camcorders, mobile and cordless phones and organisers. Even though they are not used in larger autonomous power supply systems today, it is worth having a closer look at this technology. Their electrical properties concerning efficiency and charge/discharge characteristics are very well suited to these applications. At the moment, lithium batteries are by far too expensive for applications where the high gravimetric energy density is of little benefit. However, as this is an emerging technology and cost reductions in the manufacturing process are expected, they might play a role in some autonomous power supply applications in the next few years.

The lithium-ion rechargeable battery's operation is based simply on lithium ions migration between the cathode and anode. Lithium-ion rechargeable batteries are therefore fundamentally different from non-rechargeable lithium and, for example, secondary lead acid or NiCd batteries in that the basic form of the cathode and anode materials does not change.

When the battery is charged, the lithium ions in the cathode material (lithium compound) migrate via a separator into the layer structure of the carbon material that forms the anode, and a charging current flows. During discharging, the lithium ions in the carbon material migrate backwards to the cathode material. This is known as the "rocking-chair" principle. Even though a large number of different material combinations are known under the name of lithium ion batteries, the most important materials for the commercial products are of the LiCo and the LiMn type.

The reactions for the reversible charge/discharge process are indicated below.

$$\mathrm{Li_{1-x}CoO_2} + \mathrm{C}_n\mathrm{Li}_x \rightleftarrows \mathrm{LiCoO_2} + \mathrm{C}_n \text{ (cobalt type)} \tag{18.3}$$

$$\mathrm{Li_{1-x}Mn_2O_4} + \mathrm{C}_n\mathrm{Li}_x \rightleftarrows \mathrm{LiMn_2O_4} + \mathrm{C}_n \text{ (manganese type)} \tag{18.4}$$

Li-ion batteries of the modern types as marketed today have a nominal voltage of 3.6 V. As this is far above the water-electrolysis voltage of 1.23 V, no aqueous electrolytes can be used anymore. The electrolyte here is an organic solvent with dissolved lithium salts. The cathode material is lithium cobaltite ($\mathrm{LiCoO_2}$) or lithium manganese oxide spinel ($\mathrm{LiMn_2O_4}$). The anode material is graphite of coke (graphitised carbon).

Lithium-ion rechargeable batteries have a three-layer structure consisting of a porous separator sandwiched between sheet-like cathode and anode materials, which, in the case of a prismatic cell, are wrapped around in an elliptical form. These materials are impregnated in an electrolyte and sealed in a metal case. This metal case includes a safety vent to protect the battery by releasing gas externally if the pressure inside the cell builds up to extreme levels.

Lithium batteries are potentially risky due to their very high energy density and the reactivity of metallic lithium. Incorrect handling of a lithium rechargeable battery may cause heat, explosion or fire. Therefore, it is even more important with this battery type to assure overcharge protection, over-discharge protection, over-current protection, short-circuit protection and operation at too high temperatures. Today, lithium batteries are only supplied with an integrated control electronic as a protection device. It works independent of all external chargers or monitoring devices and is therefore fully controlled by the battery manufacturer.