第一章 几何光学

1.基本规律

光程 $l = ns, \left(V = \frac{c}{n} \right).$

费马原理

$\delta l = 0, l$取极大、极小或常数$\Rightarrow i = -i', n_1 \sin\theta_1 = n_2 \sin\theta_2.$

2. 成像

①单球面折射

$$\frac{s^2}{n^2(s+r)^2} - \frac{s'^2}{n'^2(s'-r')^2} = -4r \sin^2\left(\frac{\varphi}{2}\right)\left[\frac{1}{n^2(s+r)} + \frac{1}{n'^2(s'-r')}\right]$$

保持同心性物像点：

$$\frac{s^2}{n^2(s+r)^2} - \frac{s'^2}{n'^2(s'-r')^2} = 0, \frac{1}{n^2(s+r)} + \frac{1}{n'^2(s'-r')} = 0.$$

榜轴条件：

$$\frac{n'}{s'} + \frac{n}{s} = \frac{n'-n}{r}.$$

$$f = \frac{nr}{n'-n}, f' = \frac{n'r}{n'-n}$$

$$\frac{f'}{s'} + \frac{f}{s} = 1.$$

$$V = \frac{y'}{y} = -\frac{ns'}{n's}.$$

②球面镜成像 $n' = -n.$

$$\frac{1}{s'} + \frac{1}{s} = -\frac{2}{r}, \quad f = f' = -\frac{r}{2}. V = -\frac{s'}{s}$$

③薄透镜

$$\boxed{\frac{f'}{s'}+\frac{f}{s}=1.}$$

$$f=\frac{n}{\frac{n_L-n}{r_1}+\frac{n'-n_L}{r_2}},\ f'=\frac{n'}{\frac{n_L-n}{r_1}+\frac{n'-n_L}{r_2}}.$$

$$\boxed{n'=n,\ f'=f,\ \frac{1}{s'}+\frac{1}{s}=\frac{1}{f}.}$$

$$\boxed{\begin{array}{l} s=x+f,\ s'=x'+f', \\ xx'=ff',V=-\frac{f}{x}=-\frac{x'}{f'}. \end{array}}$$

④密接透镜组

$$\boxed{s_2=-s_1',\ \frac{1}{f_1}+\frac{1}{f_2}=\frac{1}{f}.}$$

$$\boxed{P=\frac{1}{f},\ P=P_1+P_2.}$$

⑤望远镜 $M\equiv-\frac{f_o}{f_E}$

第二章 光的干涉

一.光波基本描述

1.$\boxed{v=\frac{c}{n}}$ $c=\frac{1}{\sqrt{\varepsilon_0\mu_0}}=3.0\times10^8\ m/s$，$n=\sqrt{\varepsilon_r\mu_r}$.

$$\boxed{\lambda=\frac{v}{\nu}=\frac{c}{n\nu}=\frac{\lambda_0}{n},\lambda_0=\frac{c}{\nu}}$$

2.单色波

①电场 $\vec{E}=\vec{E}_0(p)\cos(\omega t-\varphi(p))$

磁场 $\vec{B}=\vec{B}_0(p)\cos(\omega t-\varphi(p))$

②单色平面波

$\boxed{\vec{E}=\vec{E}_0\cos\left[\omega t-\vec{k}\cdot\vec{z}+\varphi_0\right]}$, $\boxed{\tilde{E}(p,t)=E_0\exp\left[-i\left(\omega t-\vec{k}\cdot\vec{r}+\varphi_0\right)\right]}$

波数$\boxed{k=\dfrac{2\pi}{\lambda},}$波矢$\boxed{\vec{k}=\dfrac{2\pi}{\lambda}=k\vec{k}_0,}$$\vec{k}_0$为传播方向的单位方向矢量。

波的相位$\boxed{\omega t-\vec{k}\cdot\vec{r}+\varphi_0=\omega t-\mathrm{R}\dfrac{2\pi}{\lambda}+\varphi_0}$, 其中 R 为$\vec{r}$在$\vec{k}_0$方向上的投影.

