Measuring the Refractive Index of Air Using a Vacuum Chamber

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WAVE OPTICS

Interference

- Significant effect on the interference fringes produced by two parallel partial mirrors when air is air pressure between the mirrors is changed

Diffraction

- Diffraction grating spectrum is dependent on the wavelength of light used.
- The wavelength of light in vacuum is slightly greater than that in air
- The effect is very small

- Can this effect be amplified?

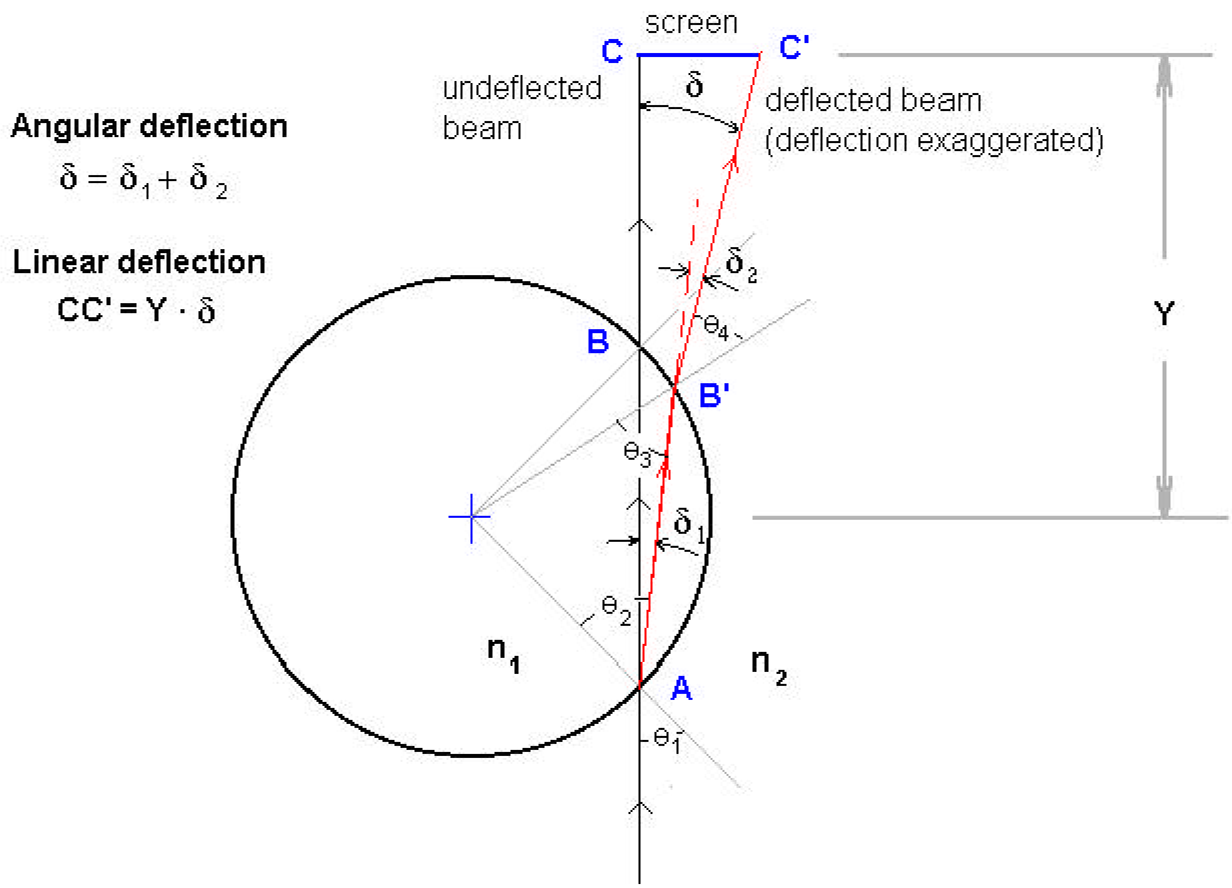
GEOMETRICAL OPTICS

Refraction of Light

- The effect is small due to very small difference in the refractive indices for air and vacuum.

- Can the effect due to refraction be magnified?

