Democratic and People's Republic of Algerian
University of 20 August 1955-Skikda
Faculty of Science
Department of Physics

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Geometric and physical optics courses and exercises

Presented by :

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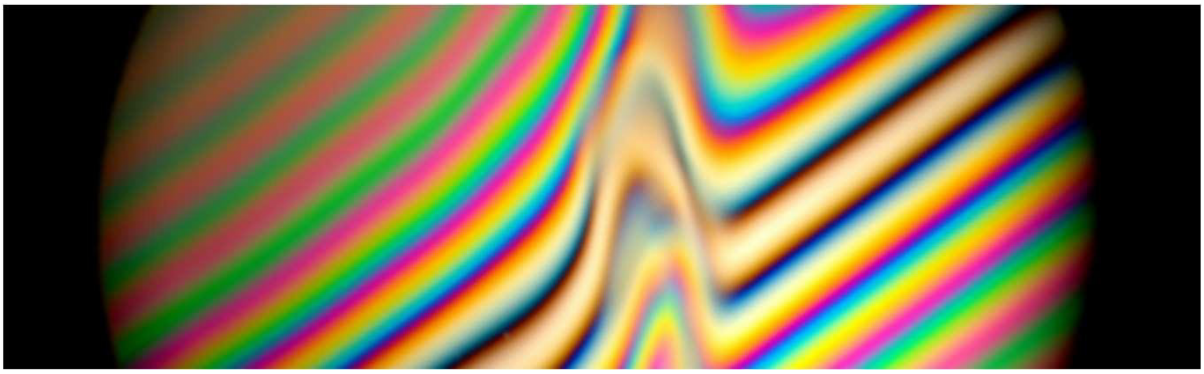
For students of 2nd LMD physics speciality and 1rt

Mater physics of material speciality



Academic year : 2024/2025

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Chapter 2 : Laws of reflection and refraction

Chapter 3 : The prism

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Chapter 6 : Thin lens

Chapter 7 : Wave optics

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Chapter 9: Polarization of light

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Geometric and physical optics courses and exercises:

Programme officiel de la matière :

Chapitre 1 : Optique géométrique

1.1- Principes et lois de l'optique géométrique

1.2- Notions de réfringence

1.3- Lois de Snell-Descartes, principe de Fermat et construction de Huygens

1.4- Miroirs sphériques et miroirs plans: formule de position et construction d'images

1.5- Dioptre plan et dioptre sphérique: formule de conjugaison, grandissement, notions de stigmatisme et construction d'images

1.6- Prisme : formules, déviation et dispersion

1.7- Lentilles minces : formules de position et construction d'images

1.8- Instruments optiques : œil, loupe, microscope, …

Chapitre 2 : Optique ondulatoire

2.1- Généralités

2.2- Principe de superposition de deux ondes monochromatiques de même fréquence

2.3- Conditions d'interférence : Notion de cohérence

2.4- Interférences de deux ondes cohérentes

2.5- Interférences à ondes multiples : Interféromètres de Michelson et de Pérot-Fabry

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3.1- Diffraction de Fresnel et diffraction de Fraunhoffer

3.2- Diffraction par une ouverture rectangulaire et diffraction par une ouverture circulaire

Chapter 1 : Geometrical optics

I.1. Brief history:

Key optical dates:

1657: Fermat imposes on the mechanical explanation of Descartes, and explains the refraction and reflection with its principle (Principle of minimal time), he concludes the opposite of Descartes, that the light propagates at a speed which decreases with increasing density of the medium.

1678: Hygens prepares his wave theory which explains with it the reflection, refraction and rectilinear propagation of light (he introduces the notion of polarization of light).

1815: Fresnel considers light as transverse waves, he explains with a great succubus the phenomena of diffraction and interference with his wave theory.

1864: Maxwell denounced his equations, existence of electromagnetic waves that propagate in the vacuum with a speed of $\frac{1}{\sqrt{u_0\,\xi_0}}$, light and heat propagate in space as electromagnetic waves.

1905: Einstein introduces the expression of the photon that constitutes light in order to apply the electronic effect.

1948: Gabor invented holography.

1970: The exploitation of optical fibres.

I.2. Propagation of light:

In vacuum, current observations lead us to consider the vacuum as a homogeneous and isotropic medium; this means the propagation properties of electromagnetic waves (and thus light). This property is announced in the form of the principle of rectilinear propagation: in vacuum, light propagates in a straight line isotropically with a constant speed C.

$$t = \frac{AB}{C}$$

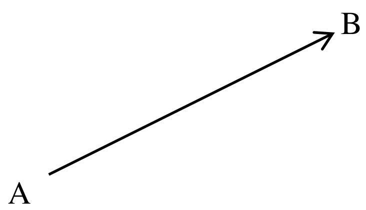


Figure I.1. Linear propagation of lighr.

I.3. In material environments:

In an absolute index medium n (n ≥ 1), the frequency of a monochromatic electromagnetic wave $\boldsymbol{\nu}$ is related to its wavelength λ by the relation**:**

$$\boldsymbol{\nu} = \frac{V}{\lambda}$$

With : V= $\frac{C}{n}$

V: is the speed of the electromagnetic wave in the medium, it is always less or equal to C

The index n depends on the wavelength of light passing through the medium, generally speaking, when the wavelength decreases, the index increases; this phenomenon is called optical dispersion which can be quantified by Cauchy's law:

$$n(\lambda) = A_1 + \frac{B_1}{\lambda^2}$$

Other laws are used to calculate indices such as the Sellmeier law given by:

$$n^2(\lambda) = 1 + a + \frac{b}{\lambda^2 - c}$$

Where :

a, b, c are also constants, the latter is often used to calculate indices of glass or crystals.

Tableau I.1. Refractive index of water and ordinary glass the three subdivisions of optics

Wavelenght λ(μm)	0,586 (bleu streak de H_2)	0.589 (yellow streak D of sodium)	0,556 (streak H de l'H_2)
Water	1,3371	1,330	1,3311
Glass	1,5157	1,5100	1,5076

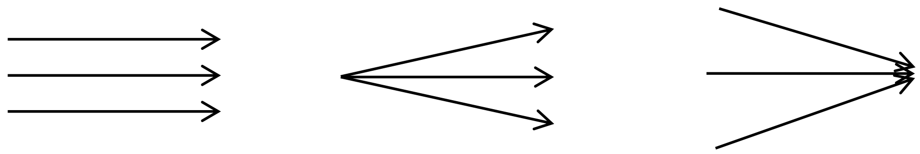
Tableau I.2. Comparaison between different modes of optics

	Optical geometric	**Wave optics**	**Optical quantum**
Validity	Large system dimensions in front of the wave length that spreads	System dimensions of the order of the wavelength that propagates	System dimensions small in front of the wave length that spreads
Concern	Light rays reflection, refraction dispersion, photometry.	Light wave electric vibration interference, diffraction diffusion,	Atomic process vibrations, electromagnetism,

		polarization.	electric and magnetic field
appearance	18^{th} century	19^{th} century	20^{th} century

I.4. The place of geometric optics and its concerns:

When the sources are placed at great distances, the rays are almost parallel, they are said to form a beam of parallel rays and that the beam is cylindrical. In general, a beam may have less different spatial configurations.



Parallel beam Diverging beam Converging beam

Figure I.2. Different beam sizes

I.5. Property of the light beam:

I.5.1. Linear propagation of light:

There is rectilinear propagation of light in a homogeneous medium. Propagation in a heterogeneous medium leads to spatial fluctuations if the heterogeneity is not regular. The phenomenon is easily observed above a flame: we see the objects located behind the flame. The observed spatio-temporal fluctuations are due in this case to an irregular and rapidly variable distribution of the air index, which is the seat of strong turbulence. Turbulence plays a particularly important and harmful role in astronomical observation instruments where it is accentuated by the magnifications of the apparatus. Even slight differences in the telescope tube (and in the atmosphere) can significantly alter the quality of images.

I.5.2. Independence of light rays:

We will then assume that the path of different light rays passing through an optical instrument are independent: this is the hypothesis of the independence of the light rays.

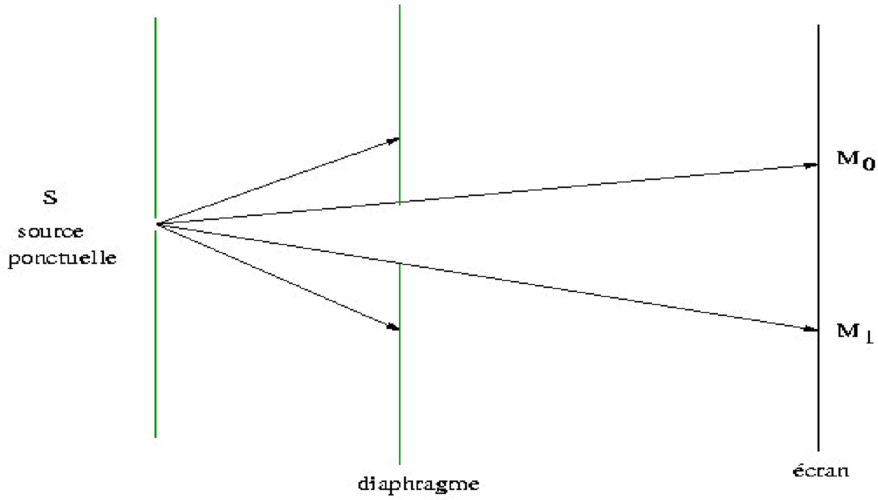


Figure I.3. Independence of light rays

By reducing the aperture of the diaphragm, the SM_1 ray can be removed. In general, there are no changes in M_0 which shows that, in this case, SM_0 is independent of SM_1.

In fact, if the source S is very fine (laser for example) and if you reduce the aperture too much, the illumination in M_0 may be modified. This is the phenomenon of diffraction. There are therefore special circumstances (which constitute the field of physical optics) where instead of being independent light rays can interfere with each other. This possibility is outside the framework of geometric optics where we assume the independence of light rays as a fundamental hypothesis.

I.5.3. Reverse return principle:

Experience shows that in a transparent, isotropic (homogeneous or not) medium the path of light is independent of its direction.

I.5.4. The object of geometric optics:

The object of geometric optics is therefore to study the path of light rays in transparent media. We will limit our study to the case of homogeneous media separated by diopters or limited by mirrors. In these environments, the light travels in a straight line.

In order to determine the path of a ray of light, we must state the laws that govern the behavior of a ray on the surface of a diopter or mirror. These laws, known as the Snell-Descartes laws, are the subject of the next chapter.

Chapter II: Laws of reflection and refraction

II.1. From the Fermat principle to the laws of Snell-Descartes:

II.1.1. Principe of Fermat:

An elegant method for studying the path of a light ray refracted and/or reflected by a repair surface called diopter was suggested by Pierre de Fermat at 1658, it is concerned with propagation time rather than the geometric path followed by light and thus defines a principle of shorter time.

To go from one to another, the light follows, among all possible trajectories those whose travel time is extremal.

II.1.2. Forme générale du principe de Fermat:

Either dl : elementary displacement of the geometric path from A to C

n : refractive index of the medium (variable).

The length travelled is: $dt = \frac{dl}{V} = n(l).\frac{dl}{C}$

$$\Rightarrow t = \frac{1}{C}\int_A^C n(l).dl = \frac{L_{AC}}{C}$$

$L_{AC} = \int_A^C n(l).dl$, the optical path from A to C

II.1.3. Reflection on a mirror:

Were: A $(x_A\ ,o); C(x_C\ ,x_C\ ); B(o,y)$

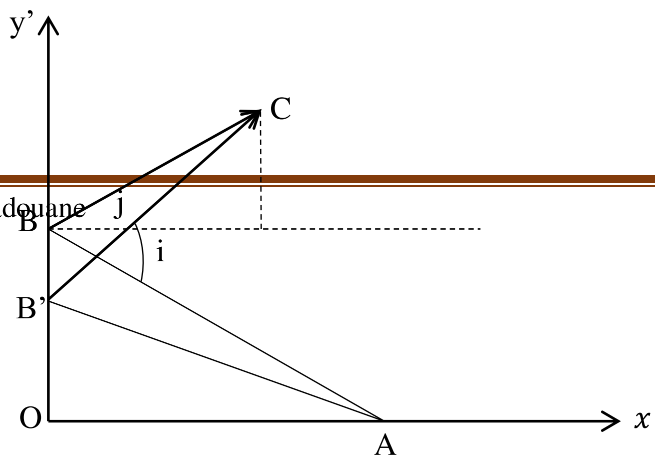


Figure II.1. Fermat's principle for reflection

$Ab = \sqrt{x_A^2 + y^2}\,,\, BC = \sqrt{x_c^2 + (y_c - y)^2}$

We have :

$$\sin i = \frac{y}{AB}\ ;\ \sin j = \frac{y_c - y}{BC}$$

$$t = \frac{AB+BC}{V} = \frac{\sqrt{x_A^2 + y^2} + \sqrt{x_c^2 + (y_c - y)^2}}{V}$$

$$\frac{dt}{dy} = \frac{1}{V}\left[\frac{y}{\sqrt{x_A^2 + y^2}} - \frac{(y_c - y)}{\sqrt{x_c^2 + (y_c - y)^2}}\right]$$

Thus :

$$\frac{dt}{dy} = 0 \Rightarrow \frac{y}{\sqrt{x_A^2+y^2}} = \frac{y}{AB} = \frac{(y_c-y)}{\sqrt{x_c^2+(y_c-y)^2}} = \frac{(y_c-y)}{bc}$$

$$\Rightarrow \quad \sin i = \sin j \Rightarrow \quad i = j$$

All incidence and reflection angles are determined to be equal $\Rightarrow$ This is called the law of reflection or first law of Snell Descartes.

II.1.4. Transmission of a light beam:

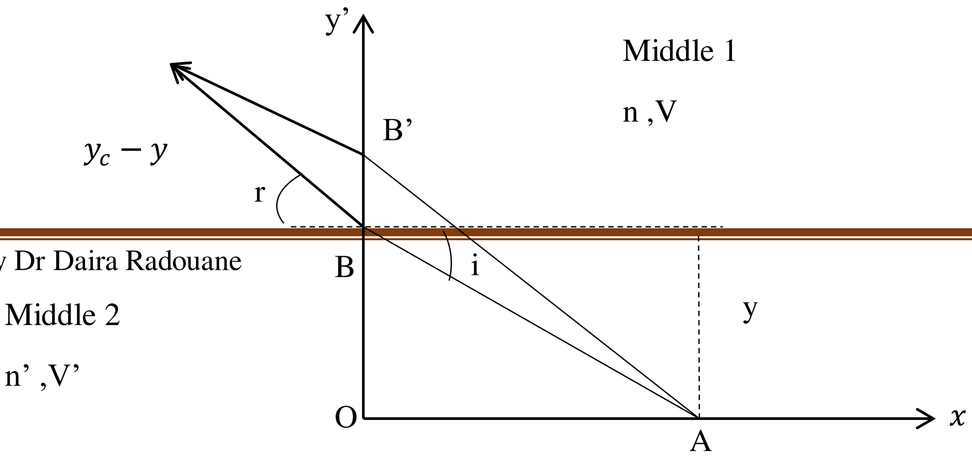


Figure II.2. Fermat principle for refraction

$$sin\, i = \frac{y}{AB}\ ; sin\, r = \frac{y_c - y}{BC}$$

$$t = \frac{AB}{V} = \frac{BC}{V'} = \frac{\sqrt{x_c^2 + y^2}}{V} = \frac{\sqrt{x_c^2 + (y_c - y)^2}}{V'}$$

$$\Rightarrow \frac{dt}{dy} = \frac{1}{V}\frac{y}{AB} + \frac{1}{Vi}\frac{y_c - y}{BC} = 0$$

$$\frac{1}{V}\frac{y}{AB} = \frac{1}{V\prime}\frac{y_c - y}{BC} \Rightarrow \frac{1}{V}\ sin\ \mathrm{i} = \frac{1}{V\prime}\ sin\ r$$

$$\Rightarrow n\ sin\ i = n' sinr\ it\ is\ the\ second\ law\ of\ Smell\ Descales$$

II.2. Spread to a more refractory environment:

II.2.1. Limit refraction:

If light passes from a medium (1) less refracting to a medium (2) more refracting, that is to say if n < n', according to the 3rd law of Descartes we have:

$$sini' = \frac{n}{n'} sini \rightarrow sini' < sini \rightarrow i' < i$$

because the two angles are acute and of the same sign figure II.3

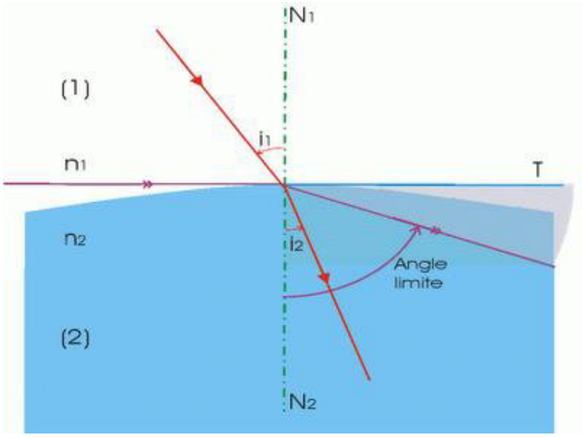


Figure II.3. Limit refraction on a diopter

Any incident ray A_1I corresponds to a refracted ray IA_2. The refracted ray approaches normal by passing through the more refracting medium. For the flush incidence, the incident ray is practically tangent to the surface of the diopter. When i1 varies between $\frac{-\pi}{2}$ to $\frac{\pi}{2}$, i' varies between the values - l and + l.

$$nsini = n'sinl \rightarrow sinl = \frac{n}{n'}$$

Remark:

If the medium (1) is air and if n is the relative index of the medium (2) with respect to air, the limit angle definition formula becomes simply:

Air/medium limit refractive angle: $sinl = \frac{1}{n}$

To study the variations of i' in function of i, it is sufficient to differentiate Descartes' 2nd law:

$$n.sini = n'.sini' \rightarrow n.considi = n'cosi'di' \rightarrow \frac{di'}{di} = \frac{n.cosi}{n'.cosi\prime}$$

II.2.2. Total reflection:

If the light passes from a more refractive medium (1) to a less refractive medium (2), the refracted ray moves away from the normal. The angle i' becomes equal to $\frac{\pi}{2}$, if the angle i takes the value l' such that:

$$nsinl' = n'sin\frac{\pi}{2} \rightarrow sinl' = \frac{n'}{n}$$

l' : is the limit refractive angle.

According to the inverse return principle of light l' or less than - l cannot be refracted: they are subjected to a total reflection and the separation surface of the two media then behaves as a perfect mirror.

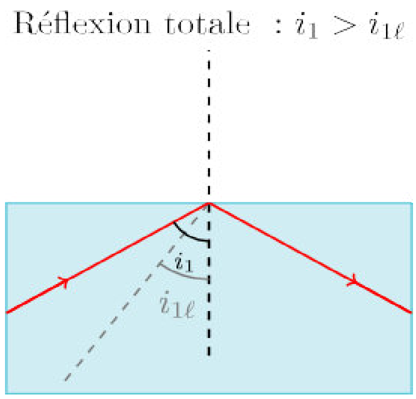


Figure II.4. Total reflection on a diopter

Chapter III : The prism

III.1. Definition :

A prism, often made of glass, is a transparent and homogeneous homogeneous medium, limited by two non-parallel plane diopters, called the input and output faces of the prism characterized by an angle A. Finally, we call base of the prism, the third face, whose edges are generally parallel to the edge.

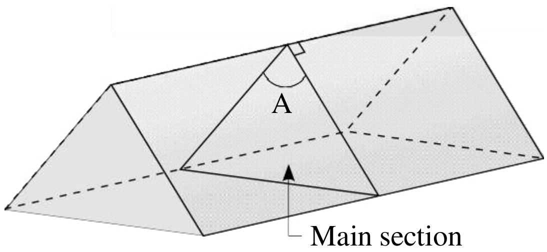


Figure III.1: Representation of the angle prism A in space.

The plane formed by the incident ray and the normal on the entry face of the prism to the plane is called the incidence plane.

III.2. Influence of a prism on the walk of a ray:

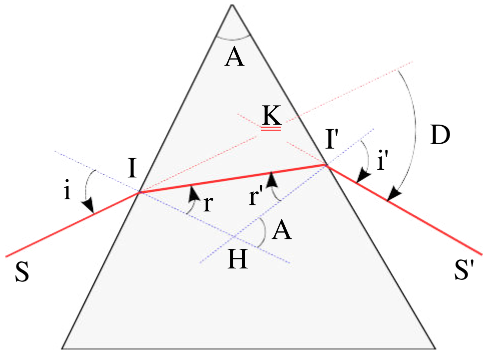


Figure III.2. Representation of the walk of a ray in a prism.

The formulas of an angle prism A:

$$n_0 \sin i = n \sin r$$

$$n \sin r' = n_0 \sin i'$$

In the triangle I I' H:

$$r + r' = A$$

The path of the beam, shown in figure III.2, shows that there is generally a deviation of angle D between the incident and outgoing rays of the prism. It can be determined analytically by examining the triangle I I’ k, or one to the relation:

$$(i + r) + (i' - r') + \pi - D = \pi, \qquad soit\ D = i + i' - A,$$

Because :

$$r + r' = A$$

It is the fourth formula of the prism.

III.3. Condition of emergence:

III.3.1. Condition on the angle at top A:

The intermediate ray II' refracts into I' if: $r' \leq \lambda \rightarrow A - r \leq \lambda \ ou \ A \leq \lambda + r$

$$r \leq \lambda \ means \ A \leq 2\lambda$$

III.3.2. Condition on angle of incidence i:

The angle of emergence i' does not exist if the radius reaches the second face at an excessive angle, exceeding the limit angle, more generally:

$$r_{1lim} = A - \arcsin(\frac{n_0}{n}) \text{ et } i_{1lim} = \arcsin\left[\frac{n}{n_0}\sin\left(A - \arcsin\left(\frac{n_0}{n}\right)\right)\right]$$

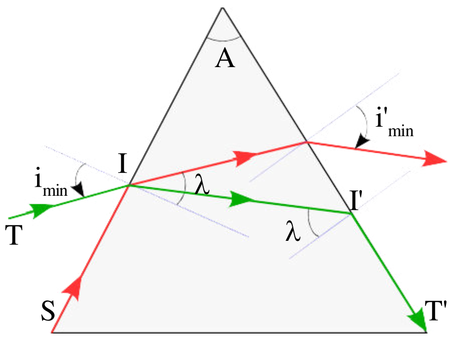


Figure III.3. Condition of incident ray surges on the prism.