复振幅$\boxed{\tilde{E}(p)\equiv E_0\exp(i\varphi(p)).}$

③单色球面波

$$\boxed{E=\frac{A_0}{r}\cos\left[\omega t-kr+\varphi_0\right]}$$

$$\boxed{\tilde{E}(p,t)=\frac{A_0}{r}\exp\left[-i\left(\omega t-kr+\varphi_0\right)\right]}$$

复振幅为$\boxed{\tilde{E}(p)=\dfrac{A_0}{r}\exp\left[i\left(kr-\varphi_0\right)\right]}$.

3.光强度

光强$\boxed{I=\langle\bar{s}\rangle=E_0^2=\tilde{E}^*(p)\tilde{E}(p).}$ $\bar{s}$是电磁波能流密度.

谱密度$i(\lambda)=\dfrac{dI_\lambda}{d\lambda}$, ($dI_\lambda$是$\lambda\sim\lambda+d\lambda$之间光强).

$$I=\int_0^\infty dI_\lambda=\int_0^\infty i(\lambda)d\lambda$$

4. 反衬度$\boxed{\gamma\equiv\dfrac{I_M-I_m}{I_M+I_m}}$

二、线性叠加原理(弱光情况下成立):

1.$\boxed{\vec{E}(p,t)=\vec{E}_1(p,t)+\vec{E}_2(p,t)+\cdots.}$

同方向光振动叠加：

$$E(p,t)=E_1(p,t)+E_2(p,t)+\cdots.$$

2.同频率、同振向波的叠加

$$E_1(p,t)=E_{10}(p)\cos(\omega t-\varphi_1(p)),$$

$$E_2(p,t)=E_{20}(p)\cos(\omega t-\varphi_2(p))$$

$$E(p,t)=E_0(p)\cos(\omega t-\varphi).$$

$$E_0^2(p)=E_{01}^2(p)+2E_{10}(p)E_{02}(p)\cos[\varphi_1(p)-\varphi_1(p)]+E_{02}^2(p)$$

$$tg\varphi(p)=\frac{E_{10}(p)\sin\varphi_1(p)+E_{20}(p)\sin\varphi_2(p)}{E_{10}(p)\cos\varphi_1(p)+E_{20}(p)\cos\varphi_2(p)}.$$

$$I(p)=I_1(p)+I_2(p)+2\sqrt{I_1(p)I_2(p)}\cos\delta.$$

$$I=I_0(1+\gamma\cos\delta),I_0=I_1+I_2.$$

三、光的干涉和相干条件

1. 相干条件

①位相差判据

当 $\delta=2\pi m,\ (m=0,\pm1,\pm2,\cdots)$ (同位相),

$I_M=(E_{01}+E_{02})^2$,称为干涉极大,对应亮纹；

当 $\delta=(2m+1)\pi,\ (m=0,\pm1,\pm2,\cdots)$ (反位相),

$I_m=(E_{01}-E_{02})^2$, 称为干涉极小,对应暗纹.

②光程差判据

位相差 $\delta(p)=k(r_2-r_1)=\dfrac{2\pi}{\lambda_0}\Delta l(p)$,

其中 $\Delta l(p)=n_1r_1-n_2r_2$.

干涉极大 $\Delta l(p)=m\lambda_0$.

干涉极小 $\Delta l(p)=\left(m+\frac{1}{2}\right)\lambda_0$.

四、杨氏实验

1.光程差 $\Delta l=r_1-r_2\approx d\sin\theta.\ \Delta l\approx d\frac{x}{D}$.

2.极大位置 $x=\frac{m\lambda_0 D}{d}\quad(m=0,\pm1,\pm2,\cdots)$.

极小位置 $x=\frac{(m+1/2)\lambda_0 D}{d}\quad(m=0,\pm1,\pm2,\cdots)$.

3.条纹宽度 $\Delta x=\frac{\lambda_0 D}{d}$.

4.光强分布

$$\delta(p)=\frac{2\pi}{\lambda_0}\Delta l(p)=\frac{2\pi}{\lambda_0}d\frac{x}{D}.$$

实验中，$I_1\approx I_2=I_0$, $I=2I_0\left(1+\cos\frac{2\pi}{\lambda_0}d\frac{x}{D}\right)=4I_0\cos^2\left(\frac{\pi d}{D\lambda_0}x\right)$.