3. REFRACTION OF A LASER BEAM THROUGH A VACUUM CHAMBER



$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

The laser beam goes straight before pumping. With vacuum inside the beam gets deflected due to refraction

Take θ_1=45^o. Solving this equation for θ_2 we get

$$\theta_2 = 45.0166^o.$$

This gives the first angle of deflection $\delta_1 = \theta_2 - \theta_1 = 45.0166 - 45 = 0.0166^o$.

The situation is symmetrical when the beam exits the chamber at the point B'. At B' we have $\theta_3 = \theta_2$ and $\theta_4 = \theta_1$.

Thus the beam deflects further at point B' through an angle δ_2 given by

$\delta_2 = \theta_4 - \theta_3 = \theta_2 - \theta_1 = \delta_1 = 0.0166^o$

Thus the net angular deflection of the beam is

$$\delta = \delta_1 + \delta_2 = 0.0332^o = 5.8 \times 10^{-4} \text{ radians}$$

If the screen is placed at a distance of 15 meters the linear deflection CC' (see Fig. 1) will be = Y. δ = 8.7 mm.

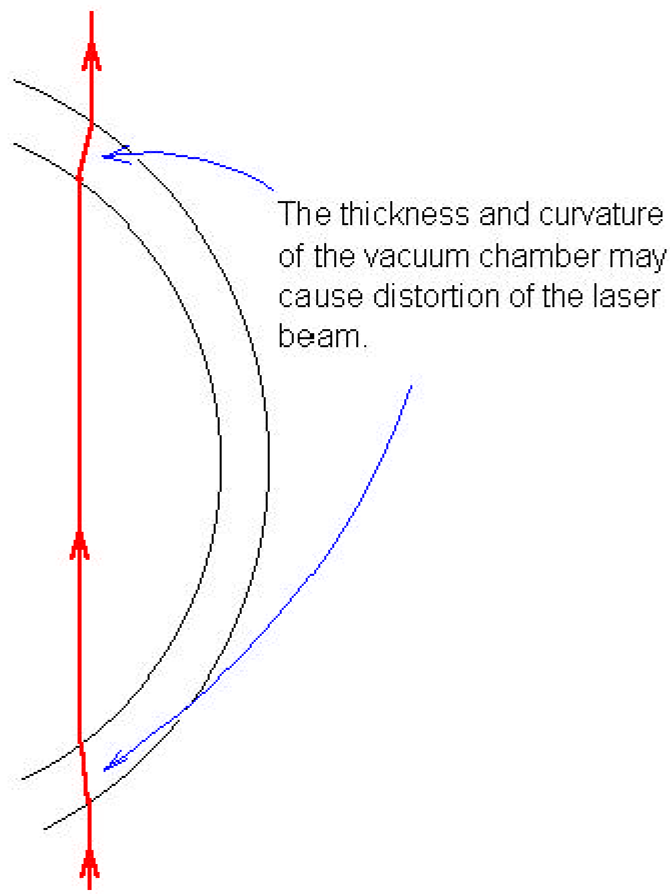
This linear deflection can be amplified in the following ways:

(a) Increase the distance Y.

(b) In place of screen in the Fig. 1 place a plane mirror and reflect the beam to another screen thereby effectively increasing the value of Y.

