Chapter 13

interference of light

Primary coverage

1 Light wave
2 The generation of the coherent light waves
3. Optical path: optical path difference
4-wave front interference —— Young's interference experiment
5-point amplitude interference —— thin film interference
6 Michael son interferometer

§ 13.1

light wave

1. Light is an electromagnetic wave

The range of visible light
$$\begin{cases} \lambda : 390 \sim 760\text{nm} \\ \nu : 7.7\times10^{14} \sim 3.9\times10^{14}\,\text{Hz} \end{cases}$$

◆ **The speed of light in a vacuum**

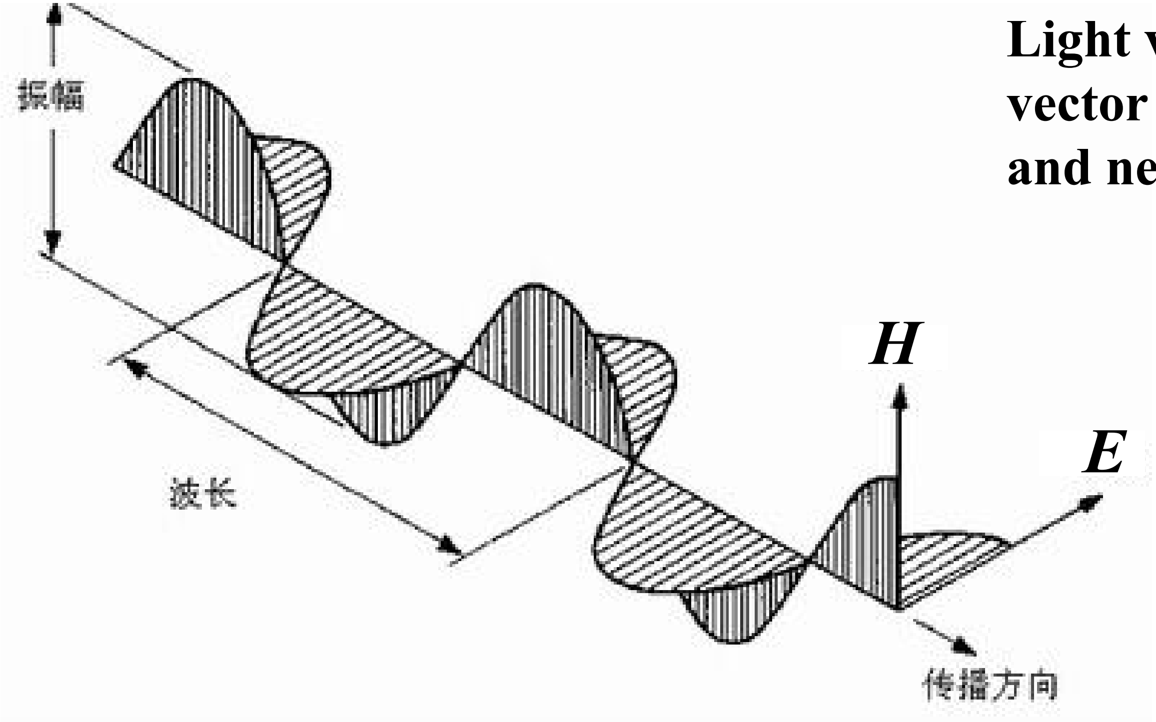
$$\boxed{c = \frac{1}{\sqrt{\varepsilon_0 \mu_0}}}$$

◆ **Speed of light in the medium**

$$\boxed{v = \frac{1}{\sqrt{\varepsilon_0 \mu_0 \varepsilon_r \mu_r}}}$$

The refractive index in the medium

$$\boxed{n = \frac{c}{v} = \sqrt{\varepsilon_r \mu_r}}$$



Light vector $\vec{E}$ represents light vector in causing human eye vision and negative light sensitivity.

2. light intensity

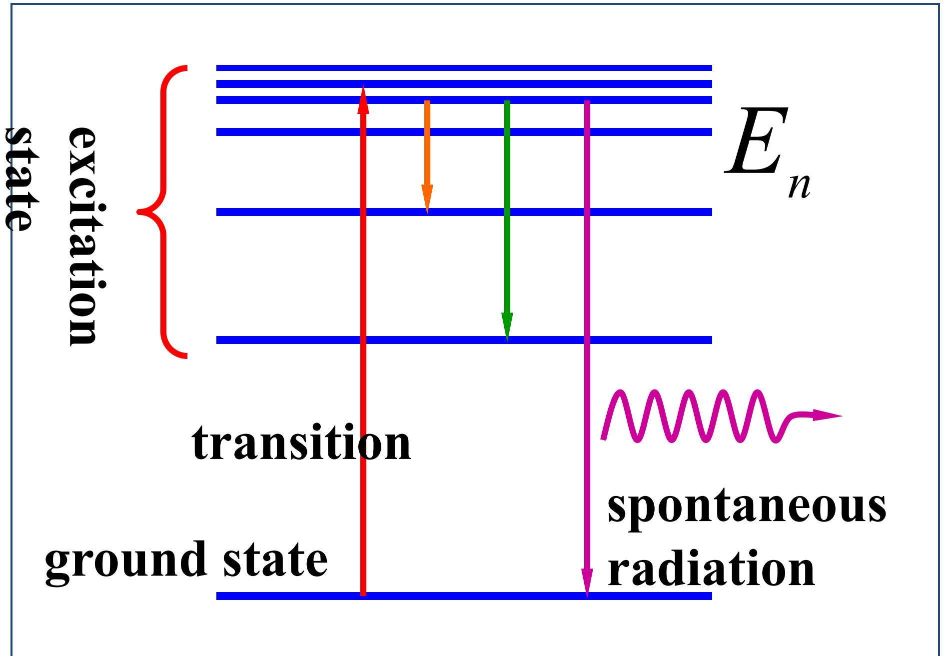
Relative light intensity in the same medium

$$I = A^2$$

§ 13.2

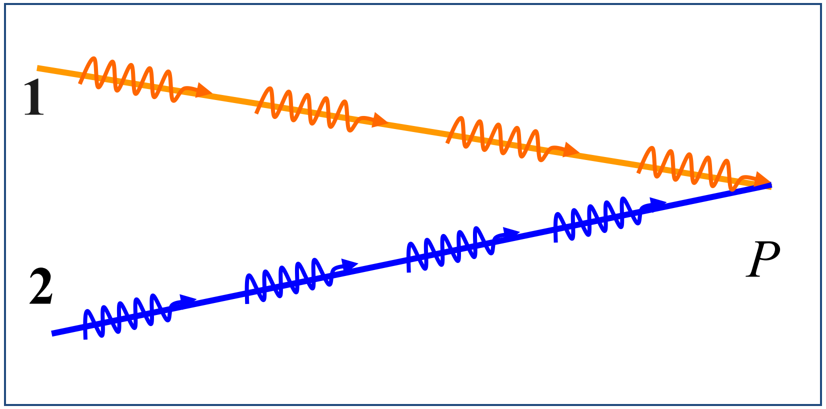
The generation of coherent light waves

1. The luminous mechanism of ordinary light sources



Atomic energy level and luminous transition

$$\Delta E = h\nu \qquad \Delta t \sim 10^{-8}\,\mathrm{s}$$

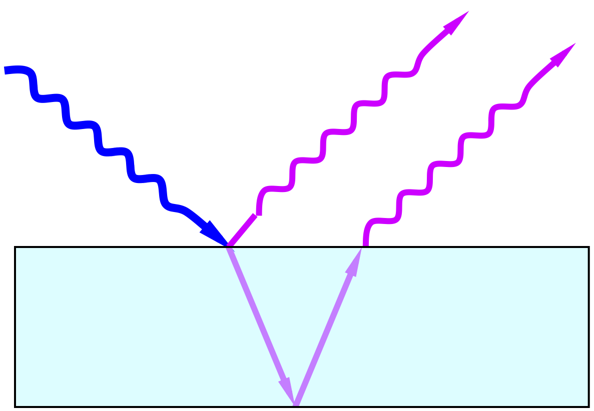


Ordinary light source light characteristics: atomic light is intermittent, each light forms a limited length of the wave column, each atomic light is independent of each other, each wave column is irrelevant to each other.

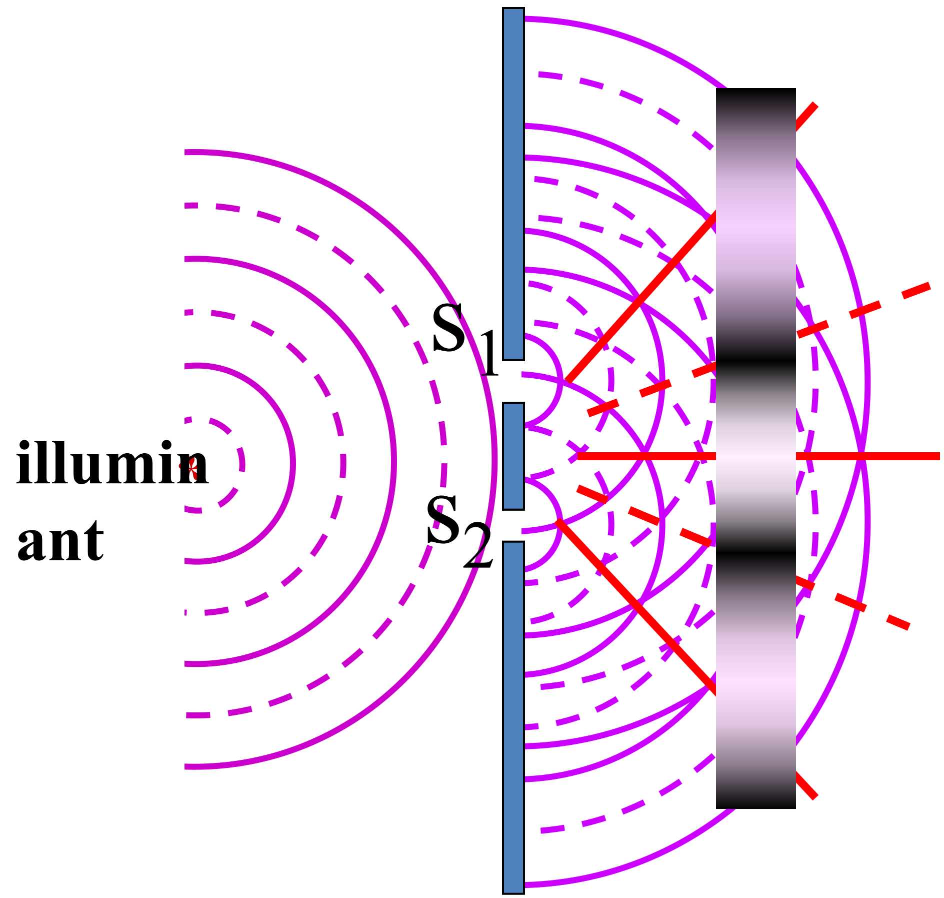
2. The generation of a coherent light

Method: Divide a wave column in two

Partition amplitude method



Split before method



§ 13.3

Optical path difference

13.3.1 Light path

The velocity of the light in the vacuum is satisfied with that in the medium

$$\frac{v}{c} = \frac{1}{n}$$

The refractive index of the medium

$$v = \lambda' \nu \qquad c = \lambda \nu$$

The wavelength in the medium

$$\boxed{\lambda' = \frac{\lambda}{n}}$$

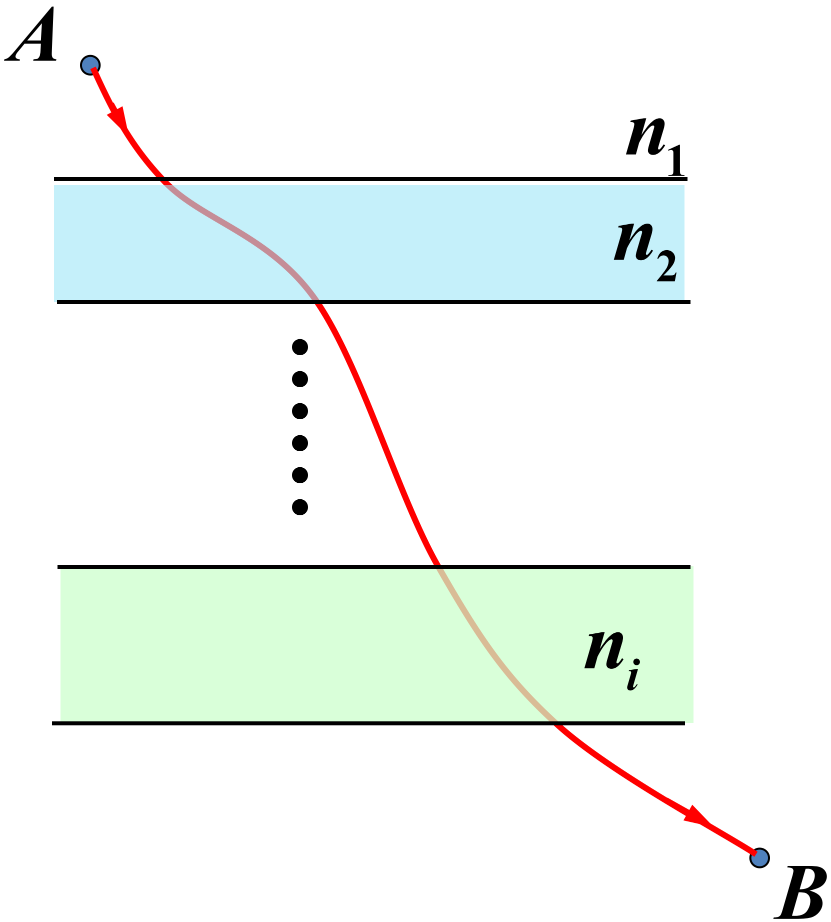
Through the path of l in the medium, the distance it travels in the vacuum at the same time interval is

$$L = \Delta t\, c = \frac{l}{v} c = nl$$

optical distance

Physical meaning: The light path is the distance that light can travel in a vacuum during the time it takes to pass through the real path in the medium.

$$\frac{L}{c} = \frac{l}{v}$$



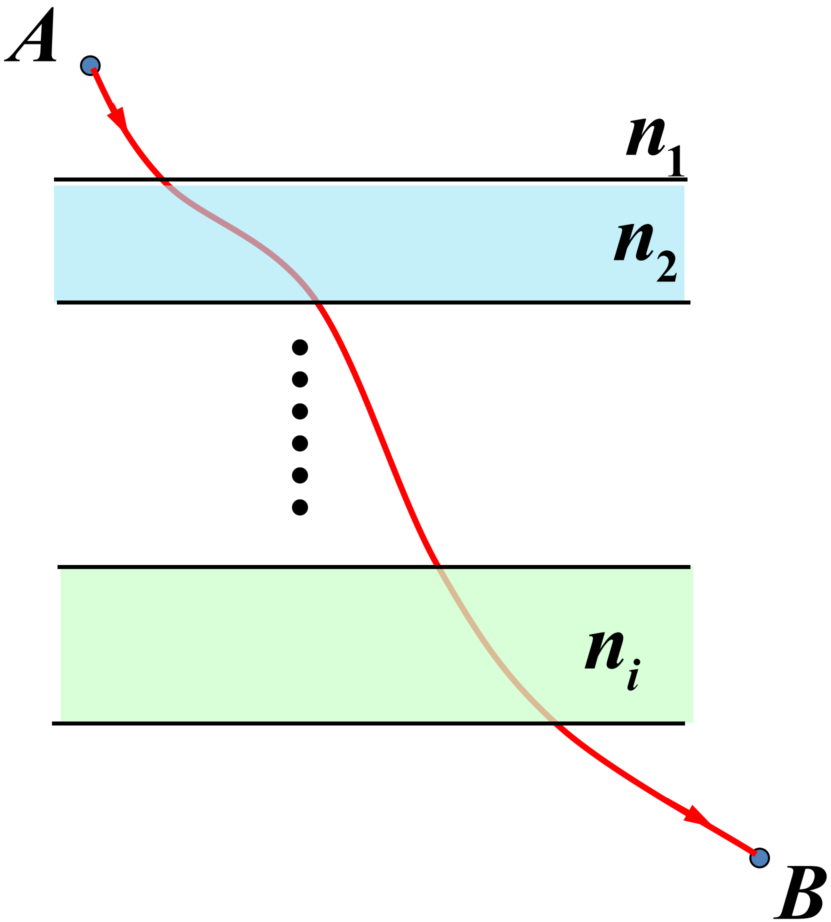
The optical path between two points A and B is

$$L = \sum_i n_i l_i$$

If the refractive index of the medium changes continuously, then the optical path between the two points A and B is

$$L = \int_A^B n\,\mathrm{d}l$$

13.3.2 Relationship between optical range difference and phase difference



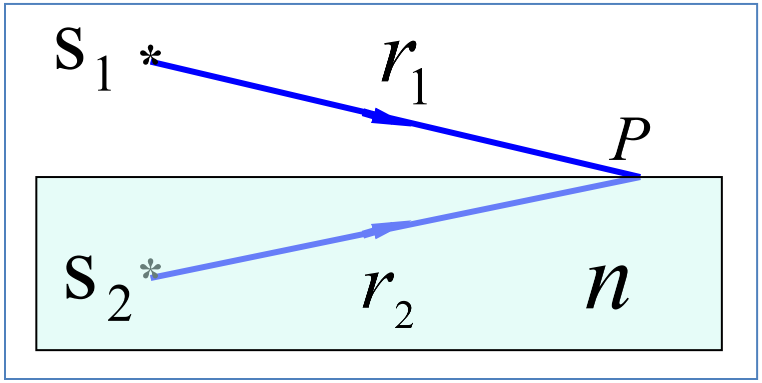
A Phase difference in B between two points

$$\Delta\varphi = \frac{2\pi}{\lambda}\sum_i n_i l_i = \frac{2\pi}{\lambda} L$$

$$\varphi = \varphi_0 - \Delta\varphi = \varphi_0 - \frac{2\pi}{\lambda} L$$

$$\varphi_1 = \varphi_{01} - \frac{2\pi}{\lambda} L_1 = \varphi_{01} - \frac{2\pi}{\lambda} n_1 r_1$$

$$\varphi_2 = \varphi_{02} - \frac{2\pi}{\lambda} L_2 = \varphi_{02} - \frac{2\pi}{\lambda} n_2 r_2$$



