Recording and reconstruction of holograms

Related topics

Dispersion, reflection, object beam, reference beam, real and virtual image, volume hologram, Lippmann-Bragg hologram, Bragg reflection.

Principle

The laser beam is divided into an object beam (illuminating beam) and a reference beam by using a beam splitter. The expanded illuminating beam is diffusely reflected by the surface of the object and then interferes with the reference beam in the plane of the hologram.

A laser light hologram is recorded and reconstructed by using the same laser light as for recording. In the second part of the experiment the object beam and the reference beam strike the hologram plate from opposite sides. This results in an interference pattern which is structured in the depth of the light-sensitive emulsion and forms semi-transparent silver layers or layers of different refractive index when the hologram is processed. For the purposes of reconstruction, the hologram can be illuminated with white light and viewed in reflection. The virtual image is due to Bragg reflection on the layers, and is monochromatic.

A white light reflection hologram is recorded by using laser light and reconstructed by using a point white light source at distance.

Equipment

Optical base plate in experiment case	08700.00	1
He/Ne Laser, 5 mW with holder	08701.00	1
Power supply for laser head 5 mW	08702.93	1
Magnetic foot for optical base plate	08710.00	6
Holder for diaphragm/beam splitter	08719.00	2
Adjusting support 35×35 mm	08711.00	2
Surface mirror 30×30 mm	08711.01	2
Surface mirror, large, d = 80 mm	08712.00	1
Beam splitter 1/1, non polarizing	08741.00	1
Object for holography	08749.00	1
Holographic plates, 20 pieces*	08746.00	1
Darkroom equipment for holography	08747.88	1

consisting of:
Plastic trays, 4 pcs.; Laboratory gloves, medium, 100 pcs.; Tray thermometer, offset, +40°C; Roller squeegee; Clamps, 2 pcs.; Film tongs, 2 pcs.; Darkroom lamp with green filter; Light bulb 230 V/15 W; Funnel; Narrow-necked bottles, 4 pcs.

Set of photographic chemicals	08746.88	1

Consisting of: Holographic developer; Stop bath; Wetting agent; Laminate; Paint

Bleaching chemicals:

Potassium dichromate, 250 g	30102.25	1
Sulphuric acid, 95-98%, 500 ml	30219.50	1

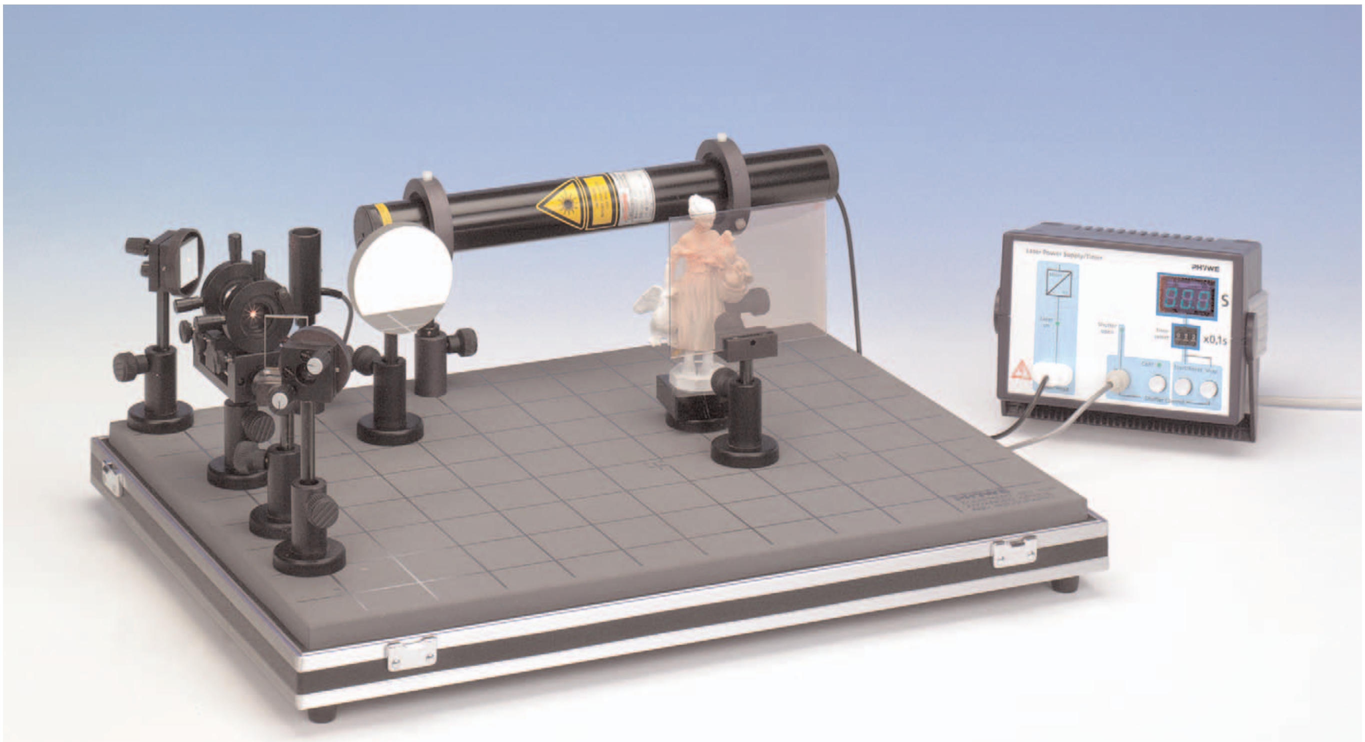
***Alternative:**

Holographic sheet film	08746.01	1
Glass plate, 120×120×2 mm	64819.00	2

Tasks

1. Record a laser light hologram and process it to get a phase hologram. Reconstruct it by verifying the virtual and the real image.
2. Record a white light reflection hologram and process it to get a phase hologram. Laminate it for reconstruction by a white light source.

Fig. 1: Experimental set-up for recording a transmission hologram.



Transmission hologram

– Perform the experimental set-up according to Fig. 7 The beam path height is 13 cm.
– Since this set-up is a *two beam arrangement* in which the reference and the object beams follow different paths after passing through the beam splitter **BS** [1,2], particular care must be taken to ensure the set-up's mechanical stability.
– Allow the laser to warm up for approximately one hour before beginning the experiment in order to avoid oscillations in the wavelength.
– The laser beam (initially without the **E20x** expansion system [1,4] is adjusted with the mirrors $\mathbf{M_1}$ [1,8] and $\mathbf{M_2}$ [1,1] in such a manner that the object **O** [10,5] is well illuminated. Then insert the beam splitter **BS** [1,2] (metallized side toward mirror $\mathbf{M_1}$), which splits the laser beam into the reference (R) and object beams (O). Half of the object beam, which has already been adjusted, passes through the splitter; whereas the other fraction is deflected to the large mirror $\mathbf{M_3}$ [4.5, 6.5]. This large mirror is now adjusted in such a manner that the beam strikes the centre of the hologram plate **H** [10,3] (or the holographic sheet film between the glass plates) at the height of the beam path.
– Now move the **E20x** expansion system [1,4] without the objective and the pinhole diaphragm, but with the adjusting diaphragms, into position. Align it in such a manner that the beam passes unimpeded through the adjusting diaphragms. Now replace these diaphragms with the objective and the pinhole diaphragm. Move the pinhole diaphragm toward the focal point of the objective. Initially ensure that a maximum of diffuse light is incident on the apertured diaphragm and subsequently, consider the expanded beam. Successively shift the positions of the objective and the pinhole diaphragm laterally while approaching the focal point in order that an expanded beam without diffraction phenomena is subsequently provided.
– If sheet film is used, the film is tightly pressed between two glass plates in the plate holder. To avoid undesirable interference phenomena and multiple reflection between the glass plates, it is advisable to press the upper edges of the glass plates together with an additional clamp or clip. Before exposing the film, wait approximately 1 to 2 minutes until the pressure and temperature equilibration between the sheet film and the glass plates has taken place.
– The photosensitive layer faces the object during the image-capture process.
– Immediately after removing a piece of film or a plate from the storage box, reclose the box.
– The exposure time of approximately 10 to 20 seconds is set on the laser power supply.
– The **development and bleaching** of the phase hologram is performed according to the procedure given below.
– The hologram can be reconstructed according to Fig. 7 if the object beam is blocked directly behind the mirror $\mathbf{M_2}$ with blackened cardboard.

Attention

Never look directly into the laser beam! The He/Ne laser has a power of 5 mW and can cause permanent damage to the retina. When tracing the path of the beam, only use absorbing or strongly diffusing materials.