III.4. Minimal deviation minimal:

For some value of i corresponding to an extremal deviation, we have therefore:

$$dD = di + di' = 0 \text{ soit } di = -di'$$

thus from :

$$A = r + r'$$

Are obtained :

$$dr = dr'$$

Finally, of the two relations of Snell Descartes:

$$\begin{cases} n_0 \ \sin i = n \sin r \\ n \sin r' = n_0 sini' \end{cases}$$

$$n_0 \cos i \, di = n \cos r \, dr \ ; \ n \cos r' \, dr' = n_0 \cos i' \, di'$$

We find:

$$\cos i \cos r' = \cos i' \cos r$$

We also have:

$$D = i + i' - A \Rightarrow \frac{\mathrm{dD}}{di} = 1 + \frac{d\,i'}{di}$$

Similarly, by derivation from the law of Snell Descartes written on both sides, we obtain:

$$n_0 cosi = ncosr.\frac{dr}{di}$$

$$n_0 cosr'.\frac{dr}{di} = ncosi'\frac{di'}{di}$$

As elsewhere:

$$r + r' = A, \ \frac{dr'}{di} = -\frac{dr}{di}$$

The final result is:

$$\frac{dD}{di_1} = 1 - \frac{\cos r_2 \, cosi_1}{\cos r_1 \, \cos i_2}$$

We have at least of deviation i= i'= i :

$$r = r' = \frac{dD}{di} \ et \ D_{min} = 2i - A$$

$$n_0 \sin i = n \sin(\frac{A}{2})$$

The angle of the minimum deviation D_m is also given by:

$$n_0 \sin (\frac{D_m+A}{2}) = n \sin (\frac{A}{2})$$

III.5. Curve pace D= f (i):

The condition of emergence we have : $i_{min} \leq i \leq 90°$

$$i = i_{min} \Rightarrow i' = 90°$$

$i = 90° \Rightarrow = i = i_{min}$ Therefore $D = 90° + i_{min} - A$

$$(\frac{\partial D}{\partial i})_{A,n} = 1 - \frac{\cos r' \cos i}{\cos r \cos i'}$$

When :

$$i = i_{min} \; ; \; \frac{\partial D}{\partial i} \rightarrow -\infty$$

$$i = 90° \; ; \frac{\partial D}{\partial i} = 1$$

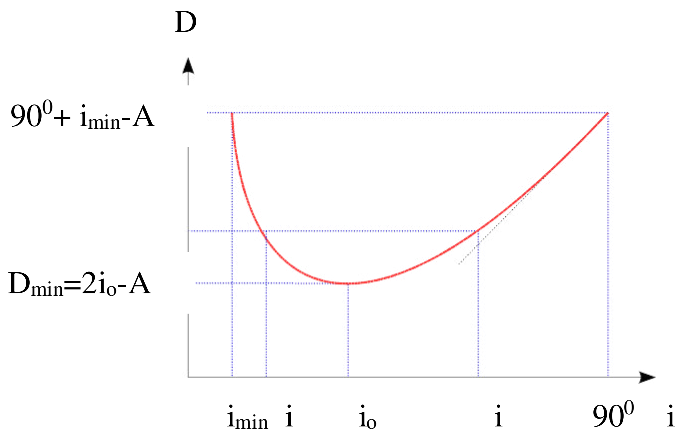


Figure III.4. Curve pace D= f (i)

III.6. Dispersion:

With an incident beam of white light, a continuous spectrum from red to violet is observed, the deviation of the rays increasing as the wavelength decreases:

$$(\frac{\partial D}{\partial})_{A,i} < 0$$

$$(\frac{\partial D}{\partial \lambda})_{A,i} = (\frac{\partial D}{\partial n})_{A,i} . \frac{dn}{d\lambda}$$

With :

$$(\frac{\partial D}{\partial \lambda})_{A,i} > 0, \qquad donc\ \frac{dn}{d\lambda} < 0$$

For optical lenses, the Cauchy relation is often used:

$$n^2 = a + \frac{b}{\lambda^2} + \frac{c}{\lambda^4}$$

From which : a,b,c are three constants determined experimentally by measuring n for three different wavelengths.

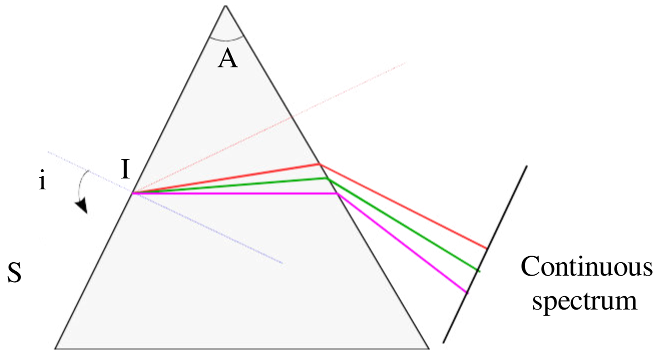


Figure III.5. White light scattering through a prism.

Chapter 4 : The spherical diopters

4.1. Definition:

A spherical diopter is a curved separation surface between two media of index n and n’ for which one can define a center c and a radius of curvature r. one defines the main axis as the axis parallel to the direction of light propagation and passing through C.

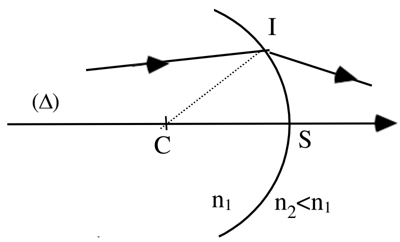


Figure IV.1: Geometric representation of a diopter.

An incident ray parallel to the axis is considered to be refracted at point I of the separation surface.

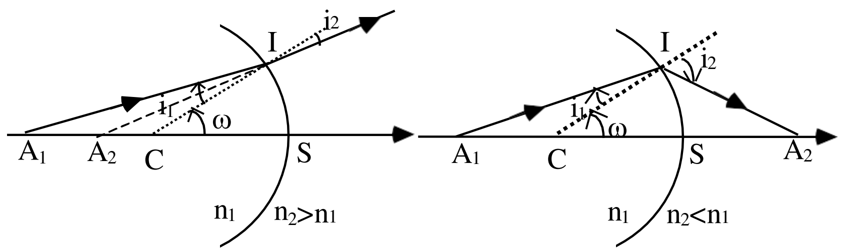


Figure 4.2: The two possible configurations of a spherical diopter.

4.2. Snell Descartes law: Conjugaison relation :

Object A is located on the diopter optical axis, it is a real object consider two particular rays from A, the first one is that spreads with zero incidence: it is on the horizontal main axis, and not deflected after crossing the diopter. The second makes in I an angle of incidence i with the normal at the spherical diopter. It is refracted and the refractive angle with the normal is noted.

In the example chosen, the two rays physically cut off from the A' axis, which is the actual image of A.

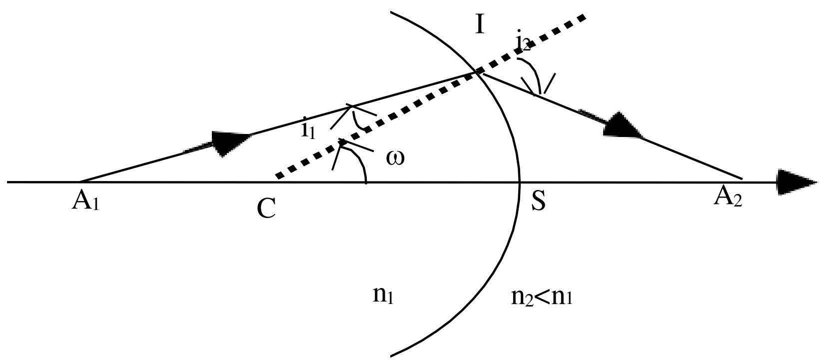


Figure 4.3 : Study of the path of a ray for a convex spherical convergent diopter.

Posing p = $\overline{SA}$; p' = $\overline{SA'}$ in the context of the appronomination of gaux, the angles defined on figure (4.3) are small $(\alpha, \alpha' et\ \omega),$ instead of the Smell Descartes relation, we will use Kepler's law take the triangles IAC and IA'C.

In IAC : $\alpha + \pi$-i - $\omega = \pi$ from which i = $\omega - \omega$

In IA'C : (-α') $+ r + \pi$- (-ω) $= \pi$ from which r= α'- ω

The Kepler equation at point I : n ($\alpha - \omega$) =n'($\alpha' - \omega$)

In the small angle approximation, we can confuse H and S and assimilate the tangents:

$$\alpha \sim tg_{\alpha} = \frac{\overline{H\,I}}{\overline{AH}} = \frac{\overline{H\,I}}{\overline{AS}} = \frac{\overline{H\,I}}{\overline{-p}}$$

$$\alpha' \sim tg_{\alpha'} = \frac{\overline{H\,I}}{\overline{A'H}} = \frac{\overline{H\,I}}{\overline{A'S}} = \frac{\overline{H\,I}}{\overline{-p'}}$$

Be remplaced $\alpha, \alpha' et\ \omega\ by\ values\ from\ Kepler's\ law$:

$$n\left(\frac{1}{p} - \frac{1}{r}\right) = n'\left(\frac{1}{p'} - \frac{1}{r}\right)$$

This fundamental relation that connects the positions of an object A and its image A' is called the conjugation relation of the spherical diopter. The following can be rewritten:

$$\frac{n'}{p'} - \frac{n}{p} = \frac{n' - n}{r}$$

4.3. study of a diopter plane:

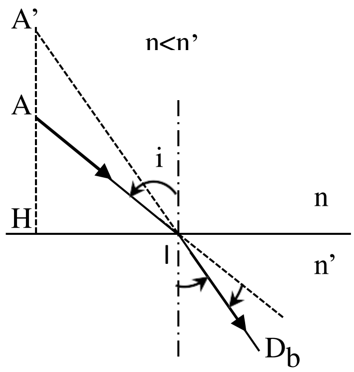


Figure 4.4: The diopter plane.

The angles of incidence (i) and refraction (r) verify Kepler's law:

$$n\ i = n'\ r$$

You can also write: $\overline{SA'} = \overline{SA}\,\frac{i}{r}$ that is :

$$\overline{SA'} =:\ \overline{SA}\frac{n}{n}$$

With conventional notations, we finally obtain the conjugation relation of the diopter plane:

$$P' = p.\frac{n'}{n}$$

4.4. Image construction through a spherical diopter:

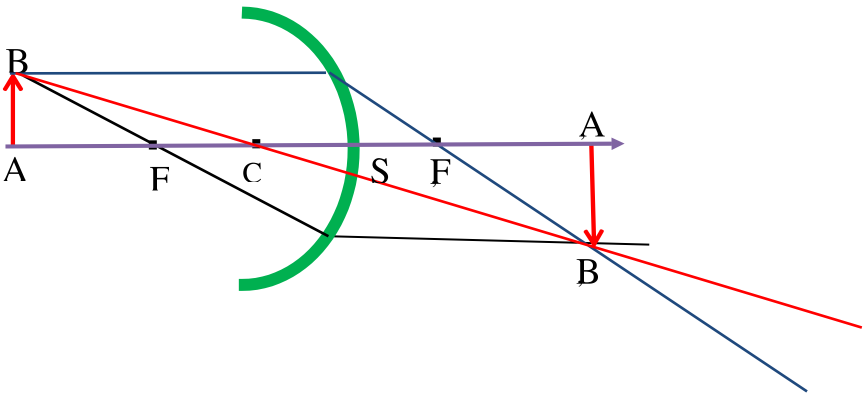


Figure 4.5: Path of three particular rays passing through in a convergent spherical diopter (n' >n)

Exemples :

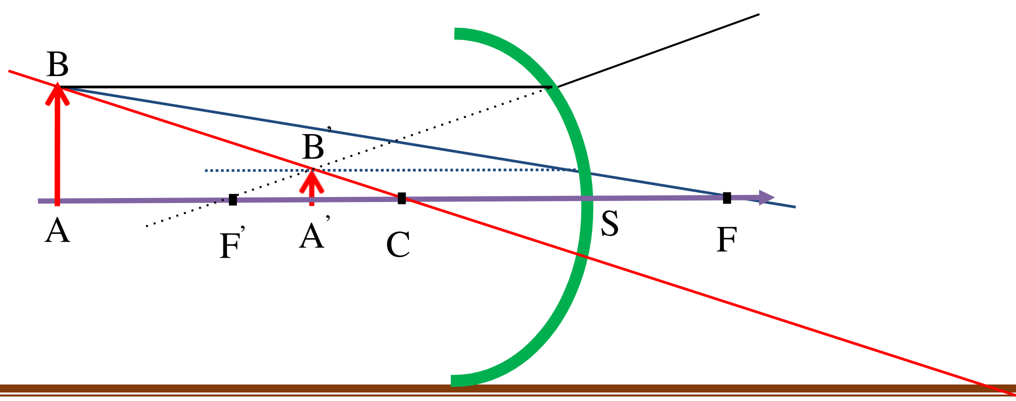


Figure 4.6. Construction of an image through a diverging spherical diopter: real object virtual image.

4.5. Calculation of focal lengths:

If the energy A' is rejected to infinity, the distance $\overline{SA'}$ =p' tends towards infinity and by definition A tends towards f. The conjugation relationship then gives us the focal length of object f which corresponds to the value of p.

$$p' \to \infty \; give \; -\frac{n}{p} = \frac{n'-n}{r} d'ou \; f = p - \frac{nr}{n'-n}$$

$$f = \overline{SF} = -r.\frac{n}{n'-n}$$

To define the image focus F', it is the object that moves away from the distance of the A' diopter which tends towards F'. The distance p tending towards infinity, the conjugation relationship gives us then:

$$p \to \infty \; is \; \frac{n'}{p'} = \frac{n'-n}{r} where \; f' = p' - \frac{n'r}{n'-n}$$

$$f' = \overline{SF'} = r.\frac{n'}{n'-n}$$

Second form of the conjugation relationship:

$$\frac{n'}{P} - \frac{n}{p} = \frac{n-n}{r} = \frac{n'}{f} = -\frac{n}{f}$$

Quantity $\emptyset = \frac{n'-n}{r}$ is called the vergence of the diopter (power) its unit is dioptrique (m^{-1}).

4.6. Transverse magnification α :

The object AB and its image do not necessarily have the same dimension or the same direction. The notion of transverse magnification α makes it possible to specify what the properties of the image are:

$$\alpha = \frac{\overline{A'B'}}{\overline{AB}} = \frac{np'}{n'p}$$

Chapter 5 : The spherical mirrors

5.1. Definition of spherical mirrors:

The spherical mirror is a portion of sphere whose surface has been covered with a fully reflective layer.

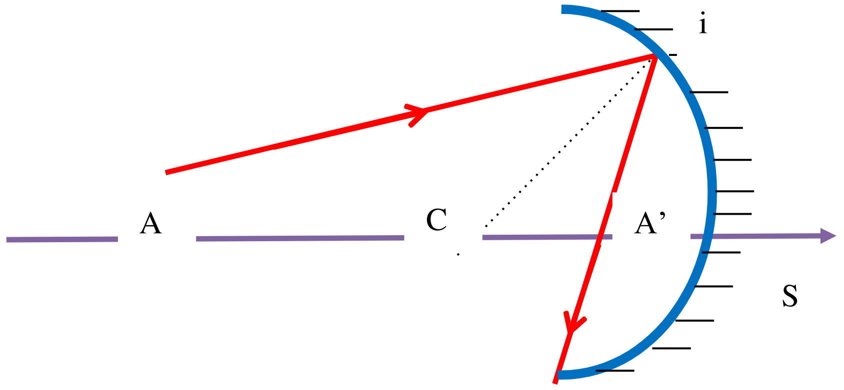
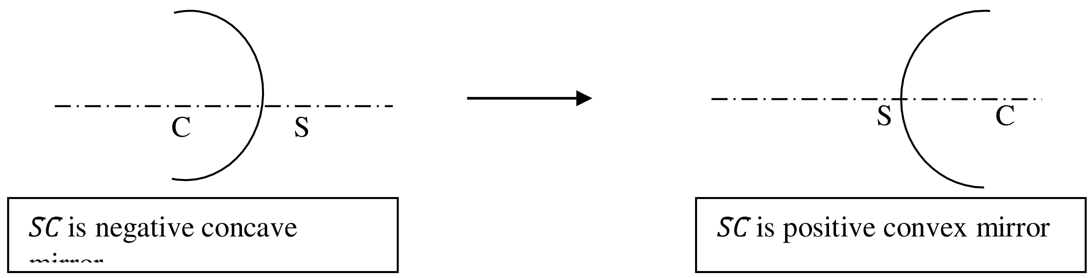


Figure 5.1 : A spherical mirror

The spherical mirror can be of two types: it is concave (r < d) or convex (r > o)



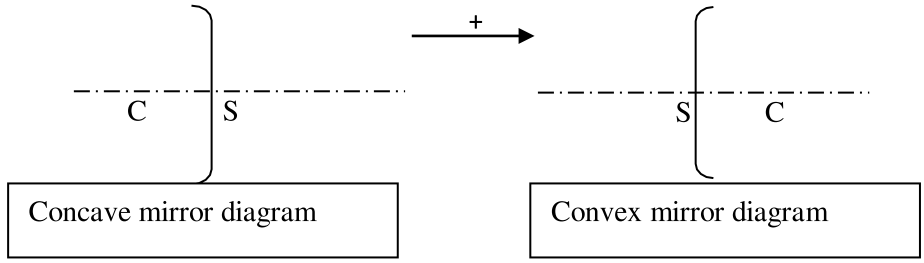


Figure 5.2 : The two configurations of a spherical mirror

5.2. The law of conjugaison :

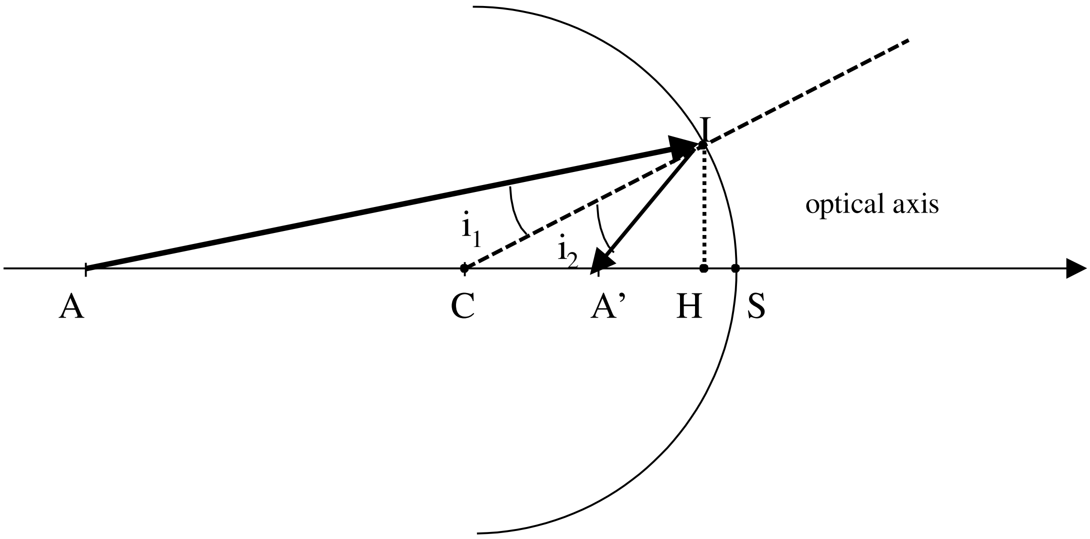


Figure 5.3 : Study of the path of a ray in a spherical mirror.

From the actual point A, located on the main axis, two particular rays are drawn, the first of zero incidence axis by the main axis. The second one, AI, made with the normal in I, an angle of incidence i and reflected. Finally, these two rays cut on the main axis in A' (real image) one lays $\overline{SA}$ = p and $\overline{SA'} = p'$in the triangles AIC and CIA', one writes :

$$\alpha + \pi - \omega - i = \pi \Rightarrow i = \alpha - \omega$$

$$\omega + j + \pi - \alpha' = \pi \Rightarrow j = \alpha' - \omega$$

The law of Snell Descartes is written j = i we finally:

$$2\,\omega = \alpha + \alpha'$$

In the small angle approximation:

$$\text{tg}\,\alpha \sim \alpha = \frac{\overline{SA}}{\overline{AS}} = \frac{\overline{SI}}{-p}$$

$$\text{tg}\,\alpha' \sim \alpha' = \frac{\overline{SA}}{\overline{A'S}} = \frac{\overline{SI}}{-p}$$

$$\text{tg}\,\omega \sim \omega = \frac{\overline{SI}}{\overline{CS}} = \frac{\overline{SI}}{-r}$$

Finally, if we report in : $2\,\omega = \alpha + \alpha'$ *we have*:

$$2.\frac{\overline{SI}}{-r} = -\overline{SI}\,(\frac{1}{p} + \frac{1}{p'})$$

Therefore :

$$\frac{2}{r} = \frac{1}{p} + \frac{1}{p'}\ ou\ \frac{1}{\overline{SA}} + \frac{1}{\overline{SA'}} = \frac{2}{\overline{SC}}$$

5.3. Study of the focal points of a spherical mirror:

When p → $\pm\infty$, its image tends towards a particular fixed position marked F' and marked by:

$$\overline{SF'} = f' = \frac{r}{2}$$

This is now the image A' which tends towards infinity if A tends towards that point F. F is therefore the focus mirror object.

$$\overline{SF} = f = \frac{r}{2}$$

5.4. The transverse magnification α and longitudinal magnification g :

5.4.1. The transverse magnification α :

The A'B' image is made of a spherical mirror and also characterized by a transverse magnification:

$$\alpha = \frac{\overline{A'B'}}{\overline{AB}}$$

The following figure is given:

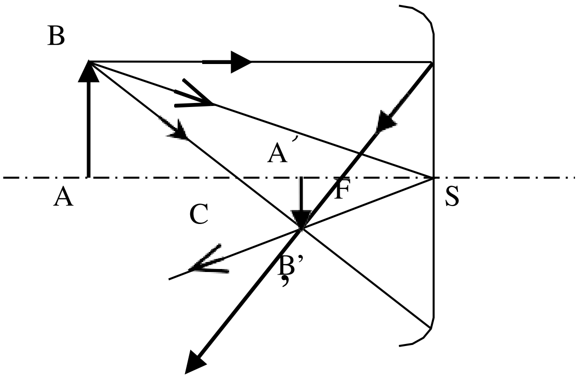


Figure 5.4 : Image construction through a converging spherical mirror.

$$\alpha = \frac{\overline{A'B'}}{\overline{AB}}$$

$$= \frac{\overline{A'B'}}{\overline{SI}} = \frac{\overline{F'A'}}{\overline{FS}} = \frac{\overline{FS}+\overline{SA'}}{\overline{FS}} = \frac{f-p'}{f}$$

$$= 1 - \frac{P'}{f}$$

From the conjugaison relation we deduce that :

$$\alpha = -\frac{P'}{p}$$

5.4.2. The longitudinal magnification g :

The longitudinal magnification g is defined by the ratio between the image and the object: it can be written:

$$g = -\frac{dp'}{dp}$$

By differentiating the second form of the conjugation relation of the spherical mirror to find:

$$\frac{1}{p'} + \frac{1}{p} = \frac{1}{f} \; soit \; \frac{dp'}{p'2} + \frac{dp}{p2} = 0$$

$$g = \frac{dp'}{dp} = -\left(\frac{p'}{p}\right)^2 = -\alpha^2$$

We note that g is always negative for a spherical mirror, which explains why an object and its image appear opposite regardless of the type of mirror considered.

