5-04 全息照相

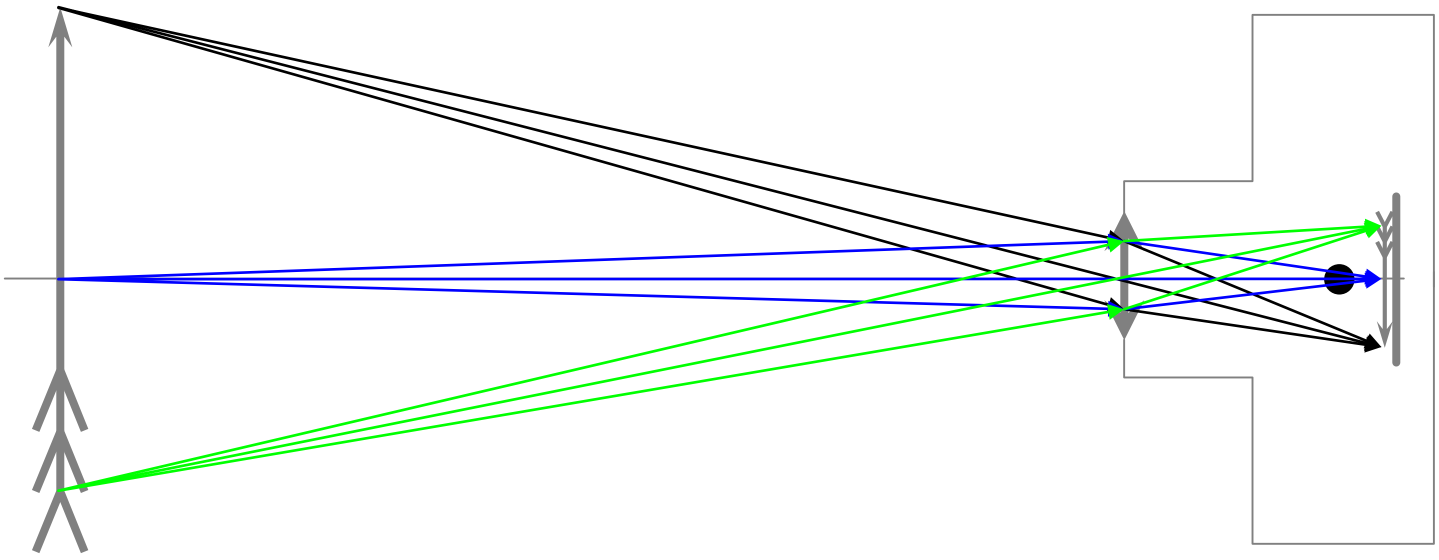
0. 全息照相(Holography)的过程与特点
1. 惠更斯—费涅耳原理的实质
2. 波前的全息记录
3. 物光波的再现
4. 线性和二次位相变换函数的作用
5. 小结