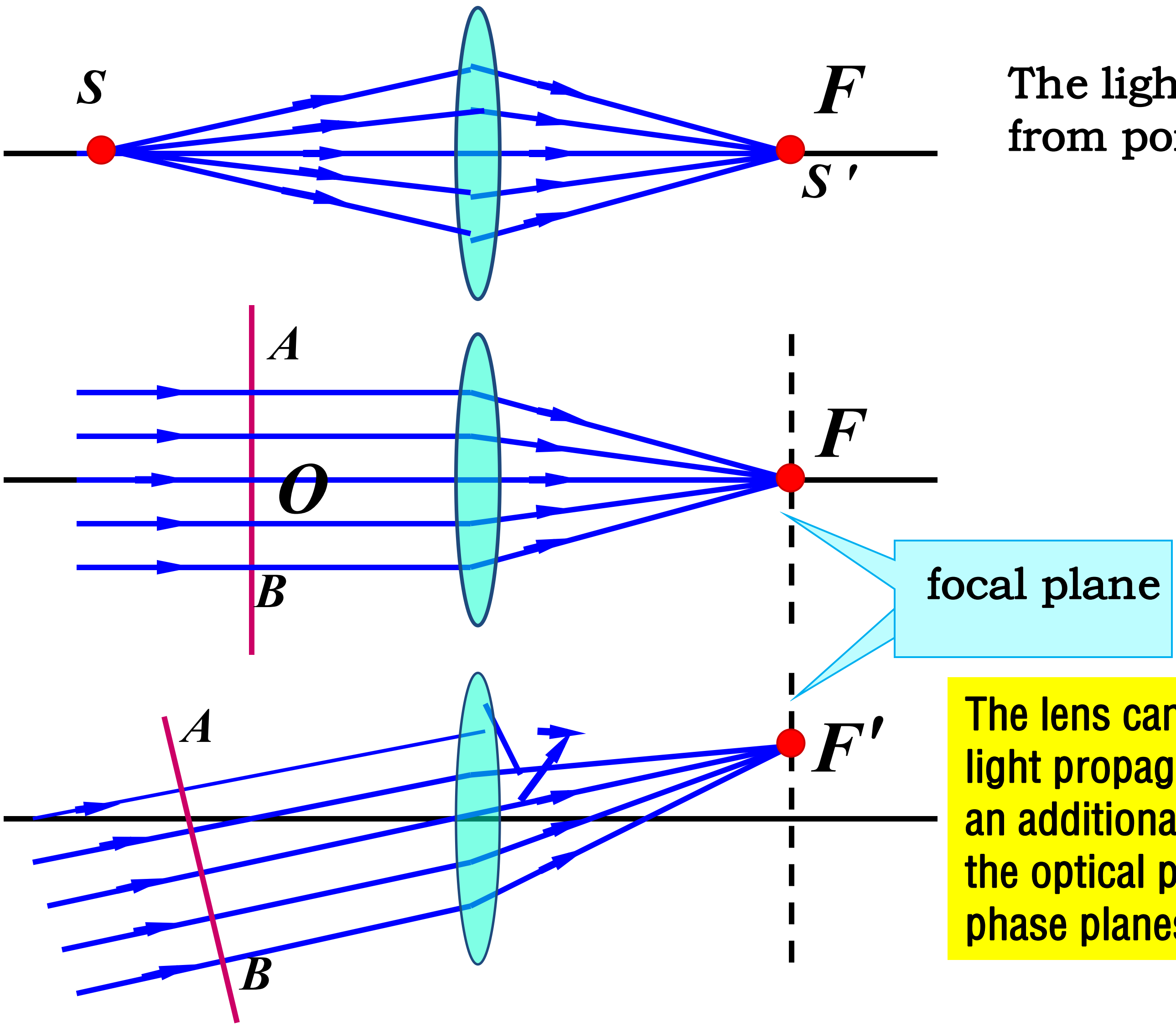
◆ **phase difference**

$$\Delta\varphi = \varphi_1 - \varphi_2 = (\varphi_{01} - \varphi_{02}) + \frac{2\pi}{\lambda}(n_2 r_2 - n_1 r_1)$$

Basic relations

$$\Delta\varphi = \Delta\varphi_0 + \frac{2\pi}{\lambda}\Delta L$$

13.3.3 Equoptical ability of ideal lens images



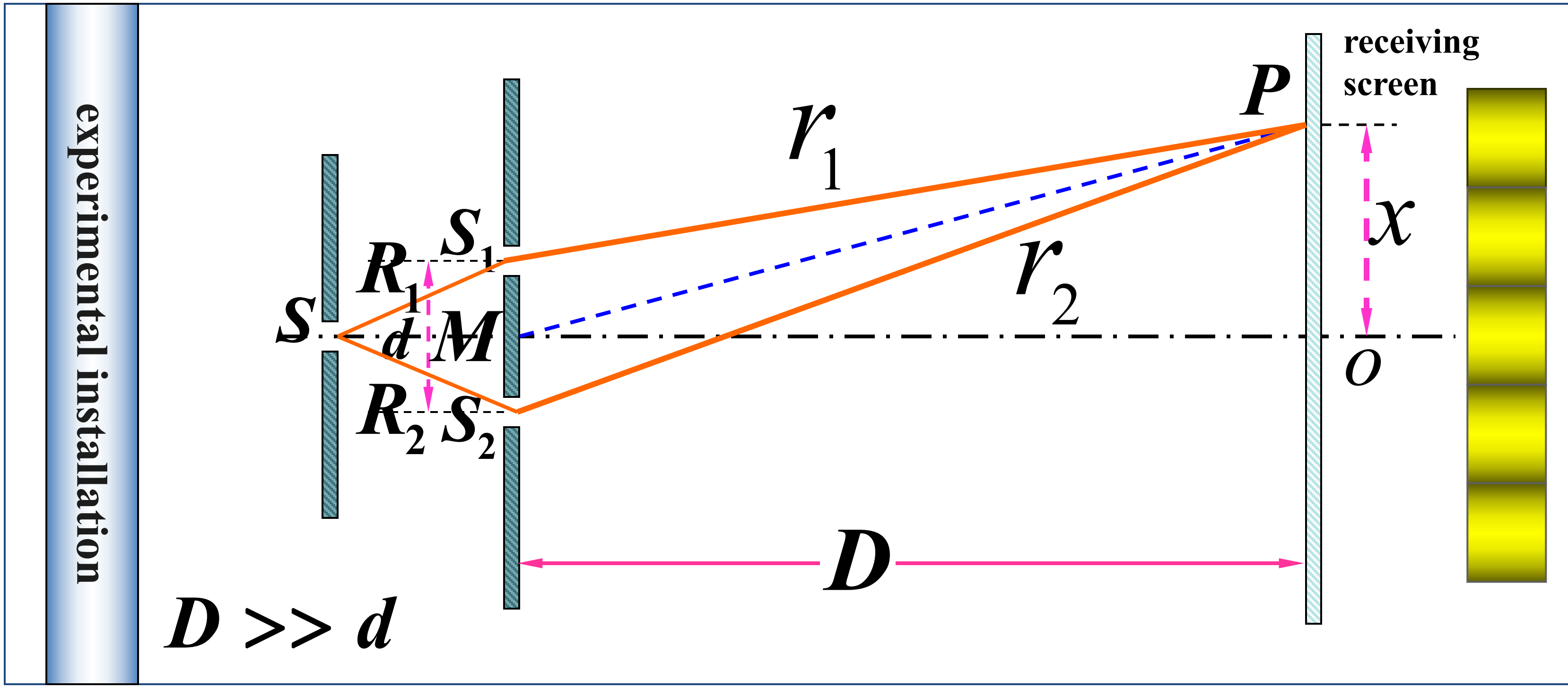
The light path of each light from point to point is equal

The lens can change the direction of the light propagation, but it does not bring an additional optical path difference to the optical path between the two equal-phase planes

§ 13.4

Breakwave front interference ——
Young's interference experiment

13.4.1 Ideal Young's interference experimental device

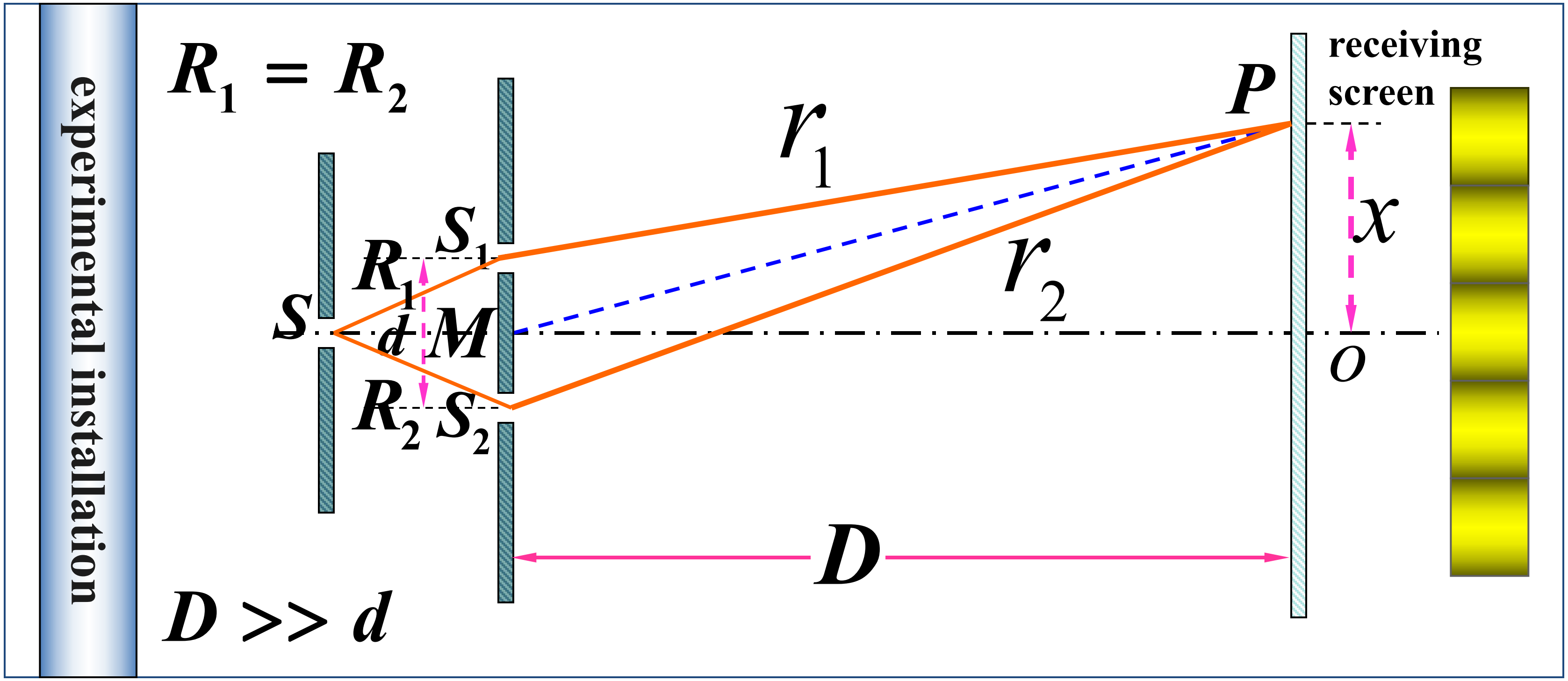


epoch

$$\varphi_{01} = \varphi_0(t) - \frac{2\pi}{\lambda} R_1, \quad \varphi_{02} = \varphi_0(t) - \frac{2\pi}{\lambda} R_2$$

The beginning of the difference $\Delta\varphi_0 = \frac{2\pi}{\lambda}(R_2 - R_1)$

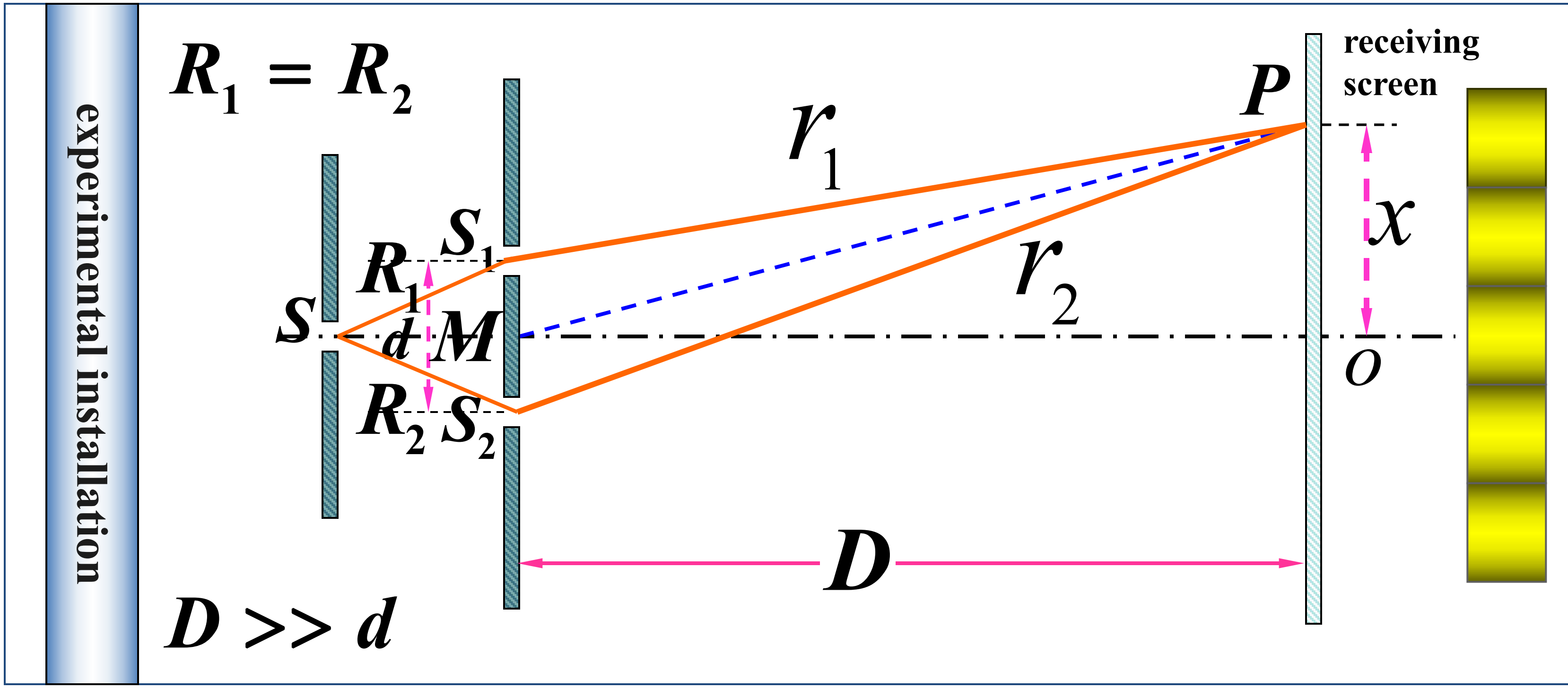
13.4.1 Ideal Young's interference experimental device



