OPTICS & LASERS

PH 201

Lec_Multi-beam Interference

Two-beam Interference

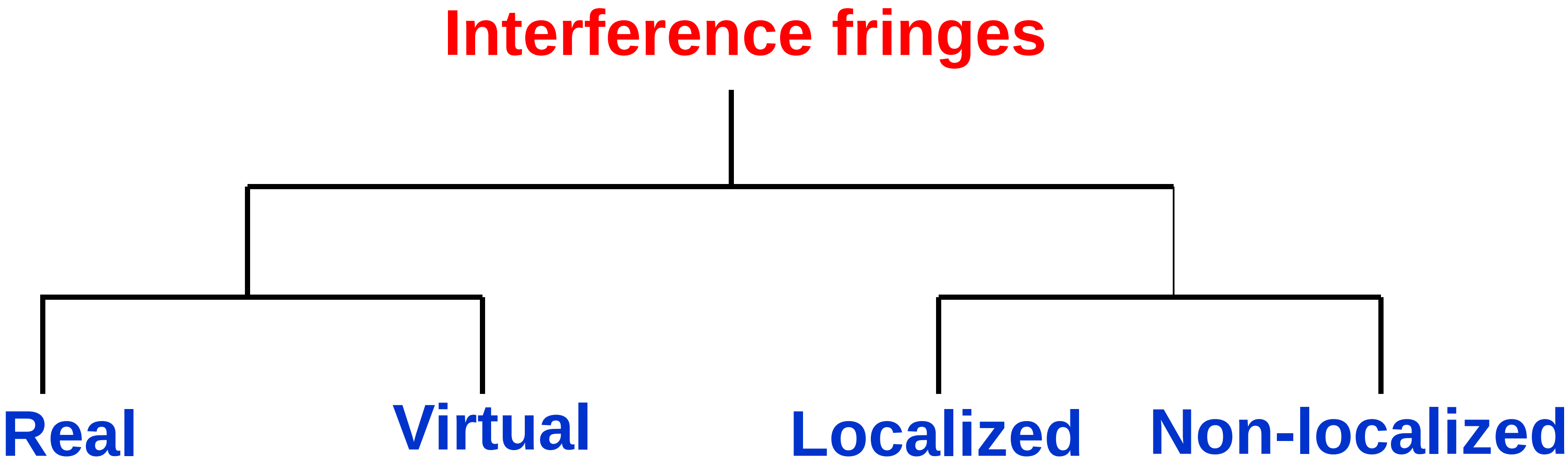
It is difficult to observe interference pattern even with two laser beams unless they are phase locked.

Thus, one tries to derive interfering waves from a single wave so that phase relationship is maintained.

Method to achieve phase relationship:

- **Division of wavefront:** A beam is allowed to fall on two closely spaced holes & two beams emanating from holes interfere.
  Ex.: Young's double slit, Fresnel biprism

- **Division of amplitude:** A beam is divided at two or more reflecting surfaces & reflected beams interfere.
  Ex.: Newton's ring, Michelson interferometer


Interference fringes
Real
Virtual
Localized
Non-localized

Real fringe

- Can be intercepted on a screen placed anywhere in the vicinity of interferometer without a condensing lens system.

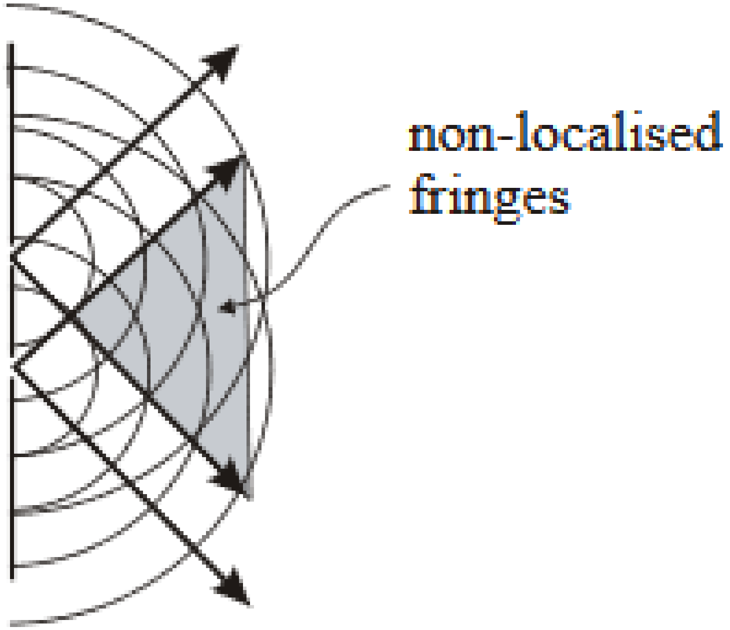
Virtual fringe

- Can’t be projected onto a screen without a condensing focusing system. In this case, rays do not converge.

Non-localized fringe

- Exists everywhere

- Result of point/line source

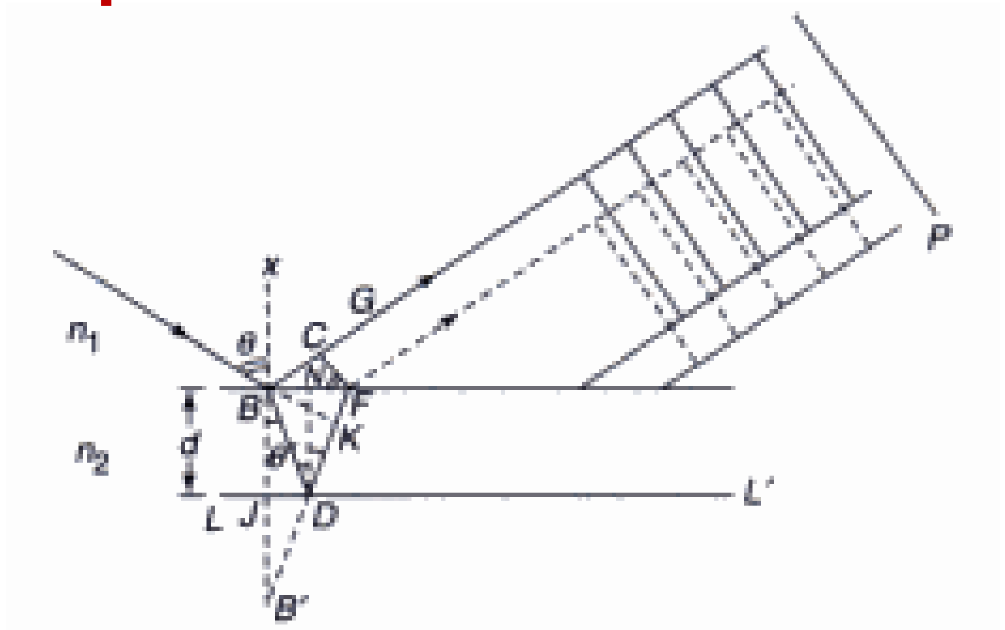


Localized fringe

- Observed over particular surface

- Result of extended source

Oblique incidence of plane wave on thin film



Optical path, Δ

$$\Delta = n_2(BD + DF) - n_1 BC$$
$$= 2n_2 d\cos\theta'$$

For a film placed in air, a phase change of π will occur when reflection takes place at B.

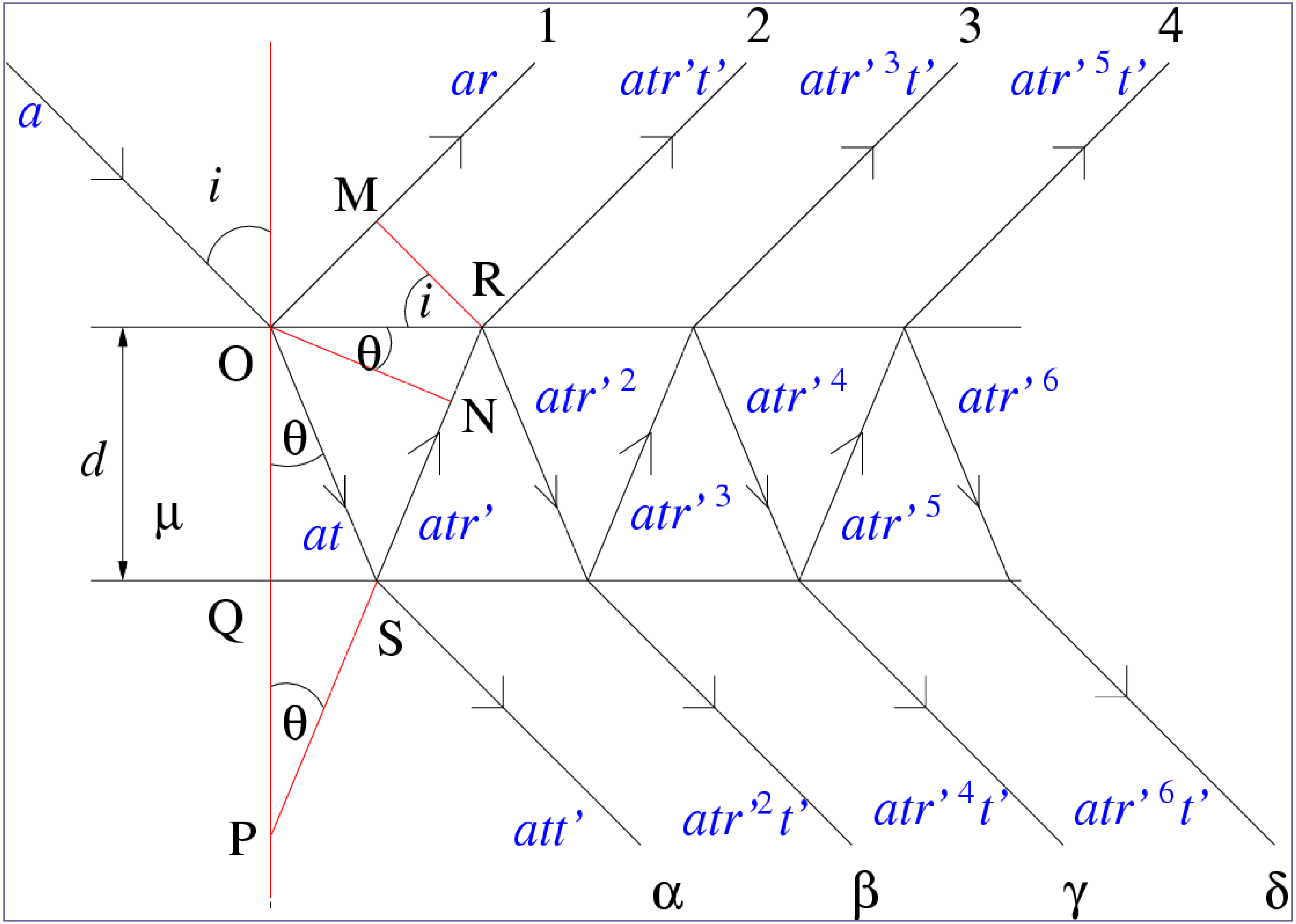
$$\Delta = 2n_2 d\cos\theta' = m\lambda \qquad Minima$$

