# 1

Introduction

An interface is an area that separates two phases from each other. If we consider the solid, liquid, and gas phases, we immediately get three combinations of interfaces: solid–liquid, solid–gas, and liquid–gas interfaces. The term *surface* is often used synonymously with interface, although interface is preferred to indicate the boundary between two condensed phases and in cases where the two phases are named explicitly. For example, we talk about a solid–gas interface and a solid surface. Surface is used for a condensed phase in contact with a gas or a vacuum. Interfaces can also separate two immiscible liquids such as water and oil. These are called liquid–liquid interfaces. Interfaces may even separate two different phases within one component. In a liquid crystal, for example an ordered phase may coexist with an isotropic phase. Solid–solid interfaces separate two solid phases. They are important for the mechanical behavior of solid materials such as concrete. Gas–gas interfaces do not exist because gases mix.

Often, interfaces and colloids are discussed together. *Colloid* is an abbreviated synonym for colloidal system. Colloidal systems are disperse systems where one phase has dimensions on the order of 1 nm to 1 μm (Figure 1.1). The word *colloid* comes from the Greek word for glue and was first used in 1861 by Thomas Graham.[1] He used the word to refer to materials that seemed to dissolve but were unable to penetrate membranes such as albumin, starch, and dextrin. A colloidal dispersion is a two-phase system that is uniform on the macroscopic but not on the microscopic scale. It consists of grains or droplets of one phase in a matrix of the other phase.

Different kinds of dispersions can be formed. Most have important applications and have special names (Table 1.1). While there are only five types of interfaces, we can distinguish ten types of disperse systems because we must discriminate between the continuous, dispersing (external) phase and the dispersed (inner) phase. In some cases, this distinction is obvious. Nobody will, for instance, confuse fog with foam, although in both cases, a liquid and a gas are involved. In other cases, the distinction between continuous and inner phase cannot be made because both phases might form connected networks. Some emulsions, for instance, tend to form a bicontinuous phase, in which both phases form an interwoven network.

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1 Thomas Graham, 1805–1869; British chemist, professor in Glasgow and London.
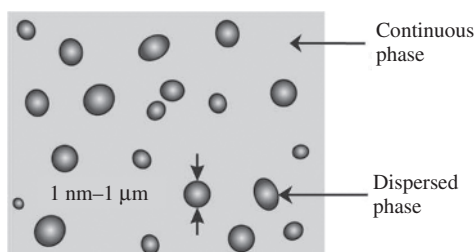
Figure 1.1 Schematic of a dispersion.

Table 1.1 Types of dispersions.

Continuous phase	Dispersed phase	Term	Example
Gas	Liquid	Aerosol	Clouds, fog, smog, hairspray
	Solid	Aerosol	Smoke, dust, pollen
Liquid	Gas	Foam	Lather, whipped cream, foam on beer
	Liquid	Emulsion	Milk
	Solid	Suspension	Ink, muddy water, dispersion paint
Solid	Gas	Porous solids	
		Solid foam	Styrofoam, soufflé
	Liquid	Solid emulsion	Butter
	Solid	Solid suspension	Concrete

Colloids and interfaces are closely related. This is a direct consequence of the enormous specific surface area of colloids. Their interface-to-volume ratio is so large that their behavior is determined mainly by interfacial properties. Gravity and inertia are negligible in the majority of cases. For this reason, colloidal systems are often dominated by interfacial effects rather than bulk properties. For the same reason, interfacial science is essential in nanoscience and technology.

Colloidal systems are often influenced by thermal fluctuation and colloidal particles move due to Brownian motion. This distinguishes them from granular matter, a material composed of macroscopic elements. The constituents of granular matter must be large enough so that they are not subject to thermal motion. Usually, the structure of granular matter depends on its history; it is generally far from being in thermodynamic equilibrium, and gravitation can play a significant role.

Example 1.1 A granular system that is dominated by surface effects is shown in Figure 1.2. A scanning electron microscope (SEM) image shows aggregates of SiO_2 particles (diameter 0.9 μm). These particles were blown as dust into a chamber filled with gas. While sedimenting, they formed fractal aggregates due to attractive van der Waals forces and collected on the bottom. These aggregates are stable for weeks or months, and even shaking does not change their structure. Thermal fluctuations are

Figure 1.2 Agglomerate of silicon oxide particles.

20 μm
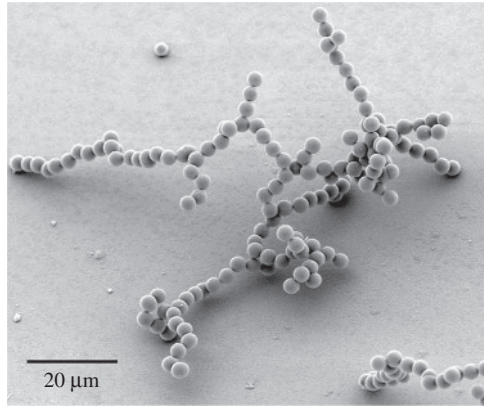
completely insignificant, and the material would count as granular matter. Still, it is not a typical granular material because once it has formed, gravity and inertia, which rule the macroscopic world, are not able to bend down the particle chains. Surface forces are much stronger.

Sometimes a distinction is made between colloidal particles, which are in the size range of 1–1000 nm, and *nanoparticles*, which are 1–100 nm in diameter. For particles smaller than ≈100 nm, sedimentation is usually negligible.

It is useful to introduce the characteristic length scale of a system. The characteristic length scale can often be given intuitively. For example, for a spherical particle, one would use the radius or the diameter. For more complex systems, however, intuition leads to ambiguous results. We suggest using the ratio of the total volume V divided by the total interfacial area A of a system as the characteristic length scale: $\lambda_c = V/A$. For a sphere of radius R_p, the characteristic length scale is $\lambda_c = R_p/3$. For a thin film λ_c is equal to the thickness. For a dispersion of spherical particles with a volume fraction ϕ, the total volume of the system is $V = N4\pi R_p^3/(3\phi)$, where N is the number of particles. With a total surface area of $A = N4\pi R_p^2$, we get a characteristic length scale of $\lambda_c = R_p/(3\phi)$.

Why is there an interest in interfaces and colloids? First, to gain a better understanding of natural processes, for example, in biology. The interfacial tension between water and lipids allows for the formation of lipid membranes. This is a prerequisite for the formation of compartments and, thus, any form of life. In geology, the swelling of clay or soil in the presence of water is an important process. The formation of clouds and rain due to the nucleation of water around small dust particles is dominated by surface effects. Many foods, such as butter, milk, or mayonnaise, are emulsions; their properties are determined by the liquid–liquid interface. Second, interfaces and colloids have many technological applications. An example is flotation in mineral processing or the bleaching of scrap paper. Washing and detergency are examples of applications encountered in everyday life. Often, the production of new materials such as composite materials involves intensive processes at interfaces. Thin films on surfaces are often dominated by surface effects. Examples include latex films, coatings, and paints. The flow behavior of powders and granular media is

determined by surface forces. In tribology, wear is reduced by lubrication, which, again, is a surface phenomenon.

Typical of many industrial applications is a very refined and highly developed technology, but only a limited understanding of the underlying fundamental processes of that technology. A better understanding is, however, required to further improve the efficiency or reduce dangers to the environment.

Introductory books on interface science are [1–3]. For a deeper understanding, we recommend the series of books by Lyklema [4–7].