phase difference

$$\Delta\varphi = \frac{2\pi}{\lambda}\Delta L, \qquad \Delta L = r_2 - r_1$$

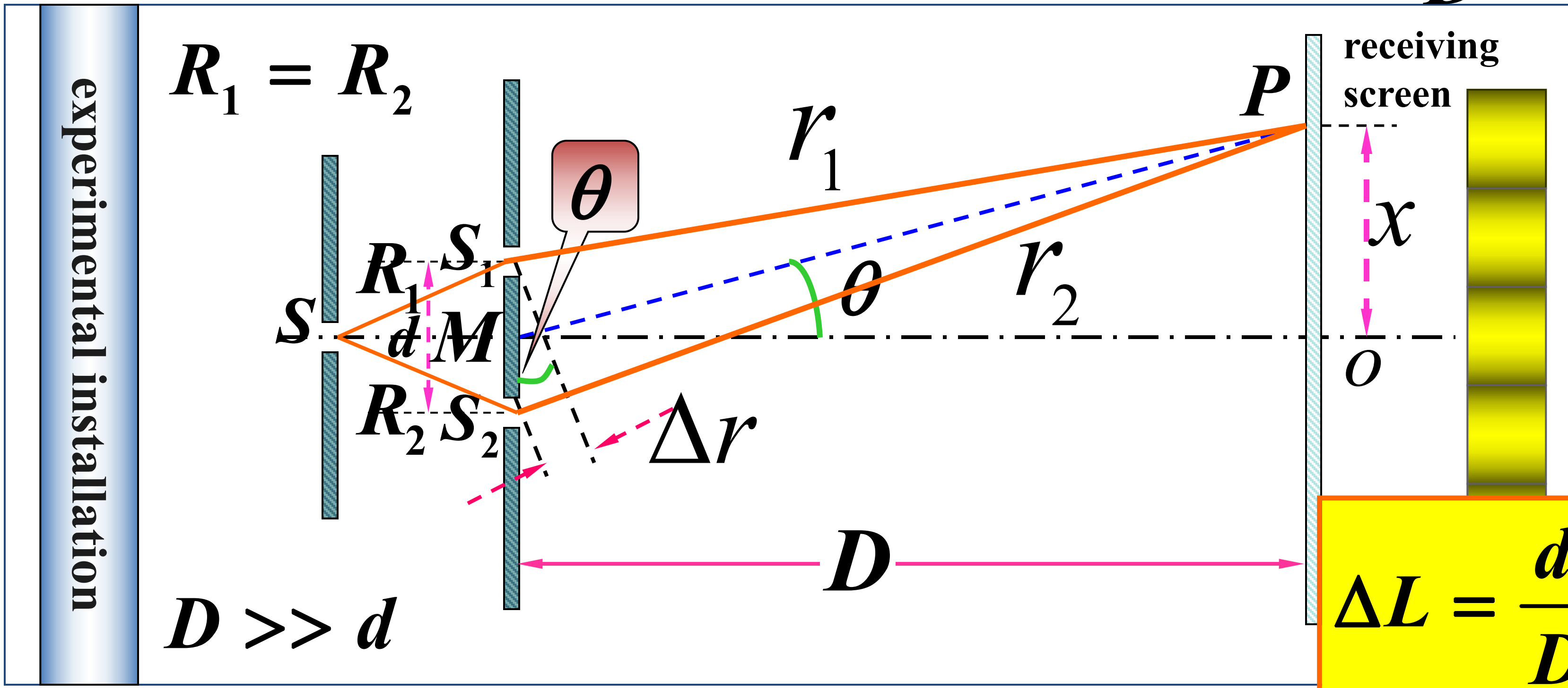
13.4.2 Distribution of interference stripes in Young's experiment



Bright grain conditions: $\Delta\varphi = \pm 2k\pi, \quad \Delta L = \pm k\lambda \quad (k = 0, 1, 2, \cdots)$

Dark lines: $\Delta\varphi = \pm(2k-1)\pi, \quad \Delta L = \pm(2k-1)\dfrac{\lambda}{2} \quad (k = 1, 2, \cdots)$

$$\Delta L = r_2 - r_1 \approx \Delta r = d\sin\theta \qquad \sin\theta \approx \tan\theta = \frac{x}{D}$$



$$\Delta L = \frac{d}{D}x$$

Bright-grain position:

$$x = \pm k\frac{D}{d}\lambda \quad (k = 0, 1, 2, \cdots)$$

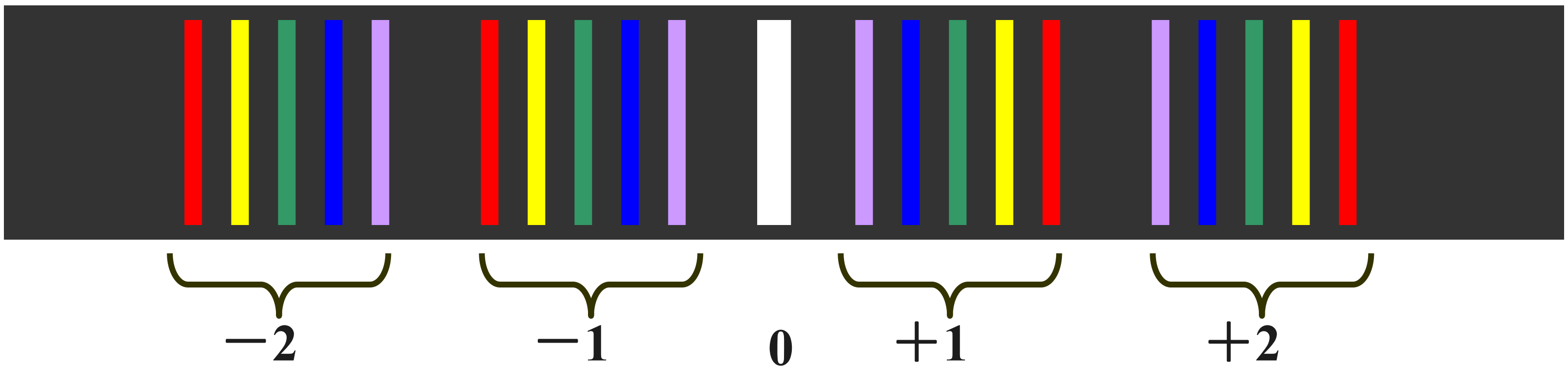
Dark line location:

$$x = \pm(2k-1)\frac{D}{d}\lambda \quad (k = 1, 2, \cdots)$$

Discuss

$$x = \pm k \frac{D}{d}\lambda \quad (k = 0, 1, 2, \cdots)$$

1. Color stripes will appear when the white light is illuminated



When white light is used, except the middle of the central bright grain is white, other stripes, because the wavelength is different, make the position of the same class bright grain is staggered, and the color stripes appear.

2. Stripe spacing $\Delta x = \dfrac{D}{d}\lambda$

◆ Double-slit interference light intensity distribution

$$A=\sqrt{A_1^2+A_2^2+2A_1A_2\cos\Delta\varphi}$$

interference term

He light strong $I=I_1+I_2+\boxed{2\sqrt{I_1I_2}\cos\Delta\varphi}$

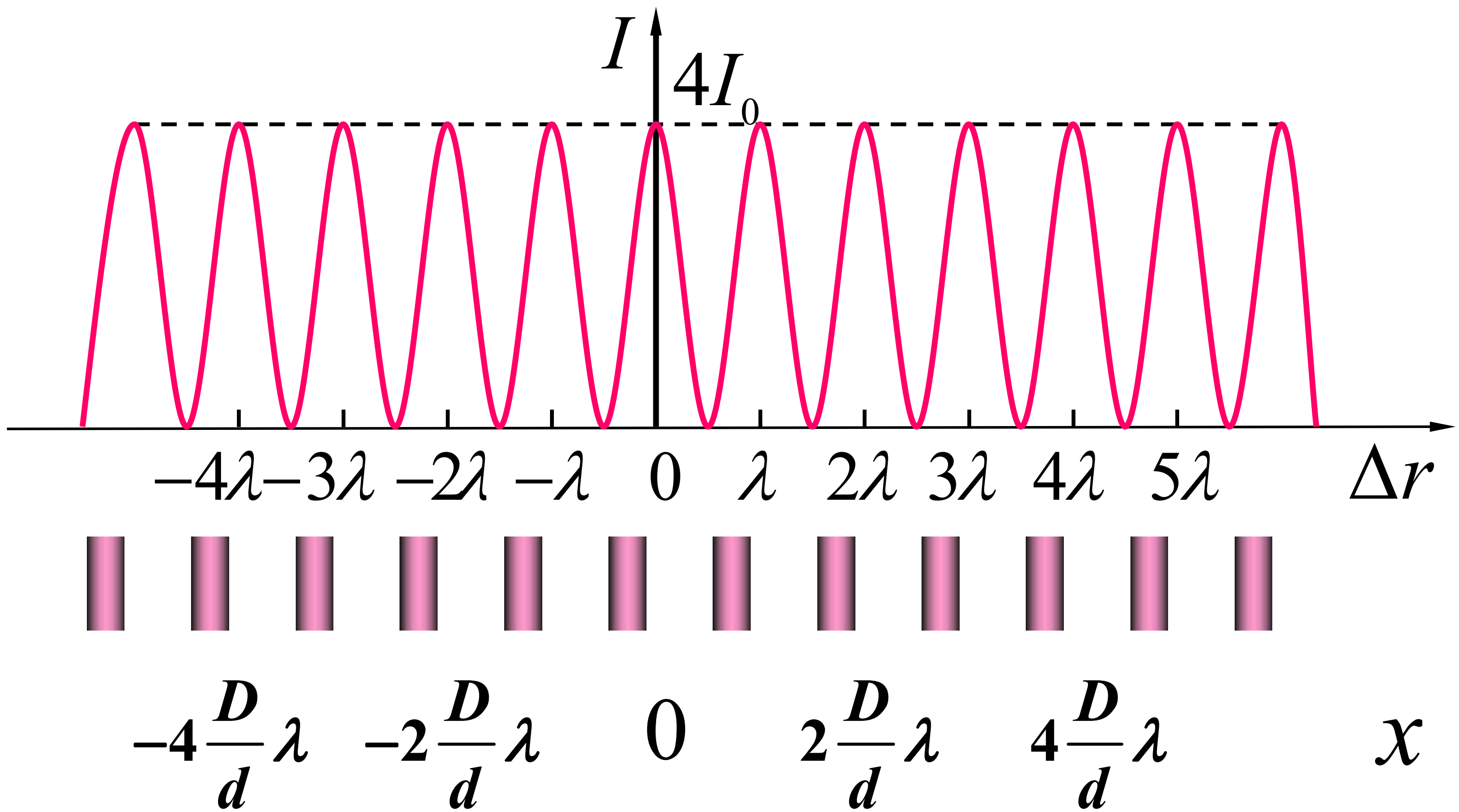
Light intensity in the pattern center $I_{\max}=I_1+I_2+2\sqrt{I_1I_2}=(A_1+A_2)^2$

Light intensity in the center of the dark lines $I_{\min}=I_1+I_2-2\sqrt{I_1I_2}=(A_1-A_2)^2$

like $I_1=I_2=I_0$

Is $I=4I_0\cos^2(\frac{\pi d}{\lambda D}x)=\begin{cases}4I_0 & \text{Light intensity in the pattern center}\\ 0 & \text{Light intensity in the center of the dark lines}\end{cases}$

Light intensity distribution map in Fig



13.4.3 Visibility of the interference stripes

Quantitative description of the clarity of the interference stripes, introducing the visibility of the stripes

$$\boxed{\gamma = \frac{I_{\max} - I_{\min}}{I_{\max} + I_{\min}}} \qquad 0 < \gamma \leq 1$$

$$\gamma = \frac{4\sqrt{I_1 I_2}}{2(I_1 + I_2)} = \frac{2\sqrt{I_2/I_1}}{1 + I_2/I_1} = \frac{2\dfrac{A_2}{A_1}}{1 + \left(\dfrac{A_2}{A_1}\right)^2}$$