$$= (m + \frac{1}{2})\lambda \qquad Maxima$$

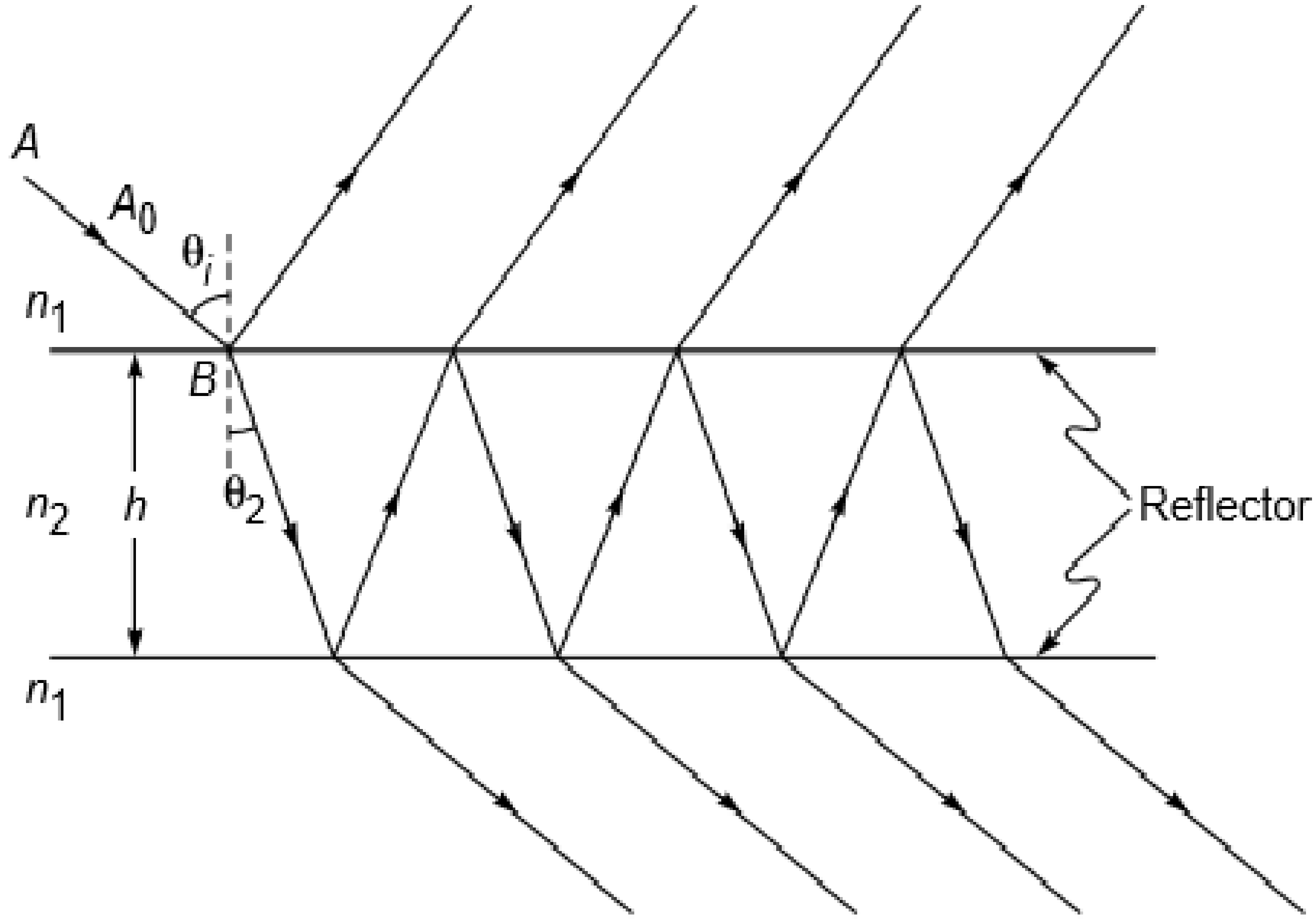
Cosine law: Wave reflected from lower surface of film traverses an additional optical path given by

$$\boxed{\Delta = 2n_2 d\cos\theta'}$$

Multi-beam Interference



Multi-beam Interference



Reflection & transmission of a beam of amplitude A_0 incident at an angle θ_i on a film of refractive index n_2 & thickness h.

Multi-beam Interference

A_0: Complex amplitude of incident wave

r_1: Amplitude reflection coefficient
t_1: Amplitude transmission coefficient

When wave is incident from n_1 towards n_2

r_2: Amplitude reflection coefficient
t_2: Amplitude transmission coefficient

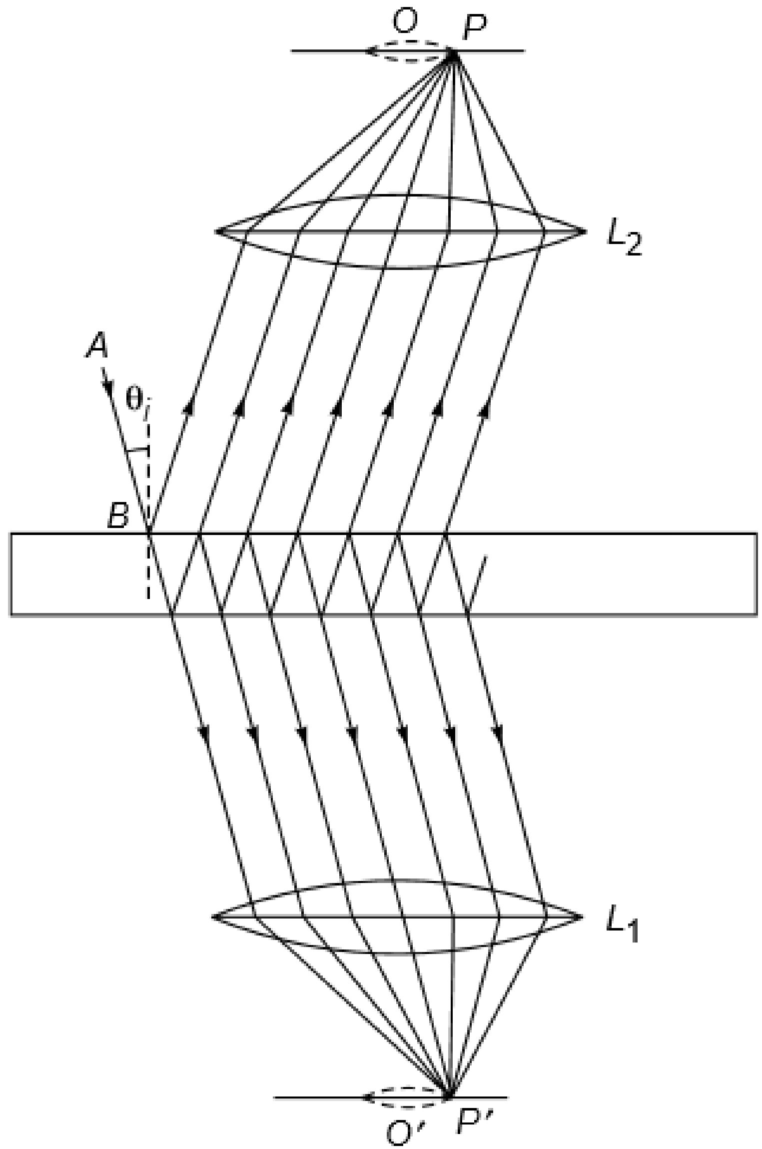
When wave is incident from n_2 towards n_1

Technique of multiple-beam interferometry is based upon situating two surfaces of high reflectivity in close proximity & using a lens to converge beams which have undergone multiple-reflection between surfaces.

In Fabry-Perot interferometer, two opposed surfaces are parallel. If two planes are not parallel, then interference fringes appear localized in wedge space.

$$R = r_1^2 = r_2^2$$

$$\tau = t_1 t_2 = 1 - R$$



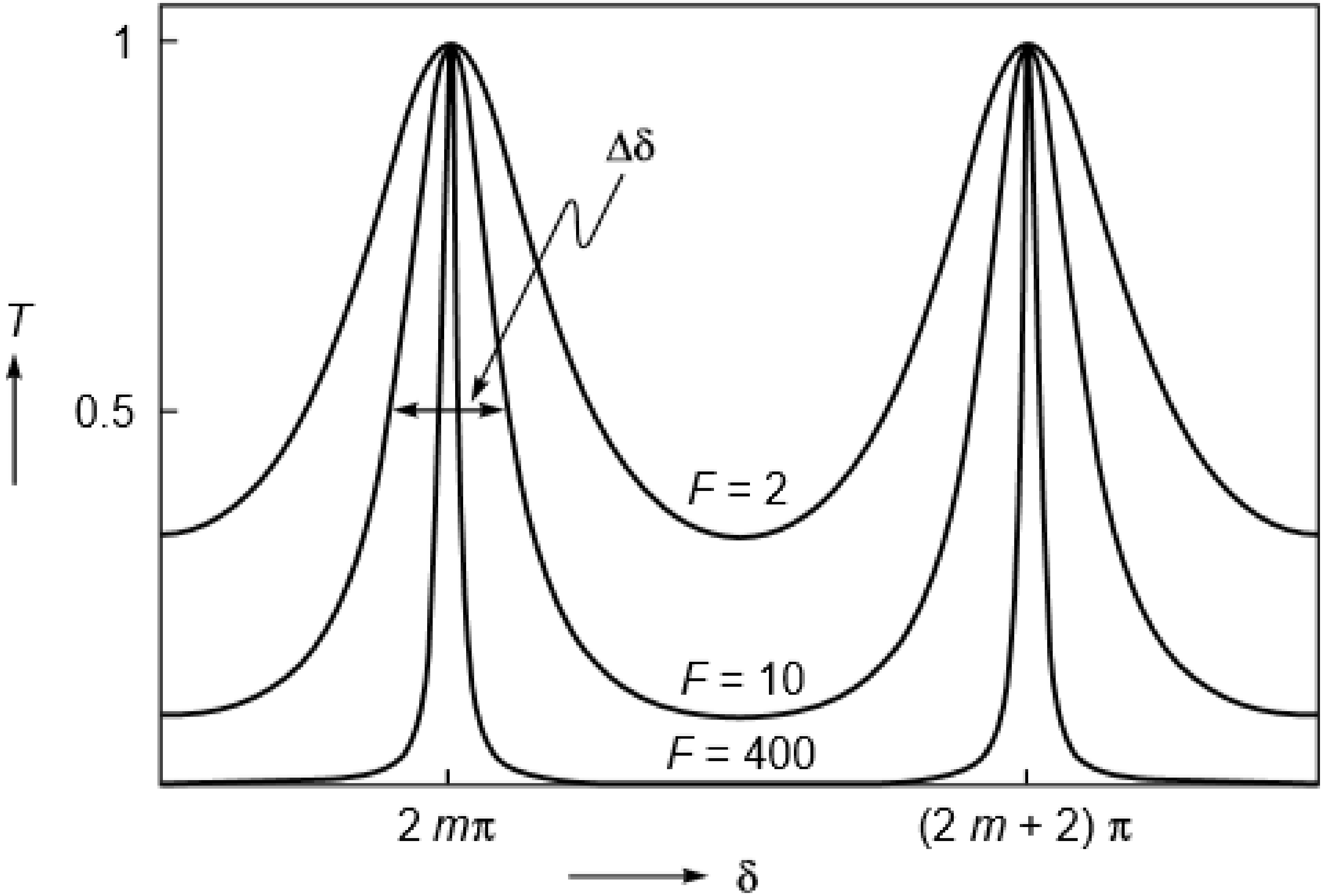
$$\mathcal{R} = \frac{F \sin^2 \delta/2}{1 + F \sin^2 \delta/2}$$