5.5. Image construction through a spherical mirror:

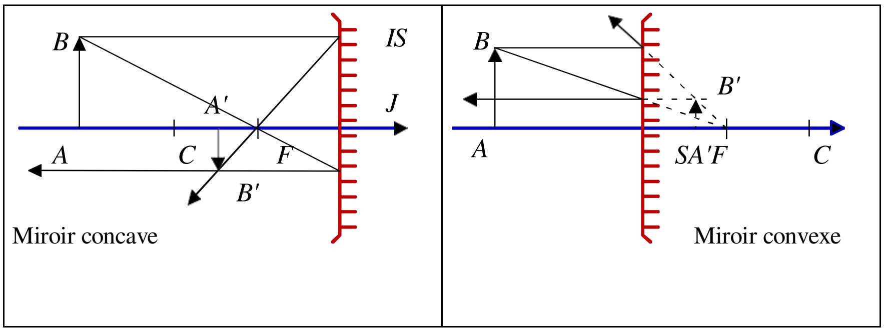


Figure 5.5. Construction of the incident ray by the method of the image at infinity

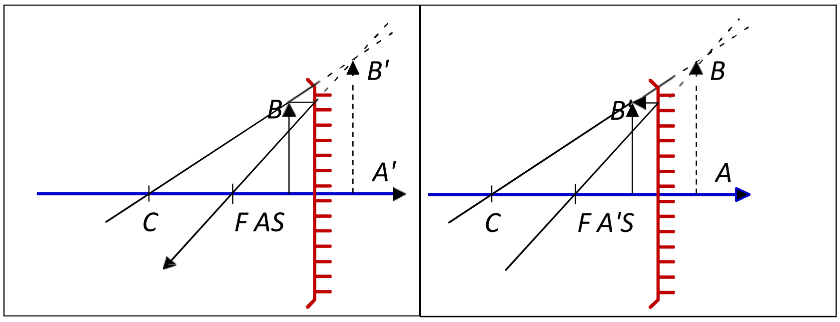


Figure 5.6. : Image of an object located between the focus and the vertex and then after the vertex

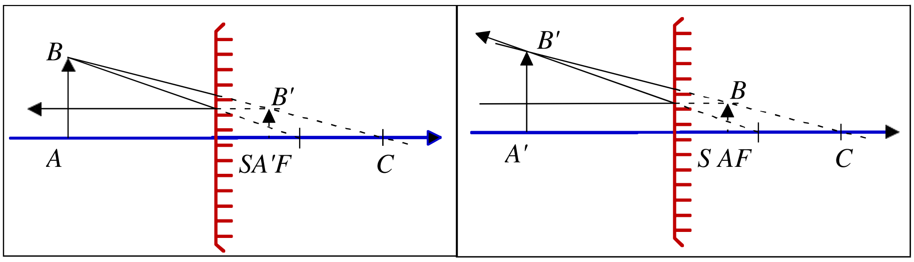


Figure V.7. Image of an object located before the vertex and then between the vertex and the focus

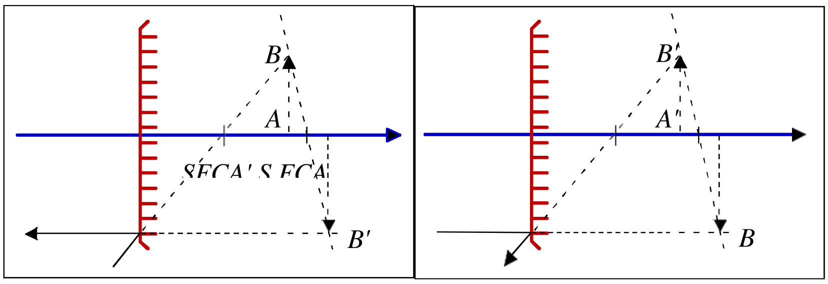


Figure V.8. Image of an object located between the focus and the center and then after the center

Real object (p < f <o)

a. Object is virtual (p > o) between focus f and S, the image is real (p' < o).

b. Objet est Virtual à droit du foyer, l'image est virtuelle (p' > o)

Tableau 5.1. Different cases

	$\alpha > 0$ *right image*	$\alpha < 0$ *inverted image*
$\|\alpha\| > 1$(*larger image*)	*right and enlarged*	*inverted and enlarged*
$\|\alpha\| < 1$(*reduced image*)	*right and reduced*	*inverted and reduced*

Chapter 6: Thin lens

6.1. Definition of thin lens:

A transparent homogeneous body, with absolute index n, limited by two diopters of which at least one is a sphere, one of the two faces can be flat. Any type of diopter being characterized by its center of curvature C and by its carbide radius r. there are two types of lenses, convergent lenses and divergent lenses.

Tableau 6.1. Converging lenses

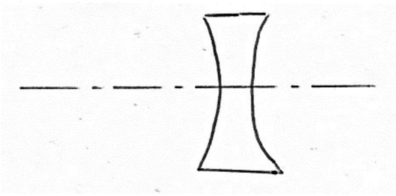
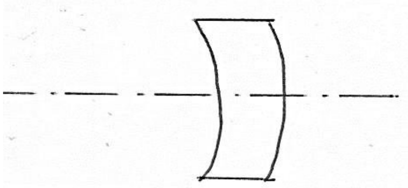
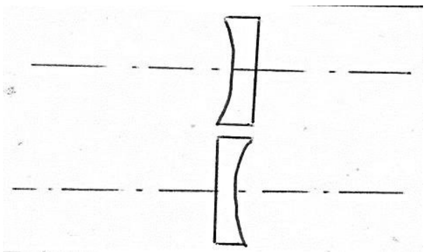
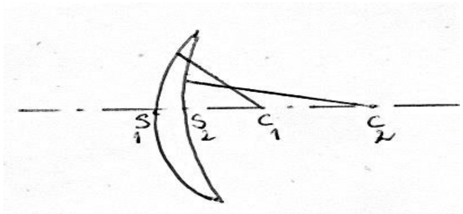
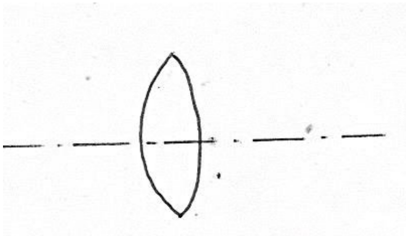
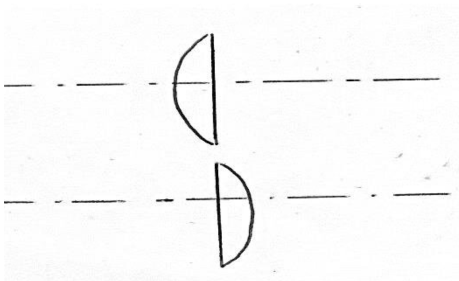
Diopter 1	Diopter 2	Cut the lens in the main plane	Name of the lens
$r_1 > 0$	$r_2 < 0$		Meniscus to thick lord
$r_1 > 0$	$r_2 < 0$		Biconcave
$r_1 > 0$ $r_1 \to \infty$	$r_2 \to \infty$ $r_2 > 0$		Concave plane

Tableau 6.2 : The divergent lenses

Diopter 1 $r_1 = \overline{S_1C_1}$	Diopter 2 $r_2 = \overline{S_2C_2}$	Cut the lens in the main plane	Name of the lens
$r_1 > 0$	$r_2 > 0$ $r_2 > r_1$		Meniscus on board thin
$r_1 > 0$	$r_2 > 0$		biconvex
$r_1 > 0$ $r1 \to \infty$	$r_2 > \infty$ $r_2 < 0$		Converxe plane

6.2. The wafer lens:

Consider in more detail an index lens n, delimited by two spherical diopters, a biconvex lens was chosen as an example. The diopter 1 of the vertex S1 are convex $(\overline{5_1C_1} = r_1 > 0)$ and convergent. The S2 vertex diopter 2 is concave $(\overline{S_2\,C_2} = r_2 < 0)$ and also convergent. All the vertices and centers of curvature (S_1, S_2, C_1 et C_2) are on the optical axis.

A lens has thickness S_1 S_2. It can be considered as a thin lens if its thickness is small before the difference in the values of the curvature radii. In this case, it will confuse S_1 and S_2 with a point S with a point S which will become the common origin of the two diopters' vertices.

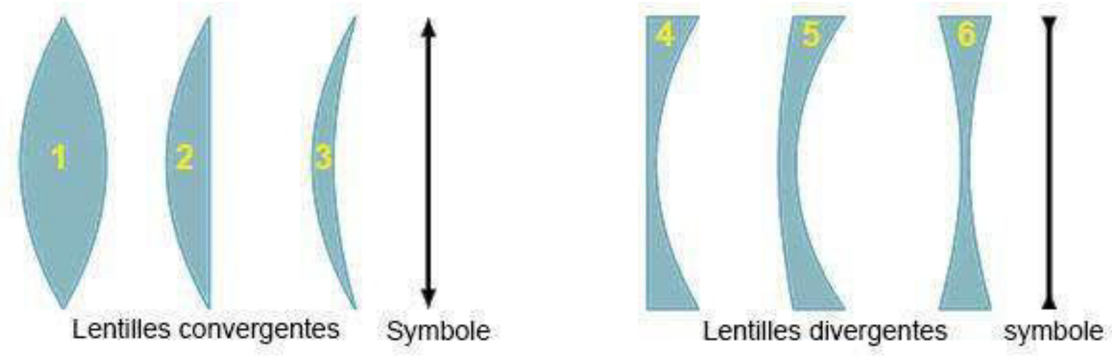


Figure 6.1. Symbol of a thin lens.

6.3. Conjugation of thin lenses:

The conjugation relation of the thin lens can be obtained by combining the conjugations relations written for each of the diopters that make up it.

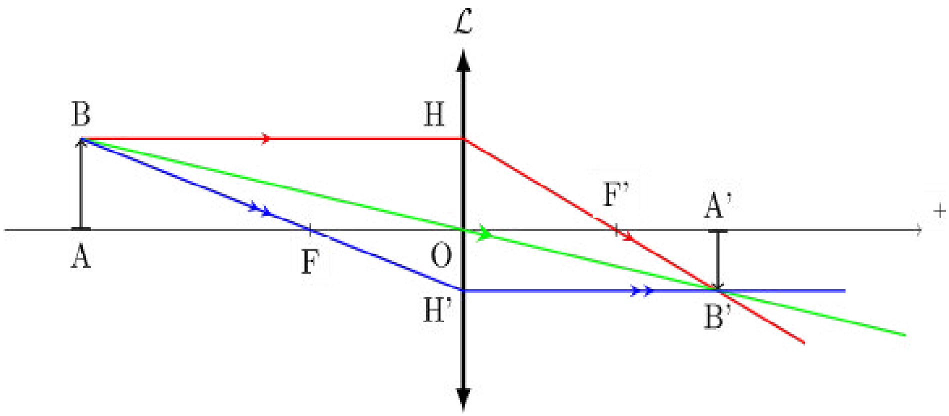


Figure 6.2 : Walk a ray through a lens.

$$\frac{n}{p''_1} - \frac{1}{P_1} = \frac{n-1}{r_1} \quad or : \frac{n}{\overline{S_{A''}}} - \frac{1}{\overline{S_1A}} = \frac{n-1}{\overline{S_1C_1}}$$

The conjugation relation for the second written diopter:

$$\frac{1}{p'_2} - \frac{n}{P_2} = \frac{1-n}{r_1} \quad or : \frac{1}{\overline{S_{2A'}}} - \frac{1}{\overline{S_2A}} = \frac{1-n}{\overline{S_2C_2}}$$

Since the lens is thin, we can merge points S_1 and S_2 into a single point S:

$$r_1 = S_1 C_1 = SC = r, r_2 = S_2C_2 = r' et\ P_2 = P''_1$$

If we add (1) and (2), we obtain the conjugation relation of the thin lens:

$$\frac{1}{P'_2} - \frac{1}{P_1} = (n-1)\left(\frac{1}{r_1} - \frac{1}{r_2}\right) ou\ \frac{1}{\overline{SA'}} - \frac{1}{\overline{SA}} = (n-1)\left(\frac{1}{\overline{S_C}} - \frac{1}{\overline{S_{C'}}}\right)$$

The second member of the conjugation equation is the vergence of the lens:

$$\emptyset = (n-1)\left(\frac{1}{r} - \frac{1}{r'}\right)(\ in\ dioptric = 1m^{-1})$$

Following the relative values of the curvature radii, two cases are distinguished:

$\emptyset > 0$ for a convergent lens

$\emptyset < 0$ for a divergent lens.

6.4. Focal points and planes of a thin lens:

a. Image focus:

When we tend p towards infinity, we obviously have:

$$p' \rightarrow \overline{SF'} = f' = \frac{1}{\emptyset}$$

b. Object focus:

Object focal length f when p'→ ∞

$$p \rightarrow SF' = f = \frac{1}{\emptyset}$$

6.5. Other forms of the conjugation relationship:

The formula for lenses can be reheated, eliminating $\emptyset$ and focusing distances are used: both forms can easily be obtained:

$$\frac{1}{P'} - \frac{1}{P} = \frac{1}{f'} = \frac{1}{f}\ when\ \frac{1}{\overline{SA'}} - \frac{1}{\overline{SA}} = \frac{1}{\overline{SF'}} = -\frac{1}{\overline{SF}}$$

$$\frac{f'}{P'} + \frac{f}{P} = 1 \quad when\ \frac{\overline{SF'}}{\overline{SA'}} + \frac{\overline{SF}}{\overline{SA}} = 1$$

De ce fait, la relation de Newton, qui positionne l'objet et son image par rapport aux foyers, s'applique aux lentilles minces :

$$(p' - f')(p - f) = ff' \quad ou\ \left(\overline{SA'} - \overline{Sf'}\right)\left(\overline{SA} - \overline{SF}\right) = \overline{SF}.\overline{SF'}$$

6.6. Image construction:

6.6.1. Case of a convergent lens:

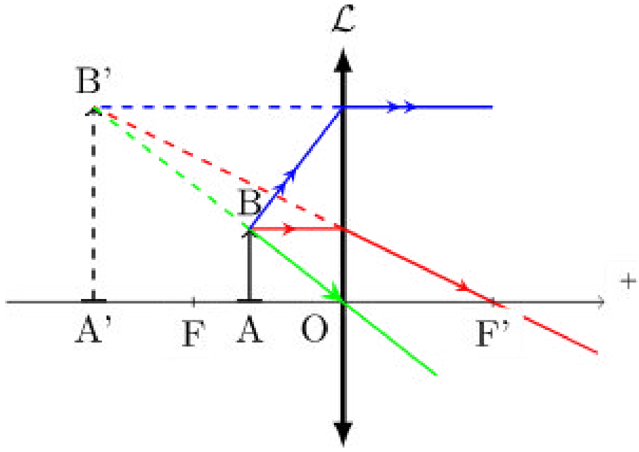


Figure 6.3. Convergent lens: real object, virtual image

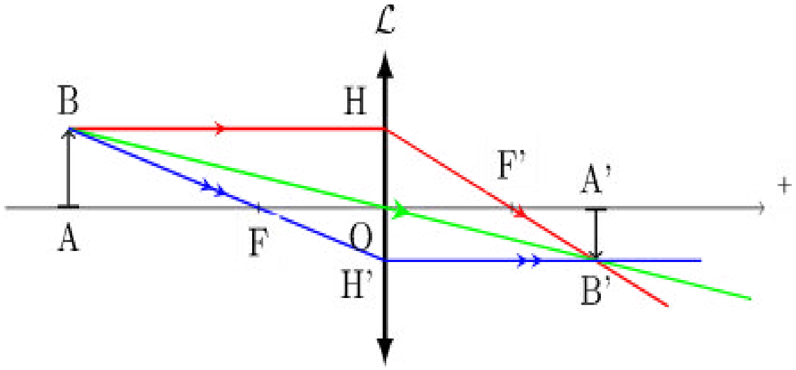


Figure 6.4. Construction of the real image of a real object by a convergent lens

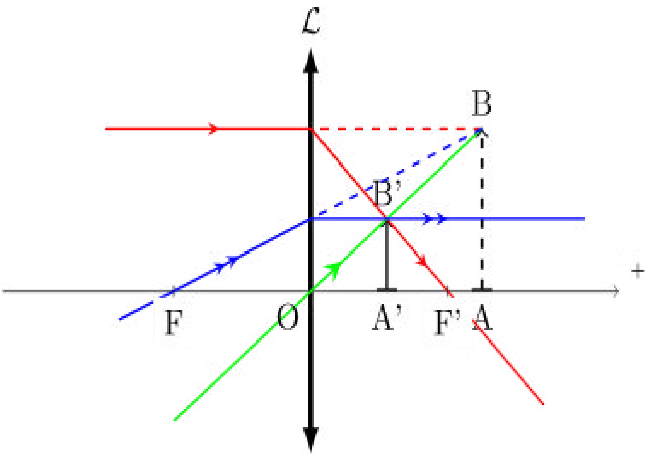


Figure 6.5. Convergent lens: virtual object, real image.

6.6.2. Case of a divergent lens:

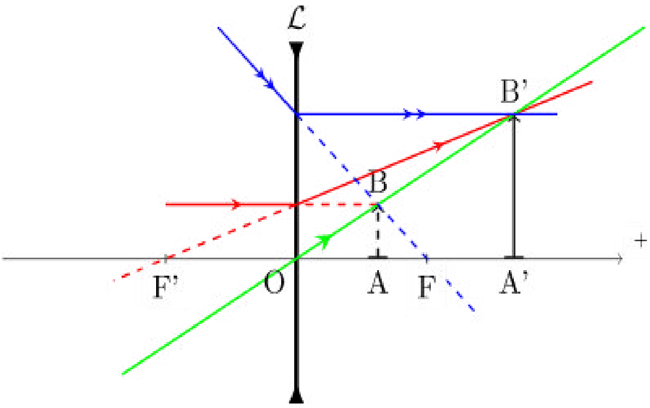


Figure 6.6. Divergent lens: virtual object, real image.

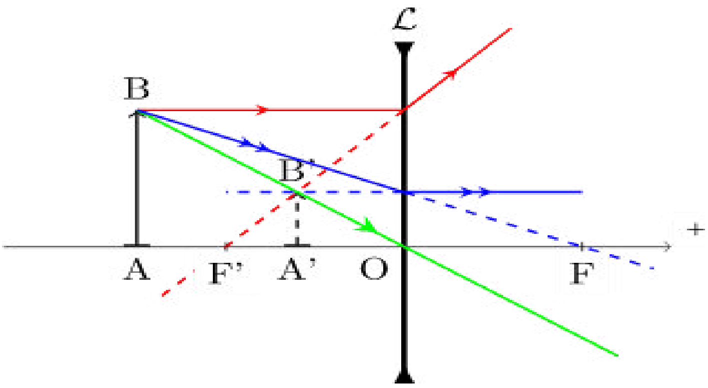


Figure 6.7. Divergent lens: real object, virtual image.

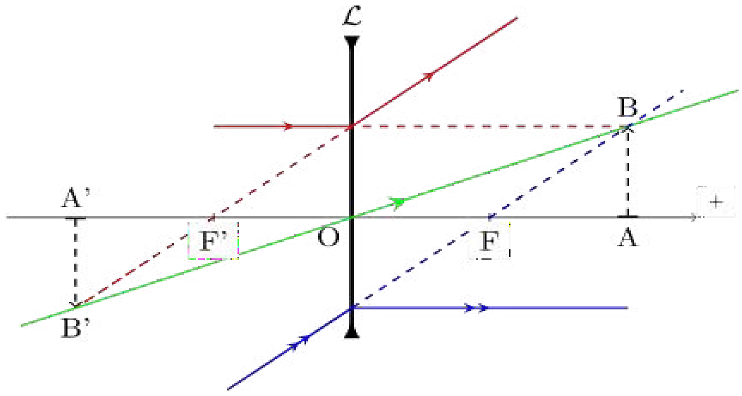


Figure 6.8. Divergent lens: virtual object, virtual image.

6.7. Transverse magnification α *and* longitudinal magnification g :

Generally, the image is different in size from the object:

$$\alpha = \frac{\overline{A'B'}}{\overline{AB}}$$

We have :

$$tg\,\alpha = \frac{\overline{AB}}{\overline{AS}} = \frac{\overline{A'B'}}{\overline{AS'}} = \frac{\overline{AB}}{-p} = \frac{\overline{AB'}}{-p'} \Rightarrow \alpha = \frac{P'}{P}$$

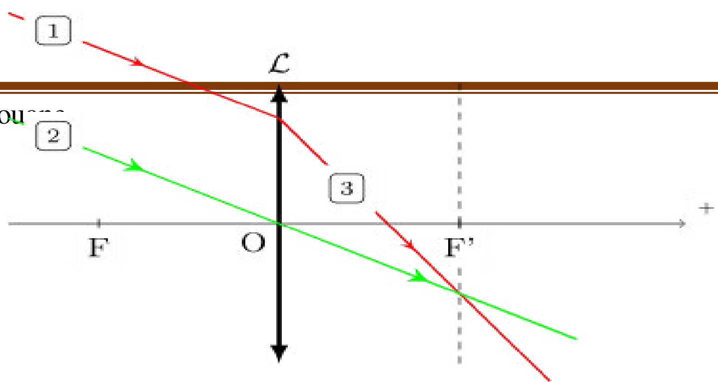
For calculus of longitudinal magnification :

$$g = \frac{dP\prime}{p}$$

$$\frac{1}{P'} - \frac{1}{P} = \frac{1}{f} d'ou \quad \frac{dP'}{P'2} - \frac{dP}{d^2} = 0 \quad d'ou\ g = \left(\frac{P'}{P}\right)^2 = \alpha^2$$

6.8. Examples of thin lenses:

a. Loupe :



A magnifying glass is made of a single lens: a lens much more elaborate as a binocular is actually doublet of lenses.

Figure 6.9 : Viewing angle through the magnifying glass

Avec la loupe :

$$\theta' = \frac{\overline{AB}}{\overline{SF}} = \frac{\overline{AB}}{f'}$$

To the naked eye: if the object is placed at a distance of d.

