# 6.2: Introduction

In this chapter we will study how light propagates. The propagation of light reveals its wave-like nature: in the double-slit experiment, we concluded from the interference pattern observed on a screen that light is a wave. To demonstrate more convincingly that light is indeed a wave, we require a detailed quantitative model of the propagation of light, which gives experimentally verifiable predictions.

But a precise description of the propagation of light is not only important for fundamental science, it also has many practical applications. For example, if a sample must be analysed by illuminating it and measuring the scattered light, the fact that the detected light has not only been affected by the sample, but by both the sample and propagation has to be taken into account. Another example is lithography. If a pattern has to be printed onto a substrate using a mask that is illuminated, it has to be realised that when there is a certain distance between the mask and the photoresist, the light which reaches the resist does not have the exact shape of the mask because of propagation effects. Thus, the mask needs to be designed to compensate for this effect.

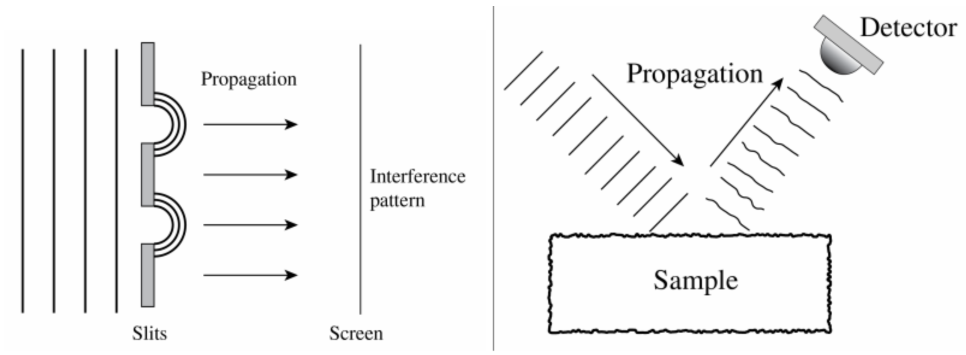


Figure $6.2.1$: A quantitative model of the propagation of light may serve fundamentally scientific purposes, since it would provide predictions that can be tested, and can be applied in sample analyses or lithography.

In Section $1.4$ we have derived that in homogeneous matter (i.e. the permittivity is constant), for every component of a time-harmonic electromagnetic field $\mathcal{U}(\mathbf{r}, t)=\operatorname{Re}\left[U(\mathbf{r}) e^{-i \omega t}\right]$ , the complex field $U(\mathbf{r})$ satisfies the scalar Helmholtz equation $1.5.14$

$$\left(\nabla^2+k^2\right) U(\mathbf{r})=0,$$

where $k=\omega \sqrt{\epsilon \mu_0}$ is the wave number of the light in matter with permittivity $\epsilon$ and refractive index $n=\sqrt{\epsilon / \epsilon_0}$ . In Sections $6.2$ and $6.3$ we will describe two equivalent methods to compute the propagation of the field through homogeneous matter. Although both methods in the end describe the same, they give physical insight into different aspects of propagation, as will be seen in Sections $6.4$ and $6.5$. The two methods can be applied to propagate any component $U$ of the electromagnetic field, provided the propagation is in homogeneous matter. With this assumption they give identical and rigorous results.

When the refractive index is not constant, Maxwell's equations are no longer equivalent to the wave equation for the individual electromagnetic field components and there is then coupling of the components due to the curl operators in Maxwell's equation. When the variation of the refractive index is slow on the scale of the wavelength, the scalar wave equation may still be a good approximation, but for structures that vary on the scale of the wavelength (i.e. on the scale of ten microns or less), the scalar wave equation is not sufficiently accurate.

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