$$F = \frac{4R}{(1-R)^2}$$

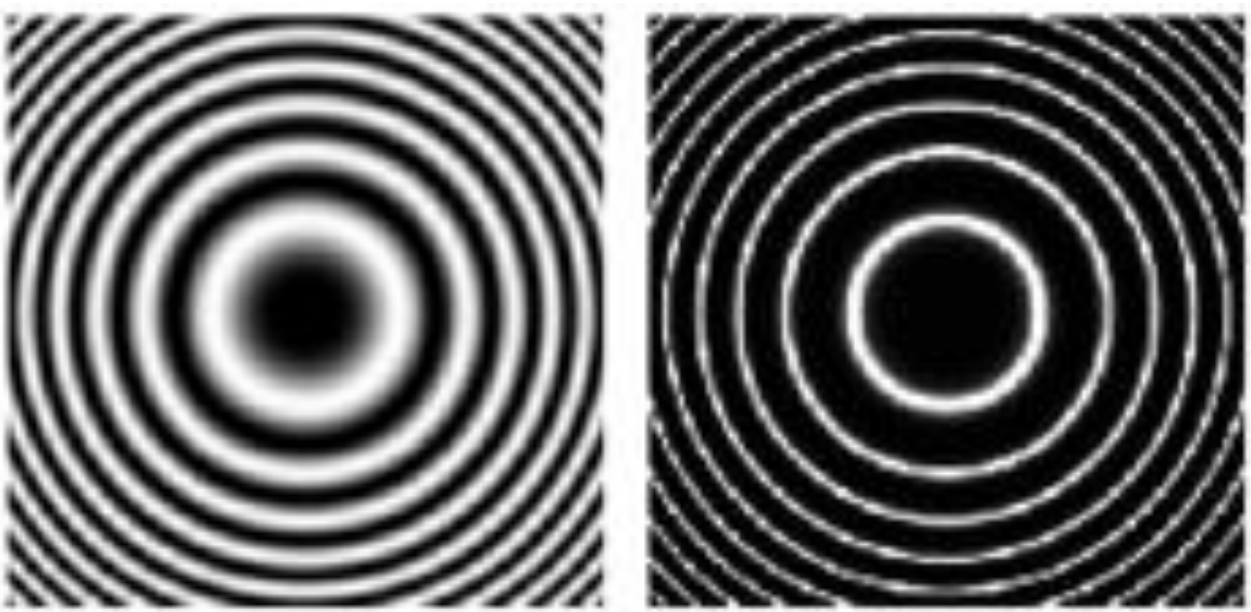
$$T = \frac{1}{1 + F \sin^2 \delta/2}$$

Any ray parallel to AB will focus at the same point P. If ray AB is rotated about normal at B, then point P will rotate on the circumference of a circle centered at O; this circle will be bright or dark depending on the value of θ_i. Rays incident at different angles will focus at different distances from O, & one will obtain concentric bright & dark rings for an extended source.

$$\Delta\delta \approx \frac{4}{\sqrt{F}} = \frac{2(1-R)}{\sqrt{R}}$$



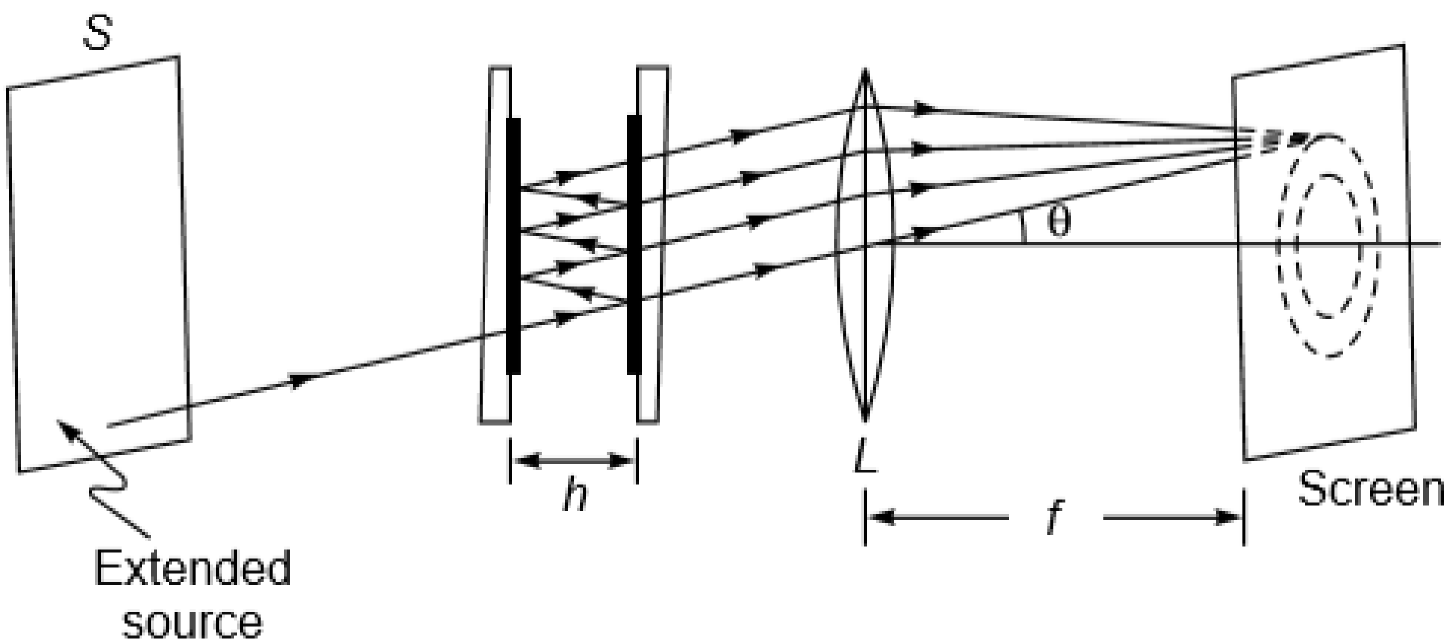
Transmittivity of a Fabry–Perot etalon as a function of *δ* for different values of *F*; the value of *m* is usually large. Transmission resonances become sharper as we increase the value of *F*. FWHM is denoted by Δ*δ.*