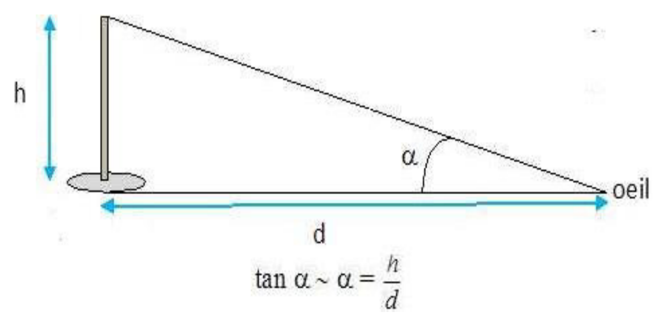


Figure 6.10: Angle of view of an object

$$\theta = \frac{\overline{AB}}{\overline{SA}} = \frac{\overline{AB}}{d}$$

For a magnifying glass, the transverse magnification tends towards infinity and no longer has meaning. We will therefore characterize a magnifying glass by its magnification G.

$$G = \frac{\theta'}{\theta} = -\frac{d}{f'}$$

Commercial magnification, the calculated magnification for an object placed 25 cm from the eye.

$$G = \frac{1}{4f'} \quad = \frac{\emptyset}{4} \quad ; \quad \emptyset: his\ veragency$$

b. Microscope:

- Reduced microscope definition:

The microscope consists of two converging systems:

The lens, a very convergent system whose focal length is of the order of mm, made up of a more or less complicated set of lenses.

An eyepiece, formed by one or more lenses of a few cm focal length (1 to 6 cm).

The lens and eyepiece are centered on the same axis and are connected to each other through the microscope tube.

In the reduced microscope, the lens is similar to a convergent thin lens.

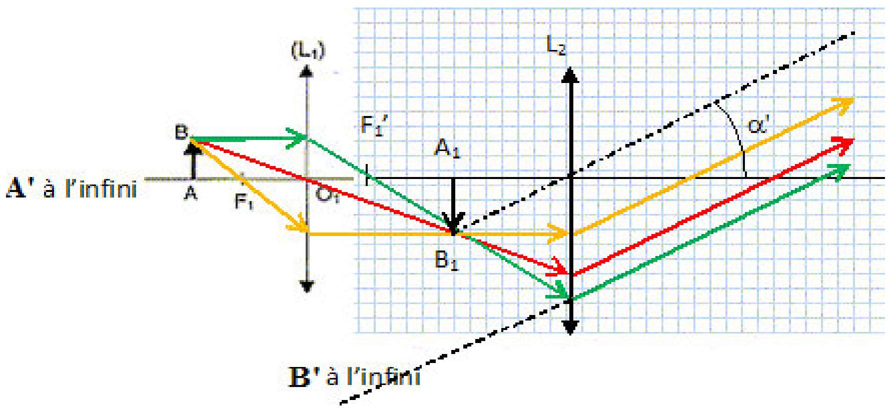


Figure 6.11: Construction of images in a microscope.

6.9. Eye:

6.9.1. Introduction:

The eye is a complex association of diopters separated by different index media. The presentation we make here concerns essentially the human eye or that of mammals in general, endowed with a faculty of accommodation by modification of the focal length image of the optical system. In this case, the clear image of an object is always formed on the retina, regardless of its position, without any change in the position of the optical elements of the eye. The resolution of the eye is defined by its ability to separate two points close together; this is equivalent to considering the separation between two neigh bouring nerve cells. The optic nerve transmits information to the brain, which interprets it.

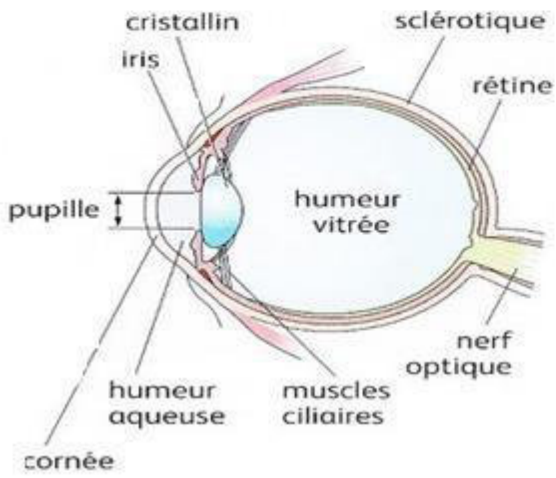


Figure 6.12: Human eye

The eye can therefore be schematized by a thin lens convergent L, optical center O and variable focal length and a projection screen E.

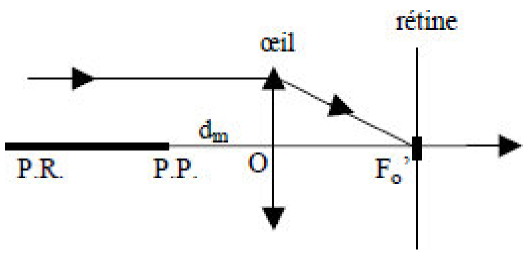


Figure 6.12. Diagram of an eye assembly.

The normal eye can see objects clearly from a “punctum remotum” (P.R.), which is infinite, to a “punctum proximum” (P.P.) about 25 cm away from the eye.

6.9.2. The defects of the eye:

The normal eye is called an emmetrope, meaning that the image of a point in infinity is formed on the retina.

An eye is called abnormal or “ametropic” when it imagines at rest a point to infinity ahead or behind the retina.

a. Myopia:

The myopic eye is too convergent: at rest, the image of an object in infinity forms in front of the retina. The vergence of a myopic eye at rest is therefore greater than 60 (Vergence) and must be decreased by interposing a divergent lens.

b. Hyperopia:

A hyperopic person sees blurry near objects while his distant vision is correct. A hyperopic eye is not convergent enough. Images of distant objects are formed behind the retina. Hyperopia is corrected by wearing convergent corrective lenses.

c. Astigmatism:

An eye anomaly in which the same point of an object gives an image spot. The cornea of the eye has an irregular shape, the vision of objects is distorted. Astigmatism makes reading difficult. This defect is corrected with non-spherical lenses.

d. Presbyopia:

Presbyopia is a vision disorder that makes it difficult to adjust the lens focal length for close-up.

Chapter 7: Wave optics

7.1. Introduction:

When two or more light waves are superimposed, it is generally not possible to describe the observed phenomena in a simple way. Consider the case of two waves from a single point and monochromatic source: in the superposition region, the luminous intensity varies from one point to another between maxima which exceed the sum of the intensities of two waves taken separately and minima which may be zero. This is the phenomenon of interference.

To specify the conditions that two waves must meet in order to interfere, it is not necessary to have a precise idea of the nature of electromagnetic waves. It is sufficient to accept the following principles:

1- Monochromatic light is composed of vibrations of a single frequency.

2- The electromagnetic vibrations propagate at the speed of light v = c n, with c: speed of light and n: refractive index.

3- They are transverse to the direction of propagation.

4- They can be represented by a sinusoidal function.

5- The duration of light emission by an atomic emitter is in the range of 10^{-9} to 10^{-8} seconds, that is to say that the waves emitted have a length between 30 cm and 3 cm. In other words, each atomic oscillator emits a very fine monochromatic wave for a short time, then another without phase relation to the previous one: the source is temporarily incoherent.

6- Each atomic oscillator works independently of its neighbors. There is generally no permanent phase relationship between the radiations they emit. It is said that the source is spatially inconsistent.

7- The wavelengths of the neighbouring oscillations are generally independent, in this case all radiations are present in the continuous spectrum and the light is called white.

8- The radiation polarizations emitted by the various oscillators are independent and randomly distributed. The source is not polarized

7.2. Theoretical Reminders:

7.2.1. Wave Optics:

Wave optics is the study of light phenomena whose correct description requires a wave description of light. The electromagnetic wave is then characterized by the fields (E, B), vectors varying in time and space, solution of linear differential equations of Maxwell. There are two parts: the electric field grader and the magnetic field guarder.

- Diffraction: the amplitude of the light wave depends on the conditions at the limits imposed

by its extension. A ray of light that passes through a hole not very large compared to the wavelength, sees its amplitude modified.

- Interference: when two waves are superimposed, it is their complex amplitudes that add up and not directly the energy they carry (their intensity). For coherent monochromatic waves, a spatial modulation of their intensity results.

7.2.2. Objectives of the study of physical optics:

- To be able to correctly highlight the phenomenon of diffraction and interference, well distinguish the two if they coexist;

- Know how to make arrangements using the techniques of projections that give observation of figures with intense and well contrasted intensities.

In all manipulations, diffraction and interference will be observed on a screen. The distance between the objects causing interference or diffraction and the screen, marked D, shall be large in front of the characteristic dimension of this object so that one can place oneself within the framework of the Fraunhofer theory (infinite diffraction).

7.3. Maxwell Equations:

$$rot\ E + \frac{\partial B}{\partial t} = 0$$
$$div\ B = 0$$
$$rot\ H - \frac{\partial D}{\partial t} = j$$
$$div\ E = \rho$$

Given that : D=εE , B=μH avec $\varepsilon = \varepsilon_0\, \varepsilon_r$; $\mu=\mu_0\mu_r \approx \mu_0$

$\varepsilon_0\mu_0 c^2 = 1$, n= n (x, y, z)

In a perfectly dielectric medium:

$$rot\ E + \frac{\partial B}{\partial t} = 0$$
$$div\ B = 0$$
$$rot\ H - \frac{\partial D}{\partial t} = 0$$
$$div\ E = 0$$

With: E =E(x, y, z). e^{-iwt} and H= $\varepsilon_0 H(x, y, z)e^{-iwt}$

Wave vector : K= $\frac{w}{c} = \frac{2\pi}{\lambda}$

$$rot\ E - ikH = 0$$
$$rot\ H + ikn^2 E = 0$$

One can forme the equation of HELMOTZ :

$[\Delta + k^2 n^2]\begin{bmatrix} E \\ H \end{bmatrix} = 0$; E (x, y, z) : $\{E_x(x, y, z)$

$\{E_y(x, y, z)$

$\{E_z(x, y, z)$

E $(x, y, z) = E(x, y).f(z)$

7.4. Superposition of two light waves:

The amplitude of the light wave is given by :

$$\vec{E} = E_0 e^{-i(\omega t+\emptyset)}$$

At point M on a superposition of two light waves from the secondary sources S_1 and S_2:

$$\vec{E} = \vec{E}_1 + \vec{E}_2 = (E_{01} e^{-i(\omega t+\emptyset_1)} \overrightarrow{e_1} + E_{02} e^{-i(\omega t+\emptyset_2)} \overrightarrow{e_2})$$

Calculation of light intensity at M point on the screen:

$$I = E.E^*$$

Thus, in point M, the following light intensity is obtained:

$$I = 2I_0(1 + \cos \Delta\emptyset)$$

Chapter 8 : Interference of two coherent waves

8.1. Principle of optical interference:

Two beams (or more) of the same frequency and coherent (having a systematic phase difference) are superimposed. This can be achieved by taking two beams from the same source and following different paths.

8.1.1. Wave Front Division:

There is a division of the wave front in devices using the principle of the following figure:

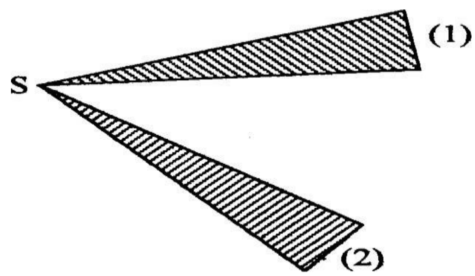


Figure 8.1. Principle of wave front division

The source S emits in all directions but only two separate portions (1) and (2) of the beam are used. These two beams then overlap in the region where the interference phenomena are observed.

Example: Young’s Slots, Fresnel’s Mirrors.

8.1.2. Amplitude division:

There is amplitude division in the case of the following figure:

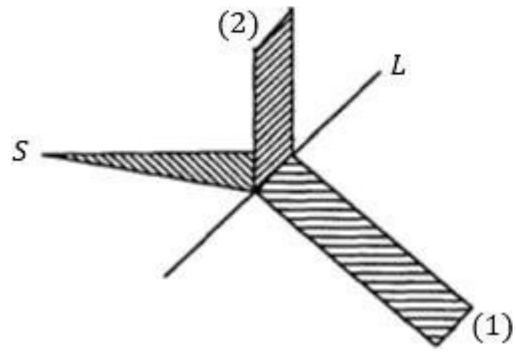


Figure 8.2. Principle of amplitude division

The incident beam is received on a semi-transparent blade L. One part (1) of the incident beam transmitted and another part (2) reflected. The two beams (1) and (2) are then superimposed in the region where the interference phenomena are observed.

Example: Michelson interferometer, Fabry Perot interferometer.

8.2. Mounting young's slots:

8.2.1. History of mounting young's slots:

In 1801, the British physicist Thomas Young envisioned a relatively simple experiment that marked a turning point in the history of science. He passes a beam of light through two slits and observes the figure formed on a screen placed behind the slits. It demonstrates the undulating nature of light.

This experiment once again played a crucial role in the history of physics when in 1961 the German physicist Claus Jönsson carried out exactly the same experiment, but with an electron beam instead of the light beam, demonstrating the wave behaviour of electrons and the particle-wave duality of matter.

Young's Slits is a famous experiment that highlights the phenomenon of diffraction of light waves Young's Slits experience. It consists in passing a beam of monochrome light through two narrow slots, located at a distance from each other comparable to the wavelength of the light used. The light that passes through the slots is projected onto a screen behind them, forming an interference pattern of bright and dark areas.

This phenomenon is explained by the fact that light is a wave which propagates by diffracting and interfering with itself. Light waves passing through the two slots interfere constructively or destructively depending on their phase shift. Areas where the waves are in constructive phase are brighter, while areas where the waves are in destructive phase are darker. The Young's slits experiment showed that light has wave properties and highlighted the phenomenon of diffraction and interference, which is the basis for many applications of modern optics such as interferometers, Holograms, etc.

Young's slits are mainly used to study the wave nature of light and quantum physics Here are some specific uses of Young's slits in physics:

1. Measurement of the wavelength of light: Young's slits can be used to measure the Indeed, Young's slits allow the historical experiment of Young which confirmed the hypothesis of the wave nature of light. This experiment involves passing a beam of light through two narrow parallel slots and observing the interference produced on a screen placed behind the slots. The observed interferences are evidence that light behaves like a wave.

2. Young's slits are also used in quantum physics to observe the phenomenon of particle diffraction, which is related to the Heisenberg uncertainty principle. Particles (for example electrons) are sent through the slits and their behaviour is observed on a detection screen. The results of these experiments show that particles can behave like waves and therefore have a wave nature as well as a corpuscular, ie particle nature.

3. In addition, Young's slits are used in the field of optics to study light propagation, image formation, interference and diffraction. These studies help to better understand the phenomena of diffraction and interference, to optimize imaging systems and optical design

To obtain interference, two waves of the same frequency and nature (same polarization) must be superimposed on one M point in space. The sources creating these two so-called coherent waves.

In the case of Young's slits, both sources S_1 and S_2 are consistent because they come from the same Source S.

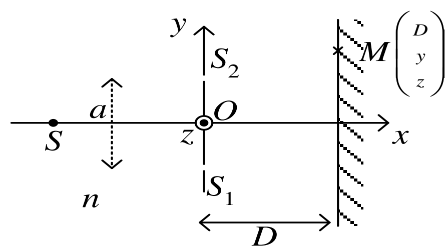


Figure 8.3: Interference with Young's slots

The walking difference Δ L is the difference in distance travelled by two waves before reaching point M.

$$\Delta L = S_1M - S_2M$$

The phase shift in this case is given by:

$$\varphi = \frac{2\pi}{\lambda}(S_1M - S_2M)\ ,\ \text{avec :}\Delta L = \int nds$$

The amplitude of the light wave is given by :

$$\vec{E} = E_0 e^{-i(\omega t+\emptyset)}$$

At point M on a superposition of two light waves from the secondary sources S_1 and S_2:

$$\vec{E} = \vec{E}_1 + \vec{E}_2 = \left(E_{01} e^{-i(\omega t + \emptyset_1)} \overrightarrow{e_1} + E_{02} e^{-i(\omega t + \emptyset_2)} \overrightarrow{e_2} \right)$$

Calculation of light intensity at M point on the screen:

$$I = E.E^*$$

$$\vec{E} = \vec{E}_1 + \vec{E}_2 = \left(E_{01} e^{-i(\omega t + \emptyset_1)} \overrightarrow{e_1} + E_{02} e^{-i(\omega t + \emptyset_2)} \overrightarrow{e_2} \right) \times \left(\left(E_{01} e^{+i(\omega t + \emptyset_1)} \overrightarrow{e_1} + E_{02} e^{+i(\omega t + \emptyset_2)} \overrightarrow{e_2} \right) \right.$$

$$= \left(E_{01} e^{-i(\emptyset_1)} \overrightarrow{e_1} + E_{02} e^{-i(\emptyset_2)} \overrightarrow{e_2} \right) \times \left(E_{01} e^{i(\emptyset_1)} \overrightarrow{e_1} + E_{02} e^{i(\emptyset_2)} \overrightarrow{e_2} \right)$$

$$= {E_{01}}^2 \overrightarrow{e_1 e_1} + E_{01} E_{02} e^{i(\emptyset_2 - \emptyset_1)} \overrightarrow{e_1 e_2} + E_{02} E_{01} e^{-i(\emptyset_2 - \emptyset_1)} \overrightarrow{e_2 e_1} + {E_{02}}^2 \overrightarrow{e_2 e_2}$$

$$\overrightarrow{e_1 e_1} = e_1 e_1 \cos(e_1, e_1) = {e_1}^2 = 1$$

$$\overrightarrow{e_1 e_2} = \overrightarrow{e_2 e_1} = e_1 e_1 \cos(e_1, e_2) = 1$$

$$= {E_{01}}^2 + E_{01} E_{02} e^{i(\emptyset_2 - \emptyset_1)} + E_{02} E_{01} e^{-i(\emptyset_2 - \emptyset_1)} + {E_{02}}^2$$

$$= {E_{01}}^2 + {E_{02}}^2 + E_{01} E_{02} \left(e^{i(\emptyset_2 - \emptyset_1)} + e^{-i(\emptyset_2 - \emptyset_1)} \right)$$

$$= {E_{01}}^2 + {E_{02}}^2 + 2 \times E_{01} E_{02} \cos(\emptyset_2 - \emptyset_1)$$

$$= {E_0}^2 + {E_0}^2 + 2 \times {E_0}^2 \cos(\emptyset_2 - \emptyset_1)$$

$$= 2\, {E_0}^2 + 2 \times {E_0}^2 \cos(\emptyset_2 - \emptyset_1)$$

$$I = 2I_0 + 2I_0 \cos(\emptyset_2 - \emptyset_1)$$

Thus, in point M, the following light intensity is obtained:

$$I = 2I_0 (1 + \cos \Delta\emptyset)$$

With :

$$\Delta\emptyset = \frac{2\pi}{\lambda} \Delta L$$

Calculation of the Walk difference ΔL :

$$\Delta L = \overline{SS_1P} - \overline{SS_2P}$$

$$= \overline{SS_1} + \overline{S_1P} - (\overline{SS_2} + \overline{S_2P})$$

$$= \overline{SS_1} + \overline{S_1P} - \overline{SS_2} - \overline{S_2P}$$

$$\Delta L = \overline{S_1P} - \overline{S_2P}$$

$$\overline{S_1P} = \left(x ; \left(y + \frac{a}{2}\right) ; D \right), \qquad \overline{S_2P} = (x ; \left(y - \frac{a}{2}\right) ; D)$$

$$= \sqrt{x^2 + \left(y + \frac{a}{2}\right)^2 + D^2} - \sqrt{x^2 + \left(y - \frac{a}{2}\right)^2 + D^2}$$

$$= D\left(1 + \frac{1}{D^2}(x^2 + \left(y + \frac{a}{2}\right))\right)^{\frac{1}{2}} - D\sqrt{1 + \frac{1}{D^2}(x^2 + \left(y - \frac{a}{2}\right)^2)}$$

$$= D + \frac{1}{2D}(x^2 + \left(y + \frac{a}{2}\right)^2) - D + \frac{1}{2D}(x^2 + \left(y - \frac{a}{2}\right)^2)$$

$$= \frac{1}{2D}\, ay + \frac{1}{2D}\, ay = \frac{ay}{D} = \Delta L$$

Therefore :

$$\Delta L = \frac{ay}{D}$$

it was generally: $D \gg a, y, z$

As well as, $S_1M = \sqrt{D^2 + \left(y + \frac{a}{2}\right)^2 + z^2} = D(1 + \frac{1}{2D^2}\left(\left(y + \frac{a}{2}\right)^2 + z^2\right)$

And $S_2M = D(1 + \frac{1}{2D^2}\left(\left(y - \frac{a}{2}\right)^2 + z^2\right) = D(1 + \frac{1}{2D^2}\left(\left(y - \frac{a}{2}\right)^2 + z^2\right)$

Thus :

$$S_1M - S_2M = \frac{ay}{D} \quad \text{et } \varphi = \frac{2\pi}{\lambda}\frac{ay}{D}$$

Shiny fringes:

$$\Delta L = q\lambda$$

Dark fringes:

$$\Delta L = (q + \frac{1}{2})\lambda$$

Hence the interfringe:

$$i = \frac{\lambda D}{a}$$

The luminous intensity at point M is written:

$$I = 2I_0(1 + \cos\Delta\emptyset) = 2I_0\left(1 + \cos(\frac{2\pi}{\lambda}\frac{ay}{D})\right)$$

The intensity oscillates between the two extreme values, I_{max}et I_{min}

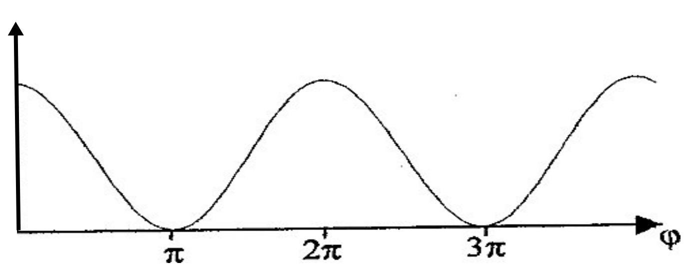


Figure 8.4. Intensity distribution on the screen

In the case where the vibrations have same amplitude we have:

$$E_{01}= E_{02}= E_0 \text{et} I(\varphi)= 2I_0\,(1+cos\varphi) = 4I_0\,cos^2\,(\frac{\varphi}{2})$$

The shiny fringes:

$$I = 2I_0(1 + \cos\Delta\emptyset)$$

$$\cos\Delta\emptyset = 1$$

$$\cos\Delta\emptyset = \cos 2k\pi$$

$$\Delta\emptyset = 0, 2\pi, 4\pi, 6\pi, \ldots$$

So we can calculate their positions in the screen:

$$\frac{2\pi}{\lambda}\frac{ay_k}{D} = 2k\pi$$

$$\frac{ay_k}{D} = k$$

$$y_k = \frac{k\lambda D}{a}$$

The dark fringes :

$$I = 2I_0(1 + \cos\Delta\emptyset)$$

$$\cos\Delta\emptyset = \cos((2k\pi + 1)\pi)$$

$$\Delta\emptyset = \pi, 3\pi, 5\pi, \ldots$$

We can also calculate their positions in the screen:

$$y_{k+1} = \frac{(k+1)(\lambda D)}{a}$$

$$y_{k+1} - y_k = \frac{\lambda D}{a}$$

$$\frac{2\pi}{\lambda}\frac{a y_k}{D} = (2k+1)\pi$$

$$y_k = \frac{(2k+1)\lambda D}{2a}$$

$$y_{k+1} = \frac{(2k+3)(\lambda D)}{2a}$$

$$y_{k+1} - y_k = \frac{(2k+3)\lambda D}{2a} - \frac{(2k+1)\lambda D}{2a} = \frac{\lambda D}{a}$$

So the interfringe for the bright and dark fringes is given by :

$$i = \frac{\lambda D}{a}$$

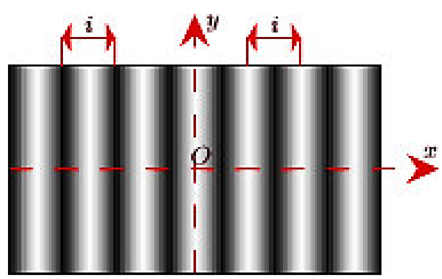


Figure 8.5. Image of the fringes obtained on the screen

Contrast is given by:

C : Constante

$$C = \frac{I_{Max} - I_{Min}}{I_{Max} + I_{Min}} = \frac{4I_0 - 0}{4I_0 - 0} = 1$$

8.3. Interference by a parallel-faced blade (intereromter of Fabry Perot):

In this case we have the Fabry Perot interferometer, from which we distinguish two intensities one reflected and the other transmitted, shown in figure 8.6.

