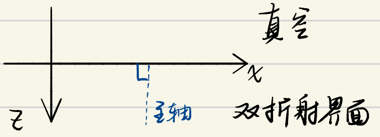
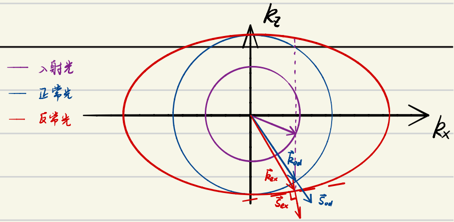
折射的示例

主轴相对界面

① 垂直

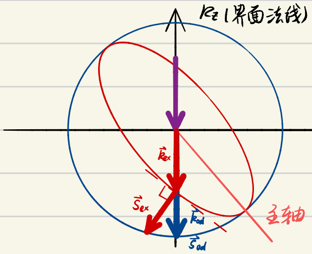




特殊情形：当入射光垂直界面入射时，正常光与反常光

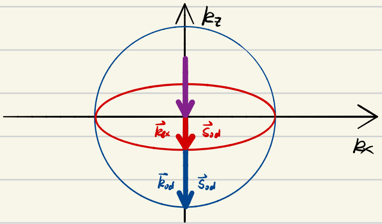
- 波矢重合（k_z 轴上 o光和e光等频面相交）
- 能流方向重合（k_z 轴上 o光和e光等频面相切）

② 倾斜



即使垂直入射
o光和e光仍会分离

③ 平行



垂直入射时
o光与e光波矢和能流方向都平行
但 $|k_{od}| \neq |k_{ex}|$

数学描述（垂直入射）

$$\vec{E}_{od}(\vec{r},t) = |E_1| \begin{bmatrix} \sin\varphi \\ -\cos\varphi \\ 0 \end{bmatrix} e^{i(|k_{od}|z-\omega t)} \overset{\theta=0}{\underset{\varphi=0}{=\!=}} |E_1| \begin{bmatrix} 0 \\ -1 \\ 0 \end{bmatrix} e^{i\omega(\sqrt{\mu_0\varepsilon_1}\,z-t)} \quad \sim \mathrm{TE}$$

$$\vec{E}_{ex}(\vec{r},t) = |E_2| \begin{bmatrix} \varepsilon_2\cos\theta\cos\varphi \\ \varepsilon_2\cos\theta\sin\varphi \\ -\varepsilon_1\sin\theta \end{bmatrix} e^{i(|k_{ex}|z-\omega t)} \overset{\theta=0}{\underset{\varphi=0}{=\!=}} \varepsilon_2|E_2| \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix} e^{i\omega(\sqrt{\mu_0\varepsilon_2}\,z-t)} \quad \sim \mathrm{TM}$$

- 正常光和反常光传播方向平行
- 正常光和反常光偏振方向垂直
- 正常光和反常光 $|k|$ 不同 ⇒ n 不同

⇒ 用来做波片

双折射光学元器件

波片

回顾

波片的琼斯矩阵

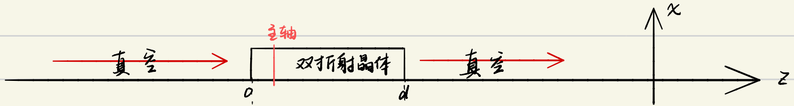
入射光 $\begin{bmatrix} E_i^x \\ E_i^y \end{bmatrix}$ 出射光 $\begin{bmatrix} E_o^x \\ E_o^y \end{bmatrix} = \underbrace{\begin{bmatrix} e^{i\varphi_x} & 0 \\ 0 & e^{i\varphi_y} \end{bmatrix}}_{e^{i\varphi_0}\begin{bmatrix} 1 & 0 \\ 0 & e^{i\Delta\varphi} \end{bmatrix}} \begin{bmatrix} E_i^x \\ E_i^y \end{bmatrix}$

双折射

设置

光轴平行于界面；入射光垂直入射时，有延迟作用

系统



TE $\begin{bmatrix} 1 \\ 0 \end{bmatrix} e^{i(kz-wt)}$ $\begin{bmatrix} 1 \\ 0 \end{bmatrix} e^{i[k_{od}(z-0)-wt+\varphi_0]}$ $\begin{bmatrix} 1 \\ 0 \end{bmatrix} e^{i[k(z-d)-wt+\varphi_d^{od}]}$