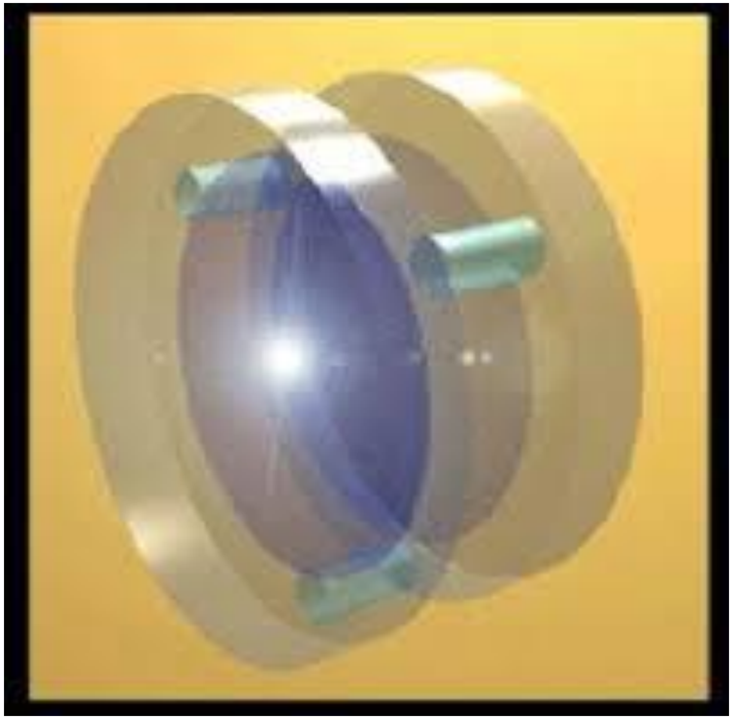
Low finesse vs. high finesse

Fabry-Perot Etalon

Charles Fabry & Alfred Perot, 1899

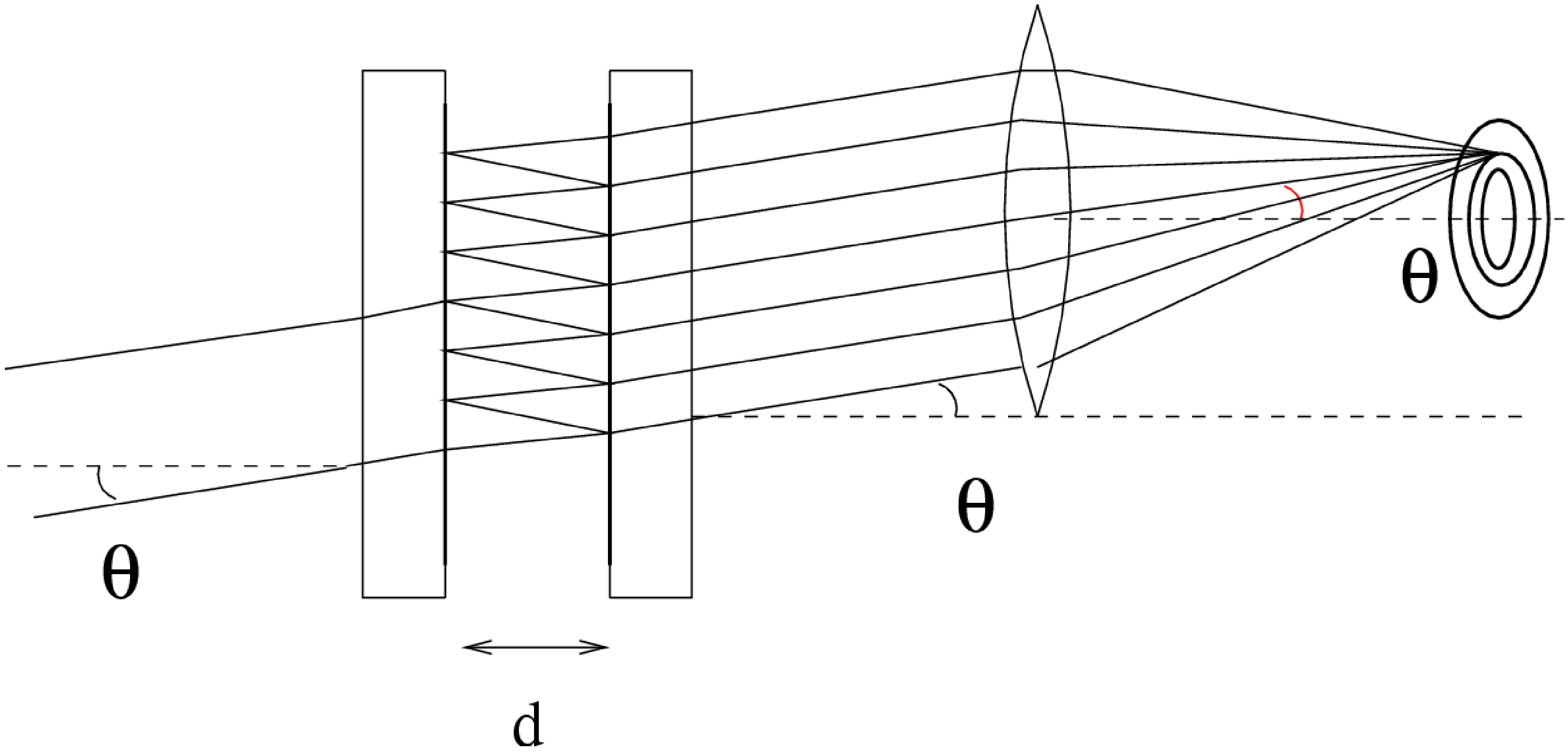


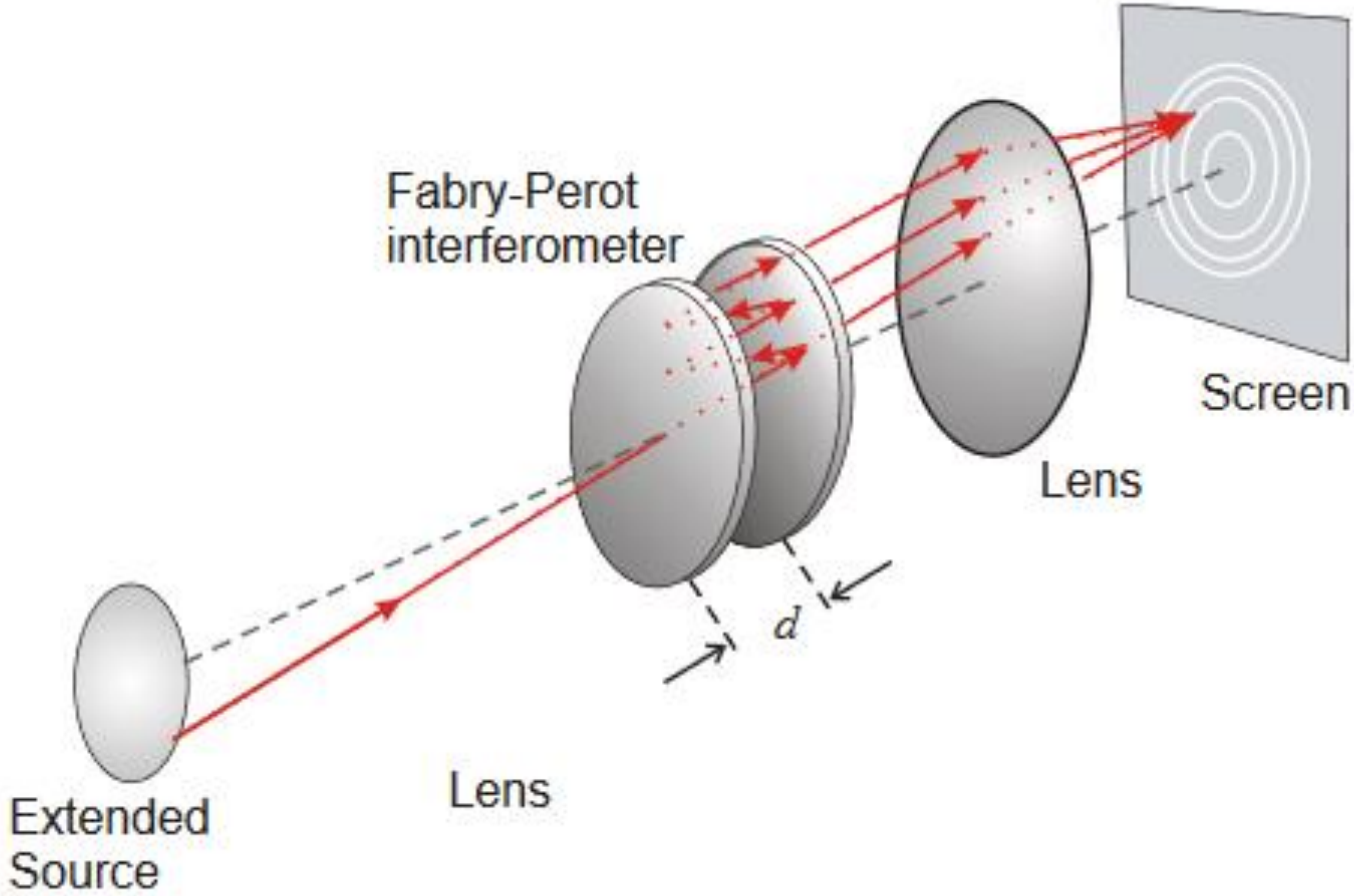
When two mirrors are held fixed & adjusted for parallelism by screwing some sort of spacer, it is said to be an *Etalon*.



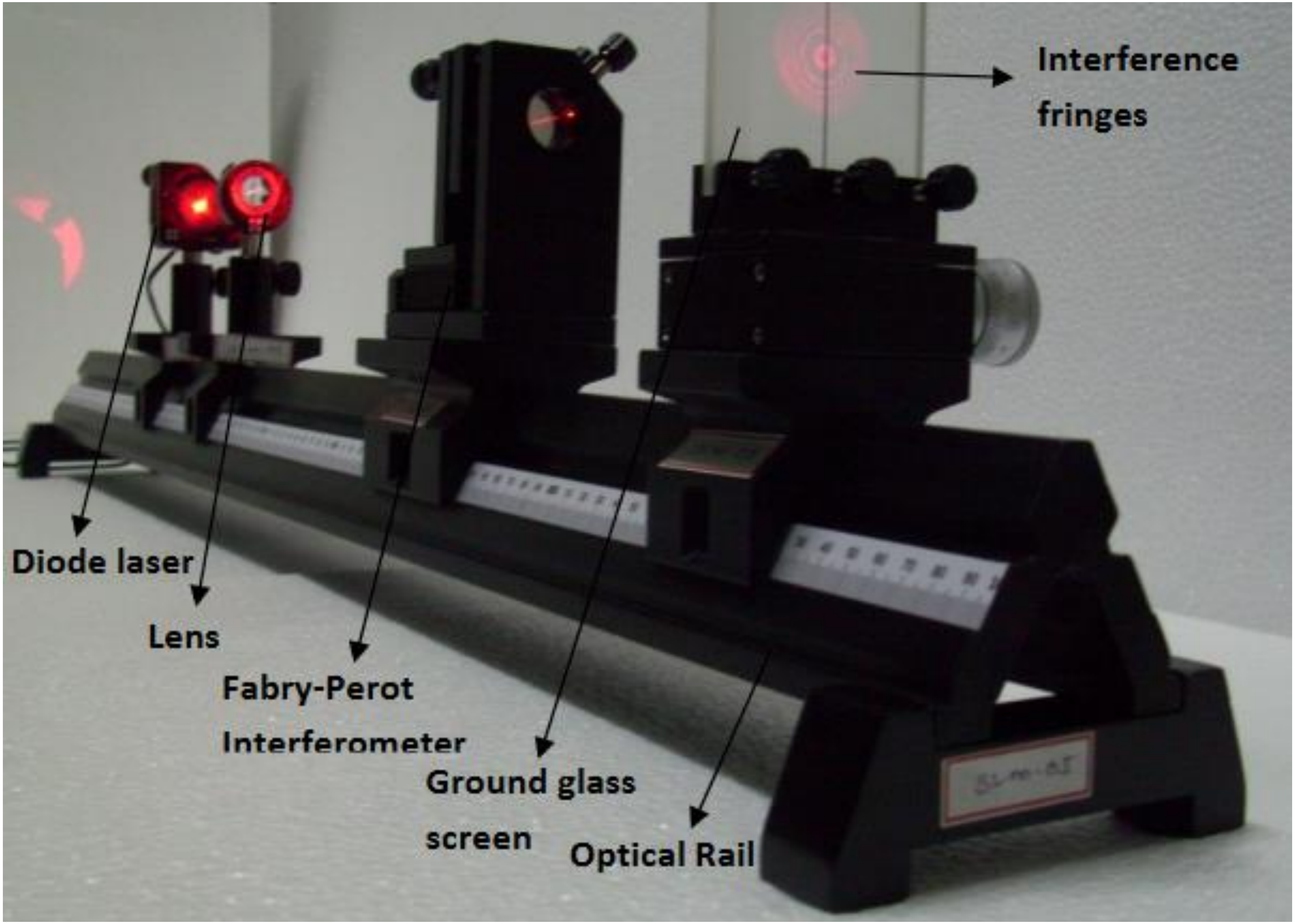
A quartz plate polished & metal-coated as an *Etalon* (with $n \neq 1$).

Fabry-Perot Interferometer

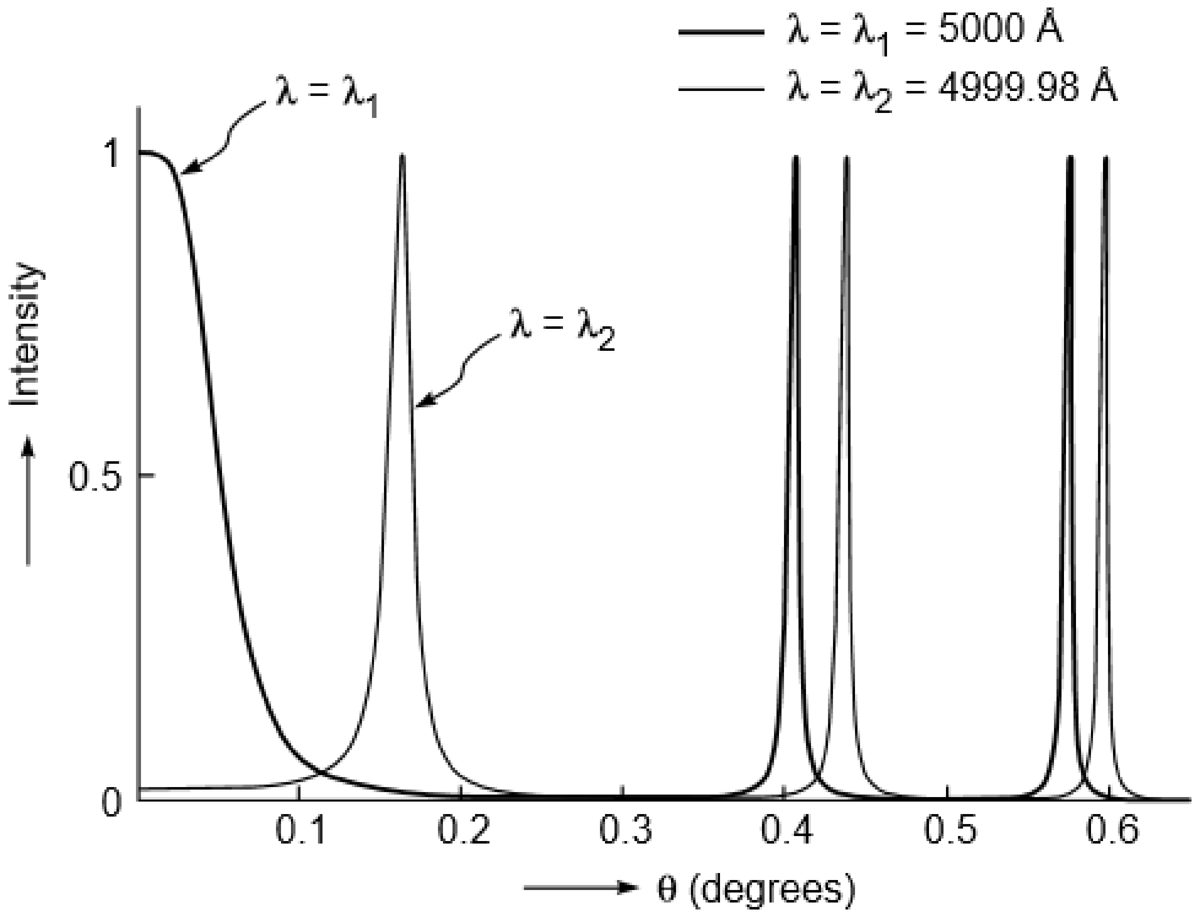




Schematic diagram of arrangement to view Fabry-Perot fringes. Parallel light from Fabry-Perot is focused on screen.