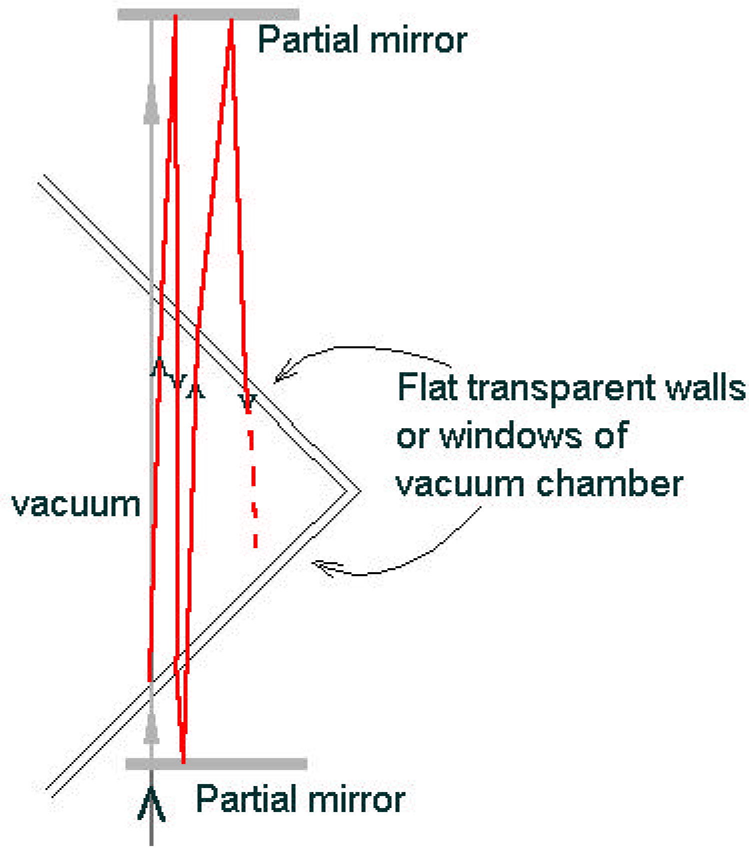
(c) Pass the beam repeatedly through the vacuum chamber by a pair of partial mirrors. With every transit through the vacuum chamber the deflection of the beam will increase.

LIMITATIONS OF THIS METHOD:

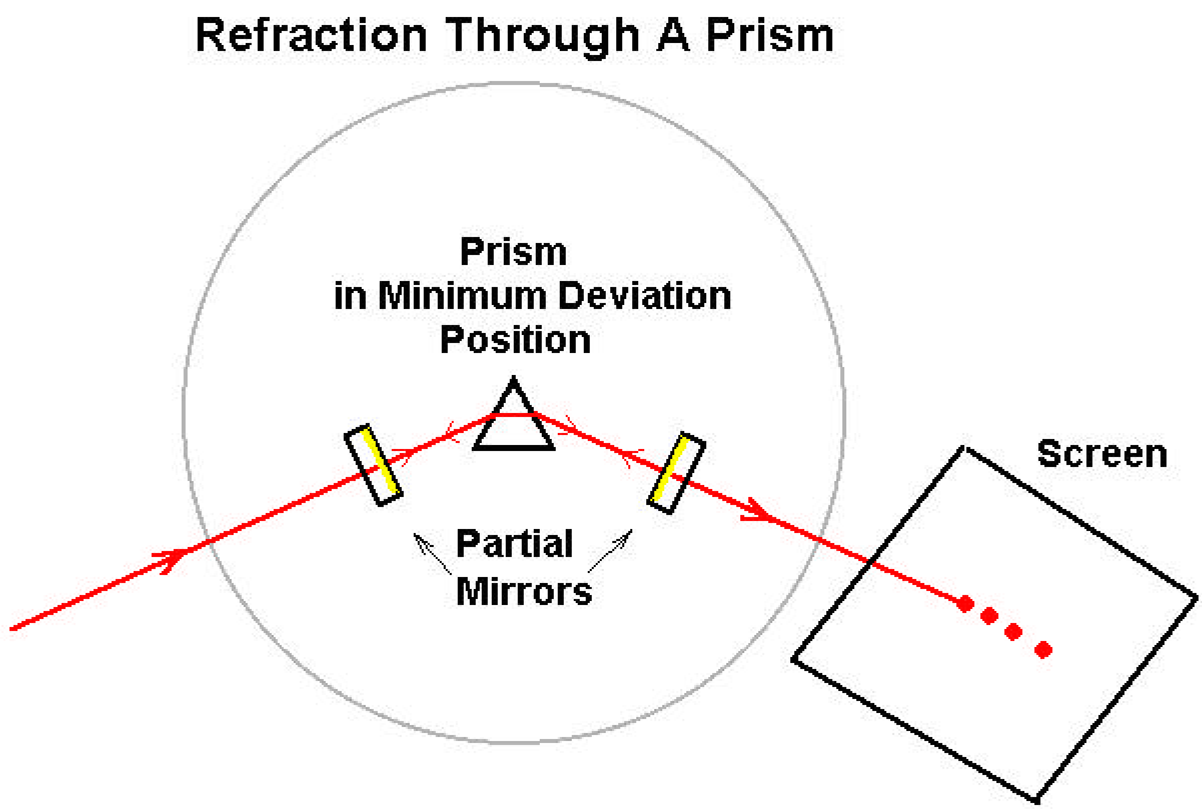


MODFICATIONS:

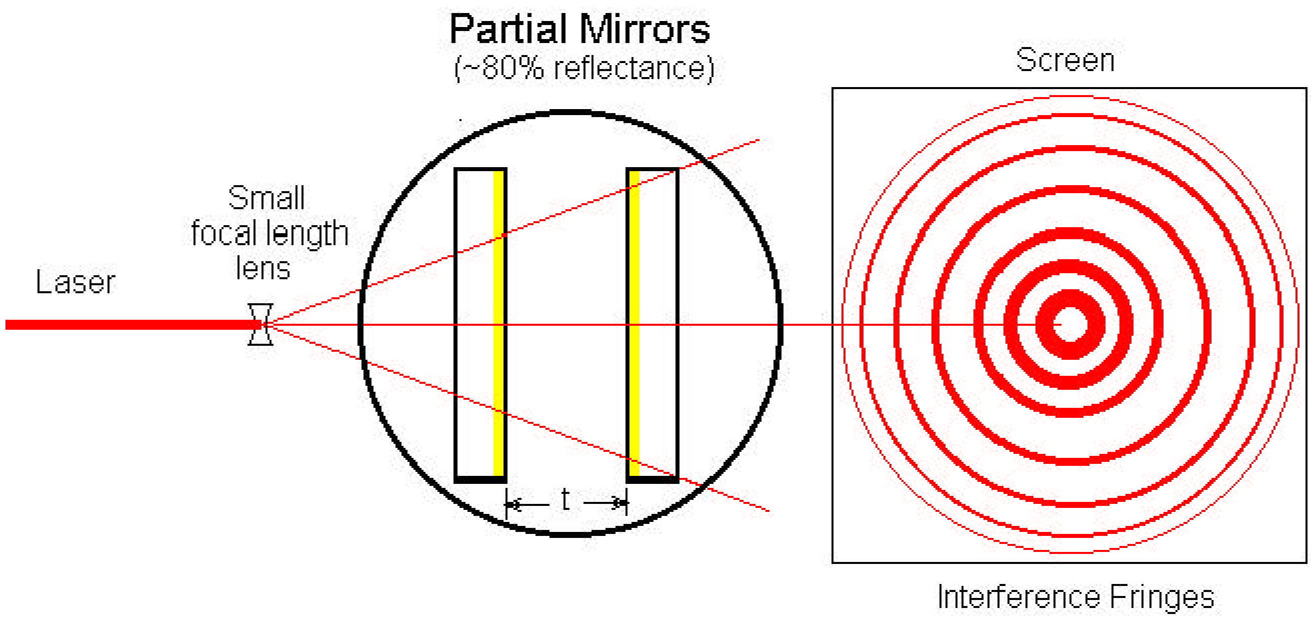
- Optically flat walls for vacuum chamber and repeated passage of the beam through the chamber to amplify the deflection