1. If, then, the largest visibility, clear stripes;

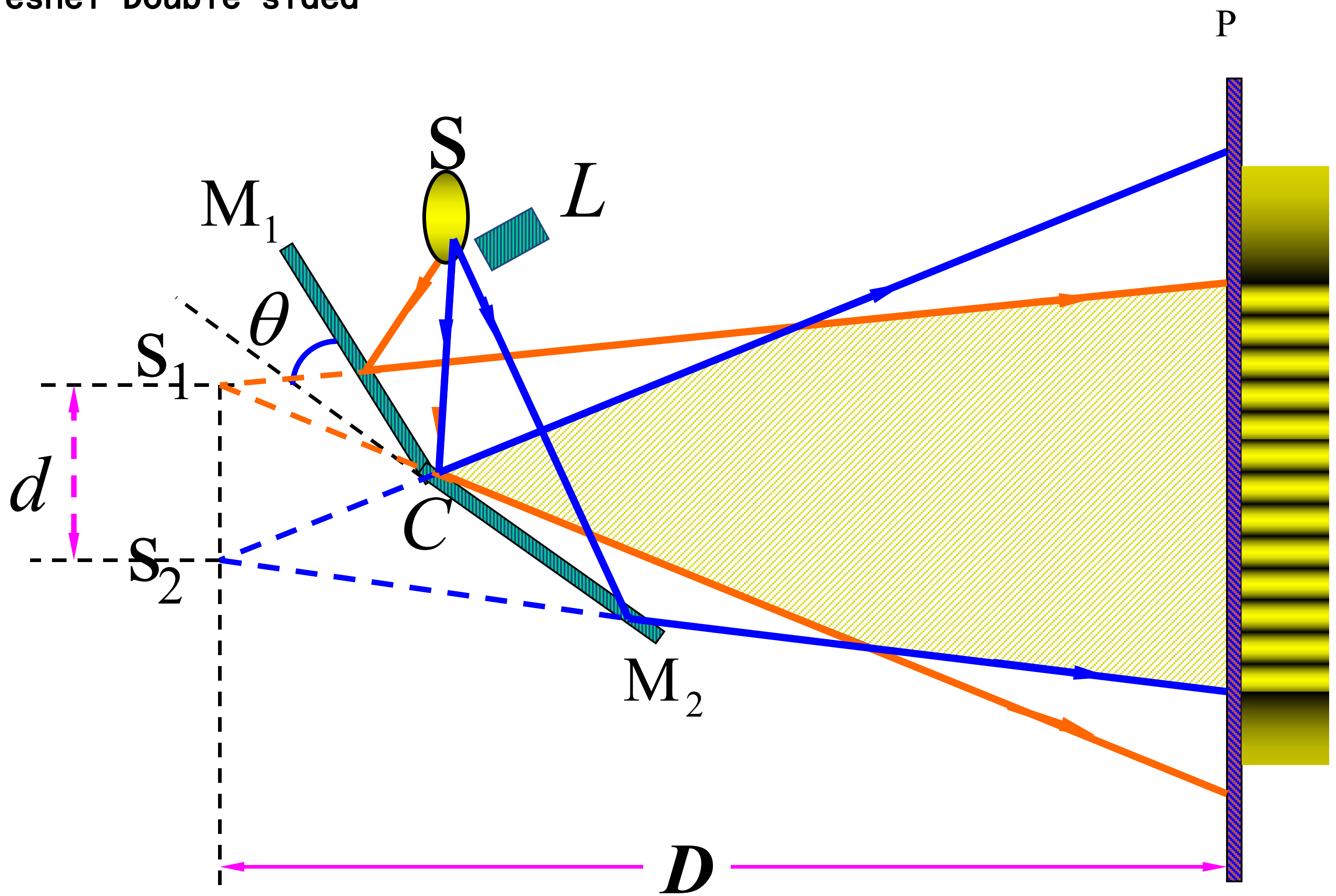
$$A_1 = A_2 \qquad \gamma = 1$$

1. If, the stripes cannot be distinguished.

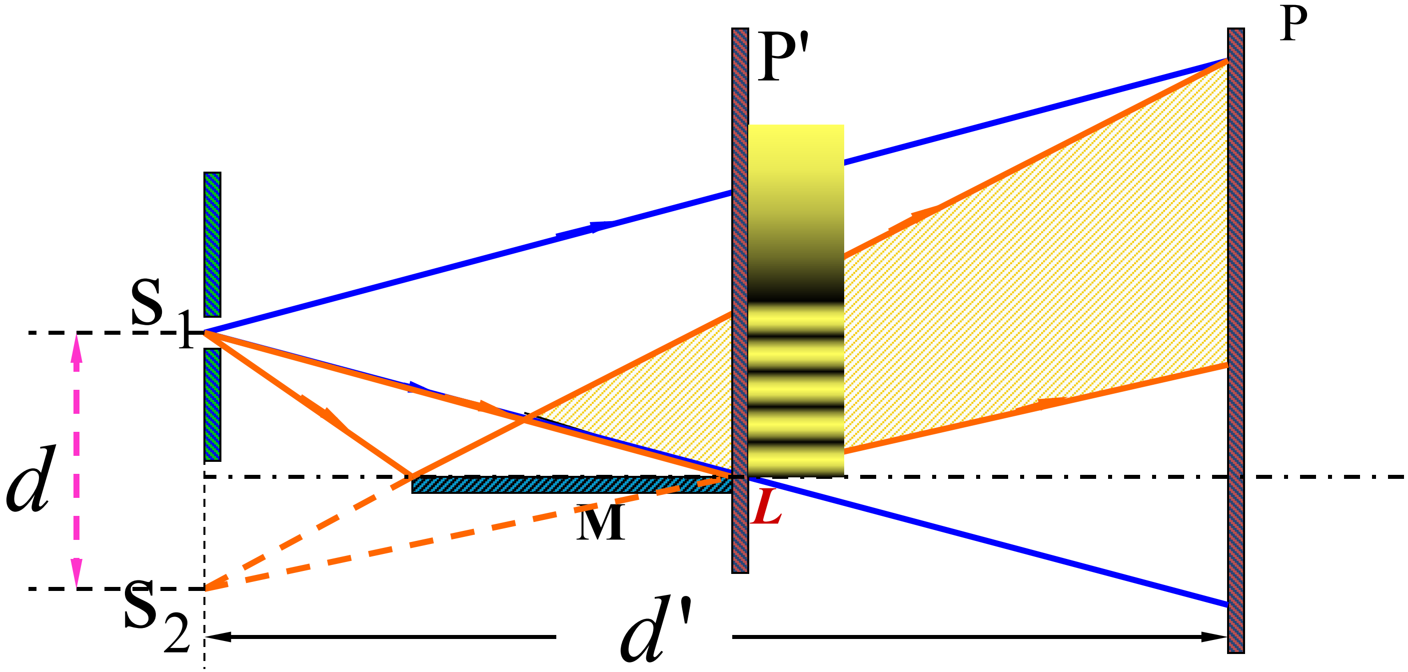
$$A_1 >> A_2 \qquad \gamma \to 0$$

13.4.6 Several other two-beam split wavefronts Interference device

1. The Fresnel Double-sided Mirror



2. Lloyd mirror



Half-wave loss: the phase of the reflected light from the medium with the large speed of light to the small speed of light changes compared with the phase of the incident light, which is equivalent to the wavelength difference of half wavelength between the reflected light and the incident light, which is called half-wave loss.

π

Example 1: monochromatic light was applied to the double seam of 0.2mm apart, and the vertical distance between the double seam and the screen was 1m.

(1) The distance from the first level of brightness to the fourth level of the same side is 7.5mm, seeking the wavelength of monochromatic light;

(2) If the wavelength of the incident light is 600nm, find the distance between two adjacent bright lines.

Solution (1) $$x_k = \pm \frac{D}{d} k\lambda, \quad k = 0, \quad 1, \quad 2, \cdots$$

$$\Delta x_{14} = x_4 - x_1 = \frac{D}{d} \cdot 3\lambda \qquad \lambda = \frac{d}{D} \frac{\Delta x_{14}}{3} = 500\text{nm}$$

(2) $$\Delta x = \frac{D}{d} \lambda = 3.0\,\text{mm}$$

§ 13.5

Divted amplitude interference —— film interference

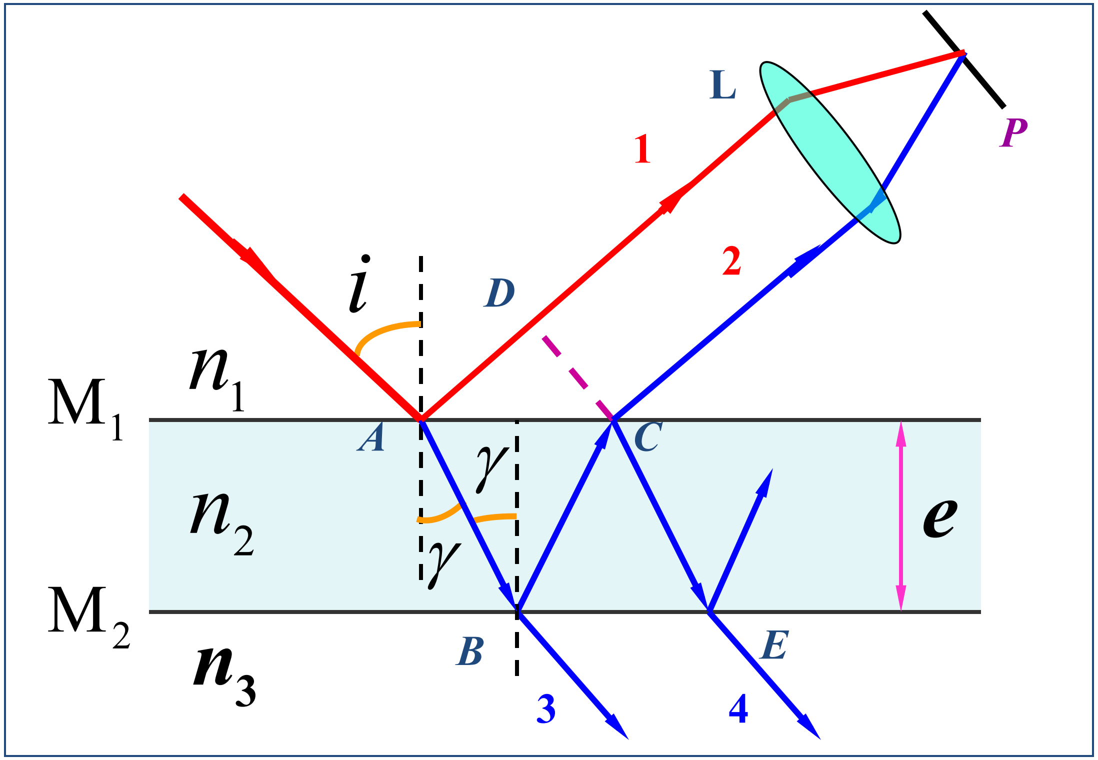
13.5.1 Such interference

$$\frac{\sin i}{\sin \gamma} = \frac{n_2}{n_1}$$

$$\overline{AB} = \overline{BC} = e/\cos\gamma$$

$$\overline{AD} = \overline{AC}\sin i$$

$$= 2e \cdot \tan\gamma \cdot \sin i$$

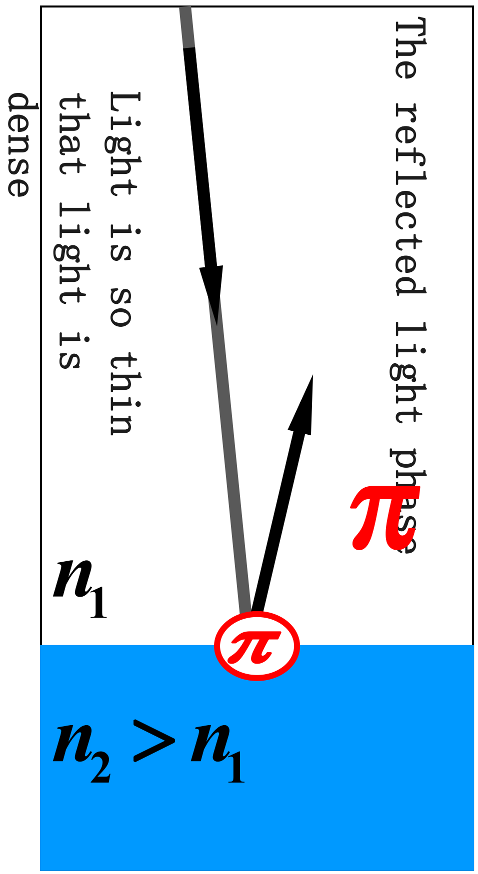


Dissemination of light range difference

$$\Delta L_0 = n_2(\overline{AB} + \overline{BC}) - n_1\overline{AD}$$

$$= 2e\sqrt{n_2^2 - n_1^2 \sin^2 i}$$

Reflectance interface conditions and the additional optical path difference



Especially for the positive incidence and grazing incidence situations

1. When $n_1 < n_2 < n_3$ or $n_1 > n_2 > n_3$, the reflection at the upper and lower surfaces of the film is the same, and there is no additional optical path difference between the reflection lines of 1 and 2, so

$$\Delta L = \Delta L_0 = 2e\sqrt{n_2^2 - n_1^2 \sin^2 i}$$

2. When $n_1 < n_2 > n_3$ or $n_1 > n_2 < n_3$ the reflection at the upper and lower surface of the film is different, there is an additional optical path difference between the reflection lines of 1 and 2, so

$$\Delta L = \Delta L_0 + \Delta L' = 2e\sqrt{n_2^2 - n_1^2 \sin^2 i} + \boxed{\frac{\lambda}{2}}$$

Total optical path difference of the parallel-plane films

$$\Delta L = \Delta L_0 + \Delta L'$$

$$= 2e\sqrt{n_2^2 - n_1^2 \sin^2 i} + \begin{cases} 0 & \text{The reflection conditions were identical} \\ \dfrac{\lambda}{2} & \text{The reflex conditions are different} \end{cases}$$

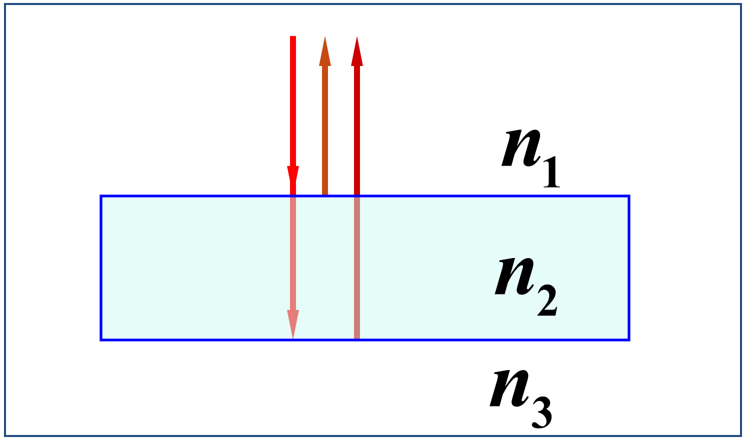
For the parallel plane film, the optical path difference depends on the incident angle i; the reflected light corresponding to the same incident angle i forms the interference stripe —— of the same level

$$\Delta L = \begin{cases} k\lambda \quad (k = 1, 2, \cdots) & \text{Ming grain} \\ (2k+1)\dfrac{\lambda}{2} \quad (k = 0, 1, 2, \cdots) & \text{Dark lines} \end{cases}$$

◆ When the light is incident vertically $i = 0^\circ$

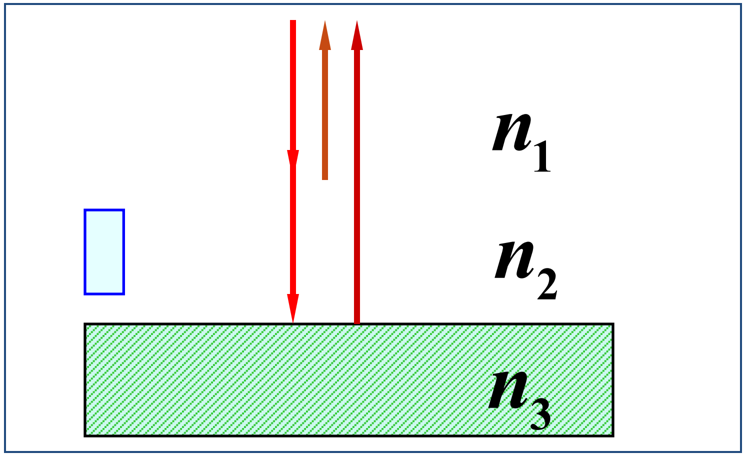
then $n_1 < n_2 > n_3$

$$\Delta L = 2n_2 e + \frac{\lambda}{2}$$



then $n_1 < n_2 < n_3$

$$\Delta L = 2n_2 e$$



like $\Delta L = 2n_2 e = (2k+1)\dfrac{\lambda}{2}$

Reflected light coherently disappears and weakens

$$e_{\min} = \frac{\lambda}{4n_2}$$

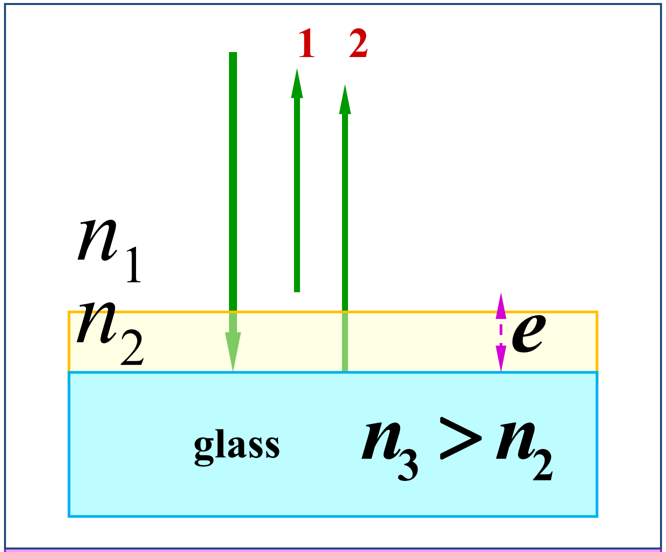
—— reflection reducing coating

◆ Increasing the membrane and increasing the membrane

The transmittance of optical devices can be improved by thin film interference.

To increase the transmittance, the minimum thickness of the magnesium fluoride film is obtained.

Known air $n_1 = 1.00$ **, magnesium fluoride,** $n_2 = 1.38$ $\lambda = 550\text{nm}$



Magnesium fluoride is an increasing penetration membrane

separate $\Delta L = 2n_2 e = (2k+1)\dfrac{\lambda}{2}$

take $k = 0$ $e_{\min} = \dfrac{\lambda}{4n_2} = 99.6\ \text{nm}$

like $e = (2k+1)\dfrac{\lambda}{4n_2}$ **only** $n_3 < n_2$

The reflected light is coherently long and enhanced

—— augmented reverse membrane

An oil leaking from a tanker (refractive index n_1=1.20) has contaminated a sea area, in the sea water (n_2=1.30) A thin layer of oil forms on the surface.

(1) If the sun is above the sea and the pilot of a helicopter looks from the plane and the oil layer thickness is 460 nm, what color will the oil layer observe?