TM $\begin{bmatrix} 0 \\ 1 \end{bmatrix} e^{i(kz-wt)}$ $\begin{bmatrix} 0 \\ 1 \end{bmatrix} e^{i[k_{ex}(z-0)-wt+\varphi_0]}$ $\begin{bmatrix} 0 \\ 1 \end{bmatrix} e^{i[k(z-d)-wt+\varphi_d^{ex}]}$

$\varphi_0 = 0$

$\varphi_d^{od} = k_{od} \cdot d + \varphi_0 = k_{od} \cdot d$ $\varphi_d^{ex} = k_{ex} \cdot d + \varphi_0 = k_{ex} \cdot d$

$$\Rightarrow \quad E_i = \alpha E_{TE} + \beta E_{TM} = \begin{bmatrix} \alpha \\ \beta \end{bmatrix} e^{i(kz-wt)}$$

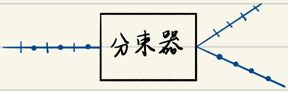
双折射晶体的J-矩阵

$$E_o = \alpha E_{TE} e^{i\varphi_d^{od}} + \beta E_{TM} e^{i\varphi_d^{ex}} = \begin{bmatrix} \alpha e^{i\varphi_d^{od}} \\ \beta e^{i\varphi_d^{ex}} \end{bmatrix} e^{i(kz-wt)} = \begin{bmatrix} e^{i\varphi_d^{od}} & 0 \\ 0 & e^{i\varphi_d^{ex}} \end{bmatrix} \begin{bmatrix} \alpha \\ \beta \end{bmatrix} e^{i(kz-wt)}$$

对垂直入射光，厚度为d的双折射晶体（光轴平行界面）的作用可由J矩阵 $e^{i\varphi_d^{od}}\begin{bmatrix} 1 & 0 \\ 0 & e^{i\Delta\varphi} \end{bmatrix}$ 描述，即这块晶体起到了波片的作用

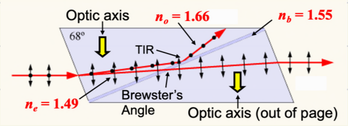
分束器

功能要求

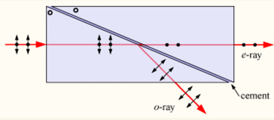


举例

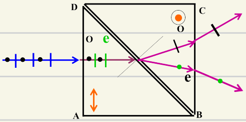
Nicol Prism →



Glan-Thompson and Glan-Air Polarizer

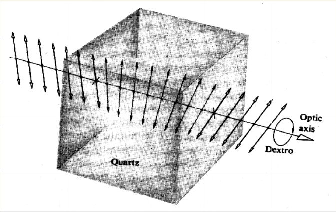


Wollaston polarizing beam splitter



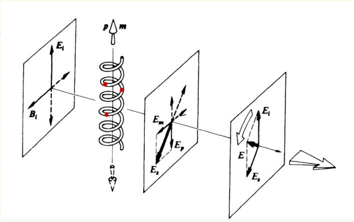
旋光性

现象描述



$$v \sim \begin{bmatrix} \cos kz \\ \sin kz \end{bmatrix}$$

机制



电荷束缚在螺旋线中运动

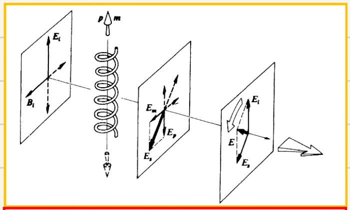
$$\xrightarrow{\text{光入射}} \begin{cases} \text{电荷沿 y 轴上下振荡(偶极辐射)} \Rightarrow E_p \\ \text{在 x-y 平面做圆周运动(同步辐射)} \Rightarrow E_m \end{cases}$$