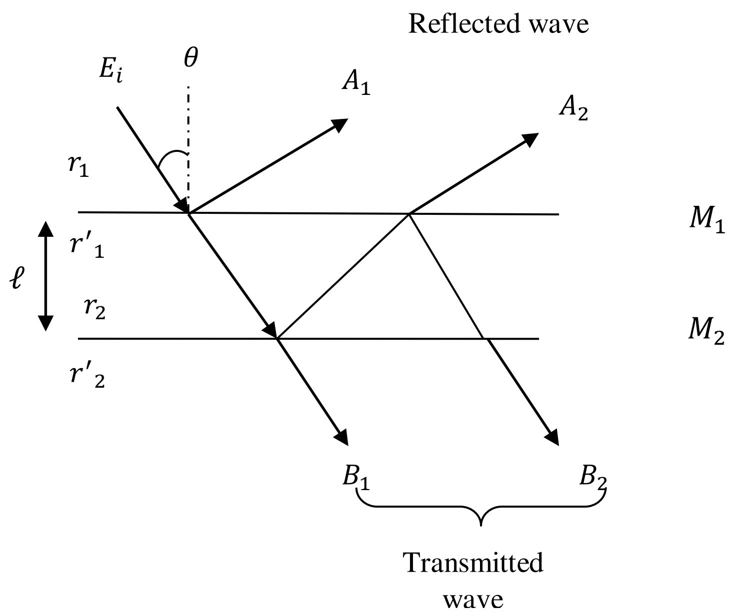


Figure 8.6 : Fabry Perot interferometer

In the case of the Fabry Perot interferometer, two intensities are calculated, reflected and transmitted, with the following coefficients of reflection and transmission:

$$r_1^2 = |r_1'^2 = R_1,\ r_2^2 = |r_2'^2 = R_2$$

The reflected wave field is expressed:

$$E_r = \sum_{i=1}^{n} A_i$$

With : $A_1 = r_1\, E_i$; $A_2 = t_1\, E_i\, r_2' t_1' e^{i\delta}$.

So the reflected field is:

$$E_r = (r_1 + \frac{r_1^2 t_1^2 e^{i\delta}}{1 - r_1' r_2' e^{i\delta}}) E_i$$

If : $r'^2 + t'^2 = 1$

$$E_r = \frac{r_1 - r_2 e^{i\delta}}{1 - r_1 r_2 e^{i\delta}} \ E_i$$

If : $r_1 = r_2 = \sqrt{R}$, we have :

$$E_r = \frac{E_i \sqrt{R}(1 - e^{i\delta})}{1 - Re^{i\delta}}, \quad \text{Avec } \delta = \frac{2\pi}{\lambda}(2nl)cos\theta$$

And the transmitted field is :

$$E_t = \sum B_i = B_1 + B_2 + \cdots\cdots\cdots$$

$$E_t = \frac{t_1 t_2}{1 - r_1 r_2 e^{i\delta}} \ E_i$$

If : $t_2 = t_1 = t_2{}' = \sqrt{T}$, So :

$$E_t = \frac{TE_i}{1 - Re^{i\delta}} = \frac{(1 - R)E_i}{1 - Re^{i\delta}}$$

The intensity of reflected beam :

$$I_r = E_r \cdot E_r^* = \frac{\sqrt{R}\left(1 - e^{i\delta}\right)}{1 - Re^{i\delta}} E_i . \frac{\sqrt{R}\left(1 - e^{-i\delta}\right)}{1 - Re^{-i\delta}} E_i$$

$$I_r = \frac{4Rsin^2\left(\frac{\delta}{2}\right) I_i}{(1 - R)^2 + 4Rsin^2(\frac{\delta}{2})} = I_i, \qquad N = \frac{sin^2\left(\frac{\delta}{2}\right)}{1 + Nsin^2\left(\frac{\delta}{2}\right)}$$

$$I_r = I_i . \frac{Nsin^2\left(\frac{\delta}{2}\right)}{1 + Nsin^2\left(\frac{\delta}{2}\right)} \qquad \text{Avec} \quad N = \frac{4R}{(1-R)^2}$$

The reflected intensity presentation is as follows:

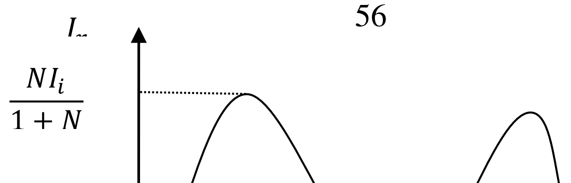


Figure 8.7 : Representation of reflected intensity [14].

The intensity of transmitted beam is:

$$I_t = E_t \cdot E_t^* = I_i . \frac{1}{1 + N sin^2\left(\frac{\delta}{2}\right)}$$

We can represent :

$$I_r = f\ (\delta)$$

We have:

$$\delta = 0\ , 2\pi\ , \cdots\cdots\cdots\cdots, 2\pi m \ \Rightarrow \ I_r = 0$$

and:

$$\delta = (2m+1)\pi \Rightarrow \ I_r = \frac{I_i N}{1+N} \ \text{ max}$$

Figure 8.8 shows the transmitted intensity:

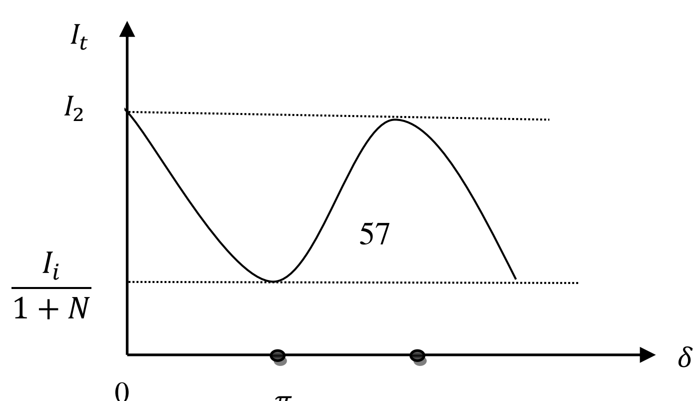


Figure 8.8 : Representation of the transmitted intensity in a parallel-faced blade [14].

Chapter 9 : Polarization of light

9.1. History: discovery and characterization of polarization:

The work on the detection and characterization of light waves and their polarization has occupied many scientists during the 17^{th}, 18^{th} and 19^{th} centuries.

The first mention of scientific observations related to a polarization phenomenon, whose nature and basis were unknown at the time, can be dated from 1669. Erasmus Bartholin, who was a mathematician and Danish doctor publishes a series of intriguing observations, which start from the observation that some images, observed through a crystal of Iceland Spath, appear split: we then speak of an «ordinary» image, and an "extraordinary" image. One of the images seems to rotate when the crystal is oriented in different positions, while the other remains fixed. When light passes through two pieces of crystal, one image may disappear according to certain orientations of the second crystal vis-à-vis the first crystal, and the rotation of a crystal changes the intensity of one of the two images. A few years later, Christian Huygens studies this phenomenon again, which he tries to explain by the presence of «secondary» wavelets, linked to a double refraction (bi-refringence), caused by the structure of the crystal. He will run into Newton, who was a supporter of a corpuscular theory of light.

Sir David Brewster, a Scottish physicist, is credited with discovering the phenomenon of light polarization in the early 19th century. It is also more than a century after the death of Newton, Etienne Louis Malus, an officer under Bonaparte, made by chance on his return to Paris from the Egyptian campaign a discovery related to the observation of a reflection of sunlight on the windows of the Luxembourg Palace, Seen through the crystal of Spath. He notices that one of the two images disappears for a certain orientation of the crystal, every 90°. He understands that there is a link between the prior reflection of light on the glass («glassy» reflection): sunlight, after reflection on the glass of the glass, could be in a condition similar to that observed after crossing a first bi chilled crystal. This phenomenon was related to the fact that reflection can cause polarization of light. The very nature of polarization is still unexplained.

Thomas Young will help to clarify the mystery of polarization: he suggests from 1816 that the vibrations of light could be in a plane not exclusively longitudinal with that of propagation (as for sound), but at least partially perpendicular (transverse) to it. Thus, a particular crystal structure could «interfere» with the vibrations and select certain orientations, explaining the appearance of double images offset in some directions when looking through some crystals. This theory, which puts the onduliveness of light in the foreground, is strongly opposed. James Clerk Maxwell, in establishing the theory of electromagnetic waves, will come to confirm this theory forty years later (1868).

9.2. Polarized light, polarizers and polarized lenses:

The polarization of light is derived from the wave theory of light. It has many applications such as polarized lenses that filter light, and some 3D films, etc. Some insects and animals use light polarization to orient themselves. Polarized light also seems to be involved in the genesis of an entoptic visual phenomenon called "Haidinger's brush". An entoptic phenomenon is induced by the eye itself (like flying flies, which are linked to floating bodies of the glass). It teaches us that the human eye is also sensitive to the polarization of light, even if this capacity is not used in any way...

This page presents the main features that make it possible to understand the phenomenon of polarization of light; the mathematical formalism is reduced to the maximum, in favor of a schematic representation allowing an intuitive and graphic understanding.

9.3. Polarization of light :

Light is an electromagnetic wave and corresponds to the simultaneous propagation of an electric field and a magnetic field, whose oscillations are mutually perpendicular. The oscillations are in a plane perpendicular to that of the direction of propagation. It should be noted that in the case of sound, the oscillations of air molecules stressed by the variations in pressure induced by the sound wave are longitudinal, in the direction of the propagation of the wave. The polarization is the direction of the oscillations of the electric field within this plane perpendicular to the propagation direction. If this direction is no longer random (constantly changing over very short time intervals), but takes place in a preferred direction, then the light is polarized.

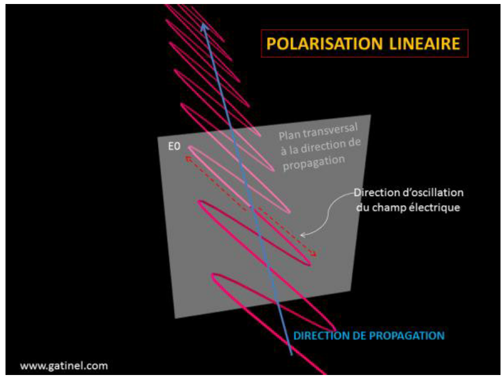


Figure 9.1 : Polarization of light

Linearly polarized light oscillates in a plane transverse to the direction of propagation: the value of the amplitude of the electric field oscillates between 0 and a maximum value E0. As long as the direction of oscillation of the electric field is identical, the light is considered to be polarized. For conventional light sources, the waves emitted successively in time are each linearly polarized, the direction of this polarization changes randomly, and their brevity means that a detector registers a light which «on average», does not have a preferred orientation for the direction of oscillation of the electric field.

If only one direction of oscillation remains, the polarization is called rectilinear.

If the direction varies continuously by making a circular loop in a clockwise (or counterclockwise) direction, the wave is polarized circularly. When the direction and amplitude vary continuously, the polarization is elliptical.

9.4. General polarization equation:

To calculate the polarization of the electric field of a polarized light:

$$E_x = E_{ox}\cos(wt)$$

$$E_y = E_{oy}\cos(wt + \emptyset)$$

$$\Longrightarrow E_y = E_{oy}coswtcos\emptyset + E_{oy}sinwtsin\emptyset$$

We have :

$$\frac{E_x^2}{E_{0x}^2} + \frac{E_y^2}{E_{0y}^2} - 2\frac{E_x}{E_{0x}}\frac{E_y}{E_{0y}}cos\varphi = sin\varphi^2$$

This equation can be represented as:

With : $E_{0x} = A_x, E_{0y} = A_y$

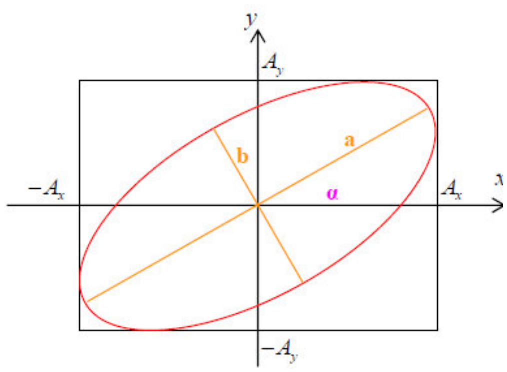
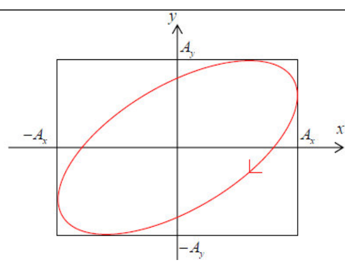
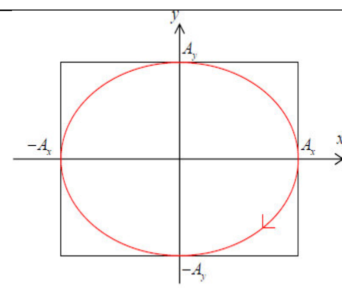
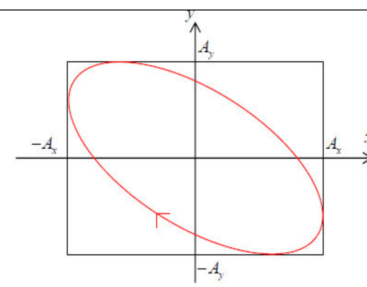


Figure 9.2 : General polarization of light (elliptical polarization)

Case : $0 < \varphi < \pi$	 **Case 1 : $0 < \varphi < \frac{\pi}{2}, \alpha > 0$**	 **Case 2 : $\varphi = \frac{\pi}{2}, \alpha = 0$**	 **Case 3 : $\frac{\pi}{-2} < \varphi < \pi, \alpha < 0$**

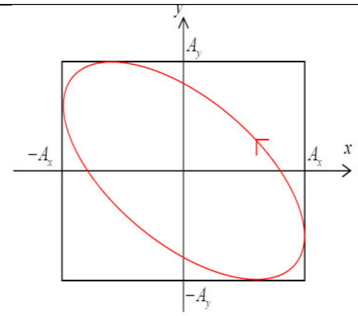
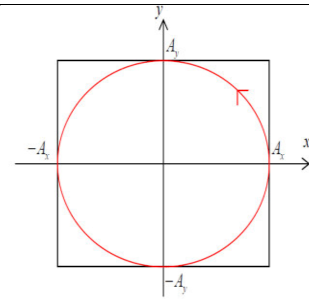
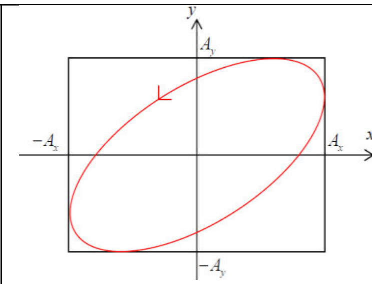
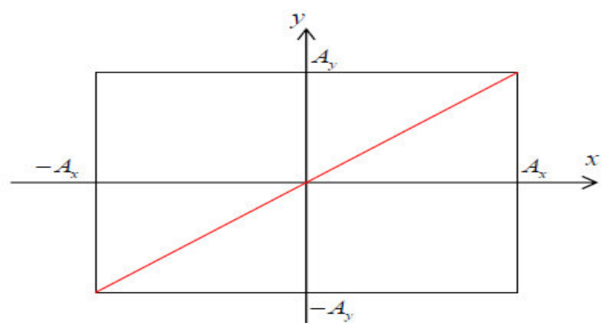
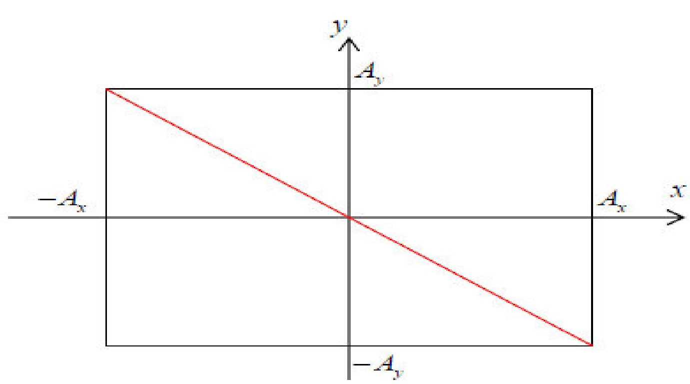
Case : $-\pi < \varphi < 0$	 **Case 4 :** $-\pi < \varphi < -\frac{\pi}{2}, \alpha < 0$	 **Case 5 :** $\varphi = \frac{-\pi}{2}, \alpha = 0$	 **Case 6 :** $-\frac{\pi}{2} < \varphi < 0, \alpha > 0$

Figure 9.3. Different kinds of polarization

If **:** $\varphi = 0\ (en\ phase)$: $\left(\frac{E_x}{A_x} - \frac{E_y}{A_y}\right) = \pm 1$



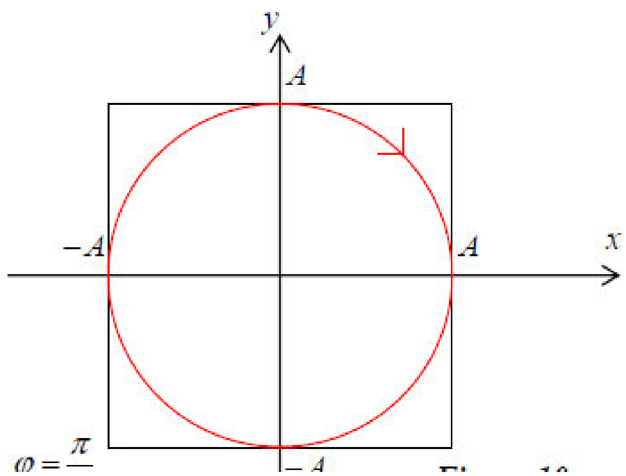
Case A : $\varphi = 0, \alpha > 0$



Case B : $\varphi = \pm\pi, \alpha < 0$

Figure 9.4 : Linear polarization

If **:** $A_x = A_y = A \; et \; si \; \varphi = \pm\frac{\pi}{2} \; we \; have : \; E_x^2 + E_y^2 = A^2$



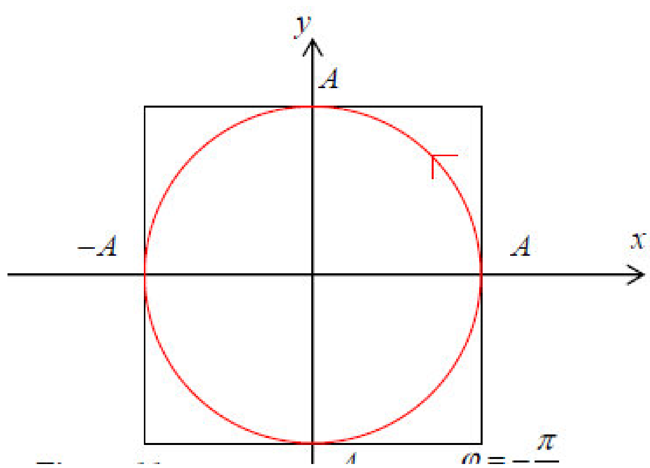


Figure 9.5: Circular polarization

9.5. Polariseurs :

Light from natural sources is unpolarized, but certain «natural» phenomena can cause at least partial polarization of the light: the diffusion of sunlight in the atmosphere is accompanied by partial polarization. The development of polarizing «filters» capable of polarizing light dates back to the 1930s.

When the polarization is rectilinear (single direction), the vector component in the perpendicular direction (always in the oscillation plane) is zero. One can imagine (and obtain in practice) «the total extinction» of this polarized light by placing a second polarizer whose axis is perpendicular to this direction. This is how solar polarized lenses and those used for viewing relief films (3D) work. If you place lenses polarized in different axes in front of the right and left eye, you can make them see different images, Of course, careful alignment of the polarization of these images with those of the polarizers of the right and left eye.

Recall again that the non-polarized light is a light whose electric field oscillates without privileged direction: it is emitted by sources such as the sun, lamps, etc. The atoms of these sources emit successive wave trains which are themselves polarized, but for very short periods (about 10-8 seconds): therefore the average orientation of the field vibration has no preferred orientation: natural light can however be decomposed into two orthogonal components with linear polarization (e.g., vertical and horizontal), which varies in phase over time.

It is therefore easy to understand that polarized light can be obtained from unpolarized light: polarization occurs when certain components are «absorbed», and there are four physical phenomena capable of producing polarized light from unpolarized light: dichroism (differential absorption by a filter), diffusion (interaction of light with fine particles), reflection (the light is reflected on a surface and polarizes during reflection), and the birefringence (the material has different properties depending on the direction taken by the light, ex: Spath crystal). We will focus on the first three phenomena.