(2) If a diver dives into the area and looks directly above, what color will the oil layer be seen?

known number n_1=1.20 n_2=1.30 d =460 nm

Solution (1) $\Delta_{\mathrm{r}} = 2dn_1 = k\lambda$

$$\lambda = \frac{2n_1 d}{k}, \quad k = 1,2,\cdots$$

$$k = 1, \qquad \lambda = 2n_1 d = 1104\ \mathbf{nm}$$

$$k = 2, \qquad \lambda = n_1 d = 552\ \mathbf{nm}$$

green

$$k = 3, \qquad \lambda = \frac{2}{3} n_1 d = 368\ \mathbf{nm}$$

(2) The optical path difference of the transmitted light

$$\Delta_{t} = 2dn_{1} + \lambda / 2$$

$$k = 1, \qquad \lambda = \frac{2n_1 d}{1 - 1/2} = 2208\ \mathbf{nm}$$

amaranth

$$k = 2, \qquad \lambda = \frac{2n_1 d}{2 - 1/2} = 736\,\mathrm{nm}$$

glow

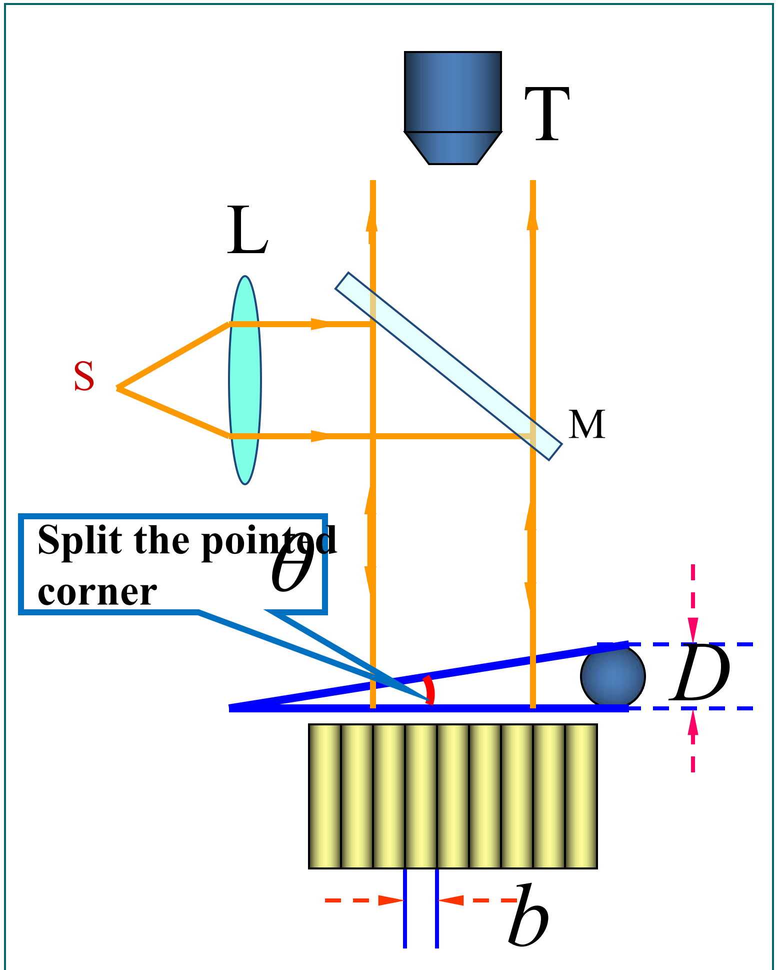
$$k = 3, \qquad \lambda = \frac{2n_1 d}{3 - 1/2} = 441.6\mathrm{nm}$$

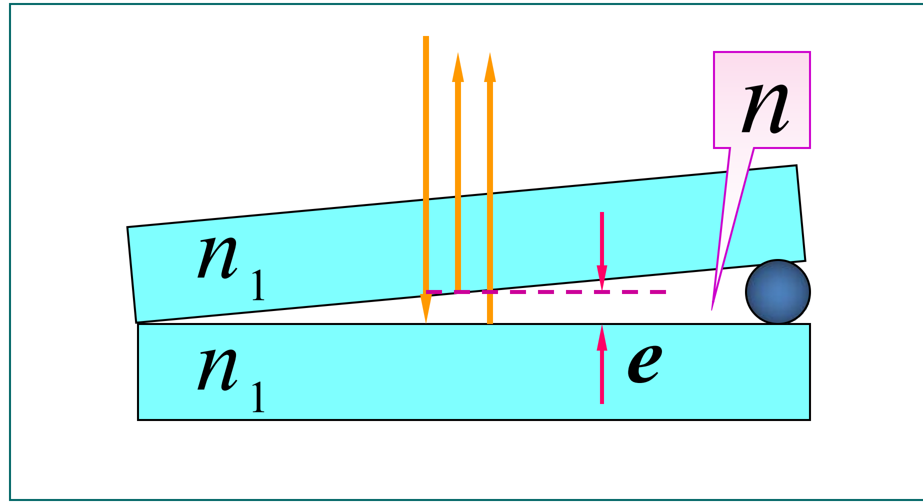
purple light

$$k = 4, \qquad \lambda = \frac{2n_1 d}{4 - 1/2} = 315.4\ \mathbf{nm}$$

13.5.2 equal thickness interference

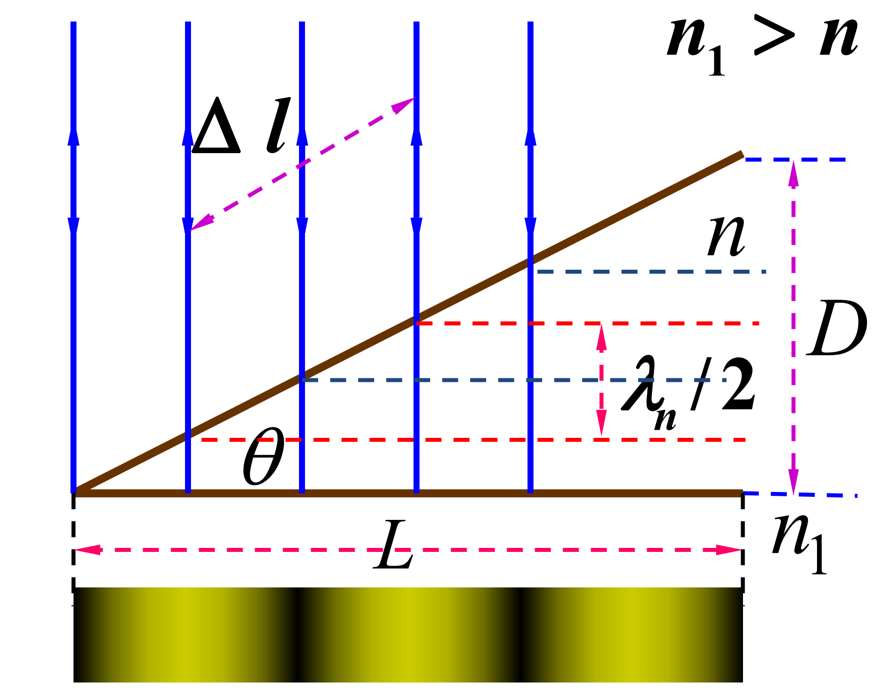
1. Split the tip





$$\Delta L = 2ne + \boxed{\frac{\lambda}{2}} \Leftarrow \boxed{n < n_1}$$

$$\Delta L = \begin{cases} k\lambda, & k = 1, 2, \cdots \quad \text{Ming grain} \\ (2k+1)\dfrac{\lambda}{2}, & k = 0, 1, \cdots \quad \text{Dark lines} \end{cases}$$



Split the point of interference

discuss

1. Split edges $e = 0$

$$\Delta L = \frac{\lambda}{2}$$ For the dark lines

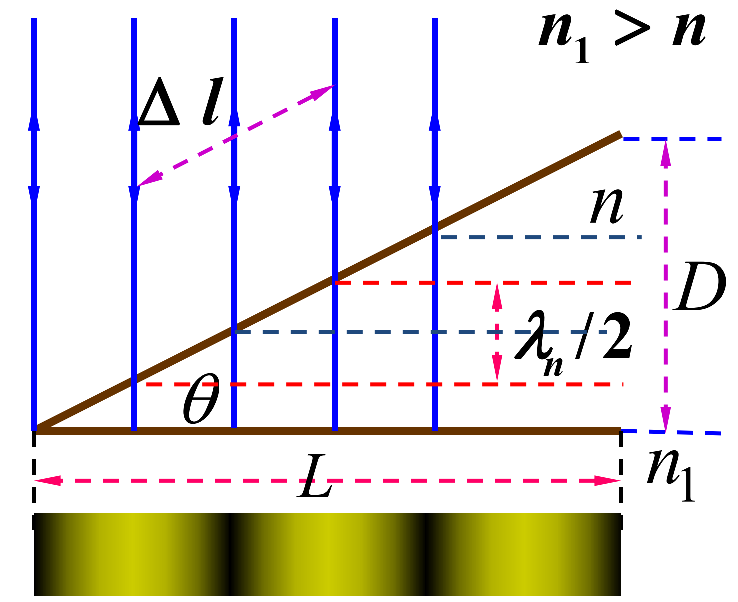
$$e = \begin{cases} (k - \frac{1}{2}) \frac{\lambda}{2n} & \text{Ming grain} \\ k \frac{\lambda}{2n} & \text{Dark lines} \end{cases}$$

2. Thickness difference between adjacent bright lines (dark lines)

$$\Delta e = e_{k+1} - e_k = \frac{\lambda}{2n} = \frac{\lambda_n}{2}$$

3. Stripe spacing (bright or dark lines)

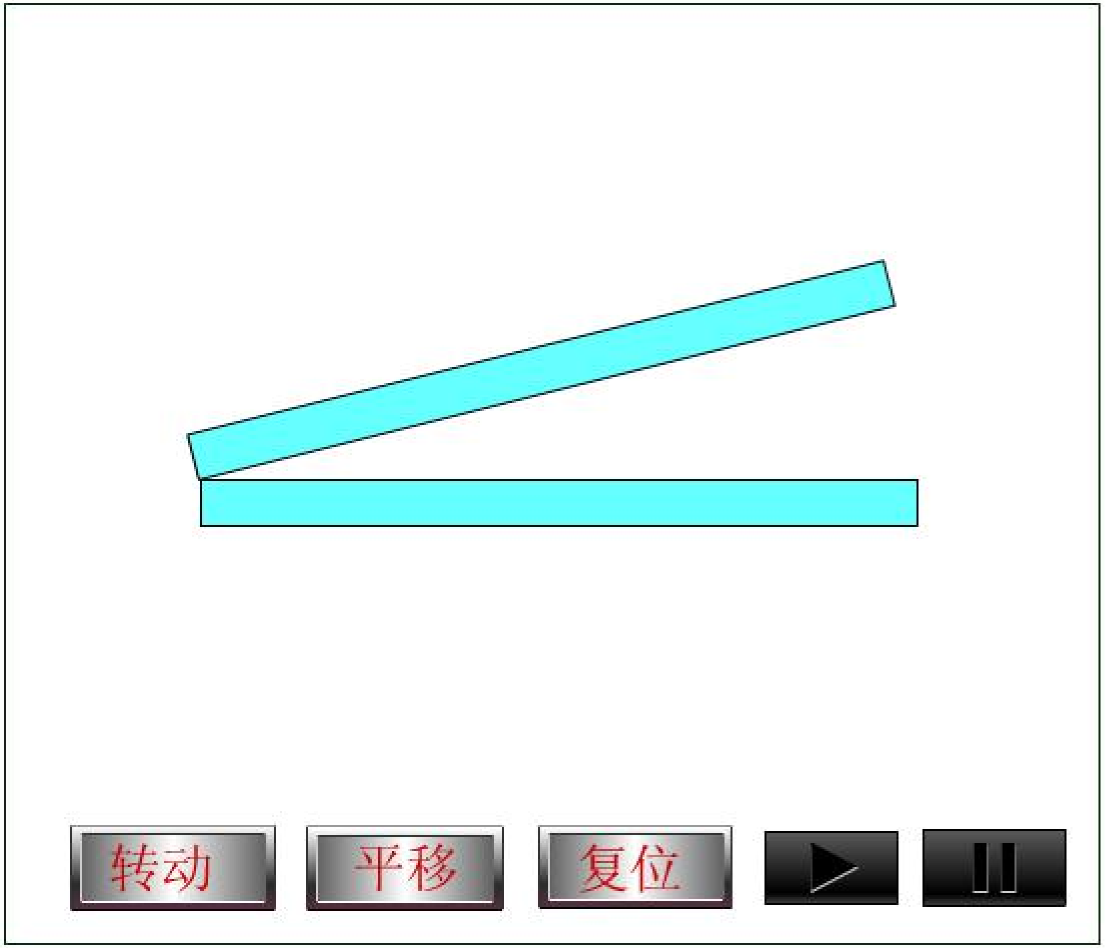
$$\Delta l = \frac{\Delta e}{\sin\theta} \approx \frac{\Delta e}{\theta} = \frac{\lambda}{2n\theta}$$



Split the point of interference

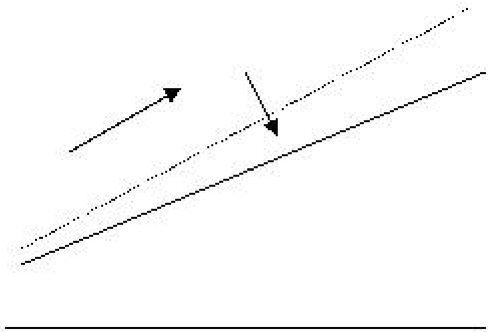
4 . The movement of the interference stripe

Each stripe corresponds to a thickness within the split tip, when this is thick
When the degree position changes, the corresponding stripe moves accordingly.

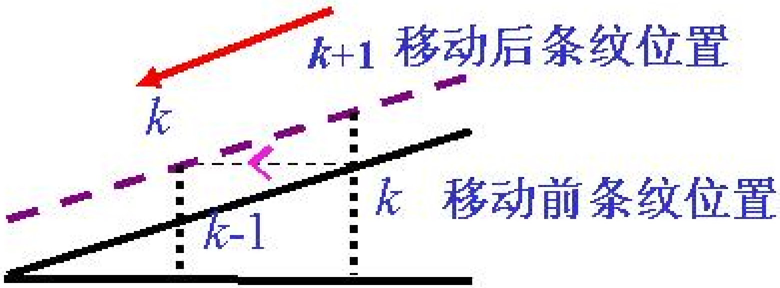


（a） λ、n不变， $\theta\downarrow$，$l\uparrow$

条纹向远离棱边的方向移动。



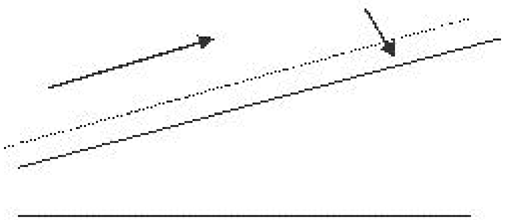
（b ） $d\uparrow$， $k\uparrow$



条纹向棱边方向平移。

$d\downarrow$， $k\downarrow$

条纹向远离棱边方向平移。

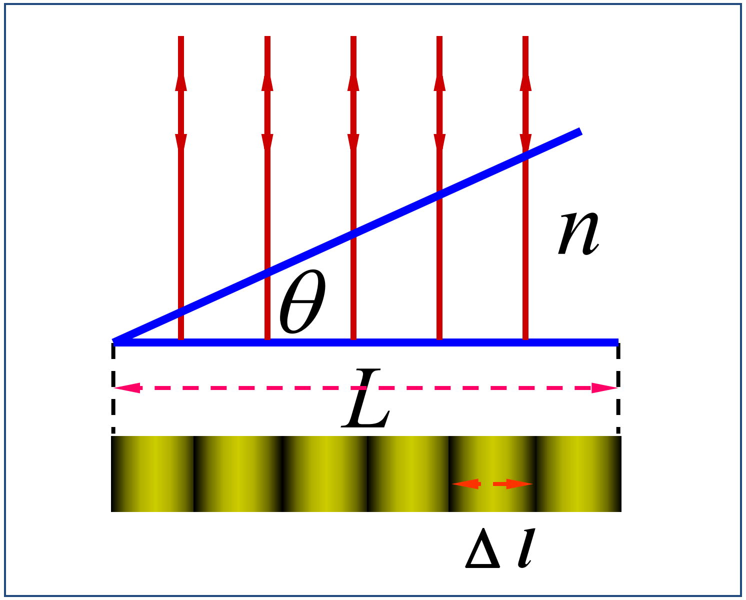


（c）$n\uparrow$，$l\downarrow$

Example 1 has a glass split tip, placed in air

$$\theta = 8\times10^{-5}\,\text{rad} \qquad \lambda = 589\,\text{nm}$$

With the vertical incidence of wavelength monochromatic light, the width of the interference stripe, and the refractive index of the glass. $b = 2.4\,\text{mm}$



separate

$$\Delta l = \frac{\lambda}{2n\theta}$$

$$n = \frac{\lambda}{2\theta\Delta l}$$

$$n = \frac{5.89\times10^{-7}\,\text{m}}{2\times8\times10^{-5}\times2.4\times10^{-3}\,\text{m}} = 1.53$$