5.最大光程差 $\Delta l_M=m'\lambda_0=\frac{\lambda_0^2}{\Delta\lambda_0}$.

6.光源 S 沿 x 方向移动 δs ,干涉条纹的移动 $\delta x\approx-\frac{D}{l}\delta s$.

7.扩展光源

●临界宽度 $b_c=\frac{l\lambda}{d}$.

干涉口径角$\beta \equiv \frac{d}{l}$,扩展光源干涉条件为$b < \frac{\lambda}{\beta}$.

●横向相干宽度$d_c \equiv \frac{l\lambda}{b}$.

●光场的空间相干性：$d < d_c$,即$\beta < \beta_c = \frac{d_c}{l}$内两点源都是相干点源.

●$b\beta_c = \lambda$.

五、薄膜干涉

1.光程差

$$\Delta L = 2nt\cos\theta_r + \frac{\lambda}{2} = 2nt\sqrt{n^2 - n_1^2\sin^2\theta_i} + \frac{\lambda}{2}.$$

2.等倾干涉

从中心向外数第 N 个亮环附近相邻两亮环间的角距离为$(\Delta N = 1)\ \Delta\theta_N = \frac{1}{n'}\sqrt{\frac{n\lambda}{t}}\frac{\Delta N}{2\sqrt{N}}$.

第 N 个亮环半径$r_N \approx \theta_N f = \frac{f}{n'}\sqrt{\frac{nN\lambda}{t}}$.

相邻两亮环间的径向距离为$\Delta r_N \approx \Delta\theta_N f = \frac{n\lambda f}{2n'^2 t\theta_N}$.

3.等厚干涉

①楔形

相邻条纹的高度差$\boxed{\Delta t = t_{m+1} - t_m = \frac{\lambda}{2\mathrm{n}}.}$

相邻条纹的间隔$\boxed{\Delta l = \frac{\Delta t}{\sin\alpha} = \frac{\lambda}{2n\sin\alpha}.}$

②牛顿环

光程差 $\theta_i = 0, \Delta L = 2t - \frac{\lambda}{2}.$

m 级亮纹半径为 $r_m = \sqrt{\left(m + \frac{1}{2}\right)\lambda R}.$

m 级暗纹半径为：$r'_m = \sqrt{m\lambda R}.$

$$R = \frac{r'^2_{m+N} - r'^2_m}{N\lambda}.$$

4.透射光

$\Delta L = 2nt\cos\theta_r.$ $(I_0 = I_r + I_t)$

5.薄膜厚度要求

$$\Delta L = 2nt\cos\theta < \Delta L_M = m'\lambda = \frac{\lambda^2}{\Delta\lambda}.$$

6.增透膜 $2nt = \left(m + \frac{1}{2}\right)\lambda, m = 0,1,2,\cdots$

7.迈克尔逊干涉仪 $\Delta t = \pm N\frac{\lambda}{2}.$

六、光场的时间相干性：$t < \tau_0.$

光波的相干长度 $L_c = \Delta L_{max} = \frac{\bar{\lambda}^2}{\Delta\lambda}$, 相干时间 $\tau_0 \equiv \frac{L_c}{c}.$

第三章 光的衍射

一、惠更斯-菲涅耳原理

$$\tilde{E}(P) = k\iint_{(\Sigma)} \tilde{E}_0(Q)F(\theta_0,\theta)\frac{e^{ikr}}{r}d\Sigma.$$

基尔霍夫公式 $\tilde{E}(P)=\frac{-i}{\lambda}\iint_{(\Sigma_0)}\frac{(\cos\theta_0+\cos\theta)}{2}\tilde{E}_0(Q)\frac{e^{ikr}}{r}d\Sigma.$

傍轴条件下,即 $\theta_0\approx\theta\approx 0, r\approx r_0$

$$\tilde{E}(P)=\frac{-i}{\lambda r_0}\iint_{(\Sigma_0)}\tilde{E}_0(Q)e^{ikr}d\Sigma.$$