- Repeated passage of the laser beam through a prism inside the vacuum chamber



1. INTERFERENCE FRINGES DUE TO A PLANE PARALLEL AIR-FILM



The spacing between the partial mirrors = t

Refractive index of air = n

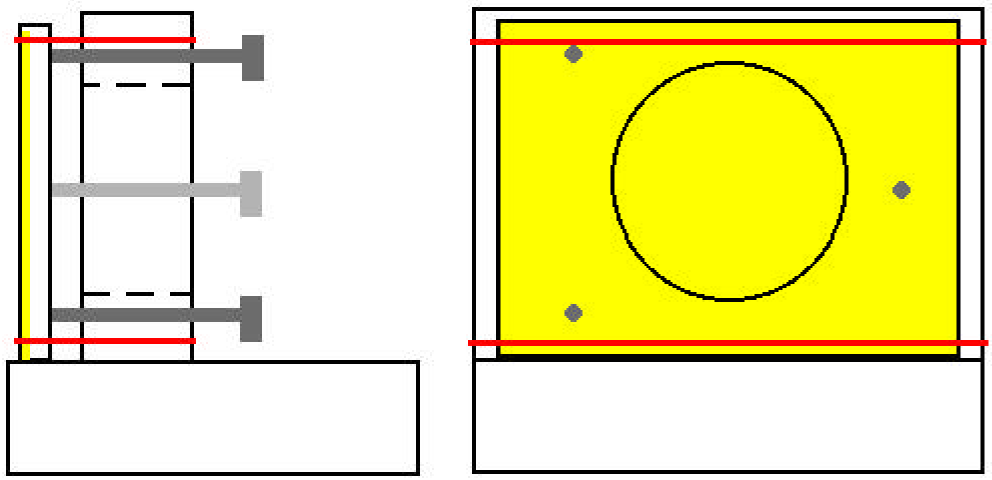
Optical path length between the mirrors with air = 2nt

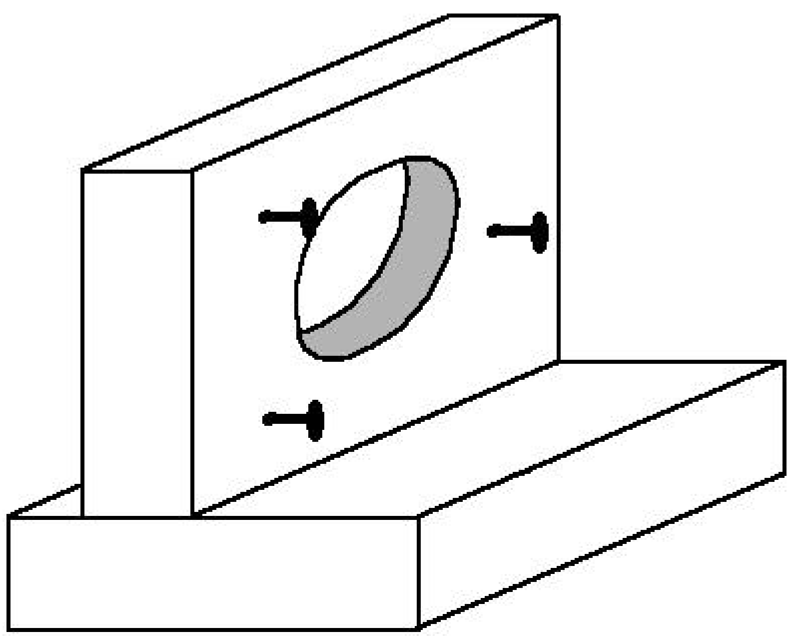
Optical path length between the mirrors with vacuum = 2t