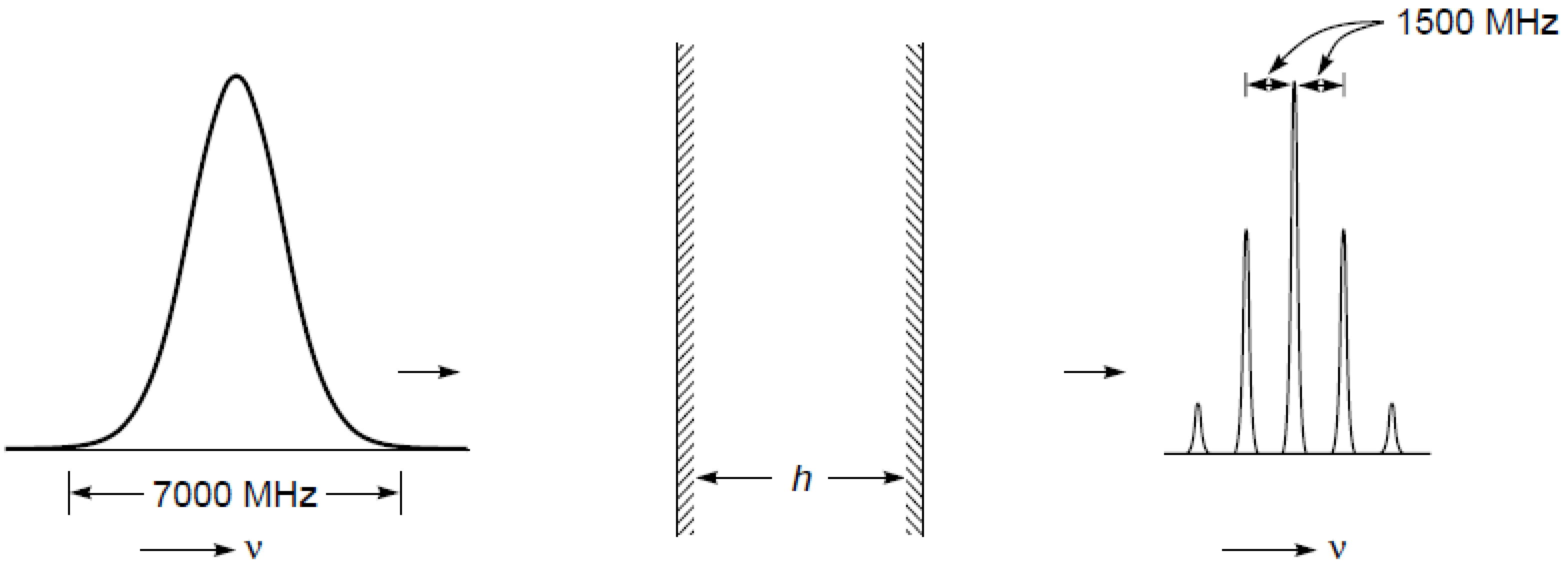


Fabry-Perot Interferometer

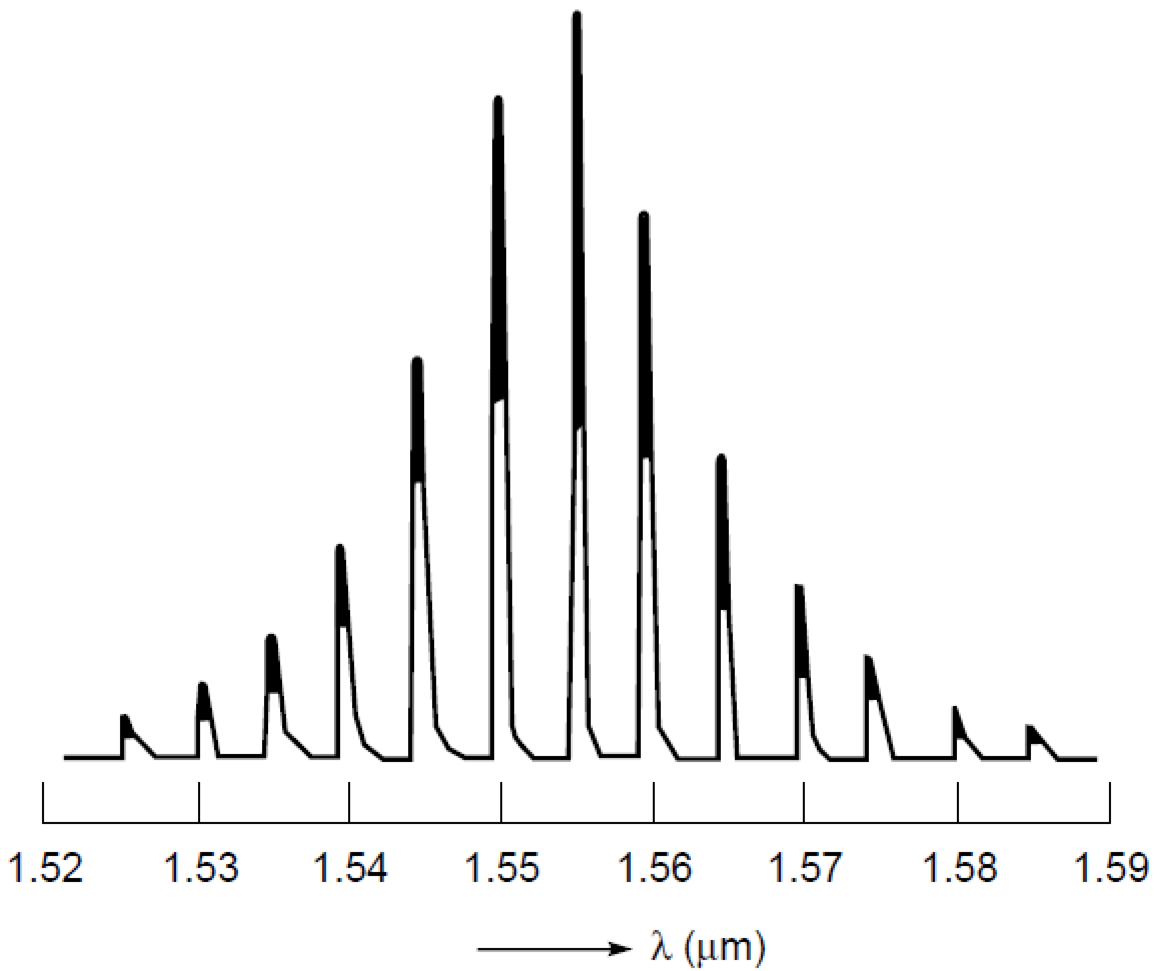


Variation of intensity with θ for a Fabry-Perot interferometer with n_2 = 1, h = 1.0 cm, & F = 400, corresponding to λ_0 = 5000 Å (= λ_1) & λ_0 = 4999.98 Å (= λ_2).

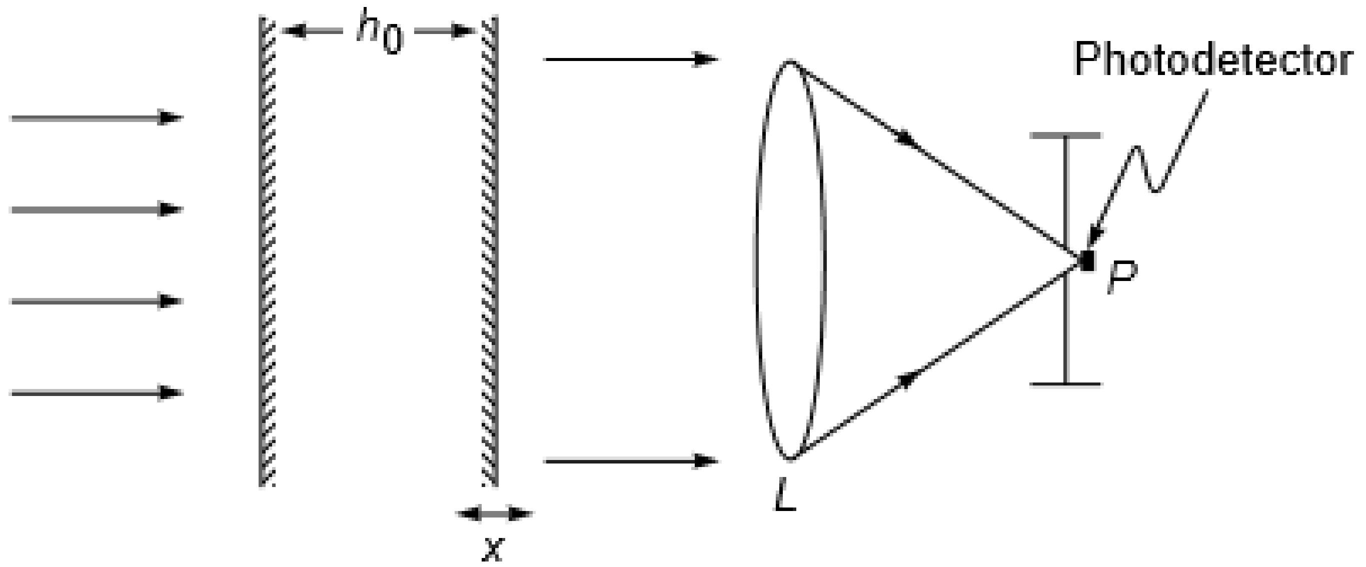
Computer generated ring pattern (on the focal plane of a lens) in a Fabry-Perot etalon with n_2 = 1, h = 1.0 cm, & F = 400, corresponding to λ_0 = 5000 Å (= λ_1) & λ_0 = 4999.98 Å (= λ_2).



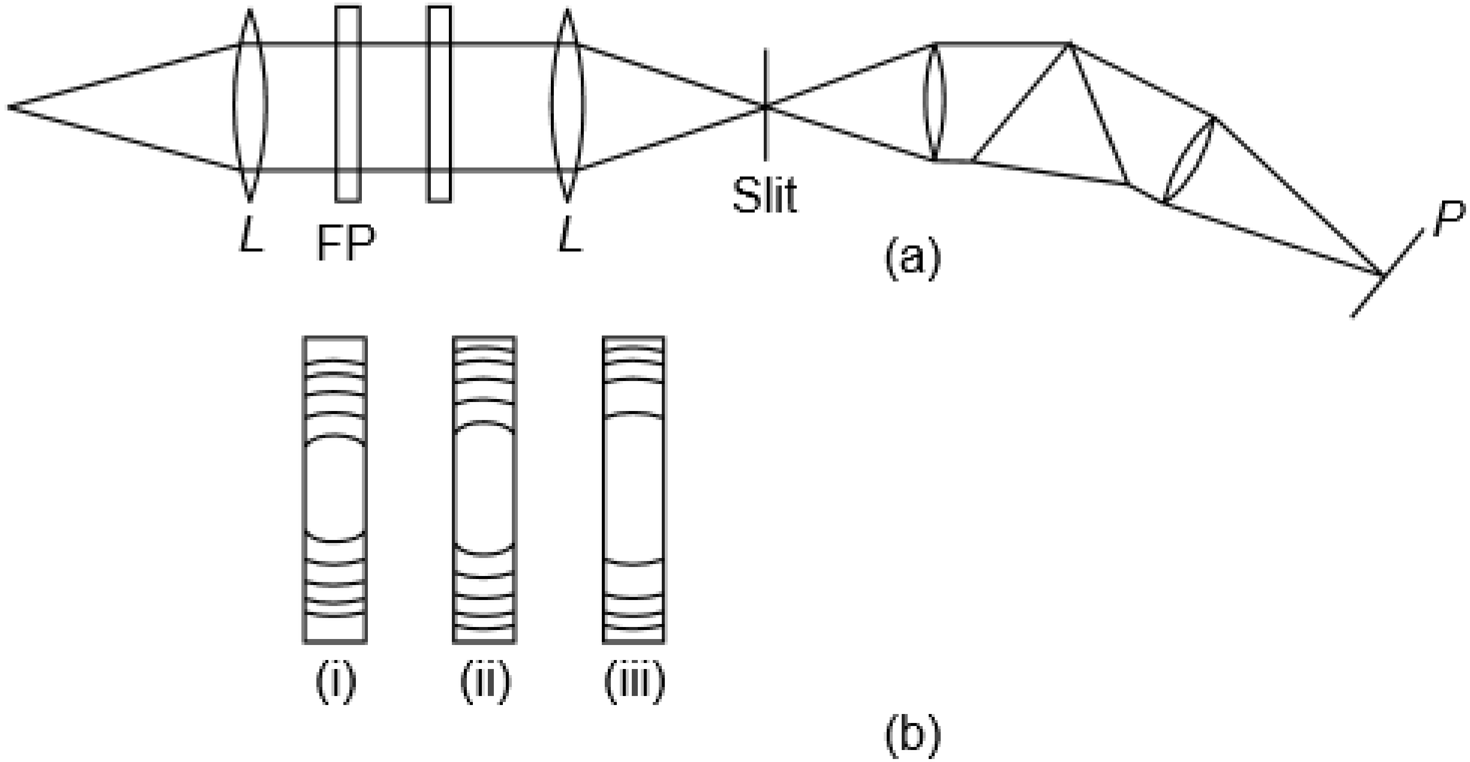
A beam having a spectral width of about 7000 MHz (around v_0 = 6 × 10^{14} Hz) is incident normally on a Fabry-Perot etalon with h = 10 cm, n_2 = 1.