二、巴俾涅原理

几何像点之外，

$$\because \tilde{E}_a(P)+\tilde{E}_b(P)=\tilde{E}_0(P)=0,$$

$$\therefore \left|\tilde{E}_a(P)\right|=\left|\tilde{E}_b(P)\right|,\Rightarrow I_a(P)=I_a(P).$$

三、菲涅耳圆孔衍射和圆屏衍射

1. $\boxed{E_0(P)=\frac{1}{2}\Delta E_{10}+(-1)^{n+1}\frac{1}{2}\Delta E_{n0}.}$

2. $\boxed{k=\frac{\rho^2}{\lambda}\left(\frac{1}{R}+\frac{1}{r}\right).}$

平行光入射圆孔,则 $\boxed{R\to\infty}$， $\boxed{k=\frac{\rho^2}{\lambda R}.}$

3.自由传播 $\boxed{E_0(P)=\frac{1}{2}\Delta E_{10}.}$

4.圆屏衍射 $\boxed{E_0(P)=\frac{1}{2}\Delta E_{k+10}(P)\neq 0}$

5.波带片

●遮住偶数带，轴上 P 点的振幅为

$$\boxed{E_0(P)=\Delta E_{10}(P)+\Delta E_{30}(P)+\Delta E_{50}(P)\cdots+\Delta E_{2n+10}(P).}$$

●遮住奇数带，轴上 P 点的振幅为

$$\boxed{E_0(P)=-(\Delta E_{20}(P)+\Delta E_{40}(P)+\Delta E_{60}(P)\cdots+\Delta E_{2n0}(P)).}$$

●半波带半径

$$\rho = \sqrt{k}\rho_1, \rho_1 = \sqrt{\frac{Rb\lambda}{R+b}}.$$

●透镜作用：$\left(\frac{1}{R}+\frac{1}{b}\right)=\frac{k\lambda}{\rho_k^2}.$

四、夫琅禾费衍射

1. 单缝

①光强

$$\tilde{E}_0(P_\theta)=\tilde{E}_0(P_0)\frac{sin(\alpha)}{\alpha}.\ I_\theta = I_0\left(\frac{sin(\alpha)}{\alpha}\right)^2,$$

其中 I_0 为衍射场中心光强度,

$\left(\frac{\sin(\alpha)}{\alpha}\right)^2$ 为单缝衍射因子.

②次极强 $\sin\theta = \pm 1.43\frac{\lambda}{a}, \pm 2.46\frac{\lambda}{a}, \pm 3.67\frac{\lambda}{a}, \cdots$

③暗纹位置 $\boxed{\sin\theta = m\frac{\lambda}{a}, (m = \pm 1, \pm 2, \pm 3, \cdots)}$

④零级亮斑的半角宽度 $\boxed{\Delta\theta \approx \frac{\lambda}{a}.}$

2. 圆孔

中心角半径：$\boxed{\theta = 0.610\frac{\lambda}{a} \approx 1.22\frac{\lambda}{D}, D = 2a.}$

最小分辨角 $\boxed{\delta\theta_m = \Delta\theta = 1.22\frac{\lambda}{D}.}$

3.光栅

①光强

●$I(P_\theta)=A_0^2(P_0)\left(\frac{\sin(\alpha)}{\alpha}\right)^2\left(\frac{\sin(N\delta/2)}{\sin(\delta/2)}\right)^2$.

●主极大：$\boxed{d\sin\theta=k\lambda, k=0,\pm1,\pm2,\pm3,\cdots}$

$I_{MAX}=N^2A_0^2\left(\frac{\sin(\alpha)}{\alpha}\right)^2$. $k_{MAX}=\frac{d}{\lambda}$.

●极小：$\sin\theta=\left(k+\frac{m}{N}\right)\frac{\lambda}{d}$. $m=1,2,\cdots N-1.(m\neq0,N)$

●主极大的半角宽度$\boxed{\Delta\theta=\frac{\lambda}{Nd\cos\theta_k}.}$

●主极大缺级：

主极大$d\sin\theta=k\lambda, k=0,\pm1,\pm2,\pm3,\cdots$

单缝极小$a\sin\theta=n\lambda, n=\pm1,\pm2,\pm3,\cdots$

当$\sin\theta=\frac{k\lambda}{d}=\frac{n\lambda}{a}$时,即$\boxed{k=\frac{dn}{a}}$缺级.