0.全息照相(Holography)的过程与特点

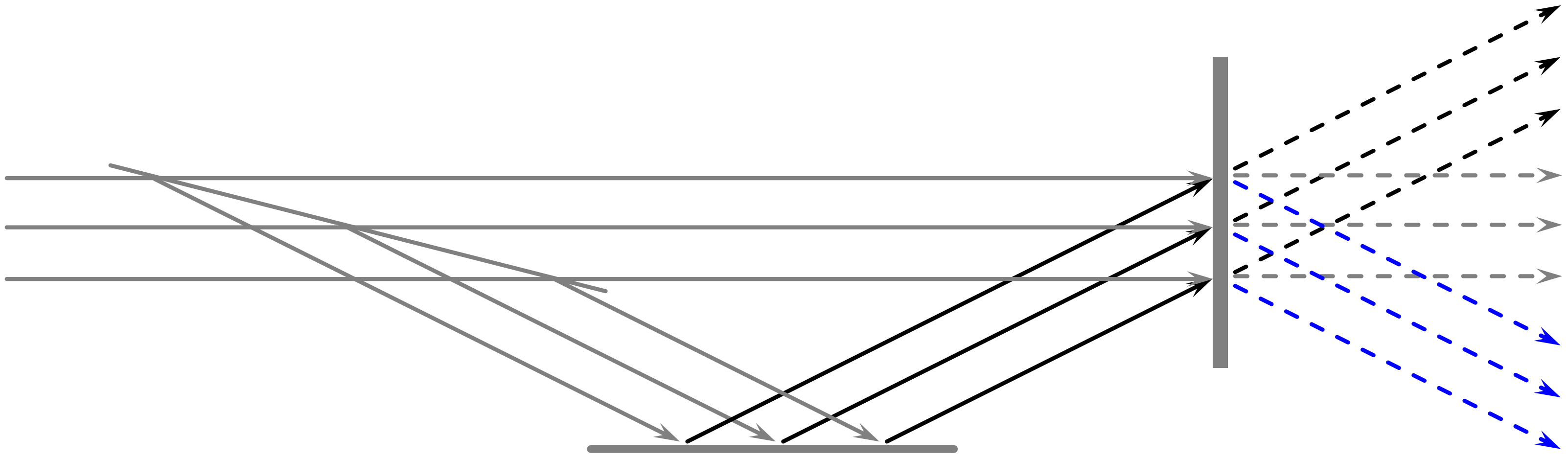
两步：记录、再现

一、全息记录：

传统照相：底片记录光强



一、全息记录：



两束平行光干涉→正弦光栅
正弦光栅对其中的一束平行光衍射→三束平行光
平行光→物，衍射光中的一束→物光的再现

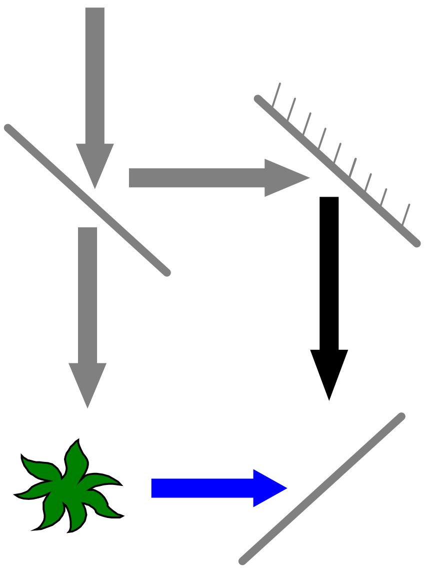
一、全息记录：

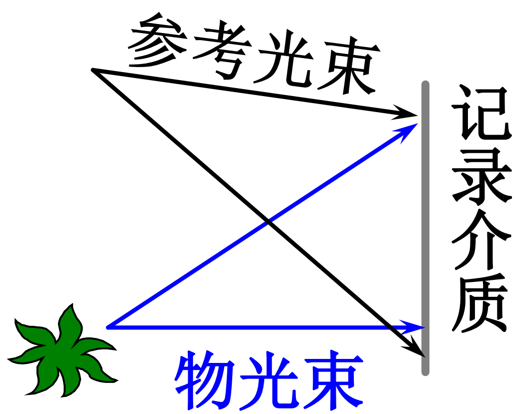
物光+参考光 ⇒ 干涉

⇓ 底片记录

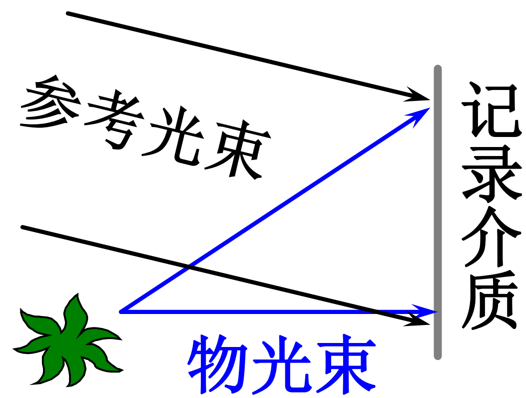
干涉图（全息图） ← 波前全息记录

振幅 位相 ← 全部光信息





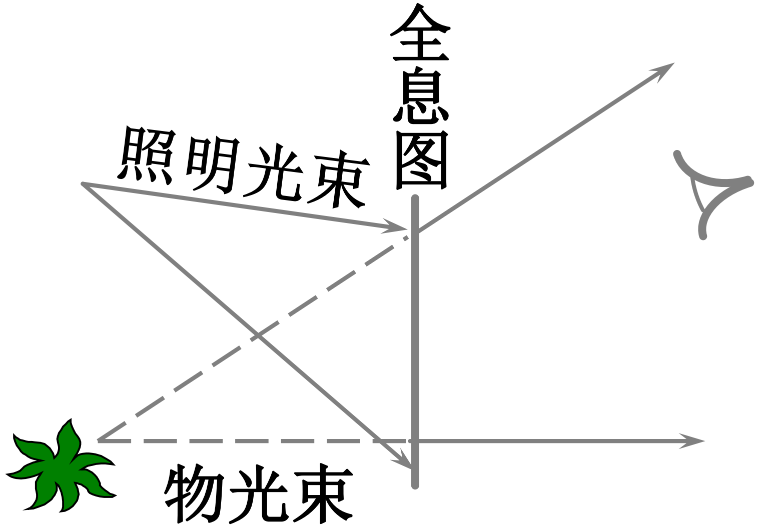
球面波照明



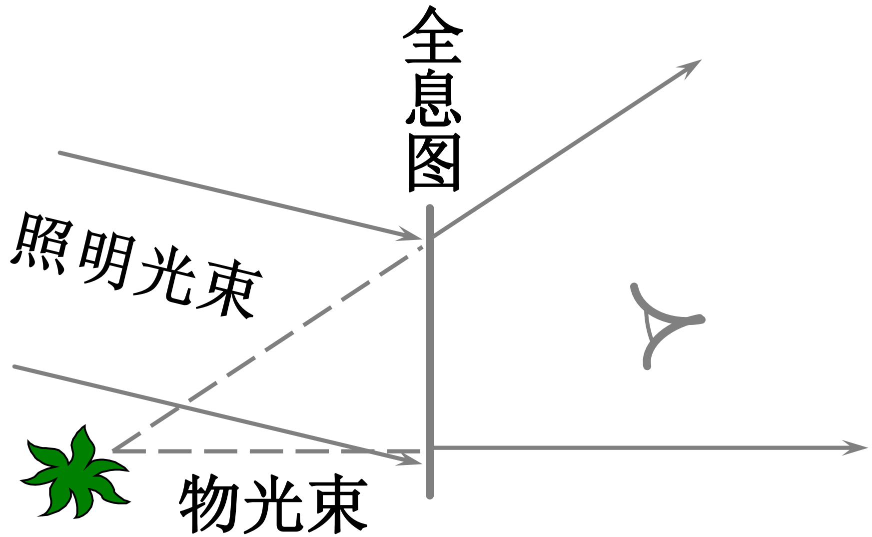
平面波照明

二、波前再现：

照明光+全息图 $\Rightarrow$ 衍射



球面波照明



平面波照明

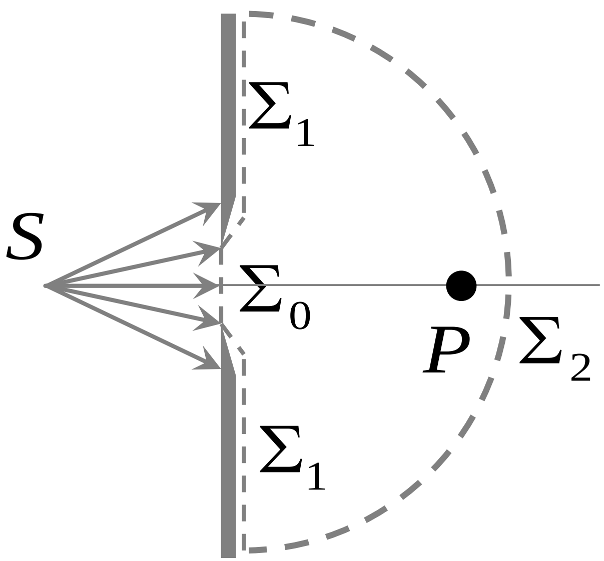
1. 惠更斯—费涅耳原理的实质

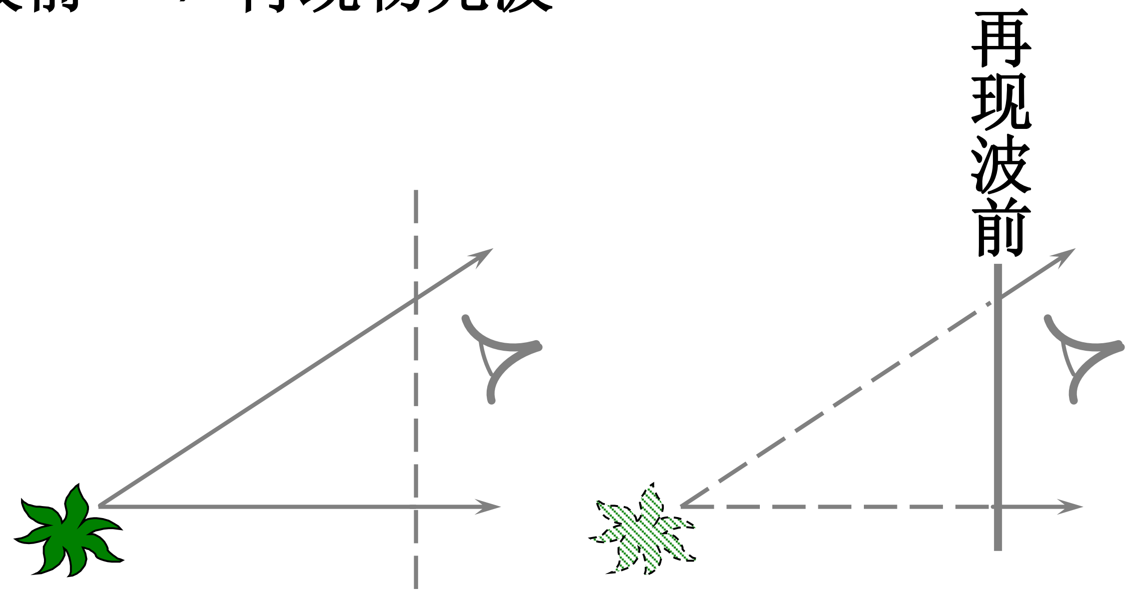
——无源空间边值定解：

无源空间中的光场分布由边界条件（波前）唯一确定。

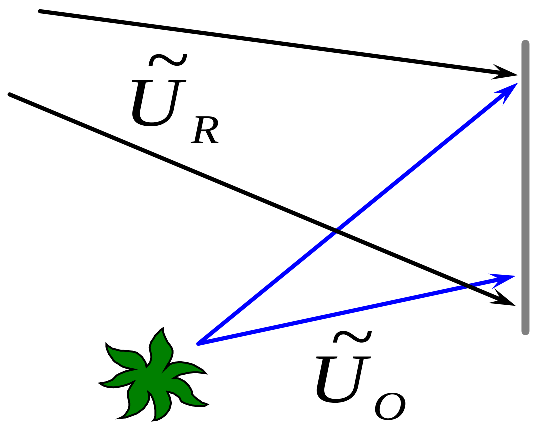
$$\Downarrow$$

再现波前 $\Rightarrow$ 再现物光波





2. 波前的全息记录



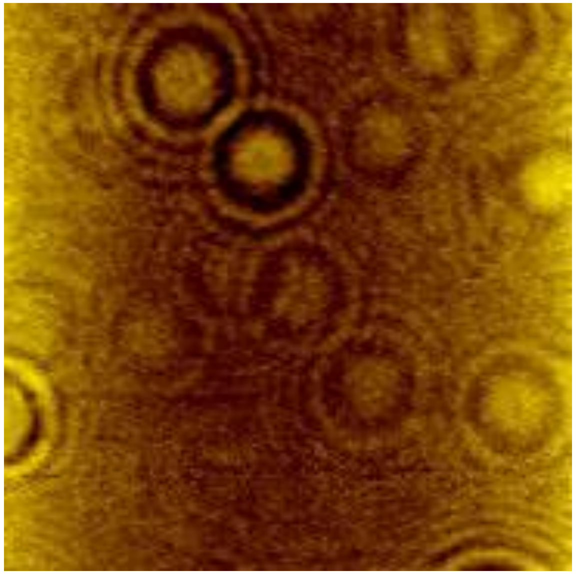
物光波：$\tilde{U}_O(Q)=\sum_{物点}u_n(Q)=A_O(Q)e^{i\varphi(Q)}$

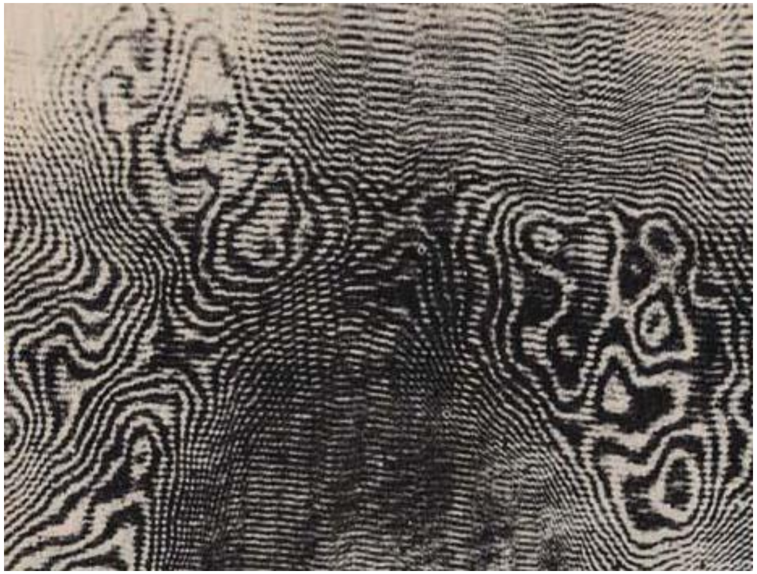
