PREPARATORY SCHOOL TO THE

Winter College on Optics 2017:

Applied Optical Techniques for Bio-Imaging

EXPERIMENTS in the DIFFRACTION LABORATORY

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Three sets of experiments will be presented, namely on:

1 - DIFFRACTION and FOURIER TRANSFORM

2 - EVANESCENT WAVES

3 - BASIC OF SPECTROSCOPY: DECOMPOSITION OF LIGHT BY DIFFRACTION GRATINGS

1-EXPERIMENTS on DIFFRACTION-FOURIER TRANSFORM

It is well known that diffraction from an aperture in a screen gives rise to a system of waves propagating from the aperture. In addition there are evanescent waves that do not propagate but "flow" along the surface. For simplicity let us refer to a plane monochromatic wave impinging normally on the screen.
At each point behind the screen the field is the result of the interference of the diffracted waves and, depending on the distance, in wavelengths, from the screen, two different regions are considered, namely **Fresnel's region** (far but not too much from the aperture) and **Fraunhofer region** (very far, practically at infinity). Depending on the shape of the aperture there are different shapes and formulas for the diffracted field.

Here we will experience diffraction of laser radiation (HeNe, wavelength 632,8nm) by
1- wires, by
2- slits of different width and by
3- circular apertures of different radius.

Of course, as our eyes see the **energy**, we will always "see" the **square of the field**. By using a moving screen we will follow the development of the field (intensity) from the diffracting screen through the Fresnel region up to the Fraunhofer region. We will check the angular dependence on the aperture width by measuring the width of the intensity patterns in the Fraunhofer region in different cases.

- Note that, mathematically, the diffracted field at infinity is the **Spatial Fourier Transform** of the field on the diffracting aperture. Commonly **diffraction is said to operate a Fourier transform**, the transform is also called **spectrum**. Each spatial frequency corresponds to a plane wave propagating in a suitable direction. As mentioned, interference of all waves gives rise to the field at any point in the space. Evanescent waves do not propagate, as they flow along the surface, and information carried by them is lost.

From the point of view of the transform, we will also check the different shapes of the patterns according to the different apertures. The transform of a Rect (slit uniformly illuminated) is Sinc = (sin(x))/x and the transform of a Circ (diffraction from a circular aperture) is a Bessel function divided its argument. Of course we "see" the modulus square of each transforms, precisely:

FUNCTION	TRANSFORM	WE SEE
1 - Rect	Sinc = [sin(arg)] /arg	**Sinc^2**
2 - Circ	Airy Function = [Bessel J_1(arg)] /arg	**Airy Function^2**

If the aperture is the border of a converging lens, the **lens carries the field from infinity to the focal plane**. This property, commonly referred to as the property of a lens of "making Fourier transforms", is the **basis of image elaboration**. It is also the explanation why the image of a source point is a diffraction figure and the reason of the "resolution" problem.

For more information on Diffraction and Evanescent waves see Lectures to Winter College 1993:

- http://indico.ictp.it/event/a02251/contribution/1
- http://indico.ictp.it/event/a02251/contribution/9

2- EXPERIMENT on EVANESCENT WAVES

Evanescent waves, such as those mentioned before, are waves that propagate, flow, along a surface and "evanesce" at a distance of few wavelengths from the surface, as the amplitude decreases exponentially from the surface. For this reason evanescent waves are also called "surface waves", and **cannot exist without a surface where they are generated and along which they propagate**. Evanescent waves are present in the phenomenon of "total reflection", in prisms and in fibers. In fibers total reflection allows guided propagation.

As usual in optics (optics approximation) one component of the fields is enough to completely describe an electromagnetic wave. An evanescent wave propagating along a surface on a direction z and evanescing normally to the surface, in the direction x, can be written in the usual complex form, Eq.1. In Eq.1 $k = 2\pi/\lambda$ and λ denote wavenumber and wavelength, respectively. Quantity $A\exp(-k\alpha_i x)$ is the amplitude and describes the attenuation in the direction x. The last exponential describes propagation along z on the surface. Quantities α_i and γ_r are such that $\gamma_r^2 = 1 + \alpha_i^2$ and guarantee that this form is a solution of Maxwell's equations.