②光谱

●色散本领定义为$\boxed{D_\theta=\frac{\delta\theta_k}{\delta\lambda}=\frac{k}{d\cos\theta_k}.}$

●瑞利判据 ：最小分辨角$\delta\theta'$等于光谱线的半角宽度, 即$\boxed{\delta\theta'=\Delta\theta}$.

●色分辨本领$\boxed{R=\frac{\lambda}{\delta\lambda}=kN.}$

③闪耀光栅 $\boxed{d\sin2\theta_B=k\lambda_B^k}$, k 级最亮.

同时,$a\approx d$, $a\sin(2\theta_B)=k\lambda_B^k$也成立，即其它干涉级均成为缺级.

④布拉格条件$2d\sin\theta = k\lambda.$.

第五章 光的电磁性

一、偏振

1. 偏振度：$P = \dfrac{I_{max} - I_{max}}{I_{max} + I_{max}}, 0 \le P \le 1.$

2.马吕斯定律$I_2 = I_1 cos^2 \alpha.$

3.布儒斯特角θ_B $tg\theta_B = \dfrac{n_2}{n_1}$.

4.e 光主折射率$n_e = c / V_e = \dfrac{sin\theta_i}{sin\theta_r^e}$.

5. 波晶片

若$(n_0 - n_e)d = \pm\dfrac{\lambda}{4} + m\lambda, m$为整数,$\varphi_{o-e} = \pm\dfrac{\pi}{2}$,则称波晶片为$\dfrac{\lambda}{4}$片.

若$(n_0 - n_e)d = \pm\dfrac{\lambda}{2} + m\lambda, \varphi_{o-e} = \pm\pi, 2\pi$,则称波晶片为$\dfrac{\lambda}{2}$片.

6. 椭圆偏振光$\vec{E} = \vec{E}_x + \vec{E}_y$.

其中$E_x = E_{x0} cos\left(\omega t - \dfrac{2\pi}{\lambda} z\right), E_y = E_{y0} cos\left(\omega t - \dfrac{2\pi}{\lambda} z - \delta\right)$.

二、光的吸收、色散和散射

1. 光的吸收$I = I_0 e^{-\alpha l}$.

2. 色散

•柯西公式：$n = A + \frac{B}{\lambda^2} + \frac{C}{\lambda^4}$.

•色散率$\frac{dn}{d\lambda} < 0$,正常色散;$\frac{dn}{d\lambda} > 0$,反常色散.

3.瑞利散射：$I_s(\lambda) \propto \frac{f(\lambda)}{\lambda^4}, a < \lambda$.

第六章 光的量子性

1.普朗克能量子 $\boxed{\varepsilon_0 = h\nu}$

2.光电效应

•$\boxed{\frac{1}{2}mv_m^2 = eV_0 = eK(\nu - \nu_0).}$

•$\boxed{E = h\nu.}$

•$\boxed{\frac{1}{2}mv_m^2 = h\nu - A,}$

•$\boxed{\nu_0 = \frac{A}{h}.}$

3.康普顿散射

$$\boxed{\Delta\lambda = 2\lambda_c \sin^2\frac{\theta}{2}, \lambda_c = \frac{h}{m_0 c} = 0.0243\overset{0}{A}}$$

4．光的波粒二象性$\boxed{E = h\nu, p = \frac{h\nu}{c} = \frac{h}{\lambda}.}$

第七章 激光

自发辐射：$\frac{dN_{21}}{dt} = A_{21}N_2$,

受激辐射：$\frac{dN'_{21}}{dt} = B_{21}\rho(\nu)N_2$,

受激吸收：$\frac{dN_{12}}{dt}=B_{12}\rho(\nu)N_1$,

谐振腔纵模$\nu_j=j\frac{c}{2nL},j=1,2,\cdots$间隔$\Delta\nu=\frac{c}{2nL}$.

说明：打黑框的公式必须理解，并且记住！不打黑框的公式要求理解其物理意义。