与参考光 $\tilde{U}_R=A_R e^{i\varphi_R}$ 干涉：

$$I(Q)=(\tilde{U}_O+\tilde{U}_R)(\tilde{U}_O^*+\tilde{U}_R^*)$$
$$=A_R^2+A_O^2+\tilde{U}_R^*\tilde{U}_O+\tilde{U}_R\tilde{U}_O^*$$

底片曝光、线性冲洗⟹全息图：

$$\tilde{t}(Q) = t_0 + \beta I(Q)$$
$$= t_0 + \beta(A_R^2 + A_O^2 + \tilde{U}_R^* \tilde{U}_O + \tilde{U}_R \tilde{U}_O^*)$$

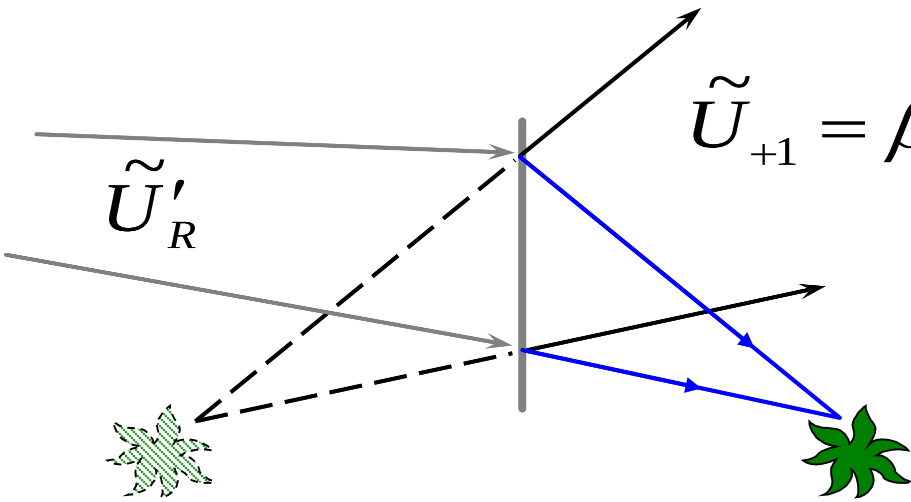




3. 物光波的再现

以 $\tilde{U}'_R = A'_R e^{i\varphi'_R}$ 照射全息图，衍射光：

$$
\begin{aligned}
\tilde{U}_T &= \tilde{U}'_R \tilde{t} \\
&= (t_0 + \beta A_R^2 + \beta A_O^2)\tilde{U}'_R + \beta \tilde{U}'_R \tilde{U}^*_R \tilde{U}_O + \beta \tilde{U}'_R \tilde{U}_R \tilde{U}^*_O \\
&= \underbrace{(t_0 + \beta A_R^2 + \beta A_O^2)\tilde{U}'_R}_{\text{0级}} \\
&\quad + \underbrace{\beta A'_R A_R e^{i(\varphi'_R - \varphi_R)} \tilde{U}_O}_{\text{+1级→虚像}} + \underbrace{\beta A'_R A_R e^{i(\varphi'_R + \varphi_R)} \tilde{U}^*_O}_{\text{-1级→共轭实像}}
\end{aligned}
$$



