To make good use of the physical properties of nanoparticles (see Part II of this book), most applications require them to be incorporated within solid materials, such as glasses, ceramics, oxides, etc. The inclusions obtained in this way are thereby protected from chemical (e.g., oxidation) or mechanical (e.g., friction or wear) alteration due to the environment. They are also separated from one another from an electrical or magnetic point of view, which limits this kind of interaction between the particles. The dispersion of particles within solid materials can be achieved in the ordinary way by exploiting precipitation effects in the solid state (e.g., alloys hardened by dispersions of nanometric precipitates, Guinier–Preston zones), but also by a great many less direct methods. Which method is finally chosen depends on several factors such as the kind of matrix and size, shape and spatial organisation of the particles, but also on the volume of material to be produced, the cost, and the difficulty involved in the process.

In this chapter, we shall discuss some of the methods commonly used today, spelling out their specific features. Quite generally, these fall into three categories: chemical methods, physical methods, and mechanical methods. The latter were treated in Chap. 19 and will not be discussed further here. In addition, there are two possible ways of dispersing the nanometric particles. One is the bottom-up approach, which means building together atoms and molecules to constitute a larger structure and incorporating them – either simultaneously or a posteriori – within the host matrix. The other is the top-down approach currently used in microelectronics, which consists in refining the microstructure of some bulk material using more and more sophisticated tools. The chemical and physical methods to be discussed in this chapter use a bottom-up approach, in contrast to mechanical processes, which generally use a top-down approach, and yield nanomaterials in the form of powders or bulk materials with varying degrees of densification.
Fig. 25.1. The Lycurgus cup at the British Museum in London dates from the Roman empire (fourth century A.D.). It appears green in reflected light and red in transmitted light, owing to the presence of nanometric inclusions of gold and silver in the glass. From [4]. See also the colour plate

25.1 Chemical Methods

Chemical methods were the first used to obtain nanometric dispersions in matrices and they are the most highly developed today for synthesising self-organised nanomaterials. In particular, they provide the greater part of the nanomaterials used in optics, where metal inclusions are embedded in bulk glasses or ceramics of varying thicknesses. There are two main types of conventional chemical method here: doped glasses (Sect. 25.1.1) and sol–gels (Sect. 25.1.2).

25.1.1 Synthesis of Doped Glasses

It has been known since ancient times how to synthesise glasses doped by metal powders for decorative applications (see Fig. 25.1). The method is still used today, particularly for synthesising nanomaterials with special optical properties, because it is very easy to implement [1]. Such glasses are usually produced by adding a metal oxide powder and a reducing agent when the glass melts. Sudden cooling of the mixture then yields a perfectly uniform, supersaturated glass, in which the metal remains in the ionised or oxidised state and the reducing agent in the state of lowest valence. A heat treatment of the glass then leads to reduction of the metal ions by the reducing agent and causes the formation of metal nanoparticles in the glass [2]. This nucleation phase can also be activated and controlled by X rays or UV irradiation [3]. At room temperature and below, diffusion processes are negligible and the nanoparticles are completely stabilised within the glassy matrix. One of the particularities of this means of synthesis is that bulk doped glasses can be made, with a narrow size distribution of nanometric inclusions in most cases. However, when low chemical reactivity and low supersaturation concentrations are required, this method can only yield low metal concentrations (of the order of $10^{-6}$ to $10^{-3}$ in volume) and it is essentially limited to the noble metals (Cu, Ag, Au).