E_i 入射光偏振

E_s 螺线管次级光的偏振

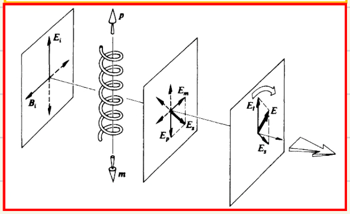
$$\begin{cases} E_p & \text{偶极辐射} \\ E_m & \text{同步辐射} \end{cases}$$

$$\vec{E}_{out} = \vec{E}_i + \vec{E}_s \qquad \vec{E}_s = \vec{E}_m + \vec{E}_p$$



left-handed material

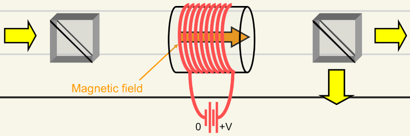
D-rotation



right-handed material

L-rotation

磁致旋光效应



总结

光学的2个范式

①

$$\begin{tikzcd} \vec{E} \arrow[dr] \arrow[dd, shift right] & \\ & Q \arrow[dl] \\ \vec{B} \arrow[uu, shift right] & \end{tikzcd}$$

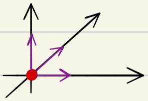
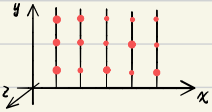
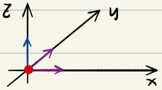
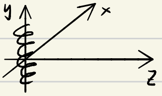
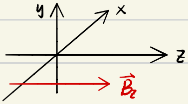
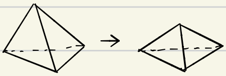
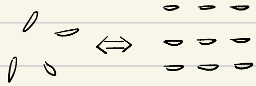
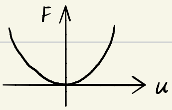
② 介质统一由折射率 n 描述

范式的意义

指导坚壁清野

指导打破范式

范式的集结

	Q	u	
色散		$\partial_t^2\begin{bmatrix}u_x\\u_y\\u_z\end{bmatrix}=-w_0^2\begin{bmatrix}u_x\\u_y\\u_z\end{bmatrix}+\frac{q}{m}\begin{bmatrix}E_x\\E_y\\E_z\end{bmatrix}$	$n(w)$
二向色性		$\partial_t^2\begin{bmatrix}u_x\\u_y\\u_z\end{bmatrix}=\begin{bmatrix}\infty&&\\&0&\\&&\infty\end{bmatrix}\begin{bmatrix}u_x\\u_y\\u_z\end{bmatrix}-\begin{bmatrix}0&&\\&\infty&\\&&0\end{bmatrix}\begin{bmatrix}\dot{u}_x\\\dot{u}_y\\\dot{u}_z\end{bmatrix}+\frac{q}{m}\begin{bmatrix}E_x\\E_y\\E_z\end{bmatrix}$	$n(\hat{E})$
双折射		$\partial_t^2\begin{bmatrix}u_x\\u_y\\u_z\end{bmatrix}=\begin{bmatrix}w_0^2&&\\&w_0^2&\\&&w_e^2\end{bmatrix}\begin{bmatrix}u_x\\u_y\\u_z\end{bmatrix}+\frac{q}{m}\begin{bmatrix}E_x\\E_y\\E_z\end{bmatrix}$	$n(w,\hat{k})$
旋光性			$n(\cdots,L_{旋})$ or $n(\cdots,R_{旋})$
F-效应 (磁致旋光)		$\begin{cases}\ddot{u}_x=-kx+E_x^{cir}(t)+q\dot{u}_yB_z\\ \ddot{u}_y=-ky+E_y^{cir}(t)-q\dot{u}_xB_z\end{cases}$	$n(\cdots,B)$
光弹性		$\begin{cases}\ddot{u}_x=-w_x^2(k)u_x+\cdots\\ \ddot{u}_y=-w_y^2(k)u_y+\cdots\end{cases}$	$n(\cdots,k)$
Kerr效应			$n(\cdots,\|E\|^2)$
P-效应	 非线性谐振子	$m\ddot{u}=k(u-u_0)^2=\underbrace{ku^2}_{\substack{\text{高阶小量}\\u\ll1\\\text{微振动}}}-2ku_0u+\underbrace{ku_0^2}_{\text{常数}}$ $\Rightarrow m\ddot{u}\approx-2ku_0u$	$n(\cdots,\|E\|)$