Typical output spectrum of a Fabry–Perot multilongitudinal mode laser diode; wavelength spacing between two modes is about 0.005 μm.

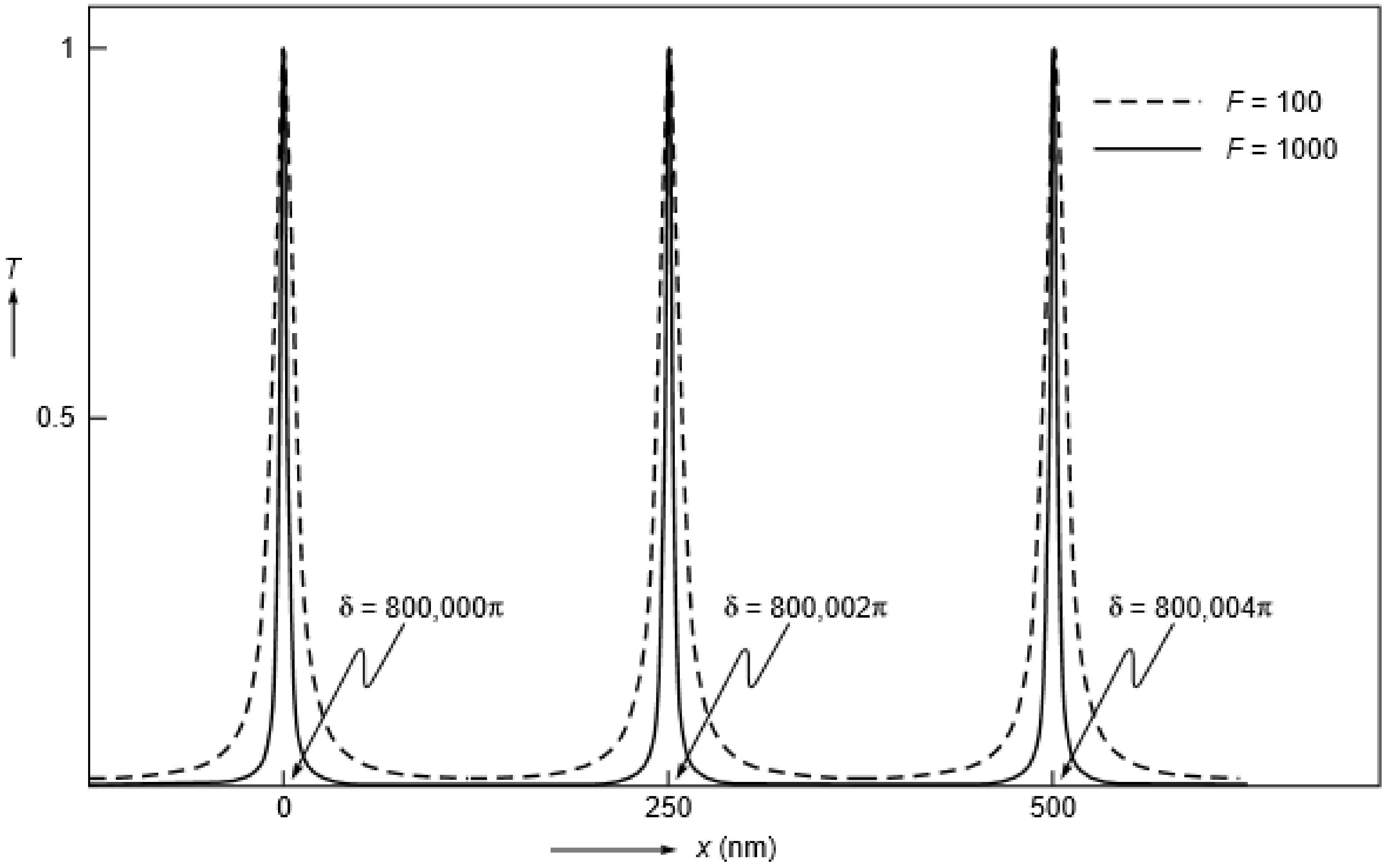


A scanning Fabry–Perot interferometer. Intensity variation is recorded (by a photodetector) on the focal plane of lens L.

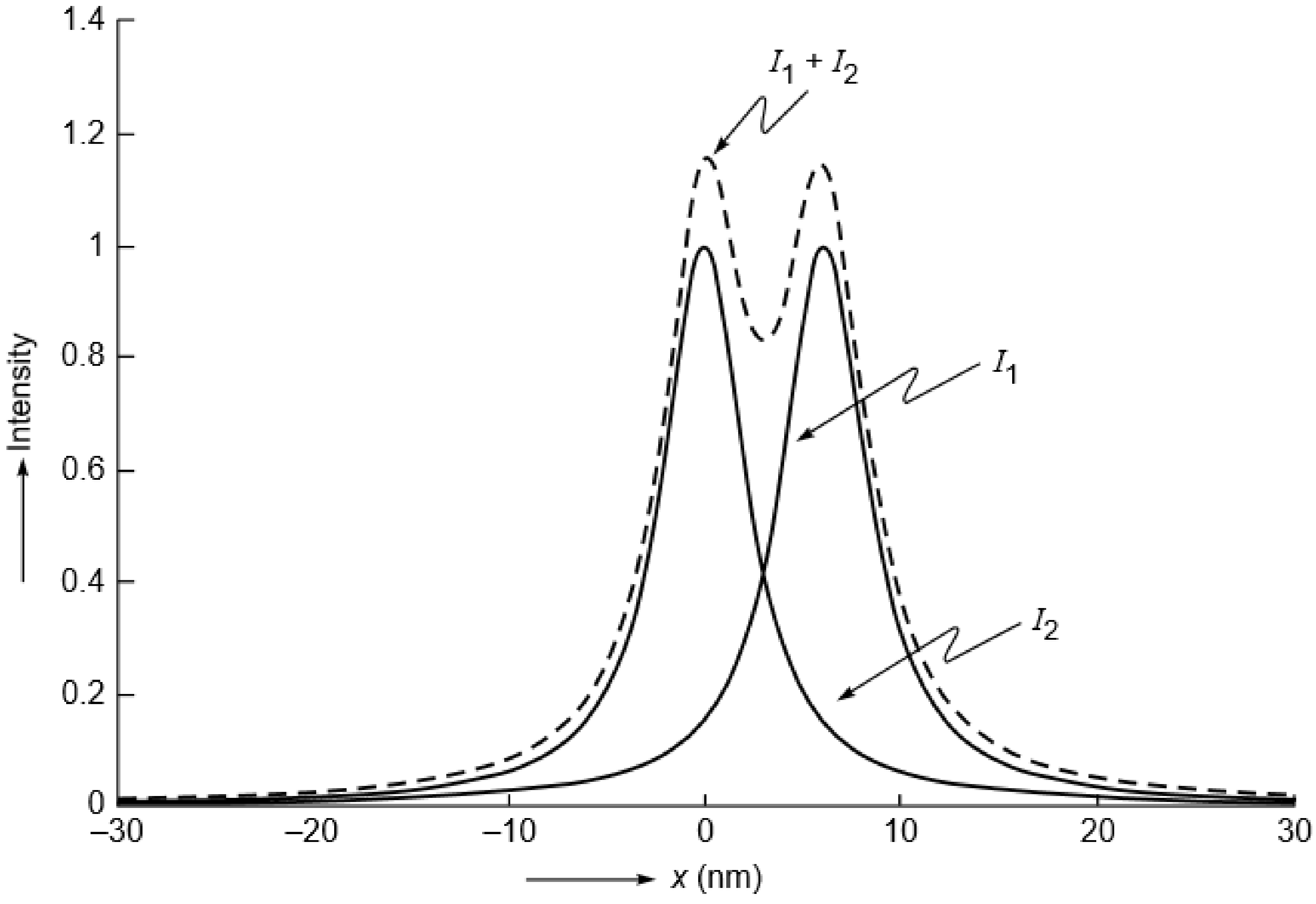


(a) A Fabry–Perot interferometer used in conjunction with a spectrograph.

(b) Interlaced fringes formed in plane of slit are separated by prism. For ex. (i), (ii), & (iii) may correspond to lines in red, yellow, & green regions, respectively, as observed on plane P.



Variation of intensity at point P with *x* for a monochromatic beam incident normally on a scanning Fabry–Perot interferometer; solid curve corresponds to *F* = 1000 & dashed curve corresponds to *F* = 100.



Individual intensity variations I_1 & I_2 in presence of two frequencies v_1 & v_2 & total intensity variation $I_1 + I_2$ when two frequencies are just resolved.