$$\tilde{U}_{+1} = \beta A'_R A_R e^{i(\varphi'_R - \varphi_R)} \tilde{U}_O$$

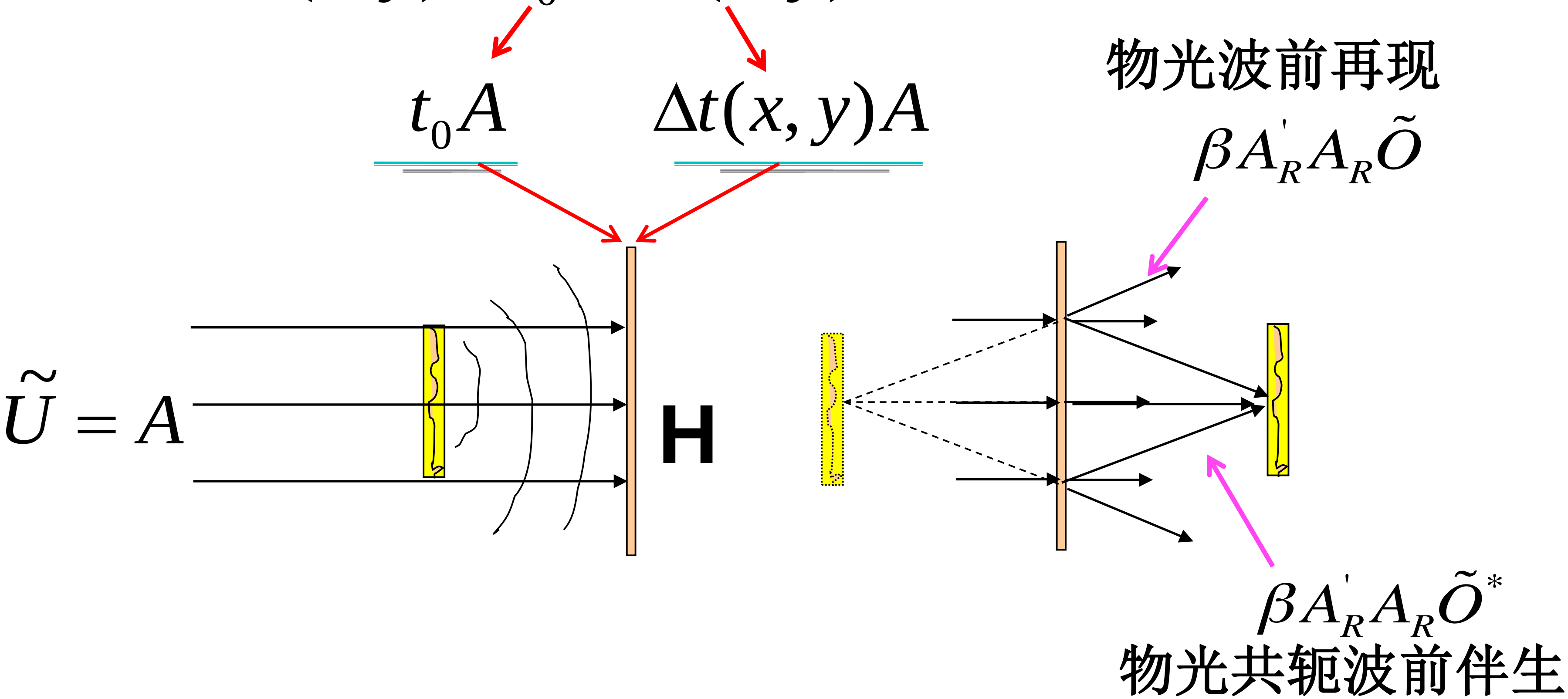
$$\tilde{U}_{-1} = \beta A'_R A_R e^{i(\varphi'_R + \varphi_R)} \tilde{U}_O^*$$