Example 1 A parallel light with a wavelength of 680 nm hits two glass sheets of L=12 cm long, with one side of the two glass pieces contacting each other and the other side separated by paper sheets of thickness D =0.048 mm. How many dark stripes will appear in this 12 cm length?

sepa rate

$$2d + \frac{\lambda}{2} = (2k+1)\frac{\lambda}{2}$$

$$k = 0,1,2,\cdots$$

$$2d+\frac{\lambda}{2}=(2k+1)\frac{\lambda}{2} \qquad k=0,1,2,\cdots$$

$$2D+\frac{\lambda}{2}=(2k_m+1)\frac{\lambda}{2}$$

$$k_m=\frac{2D}{\lambda}=141.1$$

There are 142 dark lines

例2

如图所示，两个直径有微小差别的彼此平行的滚柱之间的距离为L，夹在两块平晶的中间，形成空气劈尖，当单色光垂直照射时，产生等厚干涉条纹，如果滚柱之间的距离L变小，则在L范围内干涉条纹的

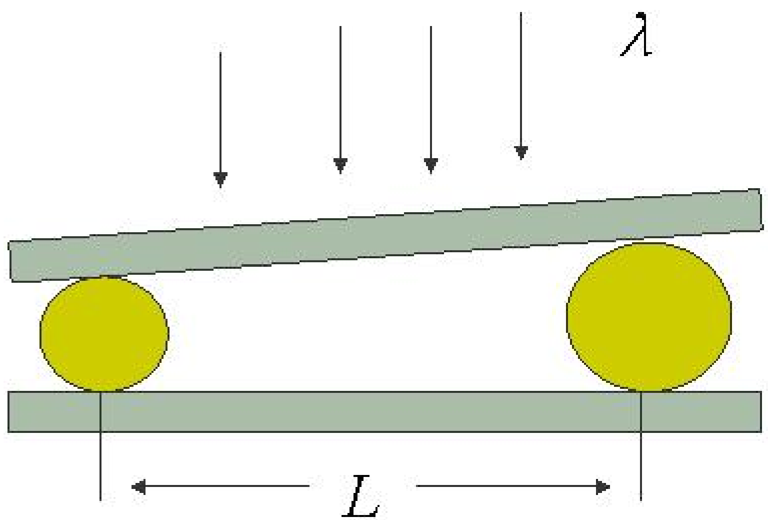
（A）数目减少，间距变大。（B) 数目不变，间距变小。

（C）数目增加，间距变小。（D) 数目减少，间距不变。

$$l=\frac{\lambda}{2n\theta}$$

$L\downarrow,\ \theta\uparrow \Longrightarrow l\downarrow$

$$\Delta=2d+\frac{\lambda}{2}$$



两个滚柱处：若用d_1和d_2分别表示其直径，则

$$2nd_1+\lambda/2=k_1\lambda$$
$$2nd_2+\lambda/2=k_2\lambda$$

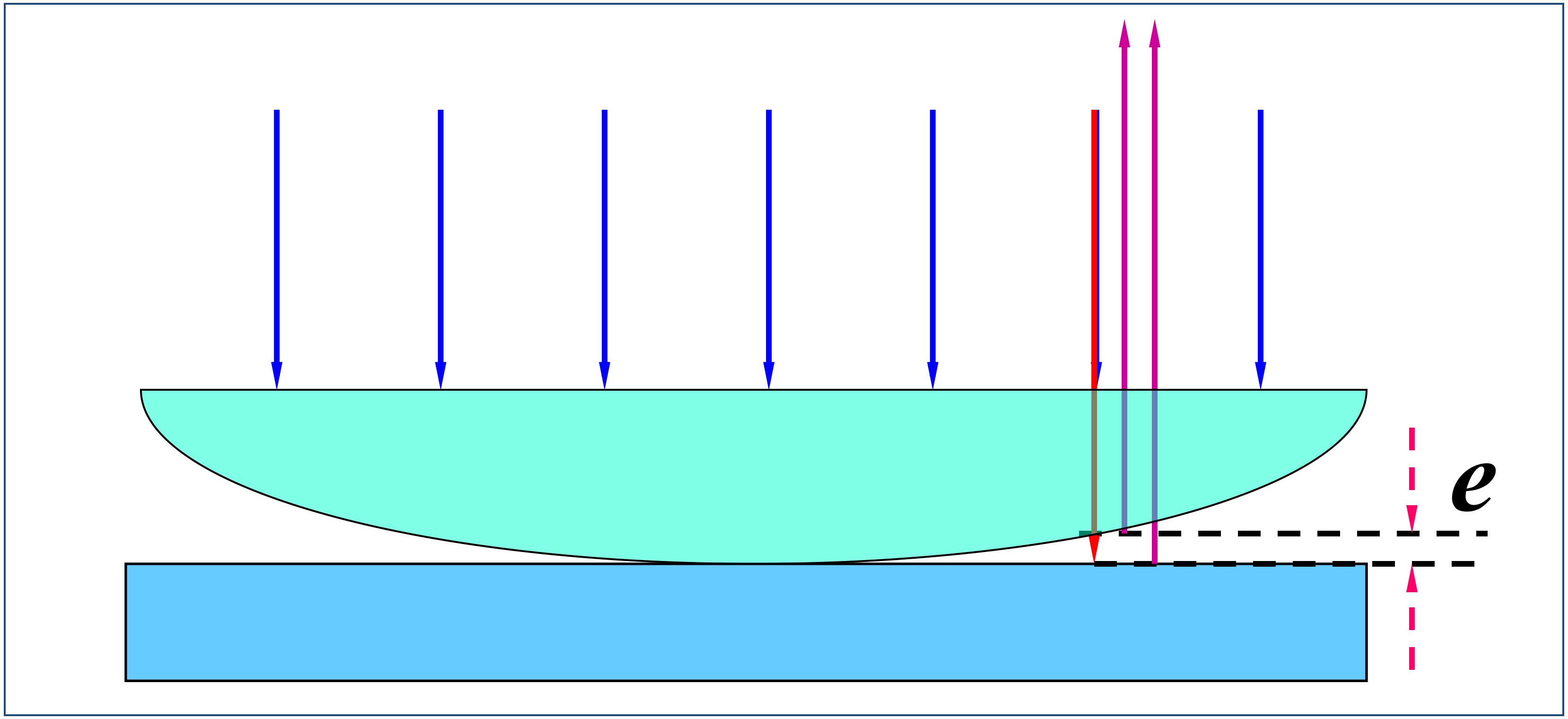
条纹数目$N=K_2-K_1$

L变小时，d_2-d_1不变

因此，条纹数目也不变。

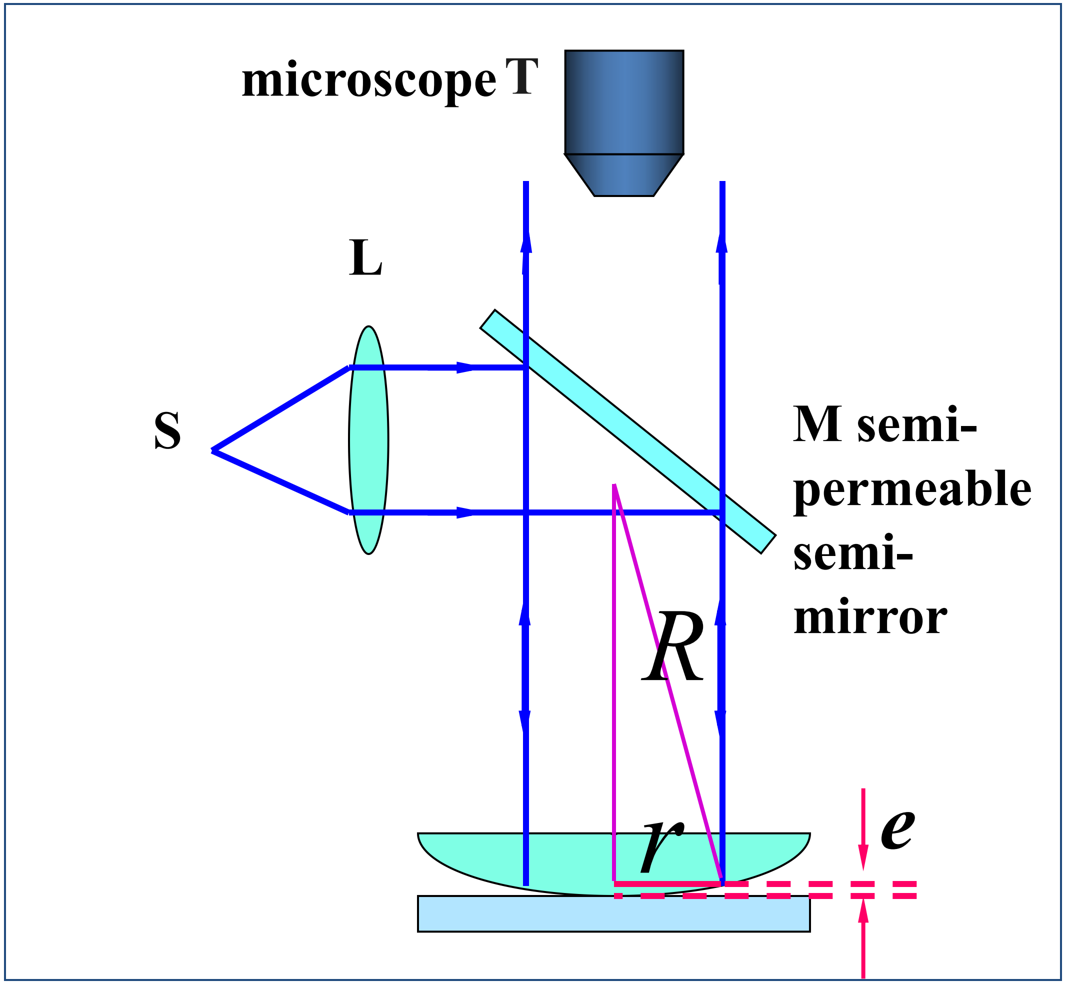
2. Newton ring

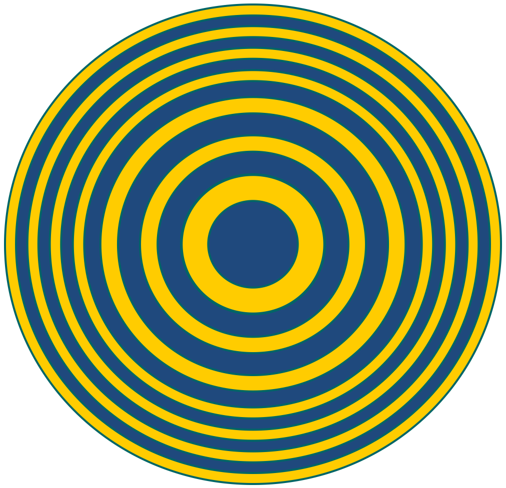
It consists of a flat glass and a flat convex lens



optical path difference $\Delta L = 2e + \frac{\lambda}{2}$

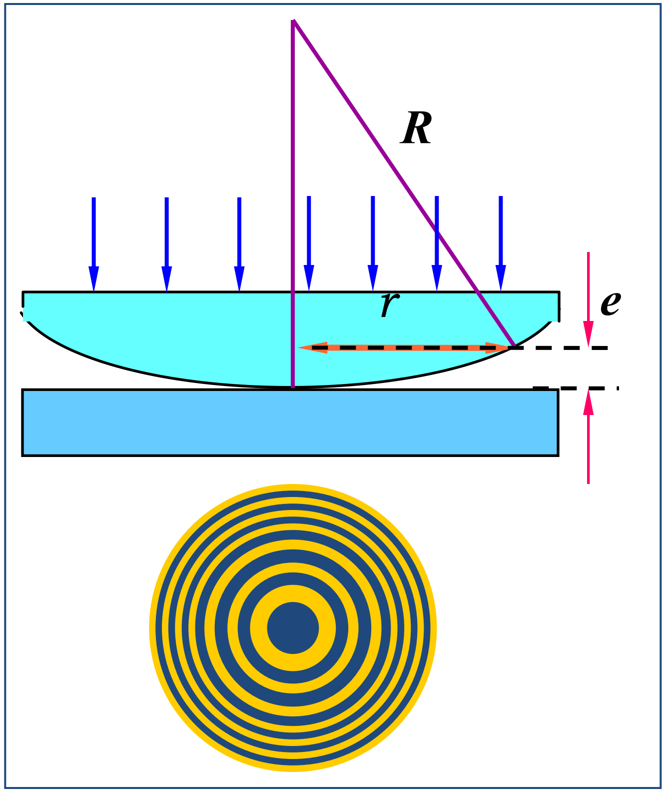
◆ Newton's ring experimental setup





The Newton-ring interference pattern

optical path difference $\Delta L = 2e + \dfrac{\lambda}{2}$

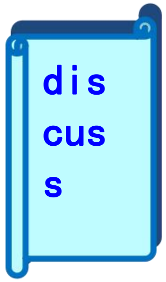


$$\Delta L = \begin{cases} k\lambda \quad (k = 1, 2, \cdots) & \text{Ming grain} \\ (k + \dfrac{1}{2})\lambda \quad (k = 0, 1, \cdots) & \text{Dark lines} \end{cases}$$

$$r^2 = R^2 - (R - e)^2 = 2eR - e^2$$

$$\because R >> e \quad \therefore e^2 \approx 0$$

$$r = \sqrt{2eR} = \sqrt{(\Delta L - \frac{\lambda}{2})R} \Rightarrow \begin{cases} r = \sqrt{(k - \dfrac{1}{2})R\lambda} & \text{Bright ring radius} \\ r = \sqrt{kR\lambda} & \text{Dark ring radius} \end{cases}$$



Bright ring radius $r = \sqrt{(k - \frac{1}{2})R\lambda} \quad (k = 1, 2, 3, \cdots)$

Dark ring radius $r = \sqrt{kR\lambda} \quad (k = 0, 1, 2, \cdots)$

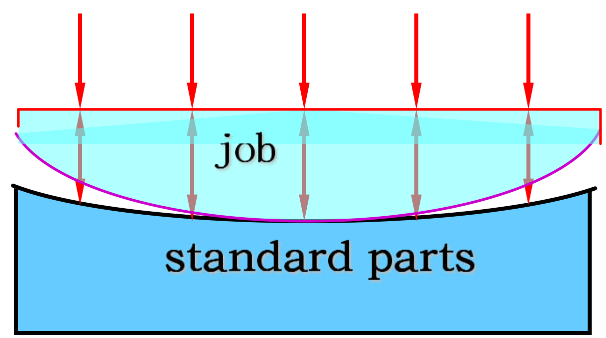
1. From the reflected light, is the central point a dark spot or a bright spot? Is the central point a dark spot or a bright spot?

2. It belongs to equal thickness interference, unequal stripe spacing, why?

3. How do the stripes change the Newton ring in the liquid?

$$n > 1$$

4. Application example: can be used to measure the wavelength of light, detect the quality of lens, radius of curvature, etc.