Polarization by reflection justifies the existence of filter lenses called polarizing. The reflection of non-polarized light on some materials produces a polarization of incident light.

9.6. Law of Malus :

Let us recall again that the unpolarized light is a light whose field Suppose that a plane wave polarised rectilinearly passes through a polarizer. Note the angle θ of this polarization with the axis of the polarizer. The outgoing wave is then polarized along the axis of the polarizer, but it is attenuated by a certain factor: if we note I_0 and $I_1$the incident and outbound intensities, then the Malus law is written:

$$I = I_0 cos^2(\alpha)$$

This law has some important consequences:

- If the polarization of the incident wave is in the same direction as the axis of the polarizer, then all light intensity is transmitted ($\alpha = 0$).
- If the polarization of the incident wave is orthogonal to the axis of the polarizer, then there is no outgoing wave ($\alpha = 90\ degree$). In this case, the polarizer is called "crossed".
- If the incident wave is not polarized, that is to say it consists of all possible polarizations, then by averaging I we get $I=I_0/2$: half the intensity passes. This is what we observe when looking at a lamp through a polarizer.

A polarizer has the effect of projecting the amplitude A_0 of the wave it receives on its axis. In the case of a rectilinear polarized wave, this projection is proportional to the cosinus of the angle θ defined above. Thus, by noting At the outgoing amplitude, we have:

$$A = A_0 \cos(\theta)$$

Chapter 10 : Diffraction of light

10.I. Diffraction:

In addition to interference, waves also have another property – diffraction, which is the bending of waves when they pass by objects or through an opening. The diffraction phenomenon can be understood by using the Huygens principle which states that Every unobstructed point on a wave front will act as a source of secondary spherical waves. The new wave front is the surface tangent to all secondary spherical waves. Figure 1 shows the wave propagation according to the Huygens principle.

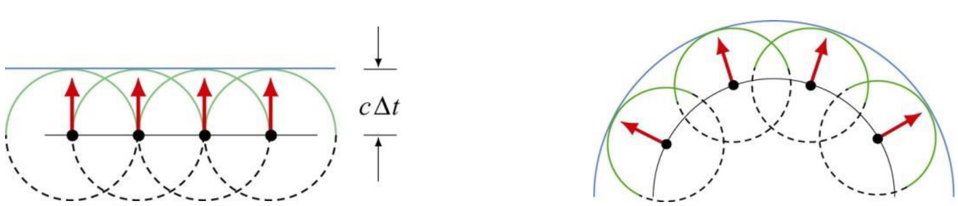


Figure 10.1. Huygens' principle

According to the Huygens principle, light waves that occur on two slits spread out and present an interference pattern in the region beyond. The pattern is called a diffraction pattern. If no bending is observed and the light wave continues to move in straight lines, no diffraction pattern will be observed (Figure 2).

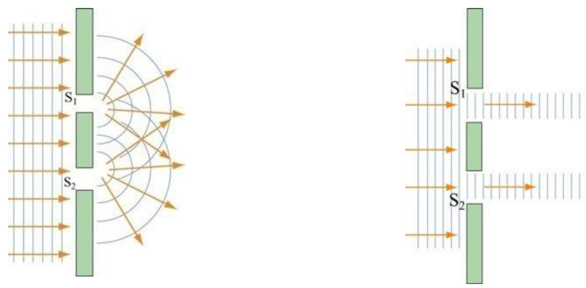


Figure 10.2. Diffraction of light

In addition to interference, waves also have another property: diffraction, Figure 2. Propagation of light leading to a diffraction pattern. No diffraction pattern if the paths of the light wave are straight lines.

We will limit ourselves to a particular case of diffraction called the Fraunhofer diffraction. In this case, all the light rays coming out of the slit are approximately parallel to each other. To make a diffraction pattern appear on the screen, a convex lens is placed between the slot and the screen to ensure convergence of light rays.

10.2. Single-slot diffraction:

In our study of the Young double-slot experiments, we assumed that the width of the slots was so small that each slot is a point source. In this section, we will take the crack width to be finished and see how Fraunhofer diffraction occurs.

In addition to interference, the waves also have another property: diffraction, let a monochromatic light source be incident on a finite width slot a, as shown in Figure 3.

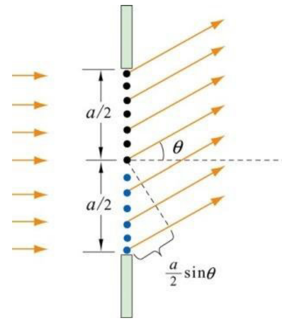


Figure 10.3. Diffraction of light through a width gap a.

In Fraunhofer-type diffraction, all the rays passing through the crack are approximately parallel. In addition, each part of the slit will act as a light wave source according to the principle of Huygens. For simplicity, we divide the slot into two halves. At the first minimum, each ray of the upper half will be exactly 180 out of phase with a corresponding ray of the lower half. For example, suppose there are 100 point sources, with the top 50 being in the lower half and 51 to 100 in the upper half. Source 1 and source 51 are separated by a distance a/2 and are out of phase with a path difference a/2. A similar observation applies to source 2 and source 52, as well as any pair that is at a distance of a/2. Thus, the condition for the first minimum is:

$$\frac{a}{2}\, sin\theta = \frac{\lambda}{2}$$

$$sin\theta = \frac{\lambda}{a}$$

Apply the same reasoning to four-point equidistant wavefronts at distance a/4, the path difference would be a sin a/4 , and the condition for destructive interference is:

$$sin\theta = \frac{2.\lambda}{a}$$

The argument can be generalized to show that destructive interference will occur when

$$a. sin\theta = m. \lambda$$

10.3. Single-slot diffraction intensity:

To calculate this, the total electric field is found by adding up the contributions of each point. Divide the simple slot into N small areas of width y a/N, as shown in Figure 4. The convex lens is used to bring the parallel light rays to a focal point P on the screen. We will assume that all the light of a given area is in phase. The relative phase shift is given by the ration:

$$\Delta L = \frac{2.\pi}{\lambda}. \Delta y. sin\theta$$

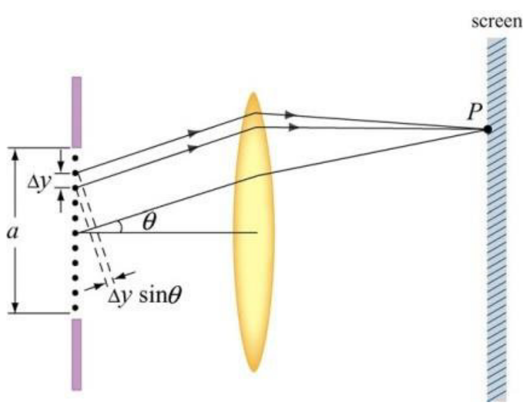


Figure 10.4. Single-slit Fraunhofer diffraction

Suppose the wavefront from the first point (counting from the top) arrives at the point *P* on the screen with an electric field given by:

$$E_1 = E_{01}. sin\theta$$

With a phase shift it will be:

$$E_1 = E_{01}.\sin(wt + \acute{\varnothing})$$

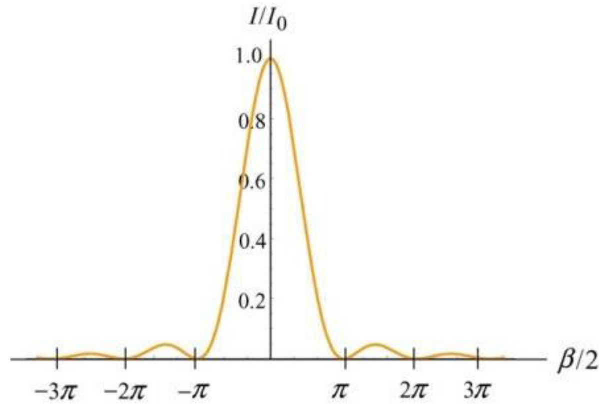


Figure 10.5. Intensity of the single-slit Fraunhofer diffraction pattern.

10.4. Circular aperture diffraction intensity :

The calculation of diffraction by a circular pupil is based on the same principle as that of a rectangular pupil. However, it is important to use pupil symmetry to perfect the calculation. Starting from the general relation:

$$E(u,v) = KA \iint t(x,y)e^{-2i\pi(ux+vy)}\, dxdy$$

We enter the cylindrical coordinates, to describe the position of the point so that:

$$x = rcos\alpha \quad y = rsin\alpha$$

So we have :

$$E(u,v) = KA \int_0^{\rho} \int_0^{2\pi} e^{-2i\pi(urcos\alpha + ursin\alpha)}\, rdrd\alpha$$

The diffraction figure having the cylindrical symmetry of the pupil we consider the calculation only in the y direction which leads to:

$$E(0,v) = KA \int_0^{\rho} \int_0^{2\pi} e^{-i2\pi v r sin\alpha}\, r dr d\alpha$$

We then use the definition of the Bessel function of order 0 given by:

$$J_0(q) = \frac{1}{2\pi} \int_0^{2\pi} e^{iqsin\theta}\, d\theta$$

Which brings us to:

$$E(0,v) = 2\pi KA \int_0^{\rho} J_0\,(2\pi v r) r dr$$

The integral of the zero-order Bessel function is then obtained by using the following property of this function:

$$qJ_1(q) = \int_0^{q} J_0(u) u du$$

Either by posing: $u = 2\pi r v$

$$\int_0^{\rho} J_0(2\pi v r) r dr = \frac{1}{4\pi^2 v^2} \int_0^{2\pi\rho v} J_0(u) u du = \frac{2\pi\rho v\, J_1(2\pi\rho v)}{4\pi^2 v^2} = \rho^2\, \frac{J_1(2\pi\rho v)}{2\pi\rho\vartheta}$$

It follow that :

$$E(0,v) = KA\; 2\pi\rho^2\, \frac{J_1(2\pi\rho v)}{2\pi\rho v}$$

With :

$$v = \frac{x}{\lambda D}$$

The intensity observed on the remote screen of D of the circular pupil is thus written:

$$I(v) = \left| KA\, 2\pi\rho^2 \frac{J_1(2\pi\rho v)}{2\pi\rho v} \right|^2$$

The Bessel functions are tabulated and the first zero of the function $J_1(S)$ is located in S=3.83. It follows that the intensity is cancelled in X_z :

$$\frac{2\pi\rho X_z}{\lambda D} = 3.83 \rightarrow X_z = \frac{0.61\ \lambda D}{\rho} = \frac{1.22\ \lambda D}{2\ \rho}$$

One can write according to the diameter of the pupil a and the wavelength λ:

$$1.22\ \frac{\lambda}{a}$$

The diffraction figure is then cancelled for the rays: 2.23, 3.23, 4.24, 5.24....

The luminous rings have as ray, in the same unit: 1.63, 2.68, 3.70, 4.71, 5.71...

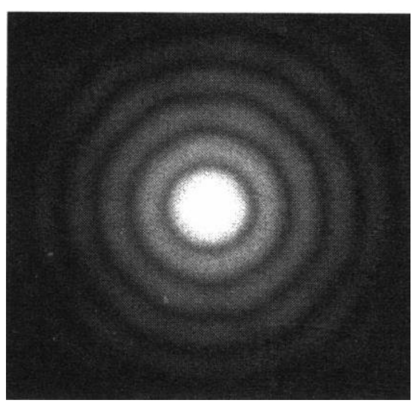


Figure 10.6. Fringes obtained by a circular opening

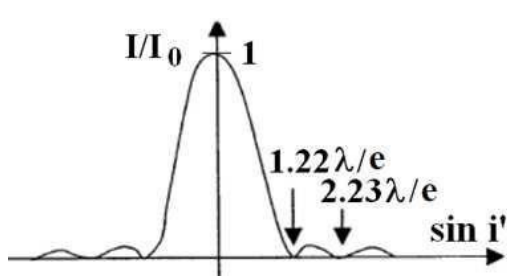


Figure 10.7. Diffraction intensity by a circular aperture

Chapter 11: Introduction to laser

11.1. History:

Laser: light amplification by stimulated emission of radiation

1960: Realization of the first laser, it is a ruby laser

1917: Einstein showed that one can amplify a radiation by passing this radiation through an excited medium, the emission of radiation by an excited material can be stimulated by a radiation interacting with this material, hence the possibility of amplifying any radiation by introducing this amplifier into a resonant cavity

1954: Production of the first radiation generator using stimulated emission by TOWNES and his team.

It is a microwave generator: MASER that it is no longer usable today. However, it was the starting point for intensive research which would lead in 1960 to the first coherent optical radiation generator or laser, consisting of a simple synthetic ruby rod with polished faces, surrounded by a helical lamp.

The extension of the principle of amplifying radiation by stimulated emission to the optical domain had been done in 1958 by Townes and Schowlow.

- The technique of optical pumping for the preparation of solid media with laser effect was proposed and described shortly afterwards by A. Kastner.

- Most of the lasers used today were invented at that time.

1. He-Ne laser appeared in 1961 working first in IR then the following year in visible (628 nm).

2. Semiconductor laser invented in the same year, but only becomes useful thanks to improvements brought about ten years later. For a few years there is no question of utility, the laser remains an invention in search of an application but very quickly the potentialities of this new tool are recognized. Large billions of dollars are devoted to it.

3. Industrial laboratories are looking at the development of lasers with powers in particular CO_2 laser for materials processing, at the end of the sixties the first lasers with industrial vocation appeared.

- The first experiments in the laboratory were disappointing, the lasers seem very fragile to users.

a- Pump pumps and optical windows must be changed frequently.

b-The operations performed are not reproducible –the laser does not have the reliability required for use in an industrial environment).

Meanwhile the research continues, the years (70) see the appearance of new lasers of powers for machining operations: drilling, cutting, welding. These reliable and increasingly satisfying lasers have become a reality [1].

11.2. Schematic of a laser:

To achieve coherent electromagnetic radiation at the given optical frequencies, three elements must be met:

1-The active environment

2-The pumping device

3-The resonant cavity

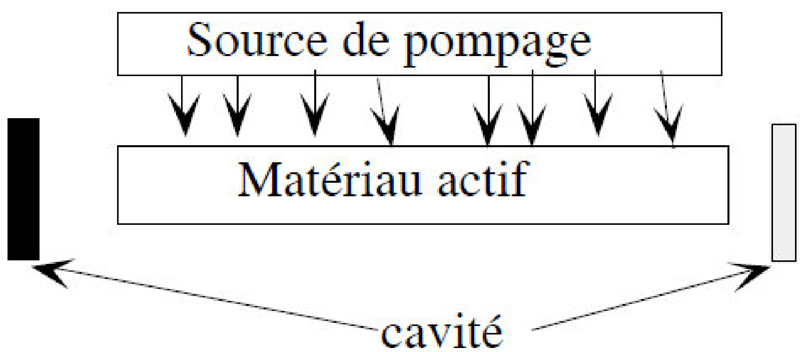


Figure 11.1: Schematic of a laser [2].

Note that the laser operation requires a pumping source, from which three pumping modes can be distinguished: optical, electronic and chemical pumping [2].

11.3. Properties of the laser beam:

11.3.1. Mono chromaticity:

The light from a laser is practically monochromatic (very precise wavelength). For the helium neon laser λ = 632.8 nm.

11.3.2. Coherence :

The laser light is coherent.

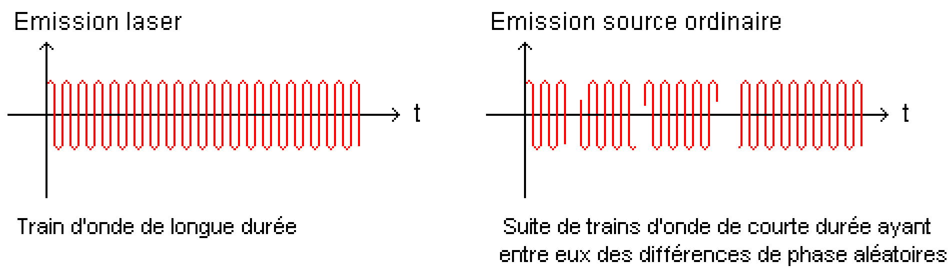


Figure 11.2: Emission of the laser and a regular source.

The light emitted by a laser is made by very long wave trains, much longer than those emitted by an ordinary source (good temporal coherence). This affects the monochromaticity.

This laser light also has a great spatial coherence: two points of the source normally placed in the direction of propagation produce luminous vibrations in phase agreement.

11.3.3. Directivity :

The laser beam is very little divergent. It is very directional.

11.3.4. Power:

The power of lasers is very variable. Low (a few mW) or medium for continuous lasers, it can become very high for pulse lasers and reach 10^6 W or even 10^{15} W for very short durations (10^{-12} s.) [3].

11.4. Energy levels:

To understand the operation of a laser, we must consider the interaction between radiation and matter at the levels of elementary atomic systems: atoms, ions, molecules.

At this scale the physical quantities quantified. Electrons can only gravitate around the nucleus following certain orbits. The passage of an electron from one orbit to another, is done with energy exchange with the outside.

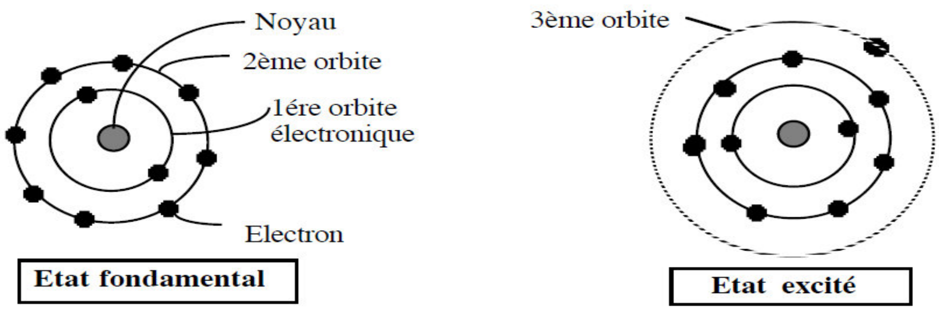


Figure 11.3: Structure of the atom. Example of the Neon atom [4].

Electrons are distributed in orbits verifying the laws of quantum mechanics.

Excited state: an electron from layer 2 has passed to layer 3, during the absorption of a photon of energy: $E=h.\upsilon$ An atomic system is characterized by a set of energy levels like the one shown in the figure.

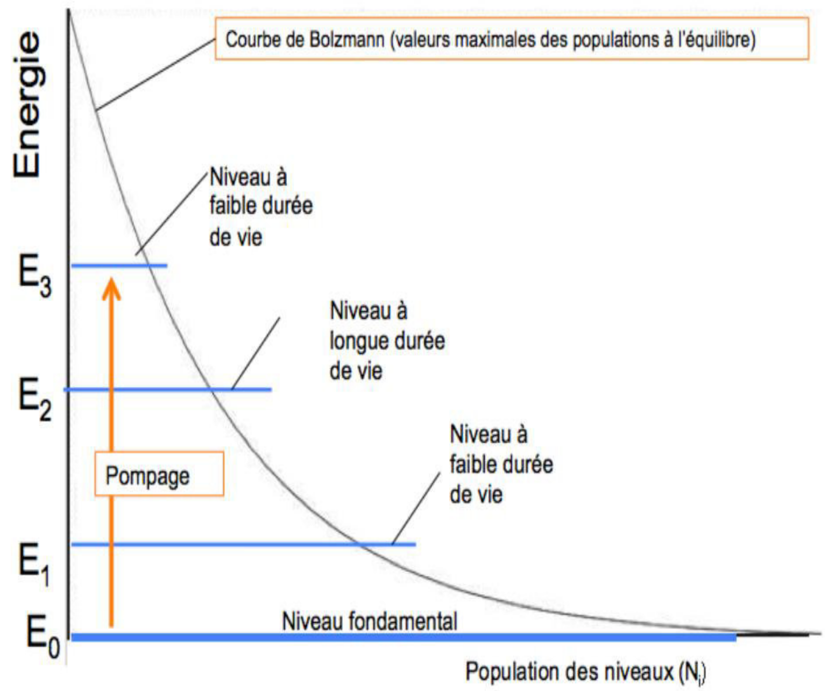


Figure 11.4 : Energy levels of different atomic states population of equilibrium levels

-Each energy level corresponds to a particular distribution of electrons. In a given set of elementary atomic systems, the population of the different levels depends on the temperature and the possible presence of energy sources interacting with the material.

At equilibrium, electrons tend to occupy the lowest energy levels. At temperature T, the population N_i of energy level E_i is linked to the population N_0 of the fundamental energy level E_0 by the relation (Boltzmann equation):

$$N_i = N_0 \exp(Ei - E0)\,/kT$$

-Molecules have a more complex electronic structure than that of figure 11.3, each electronic level is broken down into sub-levels corresponding to the vibration and rotation energies of the molecule on the scale of very low energy values, radiation of frequency υ can be assimilated to the flow of photons (elementary particles without mass), of energy E=hυ.

h: Max-Planck Constant =$6.62.10^{-34}$ j.s

Photons can interact with matter by exchanging energy with electrons.

11.5. Matter – radiation Interaction:

An atom reacts according to two processes: absorption or emission of light.

a- Absorption : corresponds to the transition between two energy levels $2\ et\ 1\ (E_2 > E_1)$

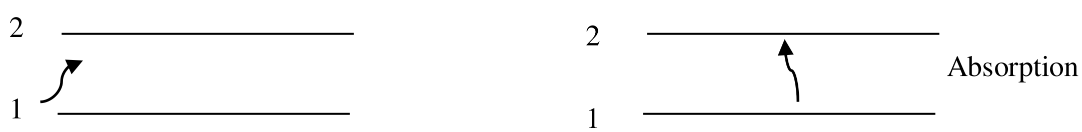


Figure 11.5 : Absorption process

With :

$$\frac{dN_1}{dt} = -W_{12}\, N_1\ .\varphi(\upsilon)$$

N_1 : number of atoms that have electrons at level 1.

W_{12} : Einstein coefficient for absorption

$\varphi(\upsilon)$: Spectral density

b- Spontaneouas emission:

When an atom has an energy different from the fundamental energy, it only retains this energy for a very short time called the life time of the level ($de\ 10^{-9} à\ 10^{-4}\ s$) .

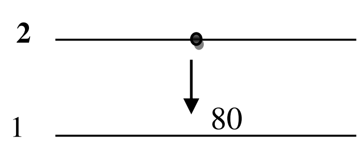


Figure 1I.6 : Spontaneouas emission process

With :

$$\frac{dN_1}{dt} = -A_{21}\, N_1$$

$$N_2(t) = N_{20}\ e^{-A_{21}t}$$

From where : N_2 : number of atoms that have electrons at level 2.

A_{21} : Einstein coefficient for spontaneouas emission.

c- Induced (stimulated) emission: The variation of the numbers of atoms at level 2 is given by:

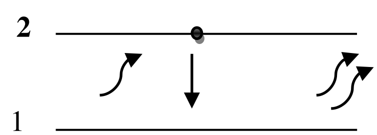


Figure 11.7 : Stimulated emission process.