$\tilde{U}_R, \tilde{U}'_R$ 都为正入射平面波：$\varphi_R = \varphi'_R = 0$，

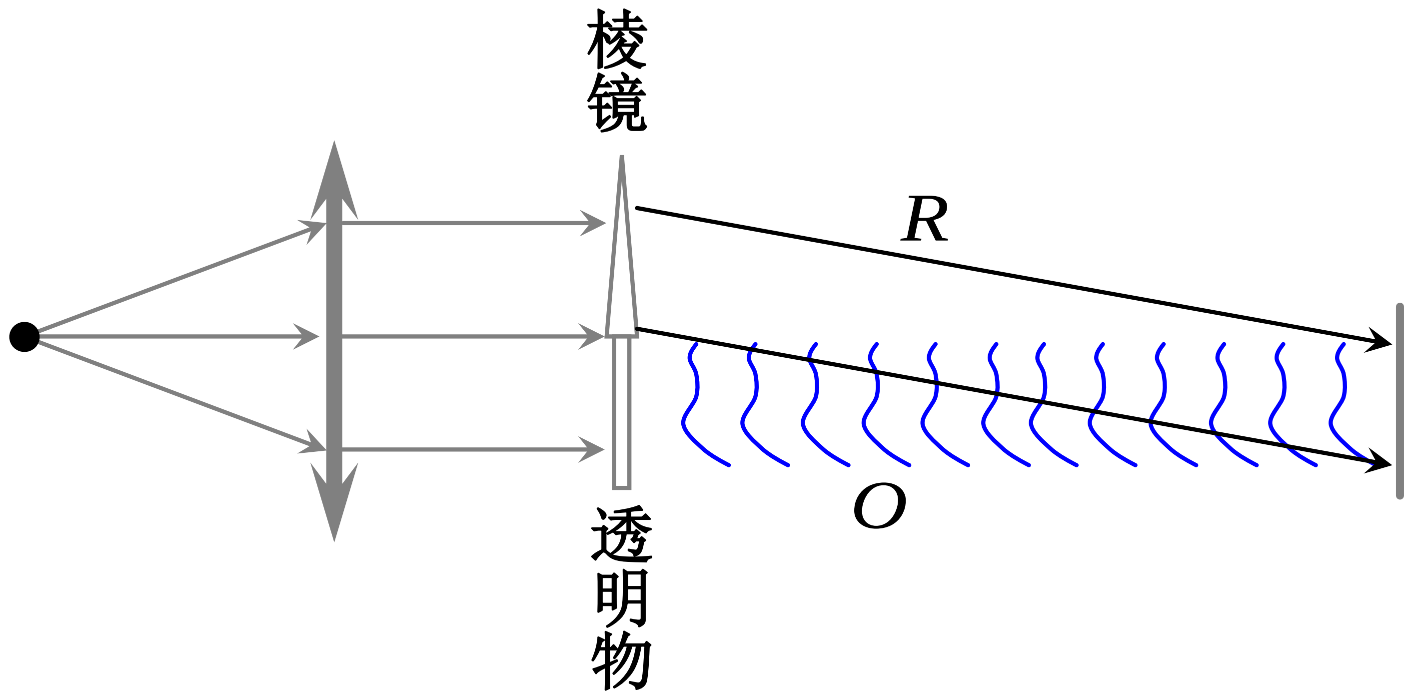
$$A_R = const.$$
$$A'_R = const.$$

共轴全息（Dennis Gabor，1948，1971 Nobel Laureate ）

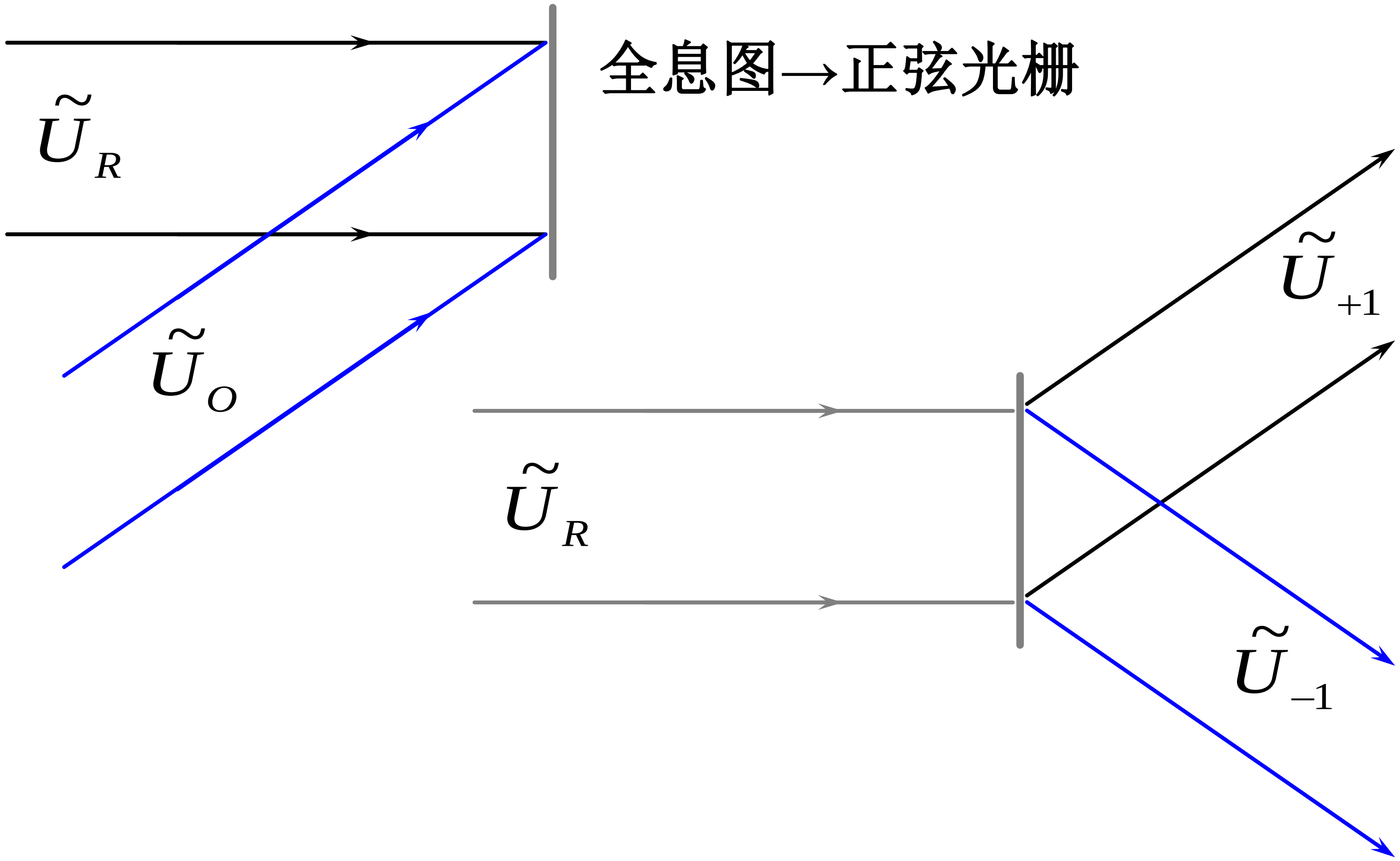
$$t(x,y)=t_0+\Delta t(x,y)$$



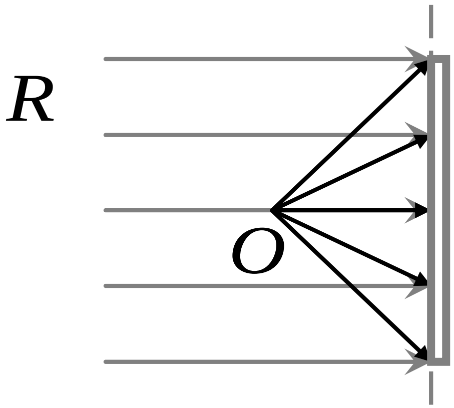
为使*0,±1*级在空间上分开→离轴全息



例　正弦光栅→平行光的全息图



例 黑白“费涅耳”波带片→轴上点光源的全息图

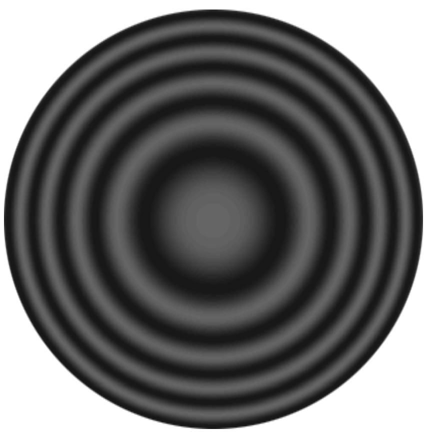


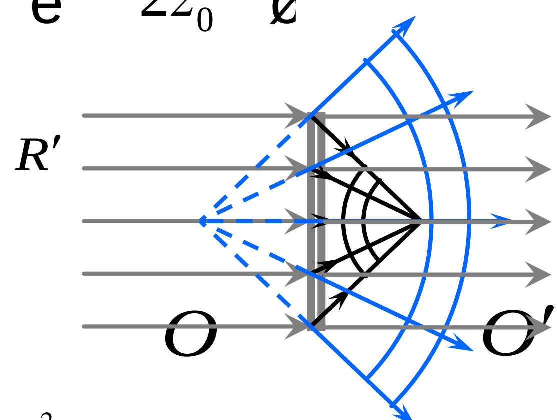
$$\tilde{U}_R = A_1 e^{i\varphi_0} \qquad \tilde{U}_O = A_2 e^{ik\frac{x^2+y^2}{2z_0}}$$

$$\tilde{U} = \tilde{U}_R + \tilde{U}_O$$

$$I(x,y) = A_1^2 + A_2^2 + 2A_1A_2\cos\left(k\frac{x^2+y^2}{2z_0} - \varphi_0\right)$$

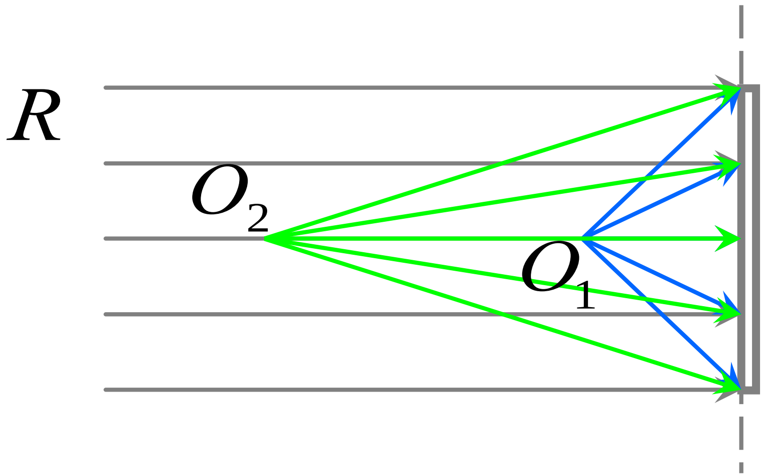
$$t(x,y) = a + bI(x,y) = t_0 + t_1\cos\left(k\frac{x^2+y^2}{2z_0}\right)$$