Sodium doublet

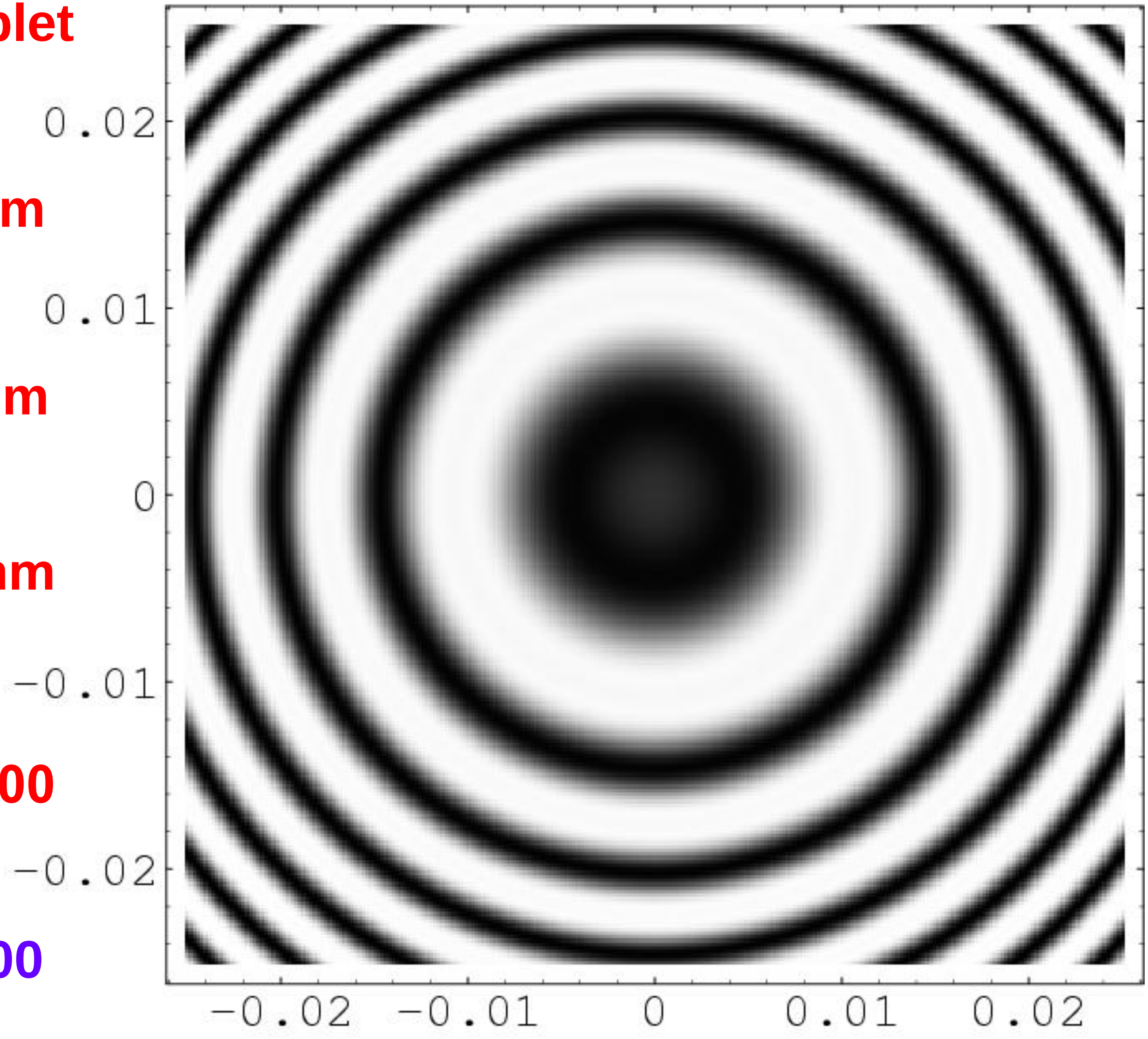
λ_1= 589.0 nm

λ_2= 589.6 nm

$\Delta\lambda$= 0.6 nm

$\lambda/\Delta\lambda$~1000

RP<1000



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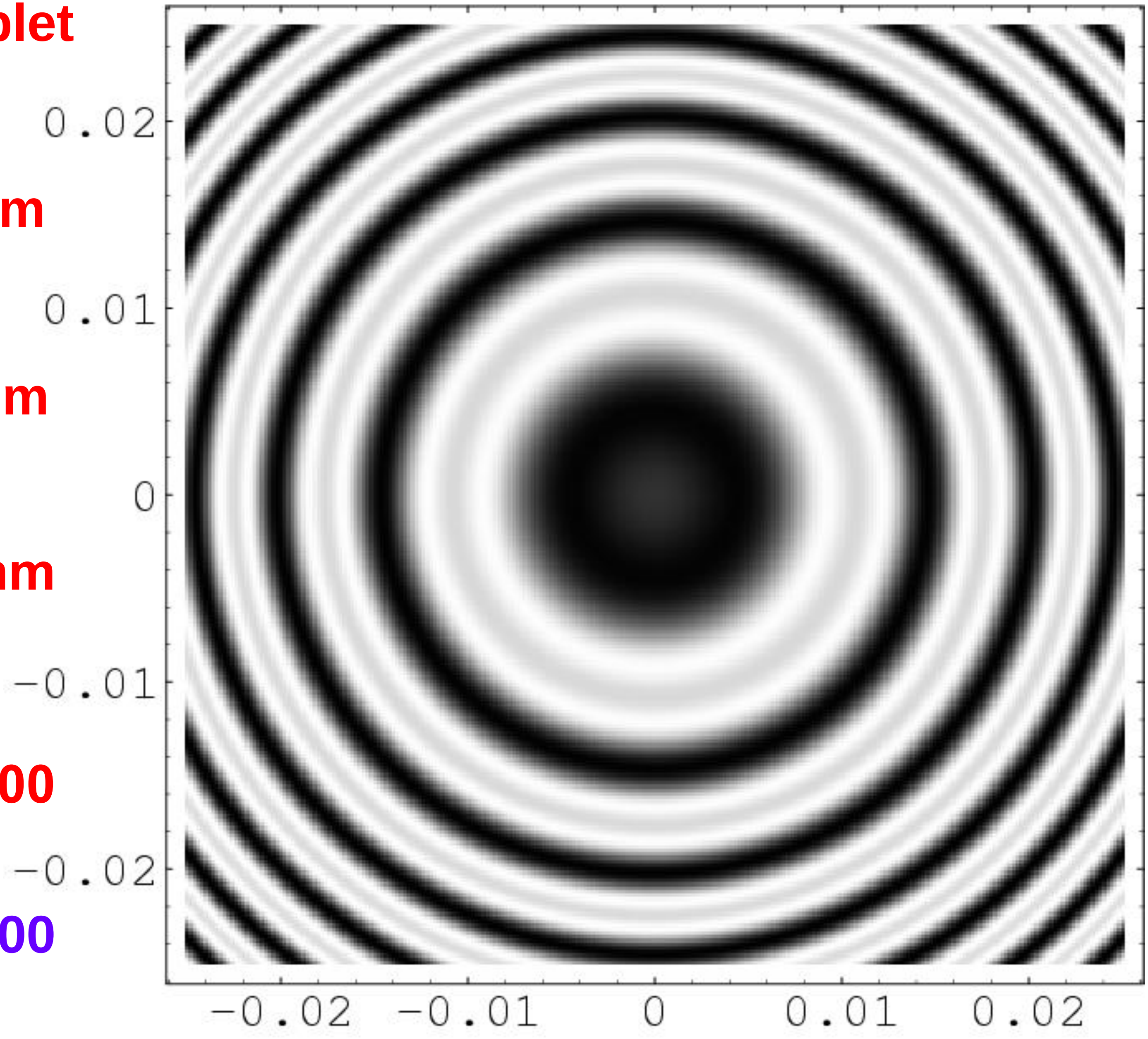

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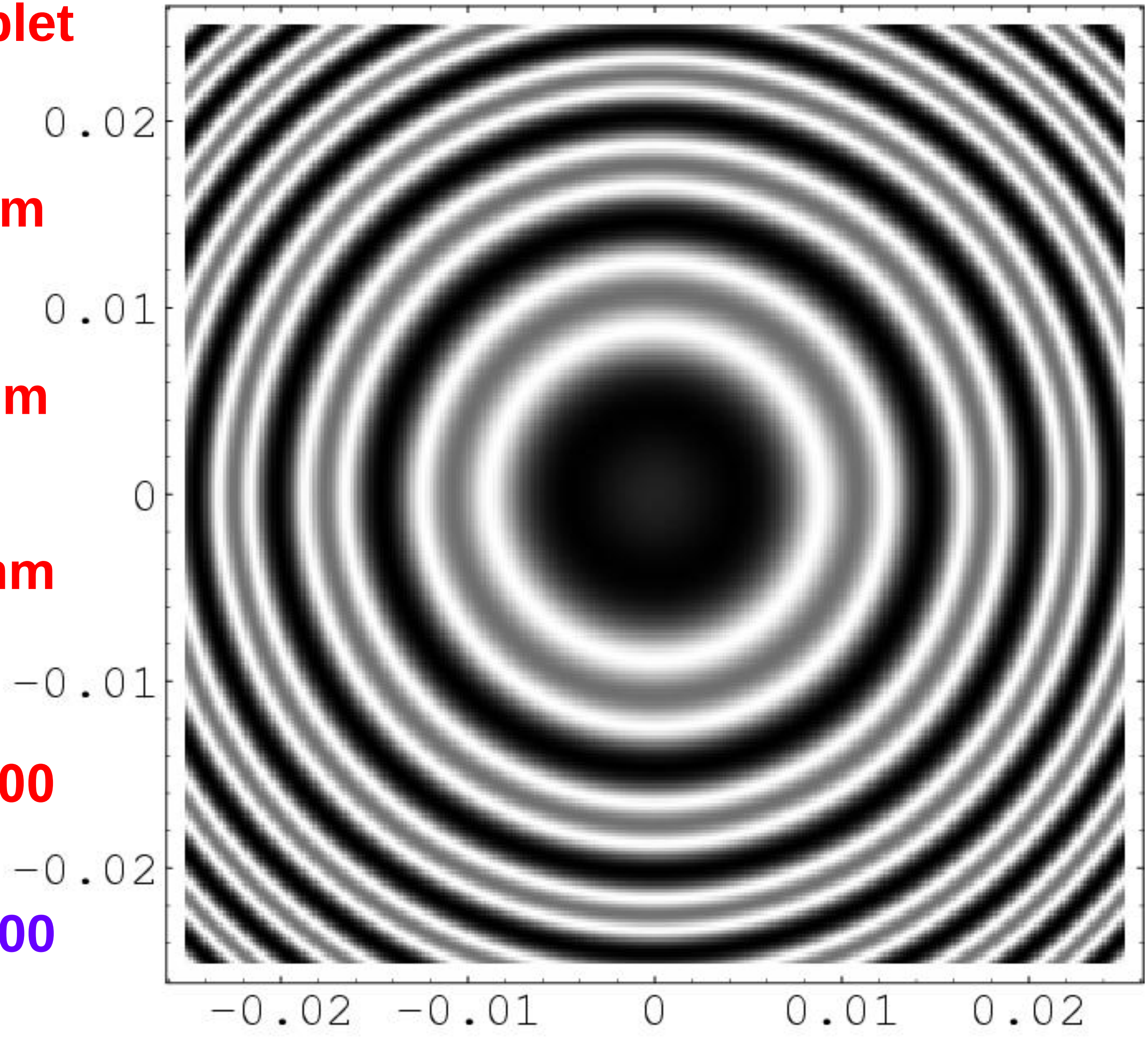
RP >1000