Number of fringes moving into the center when air is pumped out = m

Thus,

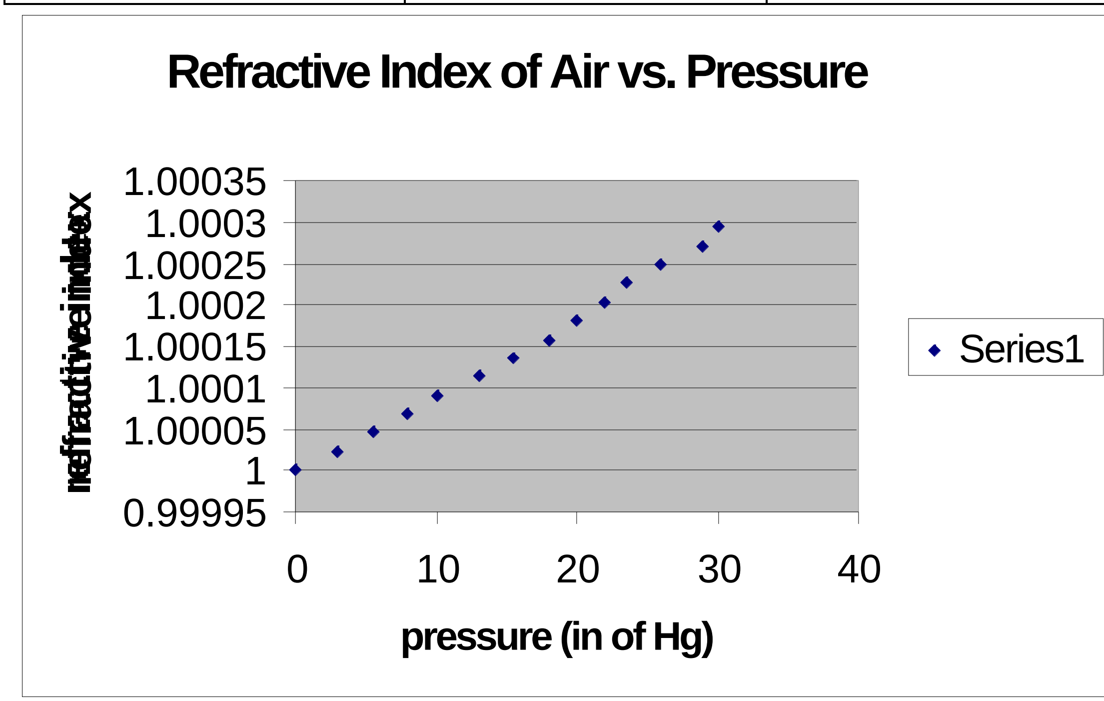
$$2t(n-1) = m\lambda$$





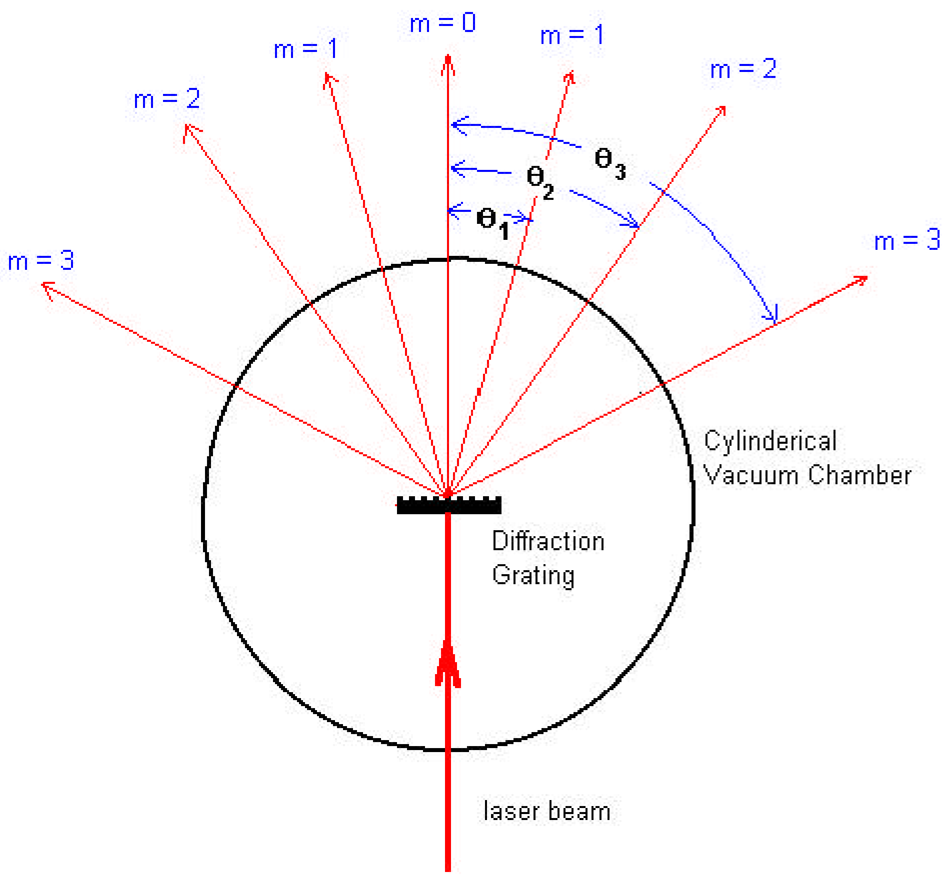
Refractive Index (n) of Air Using Air Film Between two Plane Parallel partial Mirrors