From where :

$$\frac{dN_2}{dt} = -W_{21}\, N_2\ .\varphi(\upsilon)$$

Both the absorption and stimulated emission processes are coherent (same phase) processes so the emitted photons are of the same frequency and same phase as those incident.

-Spontaneous emission is an inconsistent process.

-Emission increases the energy density of light

-Absorption reduces the energy density of light

The number of photons produced by stimulated emission is given by [5]:

$$n_i = n_2 . w(\vartheta) . F(\vartheta) . W_{21}$$

The number of photons produced per unit time [5] :

$$\frac{dn_0}{dt} = n_2 . w(\vartheta) . F(\vartheta) . W_{21} - n_1 . w(\vartheta) . F(\vartheta) . W_{12} + n_2 . A_{21}$$

$w(\vartheta)$: Density of frequency photons ϑ corresponding to the transition between the two energy levels E_n and E_m and which depends on the number of occupancy n_2 and n_1.

$$w(\vartheta) = \frac{8\pi\vartheta^2}{C^3} . \frac{h\vartheta}{\exp\left(\frac{h\vartheta}{KT}\right) - 1}$$

With : $K=1.3804.10^{-23}$ N.m/K : Boltzmann constant

$h = 6.6258.10^{-34}$ $W.S^2$: Planck constant

Einstein showed that the probability for an excited atom to emit a photon of energy ΔE per stimulated emission is equal to the probability for this same atom in its ground state to absorb a photon at the same time: $W_{21} = W_{12} = w$

It should be taken into account that the excitation in the stimulated emission is done before the end of the lifetime. In the stimulated emission our radiation will be amplified as shown in the figure above and which is the basis of the operation of our laser [5].

The following relationships are also given [5]:

$$W_{21}\, g_2 = W_{12}\, g_1 \quad ; \frac{A_{21}}{B_{21}} = \frac{8\pi h}{\lambda^3} = \frac{8\pi h\vartheta^3}{c^3}$$

Remark : If an atom cannot emit in a wavelength spontaneously, the same is true for the stimulated emission.

11.6. The properties of the laser beam:

The use of a laser for various applications depends on the properties of the laser irradiation, such as orientation, divergence, and wave or frequency characteristics, which can be adjusted by components of the laser. The characteristics affecting the properties of the laser beam: size of the average gain, location, separation and reflectivity of the mirrors of the optical cavity, and the presence of losses in the path of the beam into the cavity. Some of these characteristics determine the unique properties of the laser beam, called laser modes. Modes are wave properties concerning the oscillating character of the beam as the beam passes back and forth through the amplifier and develops at the expense of losses. The development of laser modes involves an attempt by light rays of similar wavelengths to adapt to an exact number of their waves right into the optical cavity. For example, a green laser mode light with exactly 5 x 10-5 cm fits exactly 106 complete cycles of oscillations between the mirrors in the laser cavity separated by a distance of 50 cm. Most lasers operate with two longitudinal and transverse modes that result in a complex frequency [6].

11.7. Different types of lasers:

The first laser was demonstrated in a ruby crystal by Maiman, in 1960. Since then, a large number of lasers have been invented with wavelengths in the visible, ultraviolet and infrared. These include various gas, solid, liquid, glass, plastics, semiconductors and dyes. In addition to the ruby crystal, many other crystals doped (presented as an impurity) with light rare earth ions have given a very good quality laser. The many types and models of lasers are constantly increasing and can be classified according to their production techniques. The broad categories are:

Solid-state lasers

Gas lasers

Liquid lasers

Semiconductor lasers

Chemical lasers

11.7.1. Solid state lasers:

The active medium consists of a small proportion of metal ions (active center), replacing atoms (or ions) of the crystal. Solid-state lasers may have considerable power, but their beam is not strictly monochromatic (low coherence), and their efficiency is low [6].

11.7.2. Gas lasers:

Gas lasers have a gas or gas mixture as an amplifier medium. Helium-neon, argon, carbon dioxide and lasers are the most widely used of gas lasers. Javan, Bennett and Herriott succeeded in demonstrating the first gas laser in late 1960, a few months after Maiman's discovery of the ruby laser. They used a helium-neon mixture (90% and 10% neon helium) as an active medium. In most cases, the gas is contained in a quartz or glass tube 25-100 cm long and the gas molecules are excited in an electric shock. With a few exceptions, these lasers receive their energy via the input of high-energy gas atoms. This energy is provided by applying a high voltage between the electrodes located in the gaseous medium, to accelerate the electrons required for the high energy. Gas lasers are continuous and normally have consistency. But they are much less powerful than solid-state lasers [6].

11.7.3. Liquid lasers:

The use of organic dyes allows to obtain a variable frequency emission using a diffraction network.

11.7.4. Semiconductor lasers:

The laser diode is the smallest of all known lasers, it has a size of a fraction of a millimeter. The laser is made of a semiconductor crystal, such as gallium arsenide, lead selenide, etc., with parallel faces at the ends to serve as mirrors for partial reflection. The whole laser package is very small and can be integrated into an integrated circuit if necessary. A semiconductor, as its name suggests, is halfway between a conductor and an insulator (non-metal), as far as its electrical conductivity is concerned. The semiconductor materials containing gallium and arsenic compounds have been found to generate infrared rays when current passes through them. This assumes that these semiconductors convert electrical energy into photons. But, these are the ordinary incoherent light rays and were not made by laser action, however, when the crystal of gallium arsenide is by it, the laser action. Many semiconductors serve as laser materials and they were made in the context of stimulating electricity instead of light which is used for other solid-state lasers. There are two types of semiconductors, namely, the n type and p type. To understand the operation of these devices, it is necessary to know the nature of electronic energy members in a semiconductor. A typical semiconductor has energy bands separated by the forbidden energy of the gap region. In an intrinsic semiconductor, there are just enough electrons present to fill the upper part of the occupied energy band (valence band) while leaving the next upper portion (conduction band) empty. In an n-type semiconductor, a small amount of impurity is intentionally added so that the matter is made to have an excess of electrons, which thus becomes negative. On the other hand, by adding another type of impurity in a p-type semiconductor, the material can be made to have an excess of holes (electron vacant post), which thus becomes the solid state laser is made up of a small block (approximately one square millimetre of surface area) of gallium arsenide. When p-type and n-type are formed of layers in intimate contact, the interface becomes a p-n junction. When current is applied to the block, electrons move at the junction of the n-type material region in excess, having holes type p material. In this process of electron suppression in the holes, recombination takes place leading to radiation emission. The photons that travel through the junction region stimulated more electrons during the transition, releasing more photons in the process. The laser runs along the line of the junction. Due to the polished, shiny end of the block, the stimulated emission expands considerably and a coherent beam of light is emitted from one of the two ends. With a gallium arsenide laser, a continuous beam of some milite power is easily obtained [6].

11.7.4. Chemical lasers:

In the search for alternative methods to the convention excitation of materials at light sources, scientists found that intense light produced by reactive chemicals can be used for laser excitation. A chemical laser produces a high-energy beam from the energy released when two or more chemicals react. It converts the energy produced by a chemical reaction into a particular excitation of certain species as the chemical reactions of the product can be carried out with the help of gamma rays, electrons, photons etc. flames can also be used as excitation source to initiate the laser action. Explosive gas mixture, which can also be used to excite laser radiation in the gas itself, is another pumping source. Chemical laser is potentially very efficient of a compact device. In a typical chemical laser, nitrogen is heated by an electric arc and mixed with sulphur hexafluoride. The mixture is then forced through a set of injectors and hydrogen is injected into the exhaust. The laser activity takes place when the exhaust passes between two mirrors, the laser emission was obtained in the infrared, with the help of energy produced by the reaction of hydrogen and chlorine. Hydrogen fluoride is another high-powered chemical laser that produces laser radiation in the range of 2.6 to 3.5 µm. A mixture of hydrogen and fluor is used in this laser. When the fluoride molecule is dissociated optically or by reference or by pumping, a chain of chemical reactions takes place in the reduction of the vibrationally excited hydrogen fluoride-molecule. As there is no hydrogen fluoride of the molecules in the lower state at the beginning, population inversion is easily carried out and the laser action.

Deuterium fluoride is another important chemical laser. It works similarly to this laser. It produces laser radiation in the region 3.5-4.1µm. The laser chemical produces such a large amount of energy relative to its size that it quite in execution as a potential laser weapon. Weight by weight, chemical energy source efficiency of 106 joules per pound versus traditional electric pumping which gives sources about 100 joules per pound. Because of their high efficiency and very powerful beams, chemical lasers are currently being developed for star warfare by the US program to destroy enemy missile during their space travel [6].

The different types of lasers used are shown in the table below [7]:

Tableau 11.1 : Different types of lasers.

Active medium	type	Pulse time	Power	Wavelenght	Pumping
Rubis	crystal	20 ns	10 MW	694 nm	lamp
Helium-Neon	gas	continuous	3 mW	633 nm	discharge

Glass doped with Neodymium	glass	40 ps	1 TW	1.06 µm	lamp
Neodymium-doped YAG	crystal	15 ps	10 MW	1.06 µm	lamp
Diode	Semi-conductor	continuous	100 mW	900 nm	electric
Nitrogen	gas	6 ns	500 KW	337 nm	discharge
Carbon dioxide	gas	continuous	1 KW	10.6 mm	discharge
Dyes	liquid	5ns 1 ms continuous	50 KW 1 MW 10 mW	450-900 nm	Pulsed laser Lamp Continuous laser
Hydrogen	gas	2 ns	1.5 KW	160 nm	discharge
Methyl fluoride	gas	continuous	10 W	469 nm	laser

11.8. Laser safety concepts:

Depending on the power and wavelength of the laser, it can be a real danger to vision and cause irreparable burns to the retina. Lasers are classified according to their power in the table below [8]:

Tableau 11.2 : Laser classification.

Class I	Lasers that are not hazardous to continuous vision or are manufactured to prevent human vision. Typically this involves low-power lasers or lasers in housings (examples: printers, CD-ROM drives and DVD players).
Class II	Lasers emitting visible light causing sufficient eye discomfort do not pose a danger for short periods. These can be equated with an intense light source.
Class II.a	Lasers emitting visible light that are not intended to be seen and should not cause damage when directly viewed for less than 1000 seconds (e.g., barcode readers).
Class III.a	Lasers that should not normally be dangerous if seen temporarily, but could present a danger if viewed through focusing optical devices (examples: magnifiers and telescopes).
Class III.b	Lasers which are dangerous if seen directly and can cause burns, both directly and by reflection but not by diffraction other than at short range.
Class IV	Lasers that are a hazard to both direct view and reflection and diffraction, and can also cause fire.

11.9. Lasers applications:

Although the range of possible powers is very wide, ranging from 10-6 watts to 109 watts, lasers used in the medical field have energies of a few tens of watts.

The effects of the laser beam differ according to wavelength, intensity, exposure time, irradiated tissue. Three main effects can be distinguished:

11.9.1. The thermal effect :

The thermal effect of radiation is the most widely used and leads to two essential applications. The laser beam focused on a tissue vaporizes the water from it. This results in an aseptic cut-out that reduces bleeding.

For a surface action, the argon laser (= 500 nm) is used. For deeper action, a yttrium-aluminium YAG garnet laser that delivers about 50 watts over a few square millimetres in 1 to 2 seconds. A visible He-Ne laser will be coupled to the invisible YAG laser (= 1 060 nm) to materialize the beam.

In ophthalmology, the argon laser will treat retinal detachments by making real welding points around the affected area.

In diabetic retinopathy, blood vessels of the peri-foveal retina will be hemostatized to increase fovea vascularity and improve patient vision.

The use of a laser requires taking precautions even more stringent than handling a laser not emitting in the visible: wearing protective glasses is recommended, and all reflective surfaces in the operating room must be avoided.

11.9.2. Photochemical effect :

It is used to treat tumors. The patient is given a photo-sensitiser which has the property of preferentially fixing itself on cancer cells. These absorb the laser light and pass into an excited state by emitting chemical radicals that destroy the malignant cells.

11.9.3. The electromechanical effect:

It also helps to destroy kidney stones. Focusing an intense laser beam over a surface of a few square micrometers induces overpressures accompanied by shock waves that can break up the solid granules [8].

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Travaux dirigés : Partie optique géométrique

Série N^0 1 en optique géométrique

Exercice N^0 1 :

Considérons les points de coordonnées A (x_a, 0), B (0, y) et C (x_c, y_c).

Utiliser le principe de Fermat pour obtenir la loi de Snell Descartes pour la réfraction ?

Exercice N^0 2 :

Le tableau ci-contre donne les longueurs d'onde, dans le vide, de deux radiations monochromatiques et les indices correspondants pour deux types de verre différents :

Couleur	$\lambda_\circ$***(nm)***	***n (crown)***	***n (flint)***
Rouge	*656,3*	*1,504*	*1,612*
Bleu	*486,1*	*1,521*	*1,671*

1. Calculer les fréquences de ces ondes lumineuses. Dépendent-elles de l'indice du milieu ?

On prendra $C_0 = 2,998.10^8\ m.s^{-1}$.

2. Calculer les célérités des deux radiations dans les deux verres.

3. a) Un rayon de lumière blanche arrive sur un dioptre plan air-verre, sous l'incidence $i = 60^0$. L'indice de l'air est pris égal à 1,000. Rappeler les lois de Descartes relatives à la réfraction de la lumière.

b) Calculer l'angle que fait le rayon bleu avec le rayon rouge pour un verre crown, puis pour un verre flint. Faire une figure.

c) Quel est le verre le plus dispersif ?

Exercice N^0 3 :

Deux morceaux de verre taillés en forme de triangles rectangles et isocèles d'indices respectifs N et n ont leur face AB commune. Un rayon incident arrive sur la face AD sous une incidence normale, se réfracte en I_1, se réfléchit en I_2 puis ressort en I_3 avec un angle i. Les valeurs de N et n sont telles que la réflexion soit totale en I_2.

1. Ecrire la relation de Snell Descartes aux ponts I_1 et I_3.

2. Quelles relations vérifient les angles $r\ et\ \alpha;\ \alpha\ et\ \beta$?
3. Quelle relation vérifient N et n pour que la réflexion soit limite en I_2?, calculer $N, r, \alpha, \beta\ et\ i$ pour $n = \frac{3}{2}$ quand cette condition limite est réalisée. On appelle N_0 cette valeur limite de N. Pour que la réflexion soit totale en I_2, N doit-il être plus grand ou plus petit que N_0?.
4. Ecrire la relation vérifiée par N et n pour que l'angle i soit nul. Que vaut N ?.

Exercice N^0 4 :

On fabrique un parallélépipède de verre d'indice n=1.5. Un rayon arrive en I avec un angle d'incidence i, se réfléchit sur la deuxième face en J avec un angle γ et ressort par la troisième face au point K avec un angle i'.

1. Etablir les relations entre les différents angles en I, J et K. Montrer que le rayon ne peut pas se réfracter en Jet qu'il ne peut pas se réfléchir en K. Que vaut l'angle i' ?.
2. Calculer la déviation due au parallélépipède

Exercice N^0 5 :

Soit un morceau de verre d'indice n=1.5 taillé en forme de triangle. Un rayon arrive perpendiculaire à la face AB. Quelle doit être la valeur minimale de N, l'indice de réfraction de la goutte de liquide posée sur la face BC pour qu'il y ait réflexion totale en I ?, Dans ce cas, le rayon sort il par la face AC ?.

Série N^0 2 : Prisme

Exercice N^0 1 :

a- Un prisme isocèle d'angle au sommet A repose sur sa base BC sur un miroir. L'indice de réfraction est n=1.5. Un rayon incident en I avec un angle i_1 ressort du prisme en J sous un angle i_2. Le rayon sortant se réfléchit en K sur le miroir avec un angle de réflexion β. Exprimer β en fonction de i_2 et A.

Exprimer la déviation D due au prisme en fonction de i_1, i_2 et A et en déduire l'expression de la déviation finale D' en fonction de i_1 et i_2. Dans quelle condition le déviation D' est-elle nulle ?.

b- Calculer r_1, r_2, i_2, D et D' pour $i_1=45^0$ ($A=60^0$).

Exercice N⁰ 2 :

Un prisme de verre d'indice $n_2=1.52$ dont la section principale est un triangle rectangle isocèle (angle $A=90^0$) est placé dans une cuve contenant du sulfure de carbone d'indice $n_1=1.65$.

1. Un rayon arrive parallèlement à la base BC du prisme et normalement à la paroi de la cuve. Construire sommairement la marche du rayon et calculer la déviation finale à la sortie de la cuve D.
2. En jouant sur les conditions de pression et de température on fait varier l'indice n_1 de $dn_1=+0.02$. A l'aide du calcul différentiel comment varie l'angle de déviation à la sortie du prisme.
3. La cuve est vidée et contient maintenant de l'air d'indice $n_1=1$. Le rayon incident arrive toujours parallèle à la base du prisme et normalement à la paroi de la cuve. Calculer la nouvelle déviation finale D'. Le rayon sort-il par la même paroi de la cuve ?.

Exercice N⁰ 3 :

Un rayon arrive en I avec une incidence de 45^0 sur un prisme équilatéral d'indice $n = \sqrt{2}$ Deux faces du prisme sont réfléchissantes.

1. Calculer les valeurs des angles de réflexion successifs r_1, r_2, r_3 et de l'angle de réfraction r_4.
2. Calculer et montrer que le rayon sortant est perpendiculaire au rayon incident.

Exercice N^0 4 :

Un rayon lumineux arrive normalement par la face AB d'un prisme rectangle (A=90^0, C=55^0). Il comporte deux radiations pour lesquelles l'indice du prisme vaut n_1=1.73 et n_2= 1.75.

3. Sur quelles faces du prisme vont sortir les deux radiations et avec quel angle ?.
4. Déterminer les deux déviations D_1 et D_2.

Série N^0 3 : Les dioptres sphériques et les miroirs sphériques

Exercice N^0 1 :

a- Un dioptre sphérique de rayon de courbure r égal à +2 cm, sépare deux milieux d'indice $n = \frac{3}{2}$ et n'= 1.

- Calculer les foyers F et F'
- Calculer la vergence du dioptre. Est-il convergent ?

- Sur l'axe on place une source ponctuelle en A telle que p=2 r. Quelle est la position de l'image A' ?.
- Quel est le grandissement transversal obtenu pour un objet de 1 cm de hauteur ?. Quels sont la nature, grandeur et sens de l'image A'B'. Sur la figure placer l'objet AB et construire géométriquement l'image A'B' en faisant apparaitre les rayons utilisés.

b- Reprendre le tout avec r=-2cm et p=2 r.

Exercice N^0 2 :

Un dioptre sphérique de rayon de courbure r sépare deux milieux d'indices $n = \frac{3}{2}\ et\ n' = \frac{4}{3}$ a- Exprimer les distances focales f et f' ainsi que la vergence $\emptyset$ en fonction de r, le rayon de courbure.

b- On donne r=-10 cm. Calculer numériquement f, f' et $\emptyset$. Le dioptre est il convergent ?.

c- On place un objet AB à 50 cm en avant du dioptre. Calculer la position p' de l'image ainsi que son grandissement transversal γ .

d- Sur une figure, placer les foyers F et F' et l'objet A. Construire son image A'. Quelle est la nature de A' ?.

Exercice N^0 3 :

Un miroir sphérique concave M_1 et un miroir sphérique convexe M_2 de même rayon de courbure R =1m ont leur faces réfléchissantes en regard, leurs sommets S_1 et S_2 étant distants de 2 m. On place, à égale distance de M_1 et M_2 et perpendiculairement à leur axe optique commun, un petit objet A_1B_1 de 3 cm de hauteur.

1- Construire l'image finale A_2B_2 de A_1B_1 donnée par les deux miroirs en considérant d'abord une réflexion sur le miroir M_1 puis ensuite une réflexion sur le miroir M_2.

2- Déterminer, dans ce cas, la position, la grandeur et la nature de l'image A_2B_2.

Exercice N^0 4 :

Le fond d'un cylindre est constitué d'une surface sphérique de sommet S_1, concave, réfléchissante, ayant son centre C_1 sur l'axe Δ du cylindre à une distance de 200 cm de S_1,

(S_1C_1 = - 200 cm). Le cylindre est rempli d'eau, d'indice $n = \frac{4}{3}$, jusqu'à une hauteur de 50 cm

(S_1H = - 50 cm), H étant l'intersection de la surface de l'eau avec l'axe Δ du cylindre tel que représenté sur la figure ci-après.

On désigne par ζ_1 le système optique ainsi formé.

Un point objet A_1 est placé sur l'axe Δ tel que S_1A_1 = - 212,5 cm.

1. Déterminer les positions, par rapport à S_1, des images successives A_2, A_3, A_4 données respectivement par le dioptre plan (air-eau), le miroir sphérique constituant le fond du cylindre puis le dioptre plan (eau-air).

2. Le système optique ζ_1 est équivalent à un miroir sphérique concave, noté ζ_2, de sommet S_2 image de S_1 à travers le dioptre plan.

2. a. Déterminer, par rapport à S_1, la position du centre C_2 de ζ_2.

2. b. Montrer que C_1 et C_2 sont deux points conjugués par rapport au dioptre plan.

3. Construire l'image d'un petit objet A_1B_1, perpendiculaire à l'axe Δ, donnée par le système optique ζ_1.

Série N^0 4 en lentilles

Exercice N^0 1 :

Un objet A_1B_1 et un écran E, fixes, sont distants de $A_1E = D = 180$ cm.

On déplace entre eux une lentille convergente L de distance focale $f' = 40$ cm

Déterminer :

1- les positions de la lentille qui donnent, sur l'écran, une image nette de l'objet.

2- le grandissement linéaire transversal pour chacune des positions

Exercice N^0 2 :

On se place dans les conditions de l'approximation de Gauss.

On considère une lentille mince convergente L_1 , de centre optique O_1, d'axe optique Δ et de foyers F_1 et F'_1 et un objet ponctuel A placé à l'infini dans la direction de Δ.

1. Tracer la marche de deux rayons issus de A traversant la lentille.

Quelle est la position de l'image A1 du point A donnée par L_1 ?

2. On ajoute, sur le chemin des rayons émergents de L_1 , une lentille mince convergente L_2, de centre optique O_2, de même axe optique Δ que L_1 et de foyers F_2 et F'_2 .

Déterminer graphiquement la position de l'image A_2 du point A à travers le système formé par les deux lentilles minces L_1 et L_2

2.a.- quand : $O_1O_2 = O_1F'_1 + F_2O_2$

2.b.- quand : $O_1O_2 > O_1F'_1 + F_2O_2$

Exercice N^0 3 :

Un objet AB de taille 1, 0 cm est placé 5, 0 cm avant le centre optique O d'une lentille convergente, de distance focale f' = 2, 0 cm (AB est perpendiculaire à l'axe optique).