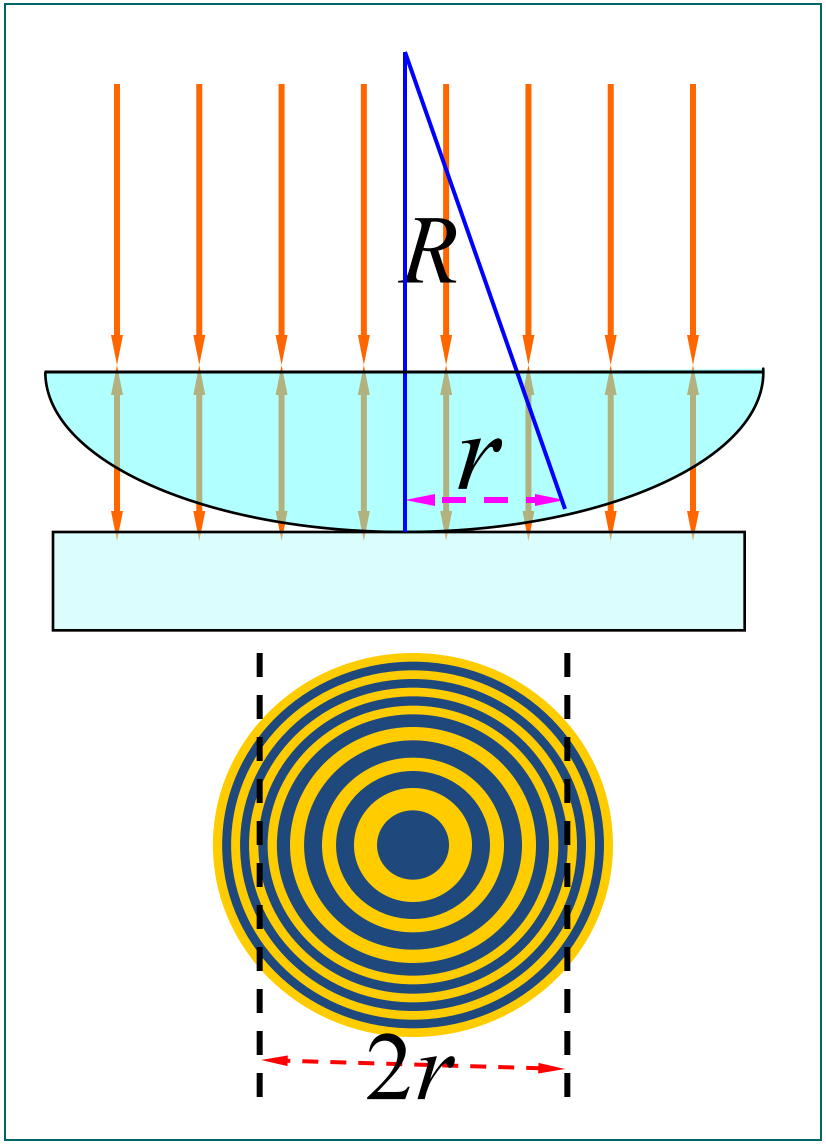


◆ Measure the radius of curvature of the lens

$$r_k^2 = kR\lambda$$

$$r_{k+m}^2 = (k+m)R\lambda$$

$$R = \frac{r_{k+m}^2 - r_k^2}{m\lambda}$$



Example 2 Using the monochromatic light with a wavelength of 633nm, the radius of the first k dark ring is 5.63mm, the radius of the k + 5 dark ring is 7.96mm, and the radius of curvature of the convex lens is R.

separate

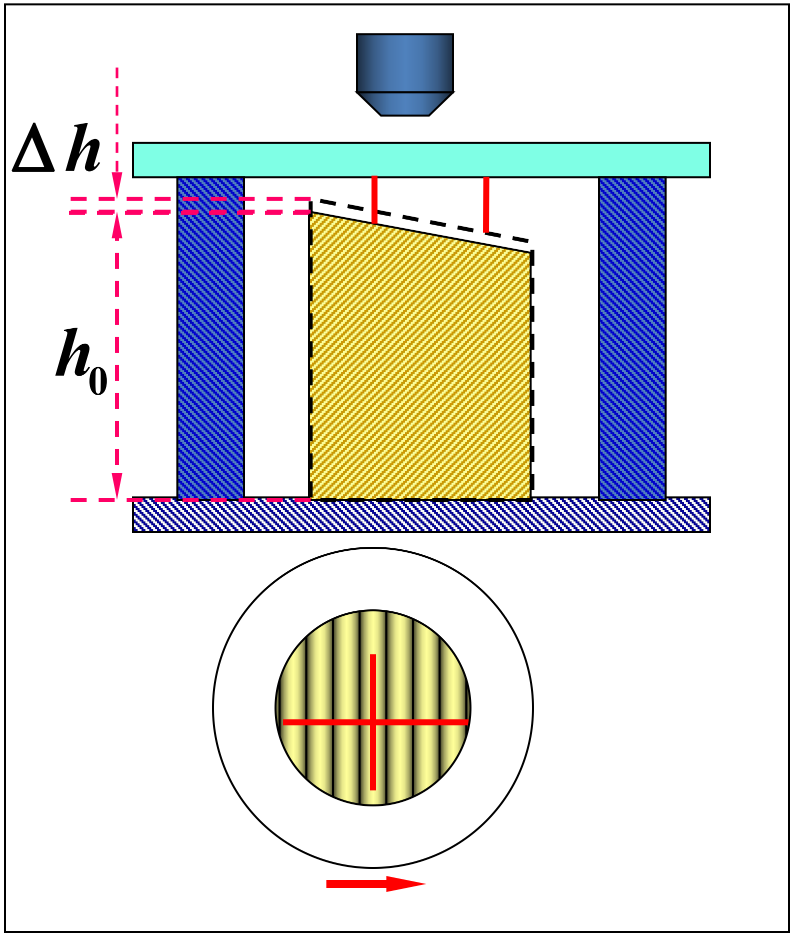
$$r_k = \sqrt{kR\lambda} \qquad r_{k+5} = \sqrt{(k+5)R\lambda}$$

$$5R\lambda = \left(r_{k+5}^2 - r_k^2\right)$$

$$R = \frac{r_{k+5}^2 - r_k^2}{5\lambda} = \frac{(7.96\mathrm{mm})^2 - (5.63\mathrm{mm})^2}{5\times 633\mathrm{nm}} = 10.0\mathrm{m}$$

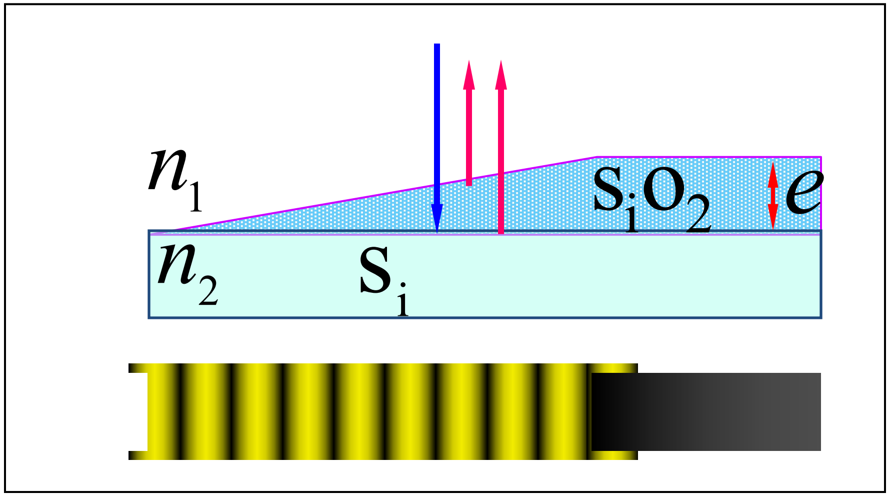
13.5.3 Film interference applications as examples

1. Interference expansion ator



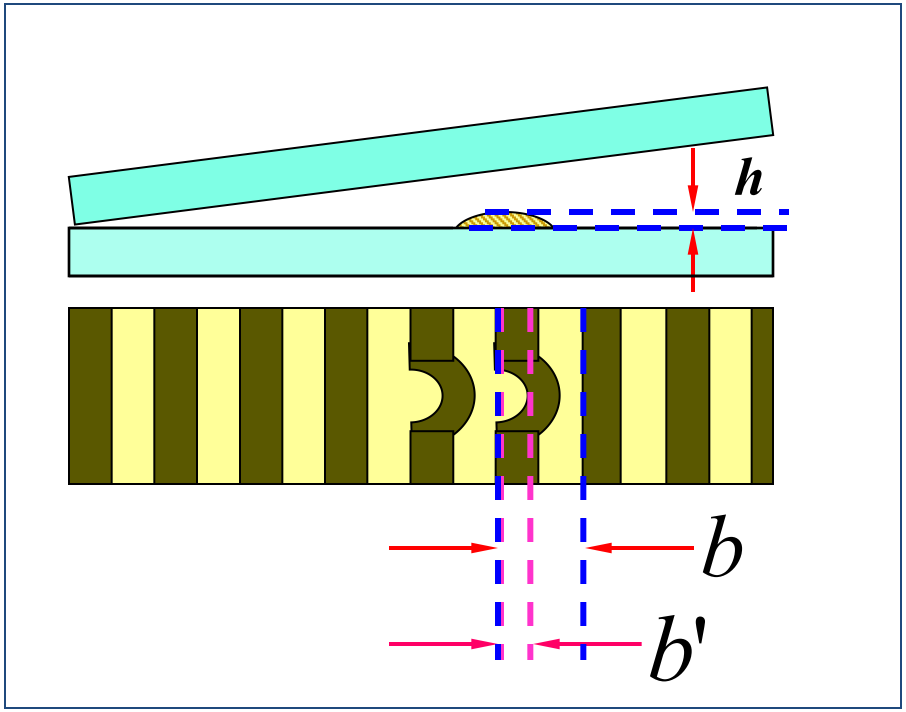
$$\Delta h = N\frac{\lambda}{2}$$

2. Film thickness measurement



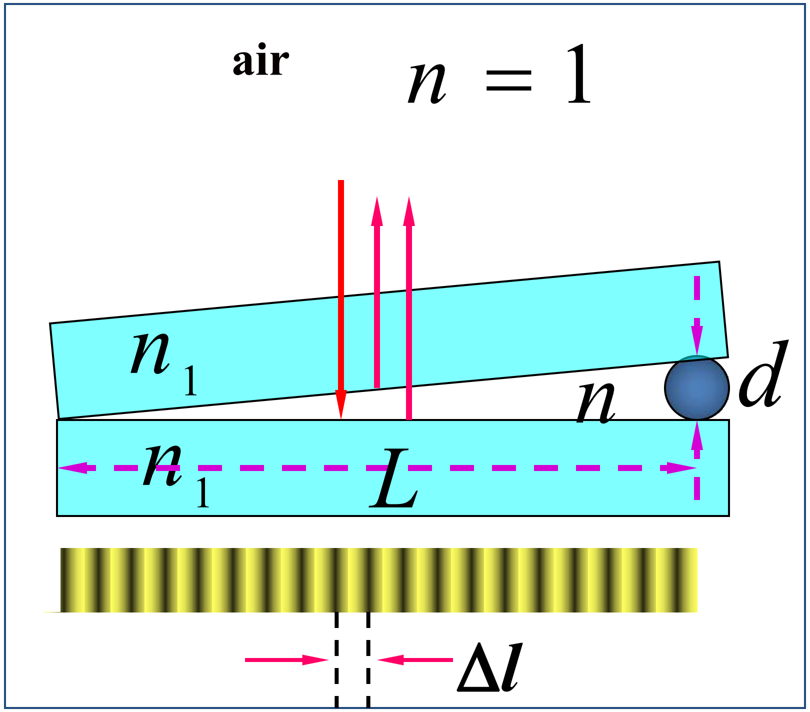
$$h = N\frac{\lambda}{2n_1}$$

3. Check the flatness of the optical component surface



$$h = \frac{b'}{b}\frac{\lambda}{2} \approx \frac{1}{3} \cdot \frac{\lambda}{2} = \frac{\lambda}{6}$$