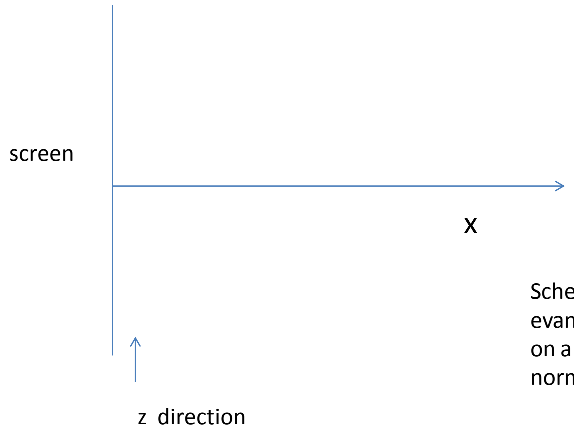

Fig 1

Scheme for description of evanescent wave flowing on a screen and evanescing normally.

$$v(P,t) = A \exp(-k\, \alpha_i\, x) \exp[i(k\, \gamma_r\, z - \omega t)]$$

Eq.1

For those who would like to learn more, this expression can be derived from a plane wave by assuming that one of the direction cosines be imaginary $\alpha = i\, \alpha_i$, (see the above mentioned lectures).

Note that the evanescent waves are the basis of the so called near field microscopy, that allows superresolution. In this case it is possible to see "spatial frequencies" of the evanescent waves (high frequencies), which "carry" small details of the object. However the main features, related to the propagating field, are lost.

When total reflection takes place at the surface of a prism, a ray is totally reflected inside the prism, however on the external surface an evanescent field is propagating. The same happens when a field propagates in an optical fiber by subsequent total internal reflections.
The phenomenon has reciprocity, that is, if an evanescent wave is produced on the surface of a prism or a fiber, it gives rise to a real field propagating inside.

EXPERIMENT: our experiment makes use of reciprocity. Initially, an evanescent field is produced on an external surface of a prism by total internal reflection of a laser beam. Then the evanescent field is collected by an optics fiber; the field becomes real inside the fiber and propagates. By looking at the fiber end one sees light.
Note that this is the basic set up for coupling between optics elements in measuring devices.

3 - BASIC OF SPECTROSCOPY: DECOMPOSITION OF LIGHT BY DIFFRACTION GRATINGS

Spectroscopy is separation of light from a source in its (time) frequency components. The basic element allowing it is the diffraction grating.

A linear diffraction grating is a transparent, or reflecting, element where a number of parallel lines are drawn. The elements can be reflecting or transmitting.
A beam impinging onto the grating is "diffracted" by each element, a system of diffracted waves propagates in reflection or transmission. Let us now refer to a transmitting grating and a beam impinging normally. The diffracted waves at each point in the space give rise to interference; there are directions where they interfere constructively and other directions where the interference is destructive. Let d denote the period of the grating and θ denote the angle between the normal to the surface and an arbitrary direction. The interference is constructive in those directions θ where one has, Fig.2,

$$d \sin\theta = m\,\lambda,$$

where m is an entire number denoting the order of the diffracted field, spectrum. It is clear that in the main direction, where m=0, there is no frequency separation. From the equation it is also clear that, apart from m=0, for any other value of m, the diffraction angle depends on the wavelength. Therefore a radiation constituted by different wavelengths can be decomposed in its basic components. By measuring angle θ it is possible to measure the wavelength of a given radiation, spectroscopy. A large number of applications are based on spectroscopy.

In addition to linear gratings there are also two-dimensional gratings, where two sets of perpendicular lines are present. In this case one has a spectrum in the space where the directions of constructive interference are given by a double set of integer numbers.

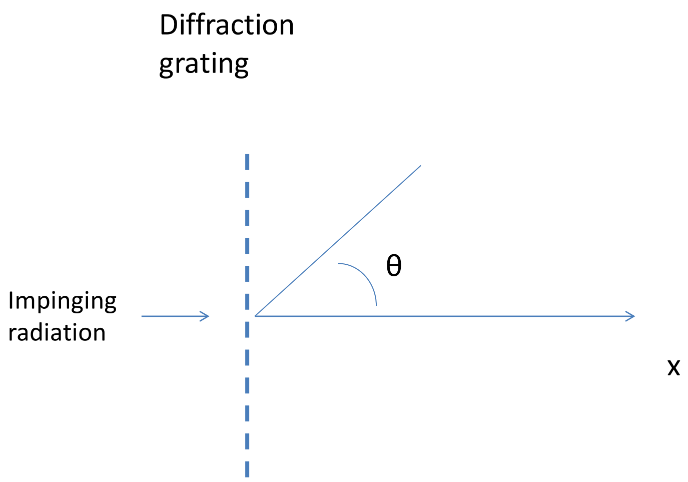

Fig. 2

Scheme for description of the spectrum from a diffraction grating

EXPERIMENTS: by use of gratings of different periods, decomposition will be shown of radiation from different sources.

By use of linear gratings of different periods (100, 300, and 600 and 1000 lines/mm) decomposition will be shown of radiation from different sources including lasers and leds. A number of orders will be seen. In particular cases the relationship between the wavelength of two lasers, namely green and red, will be found by measuring the diffraction angles. Examples will be also seen of spectra produced by a two-dimensional grating.

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