Development and bleaching

Only phase holograms are dealt with in the following, because of their better appearance in reconstruction. Therefore the following agents have to be prepared before to process the photographic plates after exposure.

1) Developer
   Mix 100 ml of holographic developer with 400 ml of deionized water and keep the mixutre ready in one of the plastic dishes.
2) Stop-bath
   Mix 12 ml of stop-bath solution with 468 ml of deionized water and keep the mixture ready in a second plastic dish.
3) Bleaching
   Dissolve 5 g of potassium dichromate in 1000 ml of deionized water. Add 5 ml of concentrated sulphuric acid. Keep the solution ready in a third plastic dish.
   Caution: Never pour water into a vessel containing sulphuric acid.
4) Rinsing
   A fourth plastic dish is filled with deionized water to rinse the bleached holograms.
   The photographic plate is processed by developing it for two minutes. After a stop-bath of 30 seconds the plate is bleached for two minutes. Finally it is rinsed for about five minutes and dried.

Avoid all skin contact while working with the developing and bleaching agents. Always wear the recommended gloves. Before recording holograms, clean all the optical components by using lens-cleaning paper and acetone. Make sure that the base plate is in a rather vibration-free position.

Only work in green light in the laboratory.

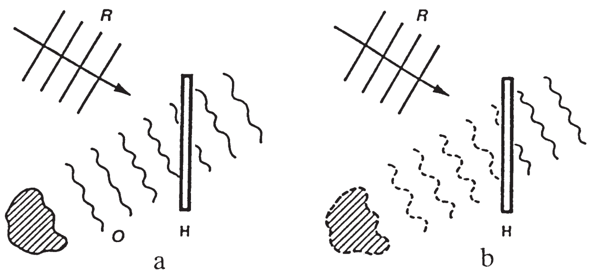
Theory and evaluation

In normal photography only the two-dimensional projection of a recorded three-dimensional object is obtained.
Holography supplies a truly three-dimensional image of the object when reconstruction is carried out. This can be done by storing the three-dimensional wave field emitted by the object using a coherent reference wave (coherent background) (Fig. 2).

The object wave and reference wave produce an interference pattern at the position of the hologram which is stored as optical density (amplitude hologram) or as a change in refractive index (phase hologram). When the developed hologram is illuminated by the same reference wave, the reconstructed object wave as was previously emitted from the actual object appears behind the hologram. The observer therefore sees the image where the object was previously situated. In qualitative terms this phenomenon can be explained as follows: the spherical wave emanating from a point on the object interferes with the (in the simplest case plane) reference wave (Fig. 3). The recorded interference pattern consists of concentric circles (Fresnel zone plate).

When reconstruction is carried out (Fig. 4), a plane wave is diffracted at the Fresnel zone plate. This creates, in addition to the light which passes through (0 = order diffraction), a divergent spherical wave (1st order diffraction) and a convergent

Fig. 2: The principle of holography:
interference of object wave **O** with coherent reference wave **R**. **H** is the hologram plate.
a) Recording b) Reconstruction



spherical wave (-1st order diffraction). Besides the virtual image at the original position of the object, there is also a real image on the other side of the hologram.

For the quantitative treatment of holography, the light source is described by a complex function.

$$E(x, y, z, t) = E_0(x, y, z)e^{i\varphi(x,y,z,t)} \quad (1)$$

The real part of this complex function is the electrical vector of the light wave.
Intensity I is obtained by time averaging (denoted by < >) and apart from a constant factor is:

$$I = \langle E \cdot E^* \rangle \quad (2)$$

A number of simplifying assumptions are made for the following calculations in order to reduce the calculating effort required and to emphasize the results which are of essential importance for holography. The following initial assumptions are firstly made:

- The time-dependent factor $e^{i\omega t}$ is equal for all waves and is therefore omitted, and it is also left out of the calculation of intensity as a result of averaging ($\omega = 2\pi f$, f = frequency).
- The hologram is regarded as an "area hologram" (i.e. thickness of photographic layer << length of light wave). It is regarded as being in the plane $z = 0$.

A far more complicated calculation for "volume holograms" leads to similar results.