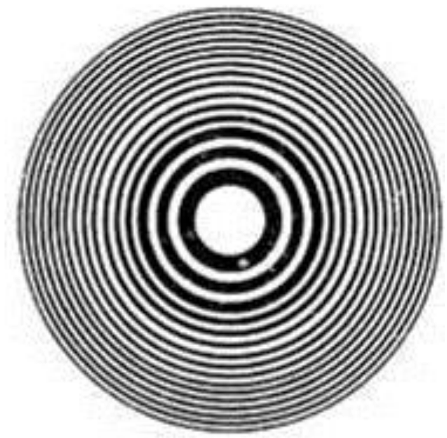


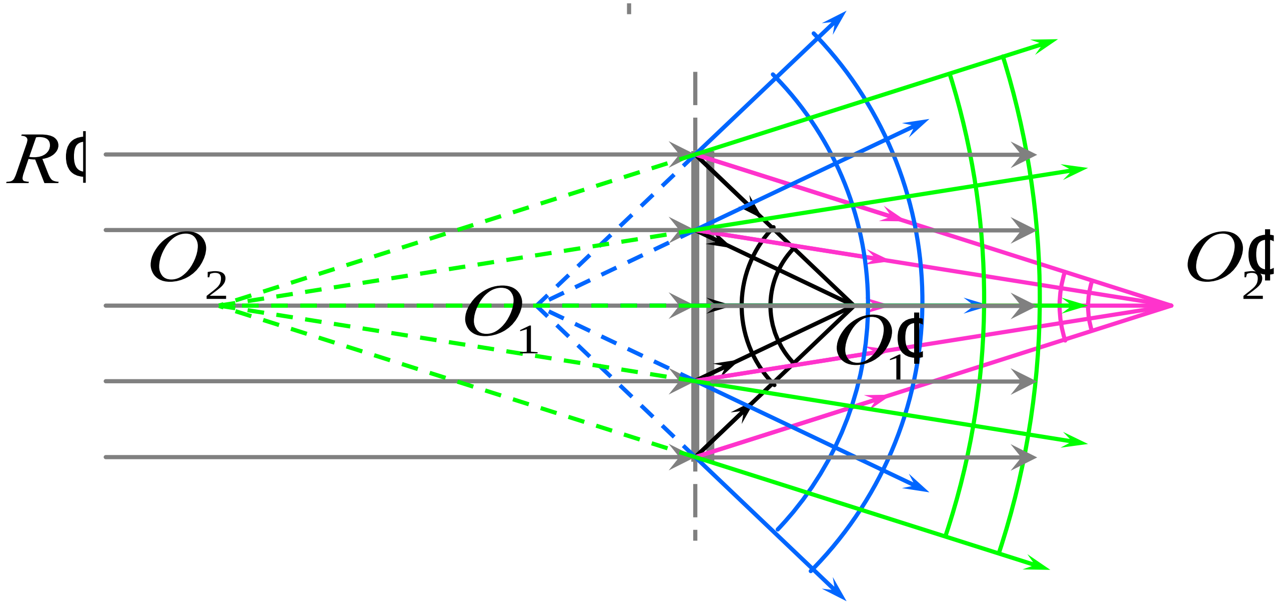


$$\tilde{U}_2(x,y) = A_1t_0 + \frac{1}{2}A_1t_1e^{ik\frac{x^2+y^2}{2z_0}} + \frac{1}{2}A_1t_1e^{-ik\frac{x^2+y^2}{2z_0}} = \tilde{U}_0 + \tilde{U}_{+1} + \tilde{U}_{-1}$$

例 黑白“费涅耳”波带片→轴上点光源的全息图

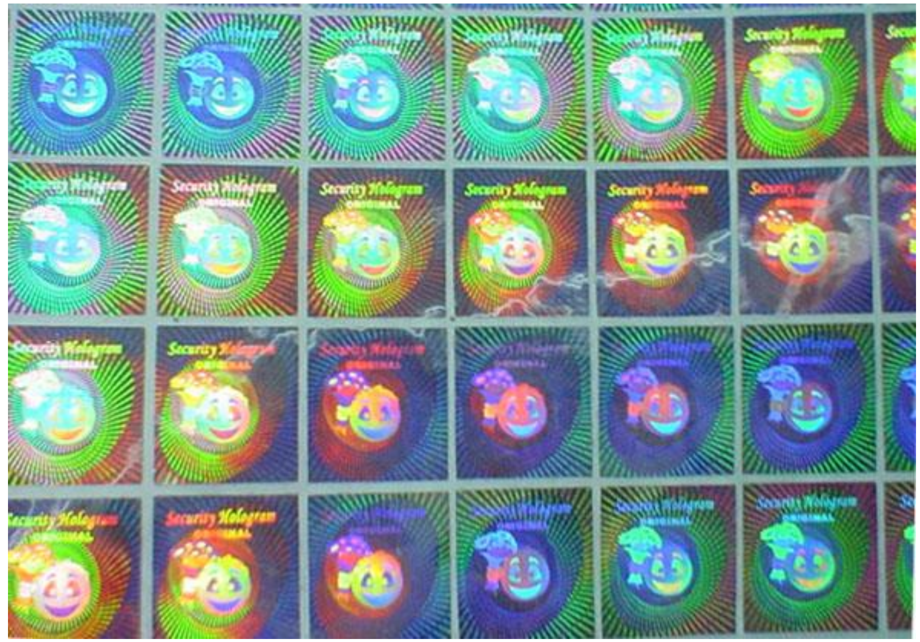


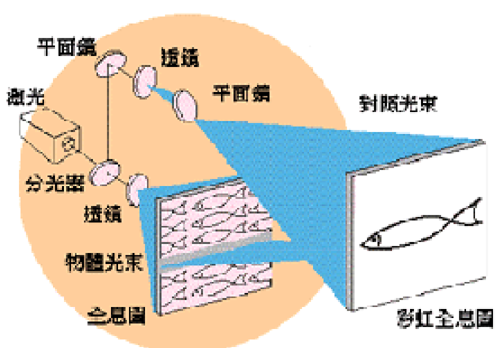


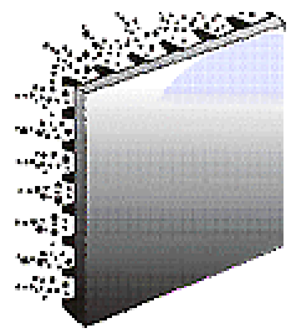


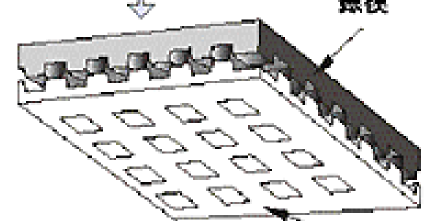
体全息
彩虹全息
真彩全息
全息加密
全息存储
全息电影
超声、微波全息
全息计量术