Pressure (in of Hg)	# of rings moved	Index of Refraction
0	0	1
3	1	1.0000226
5.5	2	1.0000452
8	3	1.0000678
10	4	1.0000904
13	5	1.000113
15.5	6	1.0001356
18	7	1.0001582
20	8	1.0001808
22	9	1.0002034
23.5	10	1.000226
26	11	1.0002486
29	12	1.0002712
30	13	1.0002938



2. DIFFRACTION GRATING EXPERIMENT

In this experiment a diffraction grating is placed in the center of the cylindrical vacuum chamber as shown in the figure below.



A laser beam is incident on the diffraction grating. The grating produces interference maxima on a screen. The angular position of a maximum (a bright spot on the screen) is given by the equation

$$d \sin\theta = m\lambda \qquad (1)$$

where

d = grating element = 1/N, (N = number of rulings per unit length)
θ = the angular position of the m^{th} order maximum
m = order of the maximum
λ = wavelength of light in air

The wavelength of light depends on the medium. Hence these maxima will form at slightly different locations when the air is pumped out of the chamber.

Let us make some sample calculations for the third order maximum with and without air inside the chamber.

For a typical grating N = 500 line/mm which give

$$d = 0.002 \text{ mm} = 2 \times 10^{-6} \text{ m}.$$

The wavelength of the He-Ne laser in air is

$$\lambda = 632.8 \text{ nm}.$$

The wavelength of the He-Ne laser in vacuum is

$$\lambda' = n\lambda = 1.00029 \times 632.8 = 632.9835 \text{ nm}.$$

Now with air at atmospheric pressure we have

$$d \sin\theta_3 = 3\lambda$$

$$2 \times 10^{-6} \sin\theta_3 = 3\,(632.8 \times 10^{-9})$$

Solving this equation we get $\theta_3 = 71.659^o$ (with atmospheric air).

With vacuum inside the chamber we have

$$d \sin\theta_3' = 3\lambda'$$

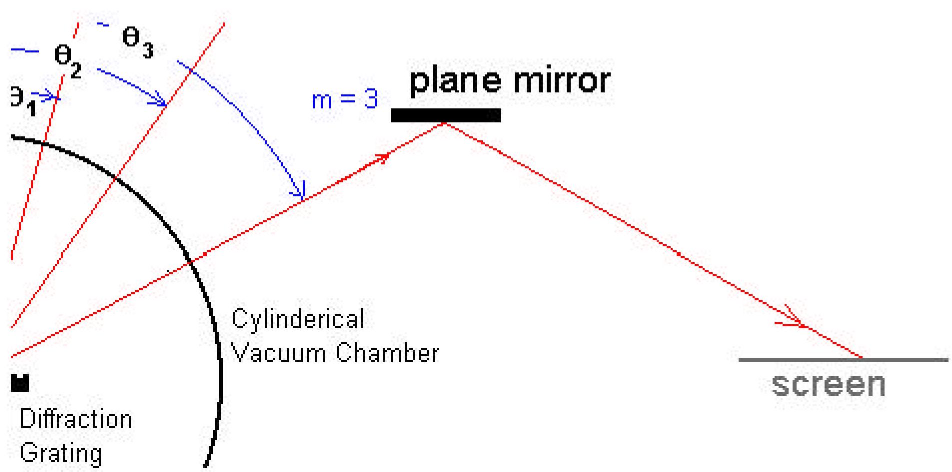
$$2 \times 10^{-6} \sin\theta_3' = 3\,(632.9835 \times 10^{-9})$$

Solving this equation we get $\theta_3' = 71.709^o$ (with vacuum).

This give a deflection of $\Delta\theta = \theta_3' - \theta_3 = 0.05^o = 8.73 \times 10^{-4}$ rad for the spot of order m =3. If the screen is Y = 5 meters from the grating the linear deflection

$$X = Y\Delta\theta = 4.4 \text{ mm}.$$

The linear deflection can be amplified by increasing Y directly or by using a plane mirror to reflect the spectrum to another screen as in the figure below.



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