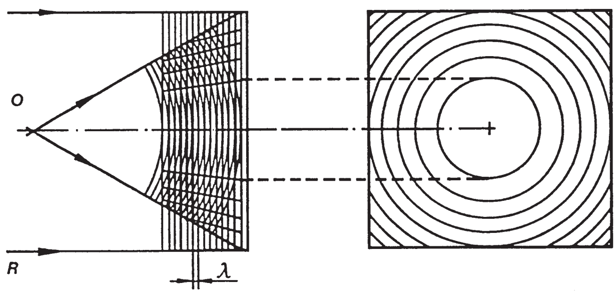
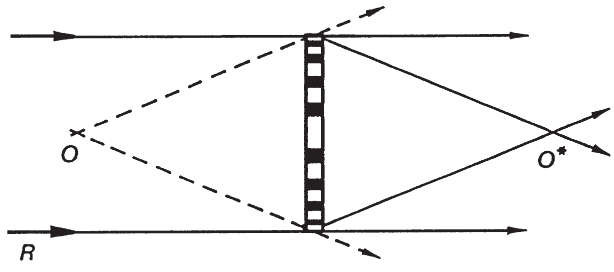


Fig. 3: Overlapping of a spherical wave emanating from **O** and a plane reference wave **R**.

Fig. 4: Reconstruction of the hologram recorded in accordance with Fig. 3.



Recording of holograms

Object wave **O** and reference wave **R** overlap in the plane of the hologram ($z = 0$) and supply a position-dependent interference pattern with intensity I.

$$O = O_O(x, y)\, e^{i\psi(x,y)} \quad (3)$$

$$R = R_O(x, y)\, e^{i\varphi(x,y)} \quad (4)$$

$$\begin{aligned} I &= (O+R)\cdot(O+R)^* \\ &= OO^* + RR^* + OR^* + RO^* \\ &= I_O + I_R + O_O R_O e^{i(\psi-\varphi)} + O_O R_O e^{i(-\psi+\varphi)} \end{aligned} \quad (5)$$

The developed hologram then has a (complex) position-dependent transmittance:

$$\tau(x,y) = T(x,y)\, e^{i\varphi(x,y)} \quad (6)$$

If the phase $\varphi(x,y)$ = const., we speak of an amplitude hologram (optical density vixed after developing). On the other hand, if $T(x,y)$ = const. (by bleaching the hologram) we have a phase hologram.

The transmittance is dependent on energy density W, the product of light intensity I and exposure time t_B (Fig. 5).
The exposure time and also the ratio of the intensities of the object and reference waves should be chosen so that the transmittance is in the linear range of the characteristic shown in Fig. 5, e.g. between W_1 and W_2 respectively between W_3 and W_4.

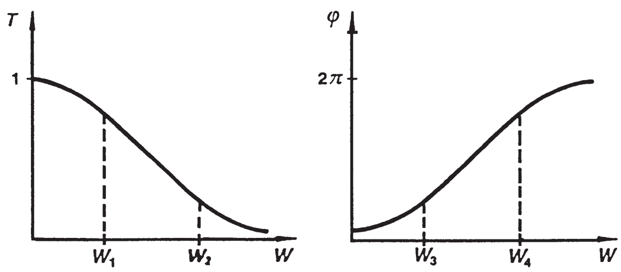


Fig. 5: Amplitude and phase transmittance in relation to energy density W for amplitude and phase holograms.

We therefore assume for the transmission of the holograms:

– the intensity of reference wave I_R and the exposure time are chosen so that the transmittance is in the linear range of the characteristic.
– $I_O << I_R$ for the intensity of object wave I_O, so that intensity modulation remains in the linear range of the characteristic.

Under these simplifying conditions we obtains for an amplitude hologram (φ = const.):

$$\tau(x,y) = a\,T_O + b\,I(x,y) \qquad (7)$$
$$a, b = \text{const.}$$

and for phase hologram (T = const.):

$$\tau(x,y) = \alpha \cdot e^{i\varphi(x,y)}$$
$$\approx \alpha\,(1 + i\varphi_O + i\,\beta\,I(x,y)) \qquad (8)$$
$$\alpha, \beta = \text{const.}$$

the series

$$e^{i\varphi} = \sum_n \frac{i^n}{n!}\varphi^n$$

for $I_O << I_R$ being interrupted after the first term. The relationship between τ und I is also approximately linear for phase holograms. The factor i means that the reconstruction wave additionally undergoes a constant phase shift on passing through the hologram.