⋮









4. 线性和二次位相变换函数的作用

附加相因子→位相型屏函数 $\longrightarrow$ 类似透镜、棱镜

例：共面照明全息

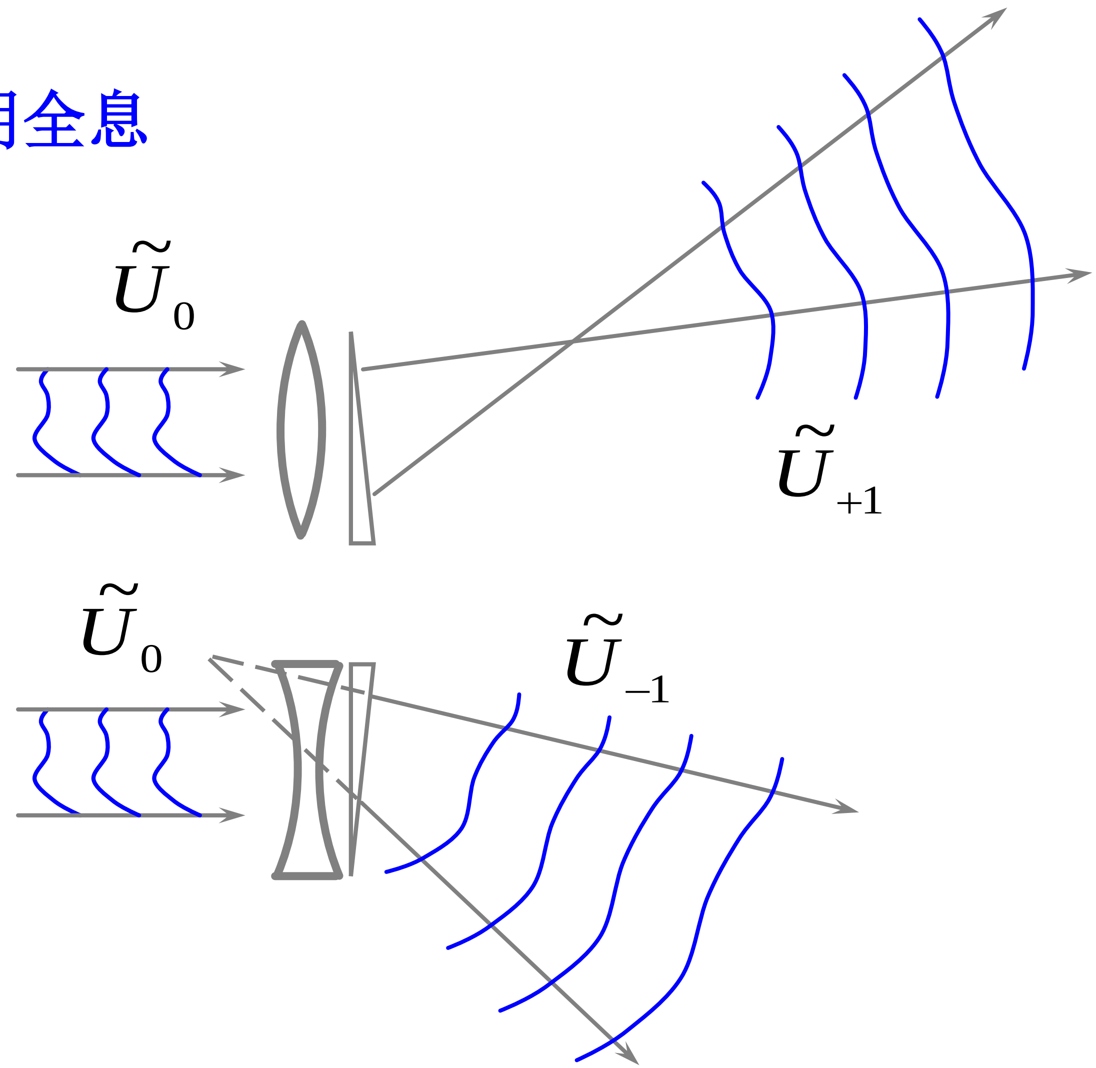
$$\begin{cases}\tilde{U}_{+1} = \beta A_R' A_R e^{i(\varphi_R' - \varphi_R)} \tilde{U}_O \\ \tilde{U}_{-1} = \beta A_R' A_R e^{i(\varphi_R' + \varphi_R)} \tilde{U}_O^* \end{cases}$$

$\tilde{U}_R$离轴球面波：

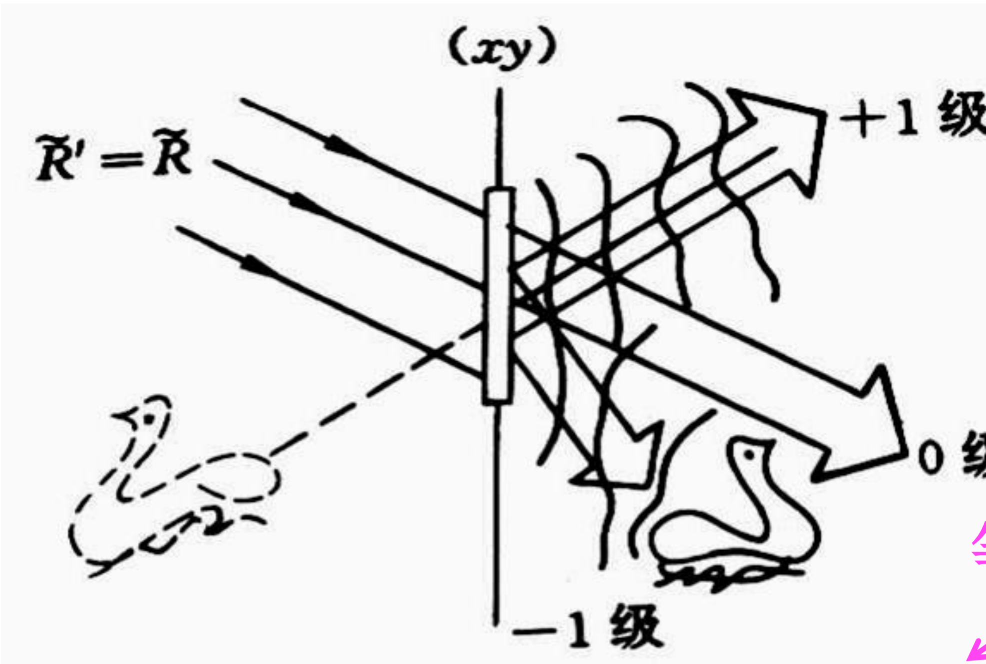
$$\underbrace{\varphi_R = k\frac{a^2 + x^2 + y^2}{2z}}_{\text{透镜，}F=z} - k\frac{ax}{z} \longrightarrow \text{棱镜，} \sin\theta = \frac{a}{z}$$

