INTRODUCTION

The effects of high hydrostatic pressure on the phase transitions and the phase diagram of water (as shown in Figure 8-1) are well known (Bridgman, 1912; Wagner et al., 1994), but until recent years, little attention has been paid to possible applications in the area of processing and preservation of foodstuffs.

High pressure offers new possibilities for food processing and preservation, not only at temperatures above zero but also in the negative temperature region. According to the principle of Le Chatelier, pressure opposes reactions associated with volume increase, such as the transition from liquid water to ice I (the common ice form at atmospheric pressure). This results in a lowering of the freezing point to a minimum of $-22^\circ$C at 207.5 MPa (Bridgman, 1912) (Figure 8-1), which suggests the possibility of new applications of high pressure such as pressure-shift freezing, pressure-induced thawing, pressure-assisted freezing and thawing, and preservation of foodstuffs at subzero temperatures in the liquid state (subzero storage without freezing) (Deuchi & Hayashi, 1992; Kanda & Aoki, 1993; Kalichevsky et al., 1995; Le Bail et al., 1997; Knorr et al., 1998). Pathways in the phase diagram associated with each of these processes are illustrated in Figure 8-2. Knorr et al. (1998) first introduced the terminology used here to distinguish between the different processes. Pressure-assisted means that the phase transition occurs under constant pressure; pressure shift refers to a phase transition caused by a pressure change; and pressure-induced means a phase transition initiated with pressure change continued at constant pressure. Unfortunately, the literature on this topic is marked by inconsistent terminology.

At certain conditions of pressure and temperature, ice polymorphs other than ice I may be formed (Figure 8-1). In contrast to ice I, these ice forms have a higher density than liquid water (at the same pressure), which explains why their
equilibrium temperature with liquid water increases at higher pressure. Ice VI may be formed at room temperature at pressures of about 900 MPa. Application of the other ice polymorphs to food processing and preservation still needs to be explored. Pressure shifting between ice polymorphs I, III, and V has been studied as a way of disrupting microorganisms (Edebo & Hedén, 1960; Hedén, 1964). However, its application to foods seems dubious because the associated volume change (greater than 17%) leads to severe tissue damage. The processes related to the transition of liquid water to ice I do not require the amount of pressure used in food pasteurization and sterilization. High pressure equipment operating under 400 MPa is less expensive and quite reliable. Therefore, these processes are likely to have commercial interest and will be considered in detail in this chapter.

THE USES OF PRESSURE IN FREEZING AND THAWING

Pressure-Shift Freezing

*Principle and Advantages*

Food freezing occurs in two stages: nucleation and crystal growth (Sahagian & Goff, 1996). Reduction of available liquid water as ice, combined with subzero temperatures, causes a reduction of chemical and biological processes, and renders freezing the preservation technology that guarantees the longest shelf life (Reid, 1990). As a consequence, freezing is widely used for food processing (meat and processed meats, fruits and vegetables, dairy and egg products, and