Reconstruction of a hologram

For the purpose of reconstruction the hologram is generally illuminated again by reference wave **R**. The wave front appearing behind the hologram (according to (7) and (5)) contains the following:

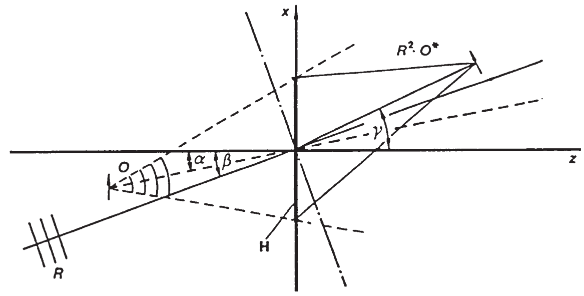
$$H = \tau \cdot R \qquad (9)$$
$$= (aT_O + bI_O + bI_R) \cdot R \quad \text{reference wave}$$
$$+\, b\,I_R \cdot O \quad \text{object wave (virtual image)}$$
$$+\, b\,R^2 \cdot O^* \quad \text{conjugate object wave (real image)}$$

The first term essentially reproduces the reference wave, slightly modified by I_O.
The second term describes the object wave, i.e. it appears to the observer as if the object were still at the same point as for the recording. I_R is constant and the image is therefore undistorted provided – **R** a plane wave.
The third term supplies a real image, known as a cunjugate image, because O* has the negative phase -φ of O.
A divergent light beam becomes convergent.

The real image

The position of the real image is studied in greater detail in the following example. Let the reference wave be a plane wave which hits the hologram at an angle β The object is at angle α when the recording is made (Fig. 6).

Fig. 6: Position of image points with oblique reference wave.



For small angles α and β (α, β << 90°) the virtual image is in mirror symmetry to the real image in relation to the dash-dot line which is vertical to the direction of the reference wave.

The following relationship is obtained by calculation: Reference wave in the hologram plane (z = 0)

$$R = R_O\, e^{i k x \sin\beta} \qquad (10)$$

Object wave in the hologram plane

$$O = O'\, e^{i k x \sin\alpha} \qquad (11)$$

where O' = object wave at angle α = 0.

In reconstruction we obtain for the conjugate image

$$R^2 \cdot O^* = R_O^2 \cdot O'^* \cdot e^{i k x (2\sin\beta - \sin\alpha)} \qquad (12)$$

it therefore appears at angle γ with

$$\sin\gamma = 2\sin\beta - \sin\alpha \qquad (13)$$

No real image exists at particular angles α and β. If

$$2\sin\beta - \sin\alpha > 1 \qquad (14)$$

there is no solution for γ. This is already the case at α = 0° for angles of the reference beam of β > 30°.

Fig. 7: Setup for recording and reconstruction of a transmission hologram.

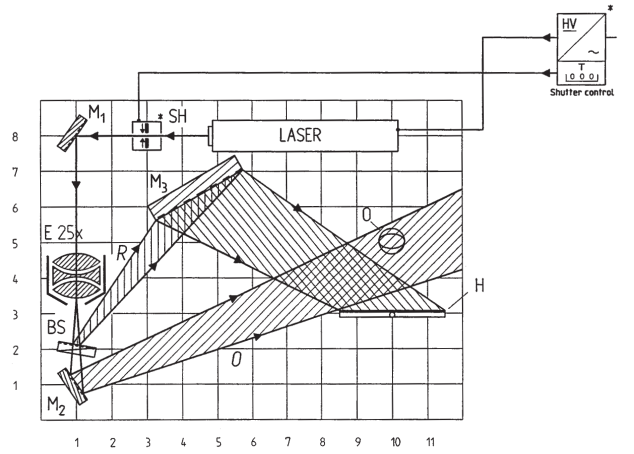
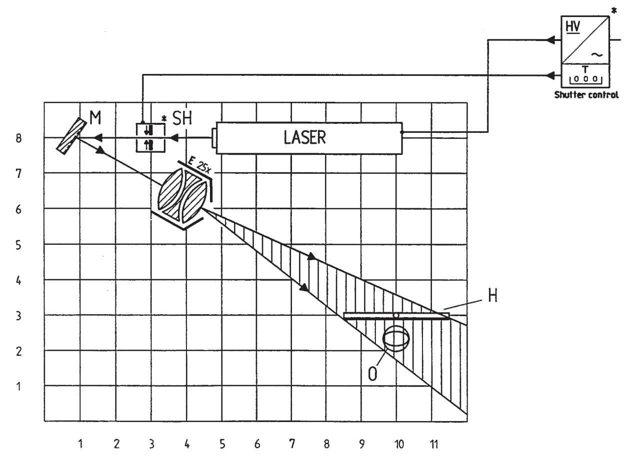


Fig. 8: Setup for recording a white light reflection hologram.