$\tilde{U}_R'$正入射球面波：$\varphi_R' = 0$

例：共面照明全息



照明光和参考光是斜入射的全同平面光：$j'_R = j_R = qx$



$$\beta A'_R A_R \tilde{O}$$

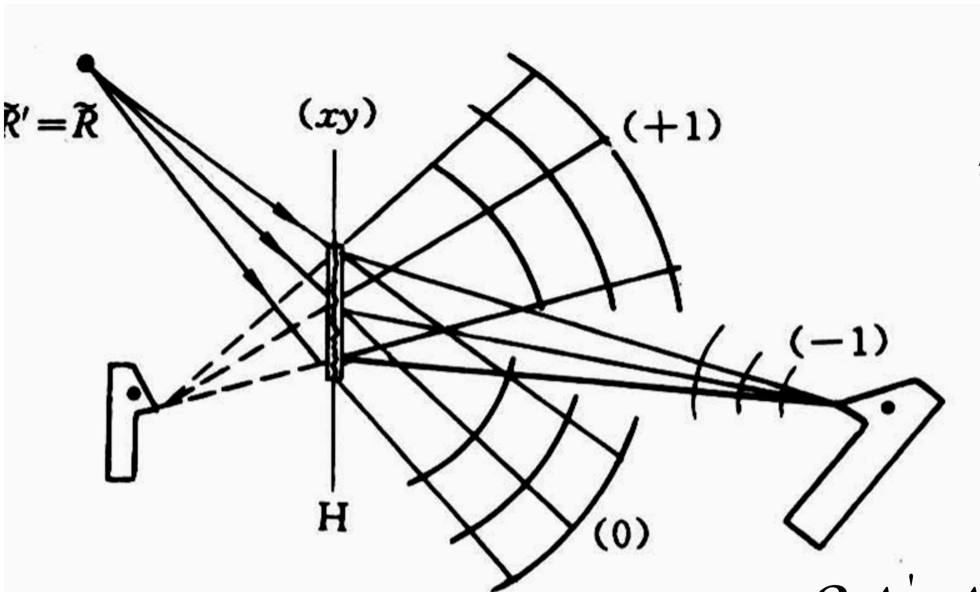
物光波前真实再现

等效棱镜

$$\beta A'_R A_R e^{i2\varphi_R} \tilde{O}^*$$

共轭波受到一等效棱镜的作用，发生偏转。

照明光和参考光是全同球面光： $\varphi'_R = \varphi_R = \dfrac{x^2+y^2}{2F}$



$$\beta A_R' A_R \tilde{O}$$

物光波前真实再现

等效透镜

$$\beta A_R' A_R e^{i2\varphi_R} \tilde{O}^*$$

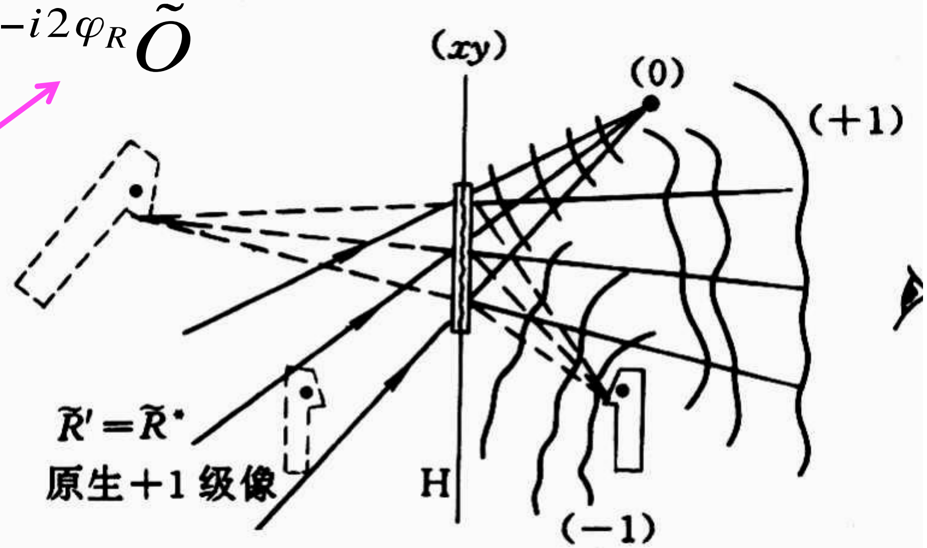
共轭波受到一等效透镜的作用，发生放大、缩小和偏转，也可能实象变成虚象。

照明光和参考光是共轭球面光: $\varphi'_R = -\varphi_R = \dfrac{x^2+y^2}{2F}$

物光波受到一等效透镜的作用，发生放大、缩小和偏转，也可能实象变成虚象。

$\beta A'_R A_R e^{-i2\varphi_R}\tilde{O}$

等效透镜



$\beta A'_R A_R \tilde{O}^*$

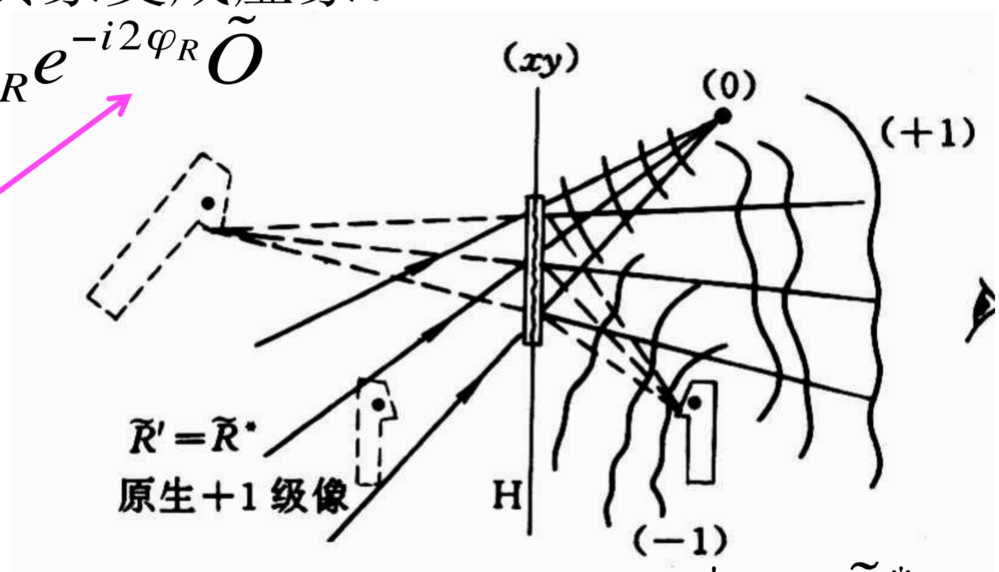
伴生实象

照明光和参考光是共轭球面光： $\varphi'_R = -\varphi_R = \dfrac{x^2 + y^2}{2F}$

物光波受到一等效透镜的作用，发生放大、缩小和偏转，也可能实象变成虚象。

$$\beta A'_R A_R e^{-i2\varphi_R}\tilde{O}$$

等效透镜



$$\beta A'_R A_R \tilde{O}^*$$

伴生实象

6. 小结

一、记录、再现两步

二、记录

$$\overbrace{\text{物光+参考光}}^{\text{相干}}$$

干涉：物光+参考光 ⎫
波前：振幅+位相 ⎭ 物光调制参考光

振幅 → 衬度　位相 → 条纹

衬度　条纹

三、再现

解调 ⎧ 衍射：照明光+干涉图
　　 ⎩ 直射光、物光波、物光波的共轭

四、原理

几何光学→波动干涉、衍射

边界条件定解

作业

p.157: 1, 2, 3, 4

思考题

1 照明光和参考光是全同球面光。在什么情况下放大和缩小？什么情况下出现虚象？

2 如果参考光为平面光，照明光为球面光，或者参考光为球面光，照明光为平面光，再或者参考光和照明光为不同球心的球面波，衍射场的情况如何？

3 用不同波长的光再现，情况如何？