1) Calculer la vergence de la lentille et préciser son unité.

2) Construire l'image $A'B'$ de AB en utilisant les trois rayons «utiles». Mesurer alors $A'B'$ et OA'.

3) Retrouver OA' et $A'B'$ par le calcul.

4) Calculer le grandissement Gt. Que peut-on dire de l'image ?

5) Nommer et rappeler les conditions d'utilisation des expressions précédentes.

Exercice N^0 4:

a) Soit une lentille de distance focale f ' = +3 cm.

On considère un objet perpendiculaire à l'axe optique de taille 2 cm respectivement à 4 cm et 2 cm en avant du centre optique. Déterminer graphiquement l'image de l'objet dans chaque cas (échelle 1/1).

Même question avec un objet virtuel situé à 10 cm du centre optique.

b) Soit une lentille de distance focale f ' = -3 cm.

Trouver l'image d'un objet réel de taille 2 cm situé à 5 cm du centre optique.

Même question avec un objet virtuel situé à 1,5 cm puis 5 cm du centre optique.

c) Retrouver les résultats précédents par le calcul algébrique.

Exercice N^0 5 : (Facultatif)

On considère une lentille convergente L_1 suivie à une distance d = 3 a d'une lentille divergente L_2 ; les modules de leurs distances focales valent respectivement $f_1 = 2$ a et $f_2 = 3$ a .

1. Déterminer par construction la position et la nature des foyers objet F et image F' de l'ensemble. Retrouver les résultats par le calcul.

2. On appelle B le point d'intersection de la droite portant un rayon incident issu de F et de la droite portant le rayon émergent correspondant. On appelle A le point de l'axe optique du système dans le plan de front passant par B .

a) Construire AB ; déterminer par le calcul la position de A, puis celle de son image A' donnée par le doublet.

b) B' étant l'image de B donnée par le doublet, calculer le grandissement de l'ensemble A B/AB' '. Que constatez-vous ?

REP :

$O_2F' = -3a/4$ et $O_1F = -3a$. 2.a) $O_1A = -3/2a$et $O_2A' = -9/4\ a$. 2.b) □□= 1.

Examen n^{0}1 en optique

Questions: (7points)

1. Si on a un rayon lumineux qui se propage d'un milieu d'indice de réfraction $n_1=1$ vers un milieu d'indice de réfraction $n_2=1.632$, donner la relation qui relie entre le rayon incident et le rayon diffracté, quel est le phénomène observé, calculer son angle critique?
2. Si on a un prisme d'angle au sommet A et d'indice de réfraction n,

On mis : i, i' : angles d'incidence sur la face 1 et 2 du prisme.

r, r' : angles de réfraction sur la face 1 et 2 du prisme.

a. Ecrire les équations descriptives du prisme (avec dessin).

b. Quelles sont les conditions d'émergences du rayon lumineux pour qu'il soit réfracté de la $2^{éme}$ face du prisme.

c. Vérification pratique : si on a $A=60^0$, n (indice de réfraction du prisme)=1.520, et i= 42°, est ce que le rayon lumineux sera diffracté du $2^{éme}$ face du prisme ?

3. Quelle est la différence entre une lentille convergente et une lentille divergente?.
4. Avec une lentille nous avons obtenus une image :
   a. virtuelle, droite et réduite:
   b. réelle, droite et agrandie

Quelle est la position de l'objet pour les deux cas : lentille convergente et lentille divergente.

5. Avec un miroir sphérique nous avons obtenus une image :
   a. virtuelle, renversée et agrandie:
   b. réelle, droite et agrandie

Quelle est la position de l'objet pour les deux cas : miroir concave et miroir convexe.

<u>Exercice N^0 1</u> : (6 points)

Deux morceaux de verre taillés sous forme de triangles rectangles et isocèles d'indices respectifs N et n ont leur face AB commune. Un rayon incident frappe AD sous une incidence normale, se réfracte en I_1, se réfléchit en I_2 puis ressort en I_3 sous l'incidence i.

Les valeurs de N et n sont telles que la réflexion soit totale en I_2.

1) Ecrire la relation de Snell-Descartes aux points I_1 et I_3.

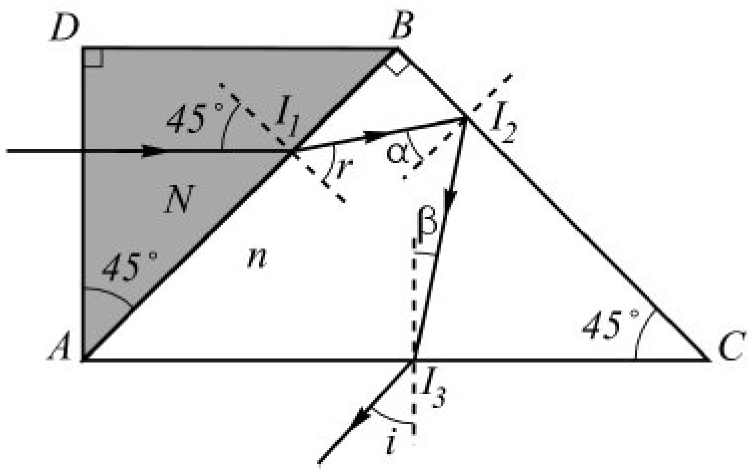
2) Quelles relations vérifient les angles r et α ; α et β ?

3) Quelle relation vérifient N et n pour que la réflexion soit limite en I_2?.

Calculer N, r, α, β et i pour $n = 3/2$, quand cette condition limite est réalisée.

On appelle N_0 cette valeur limite de N. Pour que la réflexion soit totale en I_2, N doit-il être plus grand ou plus petit que N_0?.

4) Ecrire la relation vérifiée par N et n pour que l'angle i soit nul. Que vaut N?.



<u>Exercice N⁰ 2</u> : (7 points)

a) Soit une lentille de distance focale f ' = +3 cm.

On considère un objet perpendiculaire à l'axe optique de taille 1 cm respectivement à 2 cm et en avant du centre optique. Déterminer graphiquement l'image de l'objet dans chaque cas (échelle 1/1).

Même question avec un objet virtuel situé à 2cm, 8 cm du centre optique.

b) Soit une lentille de distance focale f ' = -3 cm.

Trouver l'image d'un objet réel de taille 1 cm situé à 1 cm du centre optique.

Même question avec un objet virtuel situé à 1,5 cm puis 5 cm du centre optique.

c) Retrouver les résultats précédents par le calcul algébrique.

Examen n^{0}2 d'optique

Questions de cours : (4 points)

1. Ecrire la relation qui relie un faisceau incident, réfléchie et réfracté. Faites un schéma, que devient cette relation pour les petits angles.
2. Démontrez la formule de conjugaison d'une lentille mince convergente.
3. Construire l'image d'un objet réel par une lentille mince convergente dans le cas :

   a- $0<p<f'$, b- $p>f'$.

Exercice N^0 1 : (5 points)

On considère le rayon incident en I sur un cube de verre de 4 cm de côté. On donne AB=4cm et AI =1cm comme l'indique la figure.

1. Calculer r au point I et l'angle j au point J ?

2. Déduire les distances AJ et JB ?

3. Au point K , calculer l'angle k et déduire les distances BK et KD?.

4. Le point L est sur la même droite qui passe par J, calculer l'angle l ?.

5. Démontrez que le rayon lumineux sort avec un angle de 60^0 au point M et aussi que la distance MC=1cm.

Exercice N^0 2 : (6 points)

On considère un prisme d'angle au sommet A=60^0 et d'indice $n = \sqrt{2}$. Un rayon lumineux arrive sur le prisme avec un angle d'incidence= 45^0.

1. Faits un schéma du prisme, écrire les équations caractéristiques de ce dernier.
2. Calculer successivement les angles r, r', i' ainsi que la déviation D.

L'angle du prisme est maintenant A=61^0 et i reste égale à 45^0. Calculer la nouvelle déviation D. De combien a-t-elle varié ?

Calculer l'angle limite pour la deuxième face du prisme, que signifie t-elle ?.

Exercice N^0 3 : (5 points)

Un dioptre sphérique de sommet S et de centre C séparant deux milieux d'indices n=1 et $n' = \frac{3}{2}$ a un rayon de courbure r=10cm.

1. Ecrire sans démonstration les formules du dioptre sphérique : relation de conjugaison, grandissement transversal et distances focales.

2. Calculer la position de l'image d'un objet AB, son grandissement transversal et la nature de l'image :

-Objet à 60 cm du sommet et réel,

-Objet à 10 cm du sommet et réel ;

- Objet à 5 cm derrière le dioptre (objet virtuel).

3. Faites un dessin et mettez les éléments de ce dioptre (point A objet point A' image et les foyers aussi).

Examen d’optique

<u>Questions de cours : (6 points)</u>

4. Expliquer le principe de Fermat, c’est quoi le résultat de son application.
5. Montrez la formule de conjugaison d’un miroir, donner son agrandissement longitudinal, citer ces différents types.
6. Citer les différents types des lentilles minces, exprimer sa formule de conjugaison (sans démonstration).
7. Construire l’image d’un objet réel par une lentille mince divergente dans le cas :

   b- $F'<p<0$, b- $p>f'$.

Exercice N^0 1 : (6 points)

On a le dispositif optique composé d’une lame à face plane, d’indice $n_2 = \frac{3}{2}$ **,** cette dernière est placée sous l’eau (d’indice $n_1 = \frac{4}{3}$) comme l’indique la figure.

1. Quelle relation vérifie $r, j\ et\ \alpha$?

2. Avec ce dessin le rayon peut –il se réfléchir en J ?

3. Déterminer les conditions sur j et α pour que le rayon sorte en M en émergence rasante. L'observateur peut –il voir un rayon incident si $\alpha=20^0$et $i=45^0$?. Si oui, pour quelle valeur de α va-t-il disparaitre ?.

Exercice N^0 2 : (4 points)

Un rayon lumineux arrive en I sur un bloc de glace considéré comme prisme d'indice n=1.33

1. Ecrire les formules du prisme.

2. Calculer les valeurs de r, r', i' et D pour la valeur limite $i=90^0$.

3. Que se passe t-il en J, quelle est la condition sur i?.

4. Donner sans démonstration les angles à la déviation minimale D_{min}, calculer D_{min} et la valeur de i_{min} de i correspondante.

Exercice N^0 3 : (4 points)

Un dioptre sphérique de sommet S et de centre C séparant deux milieux d'indices n=1 et $n' = \frac{4}{3}$ a un rayon de courbure r=4 cm.

1. Ecrire sans démonstration les formules du dioptre sphérique : relation de conjugaison, grandissement transversal et distances focales.

2. Ce dioptre donne d'un objet réel AB (p=SA) une image A'B' (p'=SA') tel que le grandissement $\gamma = +2$. Calculer les distances p et p'.

3. Calculer les distances focales f et f'. Le dioptre est –il convergent ou divergent, concave ou convexe.

4. Faites un dessin et mettez les éléments de ce dioptre (point A objet point A' image et les foyers aussi).

Examen de rattrapage d'optique

Questions: (7 points)

1. Si on a un rayon lumineux qui se propage d'un milieu d'indice de réfraction n_1=1.652 vers un milieu d'indice de réfraction n_2=1, donner la relation qui relie entre le rayon incident et le rayon diffracté, quel est le phénomène observé, calculer son angle critique?

2.On veut qu'un rayon lumineux frappe la face AB d'un prisme puisse émerger par la face opposée AC.

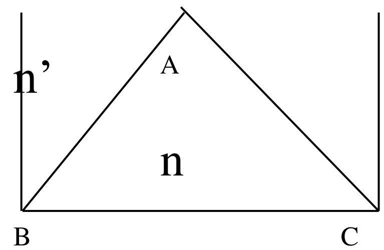
a. Quelle est la condition portant sur l'angle au sommet A du prisme ?.
b. Quelle est la condition portant sur l'angle d'incidence i ?.
c. Application : soit un prisme isocèle ABC dont l'angle au sommet est A=120° et d'indice n=3/2. Un rayon lumineux frappant les faces AB puis AC, peut-il émerger par AC ?.

Exercice N^0 1 : (5 points)

On place un prisme de verre d'angle A=60° et d'indice n=1,5 dans une cuve à face parallèle, remplie d'eau d'indice n'= 4/3.

Calculer la déviation produite par cet ensemble dans le cas d'un rayon incident normal à la cuve et au plan bissecteur du prisme.

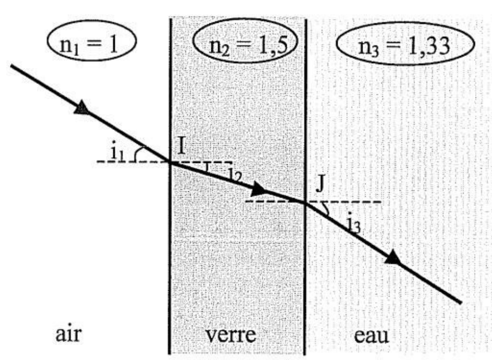
On pourra supposer que le prisme d'eau et le prisme de verre sont séparés par de minces couches à face parallèles.



Exercice N^0 2 : (5 points)

La paroi d'un aquarium est constituée d'une lame de verre à face parallèles. L'indice optique de l'air est n_1=1, celui du verre est n_2==1,5 et celui de l'eau est n_3=1,33.

1. Sachant que i_1=46°, calculer i_2 et i_3 ?
2. Quelle condition doit-on avoir sur i_1 pour qu'un rayon frappe l'aquarium en atteignant l'eau ?.
3. Inversement, est ce que tous les rayons provenant de l'eau peuvent ils atteindre l'air ?.



Exercice N^0 3 : (3 points)

Un prisme de verre d'indice n=1,4140 a pour section droite un triangle équilatéral ABC, un rayon lumineux tombe en I sur la face AB et traverse le prisme en minimum de déviation

1. Faire un schéma, calculer les angles d'incidence, d'émergence et de déviation minimale

2. Sans toucher au rayon incident, on fait tourner le prisme d'un angle autour d'un axe passant par I et parallèle à son arête.

3. Que devient le rayon émergeant pour ß=45° et ß=-45°.

Dans chaque cas, faites un schéma, et calculer la déviation totale du rayon.

Travaux dirigés : Partie optique Ondulatoire

Série n^0 1

Exercice n^{0}1 :

On considère un dispositif interférentiel des fentes d'Young d'où on a deux lentilles minces L_1 et L_2, convergentes, de même axe optique. On désigne par $f\,'$= 1 m la distance focale de la lentille L_2. Au foyer objet de la lentille L_1, on place une source ponctuelle S. La plaque des ouverture située entre les lentilles L_1 et L_2 est muni de deux ouvertures rectangulaires S_1 et S_2 identiques très fines et distantes de b = 1 mm. Le dispositif est dans l'air. La source S émet une radiation de longueur d'onde λ = 0,5 µm. On négligera le phénomène de diffraction.

a- Donner (sans démonstration) l'expression de la différence de marche δ.

b- Donner l'expression de l'éclairement I_A en un point M de l'écran E.

-On intercale, sur le trajet de l'un des faisceaux, une lame à faces parallèles (épaisseur e = 0,25 mm ; n = 1,5).

a- Donner la nouvelle différence de marche ΔL.

b- Calculer x_o la position de la frange centrale.

On suppose maintenant que le spectre d'émission de la source S est un spectre continu dans l'intervalle de fréquence $[\nu_1,\nu_2]$, et que l'intensité rayonnée, dans un intervalle de fréquence $d\nu$, est égale à $dI_{B2} = K(1+\cos(\Delta\varphi))$.

a-Déterminer l'éclairement I_{B2} en un point M de l'écran E.

b-Déduire le contraste C_{B2}.

Exercice n^{0}2 :

On considère une onde monochromatique plane de longueur d'onde λ= 632,8 nm se propageant le long de l'axe Oz avec une polarisation rectiligne.

On place un écran percé de trois trous de dimensions négligeables disposés symétriquement.

Chaque trou peut être considéré comme une source ponctuelle d'amplitude E_0 du champ électrique. On place un écran à la distance D, que l'on prendra beaucoup plus grande que l'écartement a des trous. D= 2m et a= 1mm.

1. Ecrire l'expression de la différence de marche entre le rayon passant par le trou en +a/2 et le rayon passant par le centre. De même, calculer la différence de marche entre le rayon passant par le trou en –a/2 et le rayon passant par le centre. En déduire les différences de phase des trajets (1) et (2) par rapport à celui issu du trou central O.

2. Calculer l'expression du champ électrique E observé au point P.

3. Déduire l'expression de l'éclairement lumineux E au point P. Tracer l'éclairement E en fonction de la position Y.

4. Décrire la figure d'interférences obtenue. Définir l'interfrange i et donner son expression pour le cas étudié ici. Valeur numérique de i.

Série n^0 2 !

Exercice1 :

Soient deux points A et B distants de d dans un milieu isotrope d'indice de réfraction n_0=1.

1. Évaluer le chemin optique L_{AB}.

2. On interpose à travers le rayon lumineux AB et perpendiculairement à celui-ci une lame d'épaisseur e et d'indice n. Evaluer le nouveau chemin optique L'_{AB} .

3. AN: Calculer L_{AB} et L'_{AB} si d=10cm,e=2cm et n=1,5.

4. Evaluer la difference de chemin optique **δ** entre deux rayons issus de **A**:

- Le premier effectue un trajet direct de A vers B,
- Le second se réfléchit deux fois à l'intérieur de la lame.

Exercice 2 :

On considère l'onde électromagnétique plane telle que:

$$\vec{E}(M,t) = E_M \cos(2\pi\left(5.10^{14}t - \frac{\frac{10}{10^7}}{12}\left(x+\sqrt{3}y\right)\right))$$

Déterminer sa période et sa fréquence.

1. Déterminer sa direction de propagation dans un repère orthonormé direct Oxyz.

2. Déterminer sa longueur d'onde et son nombre d'onde.

3. Calculer sa vitesse de propagation. En déduire le milieu où se propage l'onde.

4. Calculer les composantes du vecteur d'onde k.

Exercice 3 :

Une radiation monochromatique de longueur d'onde dans le vide λ_o = 488 nm (radiation verte) passe de l'air dans une eau d'indice n = 1,33.

1. Calculer la longueur d'onde dans l'eau.

2. ya-t-il un changement de fréquence de cette radiation quand on tombe dans l'eau.

3. Calculer la vitesse de cette radiation dans l'eau et sa fréquence.

4. Supposons maintenant que l'onde électromagnétique associée à cette radiation est une onde plane monochromatique de fréquence **υ**.

- Calculer le chemin optique entre deux surfaces d'onde ξ et ξ' séparées d'une distance égale à 2 µm dans l'air. En déduire la variation de phase ΔØ de l'onde sinusoïdale entre ξ et ξ'.
- Même question que mais dans l'eau.

Exercice 4 :

On considère une fibre creuse rectiligne: la gaine de la fibre est constituée d'un verre d'indice n=1,5 et on réalise le vide à l'intérieur de la fibre. On éclaire une extrémité de la fibre avec un bref signal lumineux. À l'extrémité de la fibre, de longueur L = 1 m, on place un détecteur dont le temps de réponse est noté μ.

1. Écrire l'expression de l'onde se propageant dans l'air le long de la fibre, et de celle se propageant dans la gaine de verre le long de la fibre.

2. Au bout de combien de temps le détecteur reçoit-il la première onde ? la seconde?

3. En déduire le temps de réponse que doit a voir le détecteur pour séparer les deux signaux.

4. Sachant que les détecteurs usuel sont un temps de réponse de10^{-6}s, quelle devrait être la longueur L' de la fibre pour qu'un détecteur usuel sépare les deux signaux ?

Exercice 5 :

Un laser hélium-néon (He-Ne) émet un faisceau de lumière rouge formé de bande très étroite de fréquences centrée sur ν= $4{,}74.10^{14}$ Hz.

1. Determiner l'énergie du photon.

Le faisceau laser est de puissance P= 0,1 mW et a une section S =$3{,}14.10^{-6}$m^2.

2. Déterminer l'énergie reçue pendant une seconde par un écran interceptant perpendiculairement se faisceau.

3. Déterminer la densité de flux du rayonnement, ou intensité lumineuse I.

Travaux dirigés : Partie : Physique des lasers

Série n° 1 :

Exercice 1 :

1. Calculez la longueur d'onde (en µm) d'un rayonnement qui possède une fréquence de 500000 GHz

2. Calculez la fréquence (en MHz) d'un rayonnement qui possède une longueur d'onde de 2,865 m.

Exercice 2 :

1. Répondre par vrai ou faux :

a- Lorsque la fréquence de la lumière augmente, sa longueur d'onde diminue.

b- Lorsque la période de l'onde augmente, sa fréquence augmente.

c- Lorsque l'indice du milieu change, la vitesse du rayonnement ne change pas.

2. On considère un récipient en verre remplit par un liquide, on introduit dans ce liquide un morceau de verre.

Peut-on toujours voir le morceau de verre dans le liquide quelque soit l'indice de réfraction de ce dernier. Justifier votre réponse.

Faites l'expérience en utilisant différents liquides et donner une explication simple de l'indice de réfraction.

Exercice 3 :

Nous considérons un rayonnement électromagnétique tombant sur la surface d'un matériau.

1. Ce rayonnement comporte t-il- :

   a- Un photon

   b- Deux photons

   c- Plusieurs photons

2. Les photons associés à un rayonnement visible ont –il tous :

   a- La même énergie

   b- Deux énergies

   c- Plusieurs énergies

3. Donner un encadrement énergétiques en eV des photons visibles.

Exercice 4 :

1. La proposition suivante est –elle fausse ou vraie, justifier votre réponse :

Si de la lumière violette de longueur d'onde □= 400 nm ne cause pas d'effet photoélectrique dans un métal, alors il est certain que de la lumière rouge avec λ = 700 nm peut provoquer un effet photoélectrique dans ce métal.

2. L'énergie d'ionisation du Na extrêmement pur est 2.75 eV.

a- Calculez l'énergie cinétique maximale que peuvent avoir des photoélectrons émis par Na exposé à une radiation ultraviolette de 200 nm.

b- Calculez la plus grande longueur d'onde qui peut causer un effet photoélectrique dans le Na pur.

Exercice 5 :

Calculez la longueur d'onde de Broglie associée à un électron se déplaçant à 1=1/137ème de la vitesse de la lumière (les électrons ayant cette vitesse sont considérés comme étant non relativistes), dans quelle région spectrale peut-on trouver cet électron.

Données : $h = 6{,}625.10^{-34}$J.s et $c = 3.10^8$ m/s, $1eV = 1.6 .10^{-19}$ J et $m_e = 9.109\ 10^{-31}$ kg