Reconstruction of hologram with R*

If it is the real image which is of particular interest in reconstruction, e.g. in producing hologram copies of a master hologram, the hologram is reconstructed with R*, i.e. the hologram plate is illuminated from precisely the opposite direction. Instead of (9) we then obtain:

$$\begin{aligned} H &= \tau R^* \quad (15) \\ &= (aT_O + bI_O + bI_R) R^* \\ &\quad + b R^2 O \\ &\quad + bI_R O^* \end{aligned}$$

The observer looks in the direction in which the virtual image appears in reconstruction with **R**. The real image is at the corresponding position *in front* of the hologram plate.

For reconstruction the processed photographic plate is brought back into the same position as for recording and illuminated with the same laser light. The object is eliminated and the object beam is blocked directly behind the mirror $\mathbf{M_2}$ with blackened cardboard. For the observer in front of the photographic plate a clear virtual image is created in the position where the object has proviously been. Turning the photographic plate by 180° allows the observer to see the real image in front of the plate (see theory for reconstruction with R*).

Recording a white light reflection hologram

The experiment is setup as shown in Fig. 8. The photographic plate (or film) is fixed on the holder and put into the position shown in Fig. 8 [10, 3]. The object is positioned directly behind the photographic plate. The beam expanding system **E20x** is introduced and adjusted as discribed before. The exposure time is approximately 2 seconds.
After processing and drying a dark laminate is applied to the emulsion layer of the photographic plate with the squeezing roller.
For the reconstruction of the hologram it is sufficient to have a point white light source emitting a parallel beam, e.g. a halogen spot light at 1 m distance or more or even sunlight. The best image quality is achieved if the hologram is illuminated from the same side and at the same angle as the reference beam during recording. From the continious white light spectrum only one wavelength (here the red light of the He/Ne laser) is filtered out for the reconstruction while all the others are removed. If the emulsion layer has shrunk, the colour of the reconstructed image will shift towards shorter wavelengths while expansion will cause a shift towards longer wavelengths.

Interféromètre de Jamin

Mesure de l'indice de réfraction d'un gaz

L'interféromètre de Jamin est un dispositif optique interférentiel qui se base sur la séparation d'amplitude en deux faisceaux d'un faisceau provenant d'une source lumineuse étendue. Il est constitué de deux plaques de verre épaisses dont les faces extérieures sont recouvertes d'une couche réfléchissante argentée. La figure ci-dessous illustre le chemin des rayons lumineux interférant au point d'observation (P).

Cette expérience permet de mesurer précisément l'indice de réfraction d'un gaz en observant le défilement des franges brillantes de la figure d'interférence lorsqu'un des deux tubes est progressivement rempli par un gaz tout en maintenant le vide dans l'autre tube. Le principe de la mesure consiste à déterminer la variation de l'indice de réfraction lors d'une variation de pression lorsque le tube est lentement rempli de gaz. Il a été établi que la différence entre l'indice de réfraction du gaz et celui du vide est proportionnelle à la polarisabilité atomique ou moléculaire du gaz et à sa densité à travers la relation de Lorentz-Lorenz ; si le gaz suit la loi des gaz parfaits, cette différence est proportionnelle à la pression et inversement proportionnelle à la température.

<u>Objectifs du travail :</u>

1. Comprendre et expliquer la distribution d'intensité à la sortie de l'interféromètre lorsque les faces des plaques de verre sont parfaitement parallèles.
2. Décrire la formation d'une figure d'interférence lorsque l'une des plaques de verre est légèrement inclinée de sa position verticale (vous pouvez décrire la situation symétrique lorsque les deux plaques sont inclinées dans des directions opposées et que les angles d'inclinaison sont égaux formant ainsi un coin en forme de triangle).
3. Décrire le déplacement de la figure d'interférence lorsque la différence de chemins optiques entre les deux faisceaux varie d'une valeur donnée. Evaluer le nombre de franges brillantes défilant à travers un repère fixe lorsque le gaz contenu dans l'un des deux tubes est entièrement évacué (la longueur du tube est de 200 mm).
4. Mesurer la variation d'indice de réfraction des gaz à disposition en fonction de la pression. Corriger vos valeurs pour obtenir l'indice de réfraction du gaz dans les conditions standards de pression (760 Torr) et de température (0 °C). Faites une comparaison critique de vos résultats avec les valeurs tabulées dans un Handbook de chimie et expliquez les tendances observées en vous référant à la position des éléments dans le tableau périodique de Mendeleïev. Notez que l'indice de réfraction est une grandeur physique possédant une grande dispersion spectrale.

