Chapter 1

Introduction

1.1 Introduction

Light scattering is perhaps the most fundamental of optical processes. It is encountered in many branches of the natural sciences, for example in astronomy, meteorology, atomic physics, and in solid-state physics. An important example is scattering by a spherical object. Descartes described the rainbow in terms of refraction and reflection of light rays by spherical water droplets almost 400 years ago [Haussmann, 2016]. But it was not until 1908 that Mie [Mie, 1908] provided a rigorous (but very complicated) solution to the problem of scattering of light by spherical particles. Since then, Mie's theory has been applied to fields like quantum scattering, non-linear optics, and atmospheric scattering [Hergert and Wriedt (eds.), 2012]. In this thesis, we will make extensive use of scalar Mie theory.

Another topic of this thesis is optical coherence theory. Its general framework has been described in numerous publications [Beran and Parrent, 1964; Born and Wolf, 1995; Goodman, 1985; Mandel and Wolf, 1995; Marathay, 1982; Perina, 1985; Schouten and Visser, 2008; Troup, 1985; Wolf, 2007; Gbur and Visser, 2010]. Coherence is essentially a consequence of correlations between some components of the fluctuating electric field at two (or more) points in space or in time, and is manifested by the sharpness of fringes in Young's interference experiment. The basic tools of coherence theory are correlation functions and correlation matrices which, unlike some directly measurable quantities such as the spectrum of light, obey precise propagation laws. With the help of these laws one may determine, for example, spectral and polarization changes that occur as the light propagates.

In this thesis we study the effects of coherence on scattering. We therefore begin by briefly reviewing these two topics.

1.2 Elements of optical coherence

In physics one can distinguish two types of processes: those that are *deterministic*, and those that are *random*. Deterministic processes are predictable. In classical mechanics, for example, knowledge of the present position of an object, together with its mass, velocity and the forces that act upon it, completely determines its future position and velocity. Random processes, on the other hand, are inherently non-predictable. An example is provided by quantum mechanics, which holds as a central tenet the stochastic nature of an event like spontaneous emission. Such random or *non-deterministic* processes can be characterized by their statistical behavior. This behavior describes the average value of a process, how much it fluctuates, and how fast or slow these fluctuations occur in space and time. In other words, we can describe random processes by their mean, their standard deviation, and their correlation functions. We begin this informal description of random optical processes by briefly reviewing fundamental concepts such as the complex analytic signal representation, ensembles, ergodicity and stationarity. This will allow us to introduce correlation functions in both the space-time domain (Section 1.2.2) and the space-frequency domain (Section 1.2.3). The propagation of correlation functions is governed by precise laws, as is discussed in Section 1.2.4.

1.2.1 Complex analytic signals

Although optical fields are real-valued, it is often more convenient to use complex-valued quantities. We therefore begin our mathematical description of wave fields by introducing their so-called *complex analytic signal representation* [Mandel and Wolf, 1995, Sec. 3.1]. Let us write a scalar optical field $u(\mathbf{r}, t)$, where $\mathbf{r}$ denotes a position in space and t is a moment