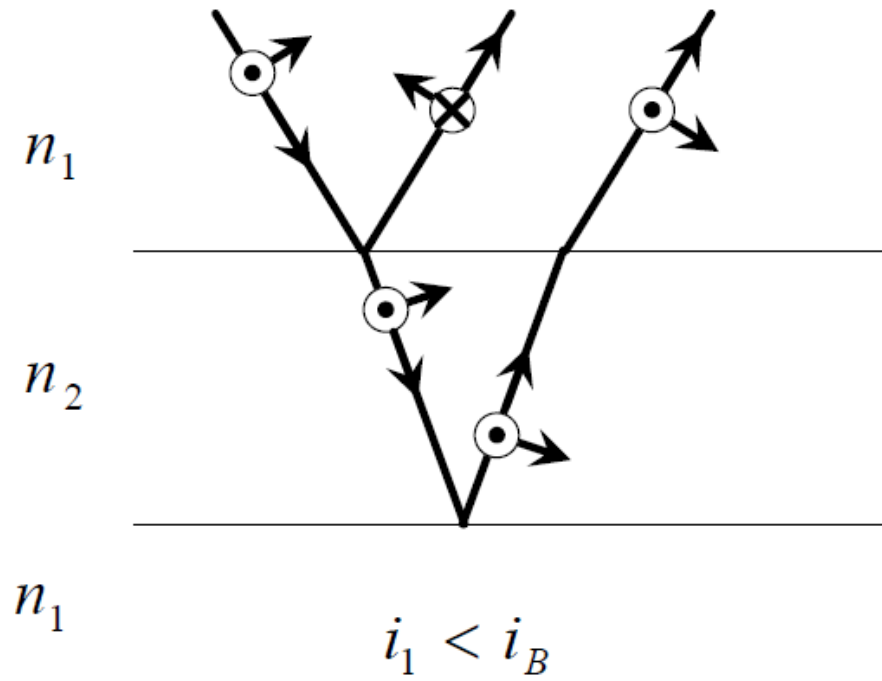


半波损失:

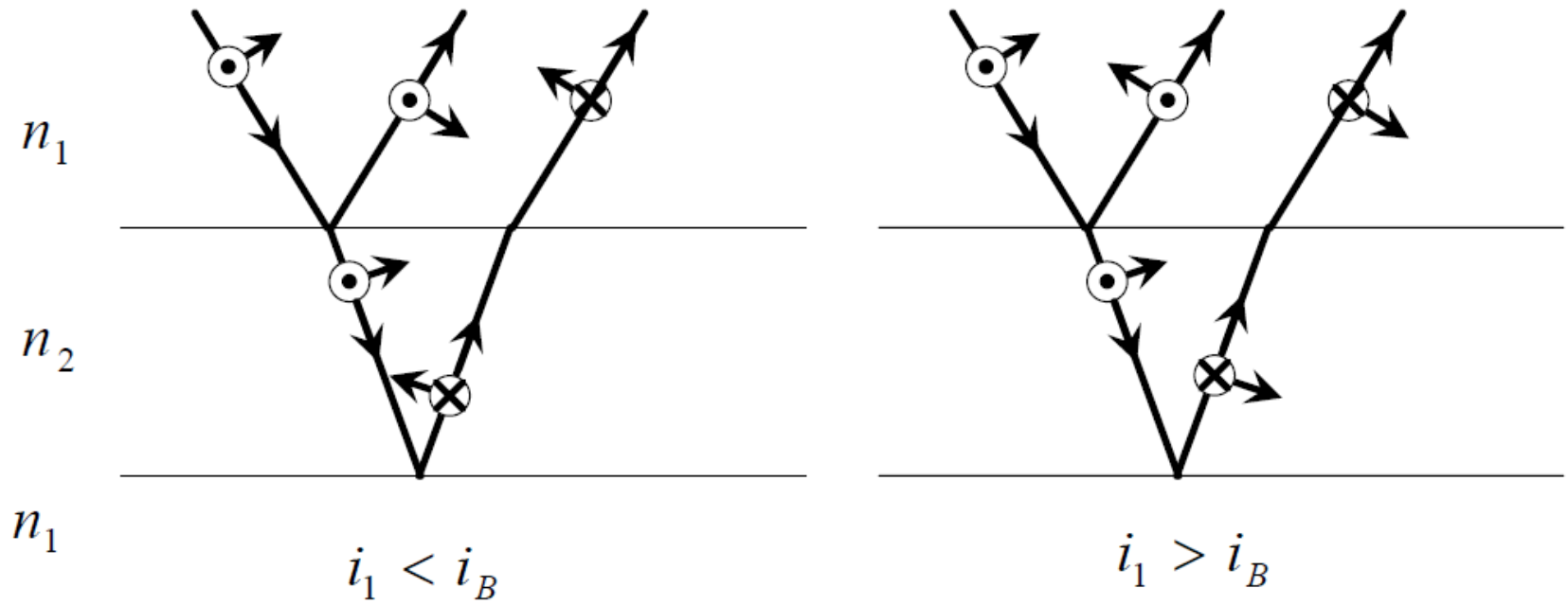
$$\Delta L' = \Delta L \pm \frac{\lambda}{2}$$

正入射或掠入射时，当光从光疏媒质向光密媒质传播时，反射光的 $\lambda/2$ 附加光程差称为半波损失。从光密媒质向光疏媒质传播时的反射、以及透射光没有半波损失。

$$n_2 > n_1$$



$$n_2 < n_1$$



5 反射、折射光的偏振现象(非正入射)

1. 自然光 (包括部分偏振光) \rightarrow 反射、折射光是部分偏振光 (非 i_B) ;
2. 圆偏振光 \rightarrow 反射、折射光是椭圆偏振光 (非 i_B) ;
3. 椭圆偏振光 \rightarrow 反射、折射光是椭圆或者圆偏振光 (非 i_B) ;
4. 线偏振光 \rightarrow 反射、折射光是线偏振光 , 但振动面有旋转 ;
5. 全反射 \rightarrow 考虑实际入射光sp偏振的相位差
6. 布儒斯特角 \rightarrow 反射光是s偏振

作业：P264 , 3 , 4 , 6 , 8 , 11