Daniel Oberli

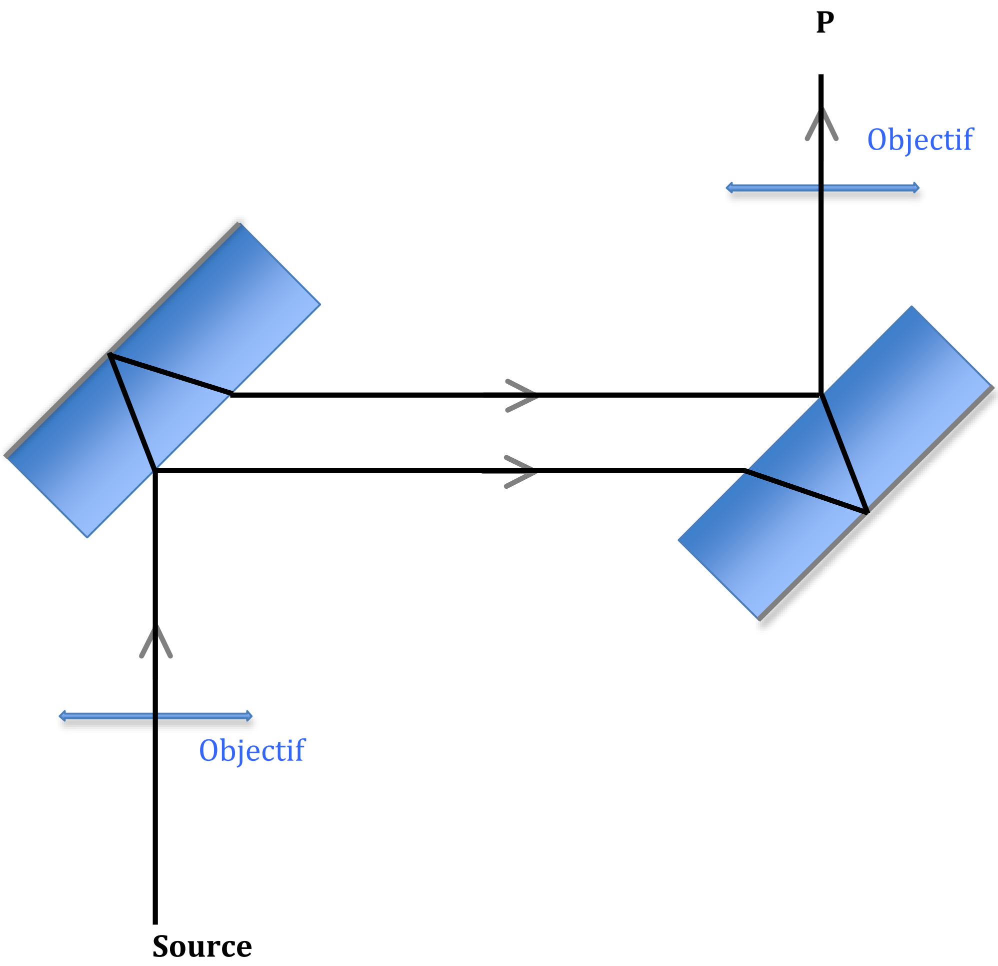


Figure : Schéma illustrant le trajet des rayons lumineux interférant sur un écran placé en position (P). Les rayons lumineux parasites n'ont pas été représentés sur le schéma.

Bibliographie :

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- M. Born et E. Wolf, Principles of Optics, 7 ième édition, Chapter II (Cambridge University Press, 1999).
- C. Kittel, Introduction to Solid State Physics, 8 ième édition, (publié par J. Wiley, New Jersey, 2005).
- Table des indices de réfraction: https://refractiveindex.info

Recommandation :

Avant d'enclencher la pompe à vide, assurez-vous toujours que les cylindres de gaz soient tous fermés hermétiquement et que la vanne de remise à l'air soit également fermée!