4. Measure the diameter of the filament

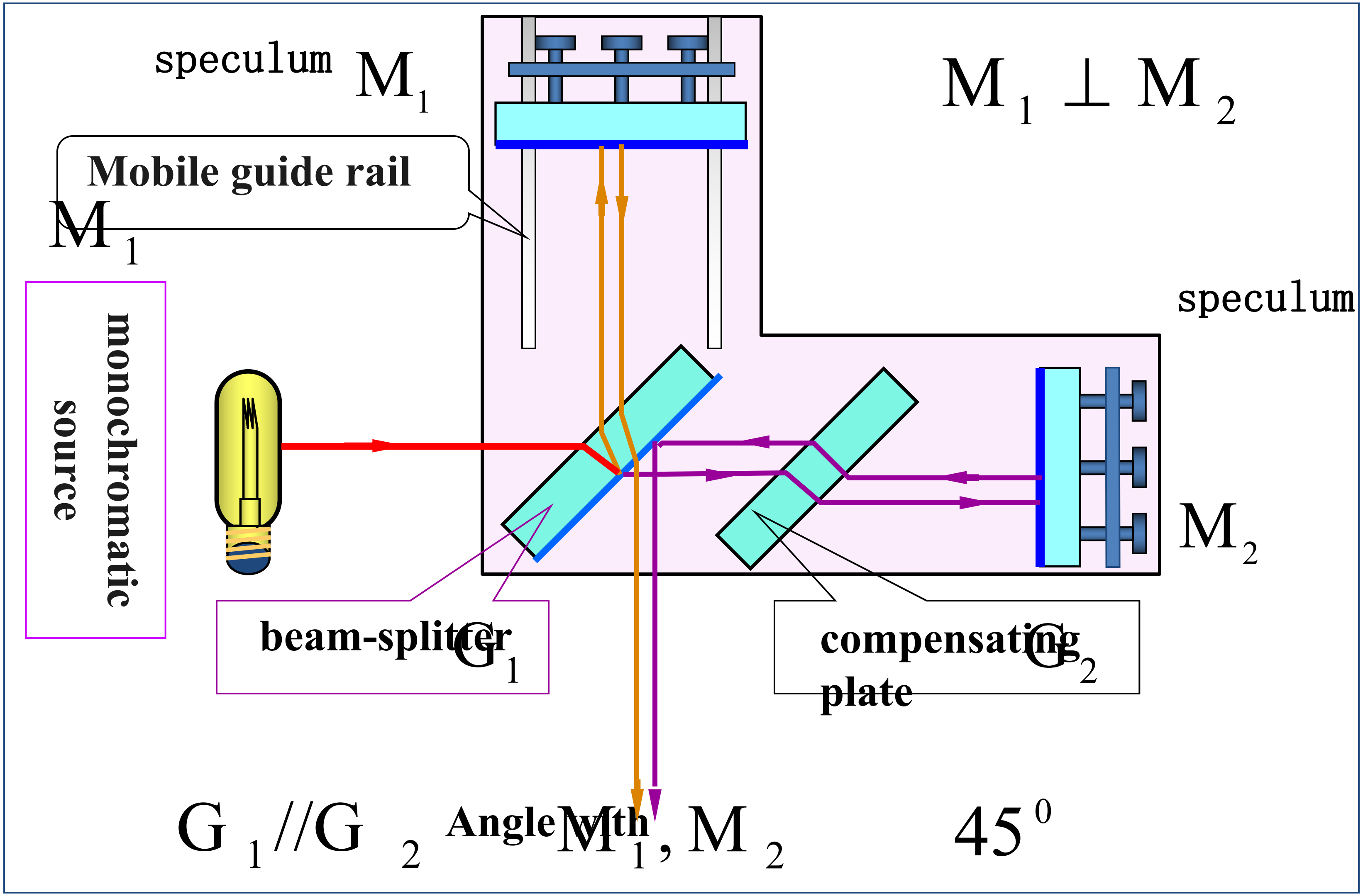


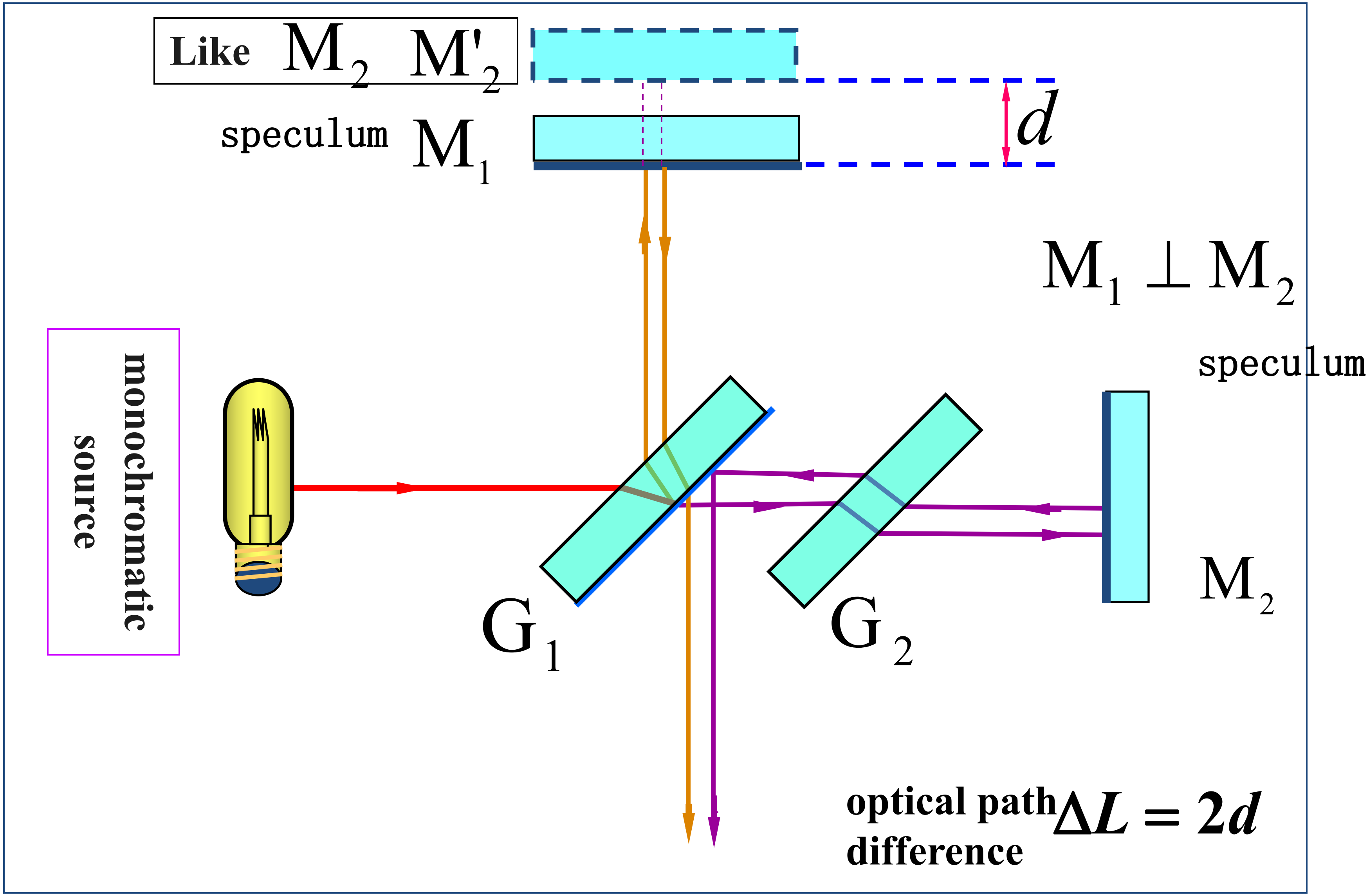
$$d = \frac{\lambda}{2n} \cdot \frac{L}{\Delta l}$$

§ 13.6

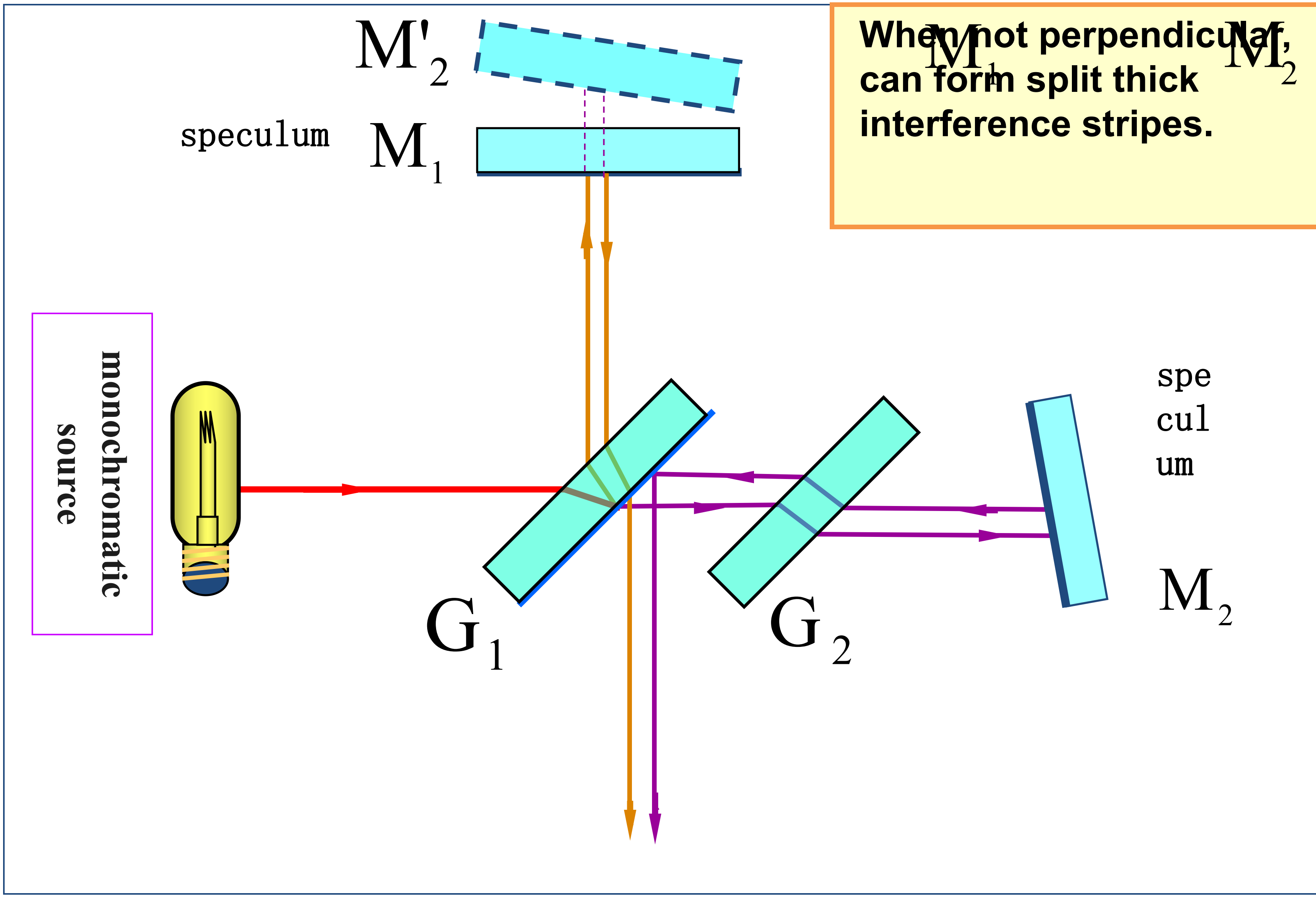
Michelson interferometer

1. Michael sun interferometer



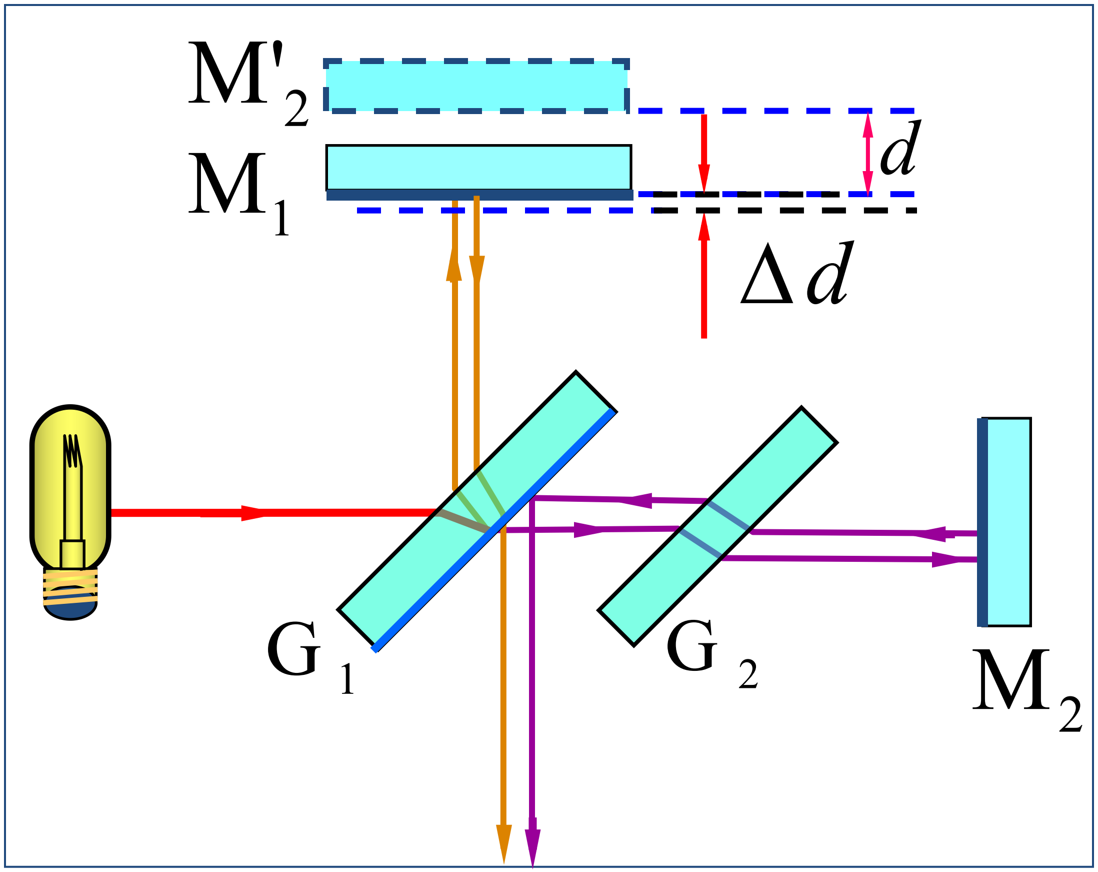

Like M_2 M'_2
speculum M_1
d
$M_1 \perp M_2$
speculum
monochromatic source
G_1
G_2
M_2
optical path difference $\Delta L = 2d$

When not perpendicular, can form split thick interference stripes.



Main characteristics of the Michael son interferometer

The two coherent beams are completely separated in space, and the light path difference between the two beams can be changed by moving the mirror or adding a medium sheet to the light path.



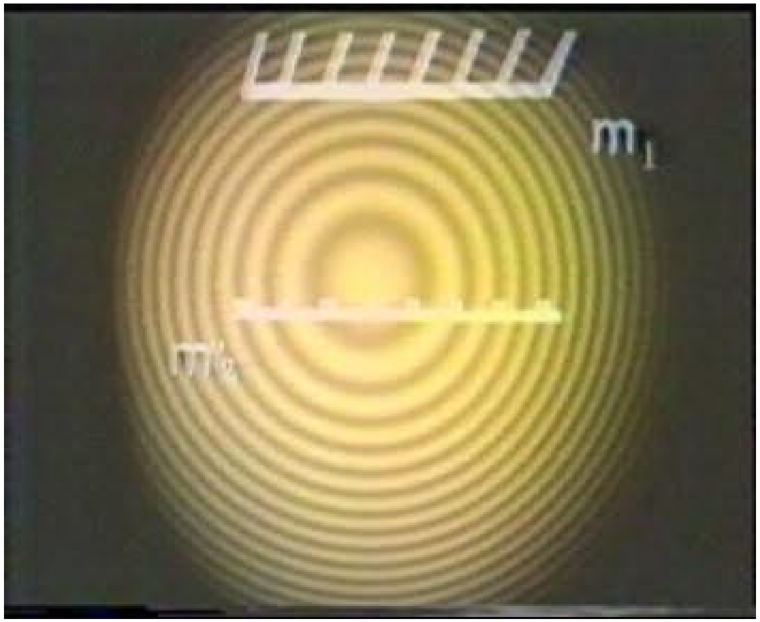
Mobile mirror

$$\Delta d = \Delta k \frac{\lambda}{2}$$

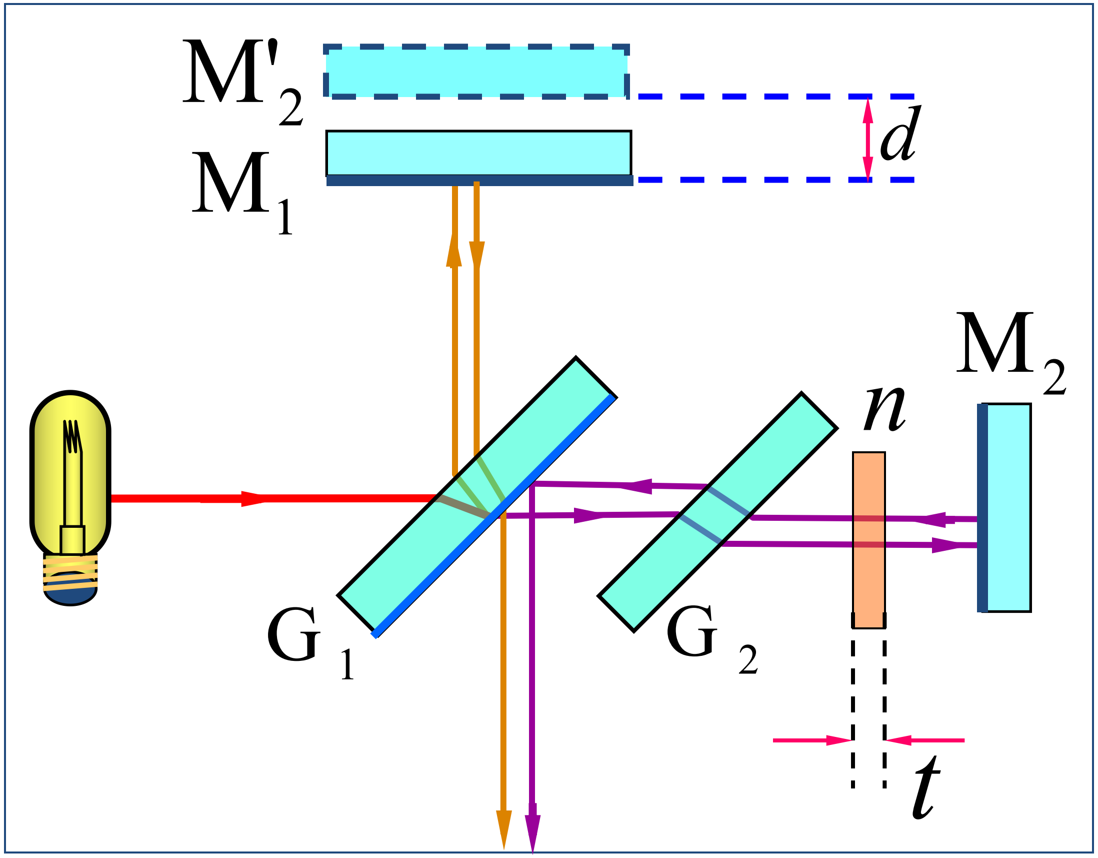
M_1 **displacement distance**

Number of interference fringe moves

The movement of the interference stripe



When the distance between M_1 M_2 them becomes larger, the circular interference stripes grow from the center and expand outward. When the distance changes small, the circular interference stripes shrink to the center and dilute.



optical path difference $\Delta L = 2d$

Light path difference after inserting the medium sheet

$$\Delta L' = 2d + 2(n-1)t$$

Changes in light range difference

$$\Delta L' - \Delta L = 2(n-1)t$$

Medium sheet thickness

$$2(n-1)t = \Delta k \lambda$$

Number of interference fringe moves

$$\boxed{t = \frac{\Delta k}{n-1} \cdot \frac{\lambda}{2}}$$

In the two arms of the Michelson interferometer, insert, respectively

$l = 10.0\text{cm}$ $1.013\times10^{5}\,\text{Pa}$

Long glass tubes, one vacuum and the other store pressurized air to measure the refractive index of the air. The light wavelength is 546nm. During the experiment, air is gradually filled into the vacuum glass tube until the pressure is reached. During this process, 107.2 interference stripes are observed.

n

$1.013\times10^{5}\,\text{Pa}$

n

separate

$$\Delta L_1 - \Delta L_2 = 2(n-1)l = 107.2\lambda$$

$$n = 1 + \frac{107.2\lambda}{2l} = 1 + \frac{107.2\times546\times10^{-7}\,\text{cm}}{2\times10.0\text{cm}}$$

$$= 1.00029$$