in the laboratory. Their growth is accelerated by long periods at a low state of charge and thus low acid concentrations. As described in Section 18.4.7.4.2, the solubility of $PbSO_4$ increases at low acid concentrations. For example, the solubility of $PbSO_4$ is 2 mg/l at a sulphuric acid density of 1.28 g/cm^3, and is already 35 mg/l at a density of 1.02 g/cm^3. The higher the solubility the higher is the rate of recrystallisation and hence the rate of formation of large sulphate crystals and dendrites. The danger of dendrite growth can be counteracted by thicker separators and by operating the battery at high states of charge.

In general, a short circuit is a defect that causes a sudden and complete breakdown in the battery. Short circuits can occur from dendrites between the electrodes and the sludge in flooded batteries from active material accumulated as a result of active-material shedding under the electrodes. If the amount of material exceeds the free-electrolyte height under the electrodes, short circuits occur through the "mud". Microscopic short circuits through the separator affect particularly the self-discharging properties of a battery.

18.4.7.4.6 Reverse charging

If a battery is subjected to a discharging current even after the battery has been fully discharged, the potential changes its sign.

Reverse charging of an individual cell can occur in strings of series-connected cells. The battery voltage and therefore the depth of discharge protection are controlled on the basis of overall string voltage. A single cell within the string may have lower capacity due to manufacturing deviations or due to accelerated ageing. In consequence, the low-capacity cell can be over-discharged resulting in reverse charging.

In case of reverse charging, PbO_2 is formed at the original Pb electrode and vice versa. Although this type of reverse charging can sometimes increase the capacity for a short time, it is certainly detrimental to the cell lifetime in the long term. The main cause of damage is the oxidation of additives in the lead sponge of the negative electrode, which are included to maintain the high porosity of the electrode. If these additives are destroyed, large lead crystals form in the negative electrode resulting in a loss of internal surface area and therefore in an irreversible loss of capacity.

The danger of reverse charging can be reduced if the voltage of the individual cells is monitored and used as the criterion to end discharging (rather than the total voltage of the battery). Alternatively, it can be prevented by allowing charge equalisation between the cells of a series connection [12].

18.4.7.4.7 Ice formation

Figure 18.21 shows the dependence of the freezing point of diluted sulphuric acid on the electrolyte concentration. Ice must be prevented from forming in a battery under all circumstances, as it is then practically impossible to operate the battery (in particular, a frozen battery can hardly be charged) and it is possible that the cell housing may burst (battery breakdown and contamination of the surroundings with sulphuric acid).

For operating modes with very low discharge currents, or if the deep-discharge protection is inactive or non-existent, it is possible to reach extremely deep discharge,