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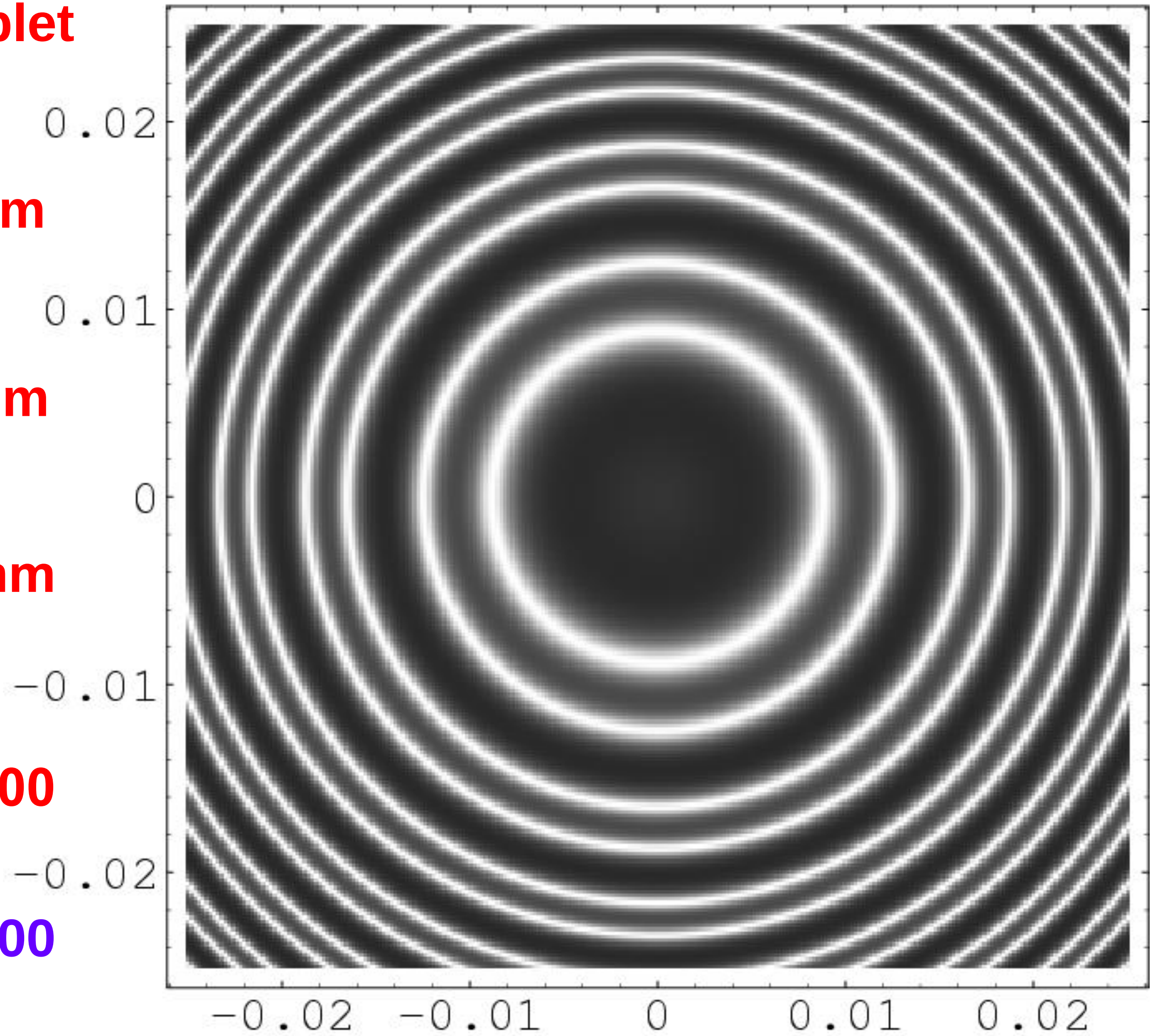
RP >> 1000



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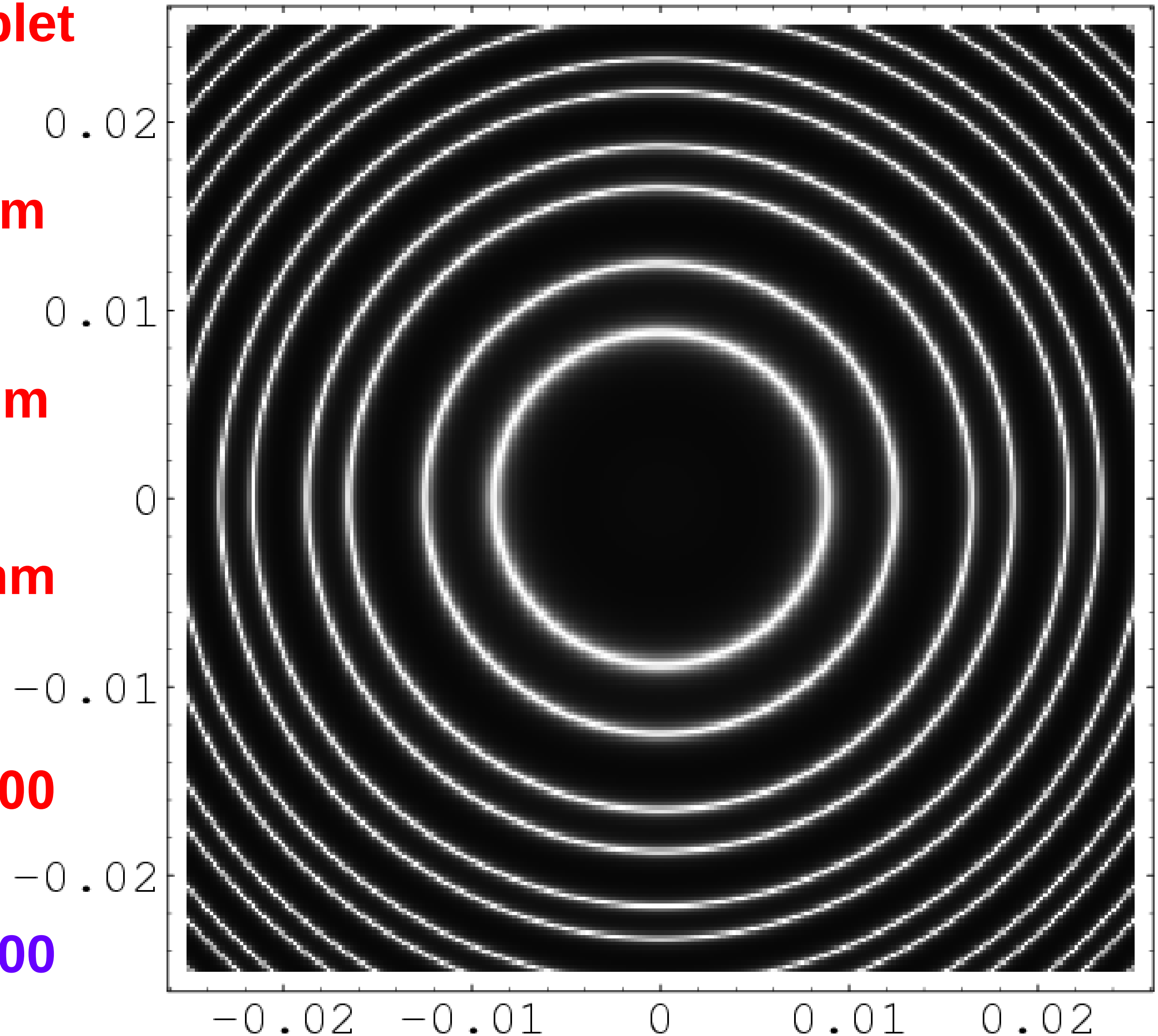
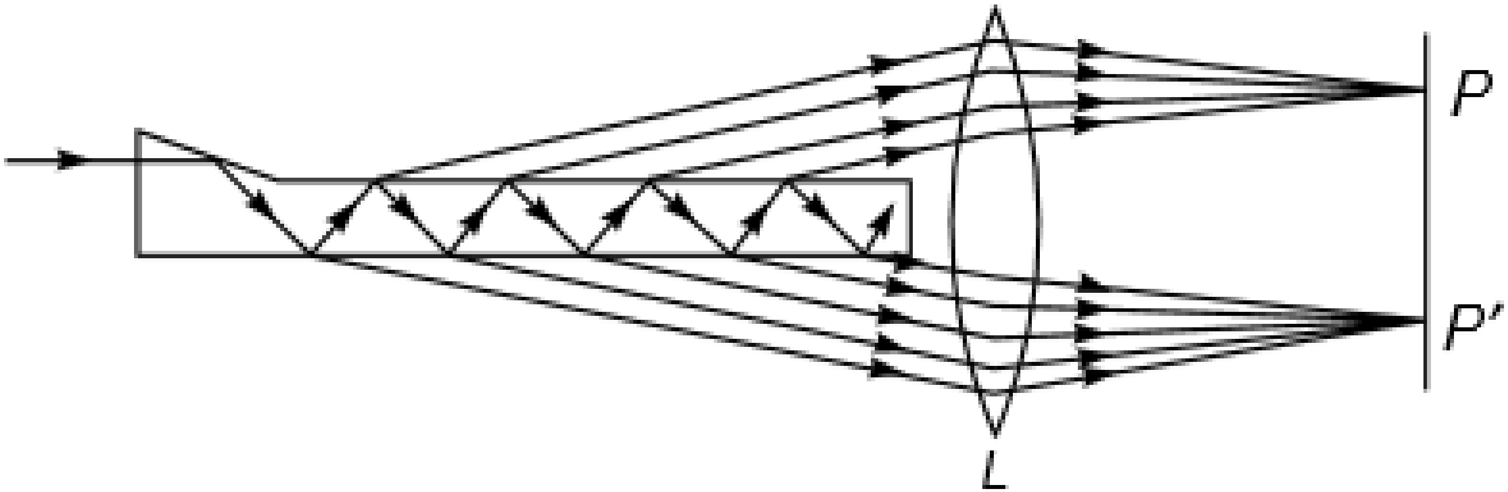
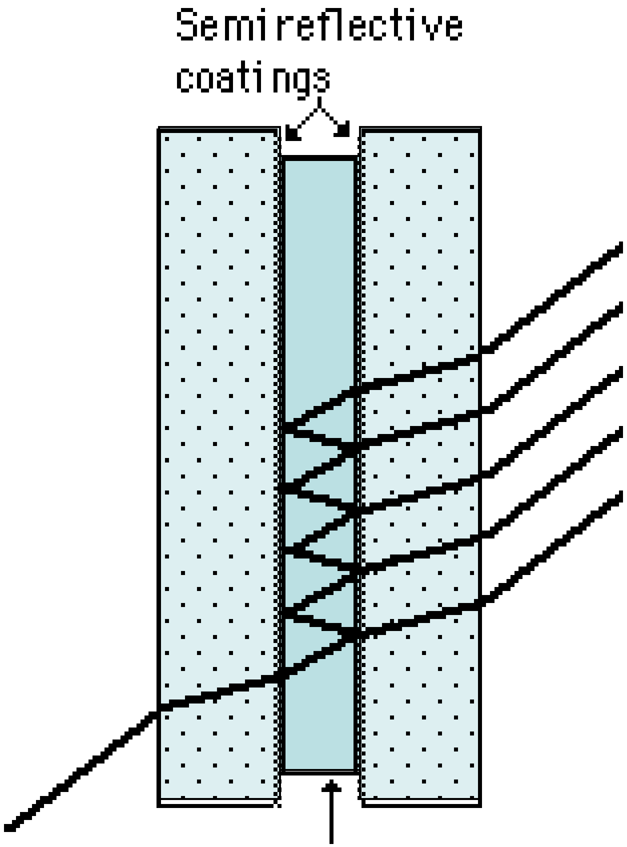


Lummer–Gehrcke plate



- Unlike in Fabry-Perot interferometer, space between reflecting surfaces is a dispersive medium.
- No. of reflections is also not very large as in the case of Fabry-Perot interferometer; no. of reflections depends on length of plate & angle θ. Thus, RP of instrument depends on length of LG plate.
- Earlier, LG plates were used in high resolution spectroscopy. However, they have been replaced by more flexible Fabry-Perot interferometer.

Interference Filter



An interference filter is designed for normal incidence of 488 nm light. The refractive index of the spacer is 1.35. What should be the thickness of the spacer for normal incidence of light?

$$2n_2 h\cos\theta_2 = m\lambda$$

$$2n_2 h = \lambda$$

$$h = 180.74 \quad \text{nm}$$

It will pass different wavelengths if the angle of incidence is not 90^{o}.

LIGO - Laser Interferometer Gravitational Wave Observatory

To detect gravitational waves, one of the predictions of Einstein's general theory of relativity

Hanford Nuclear Reservation, Washington, Livingston, Louisiana

Arm length: 4 Km, Displacement Sensitivity: 10^{-16} cm

When Gravitational waves pass through the interferometer they will displace the mirrors!