Lithium ion Table of Contents

1

Overview of Lithium Ion Batteries

■1-1 Feature of Lithium-ion Battery

Lithium secondary battery is a general term of battery that uses lithium metal, lithium alloy or material absorbing lithium ion for negative active material.

Lithium-ion battery uses carbon material for the anode and lithium ions exist in the carbon material. It means that there is no metallic lithium at any state of charge during normal usage. In order to differentiate from the batteries that use lithium metal or lithium alloy as the anode, it is called Lithium-ion battery.

Main features of SANYO Lithium-ion battery are as follows.

(1) High energy density with volumetric energy density 1.5 times higher and gravimetric energy density 2 times higher than that of high capacity model of Ni-Cd battery. This means that Lithium-ion battery is much more suitable for lighter or smaller portable applications.

(2) Voltages are high with average operating voltages at 3.6 to 3.7V and these are approximately the same as three cells in series of Ni-Cd or Ni-MH batteries. It means that using Lithium-ion batteries reduces the number of cells in actual use.

(3) Discharge curves are flat because of highly crystallized carbon graphite used as the anode.

(4) Long cycle life normally 300 to 500 charge discharge cycles can be achieved.

(5) Self-discharge is 10W, approx 2% / month at room temperature.

(6) There is no memory effect as in Ni-Cd batteries.

(7) Safety is high due to no metallic lithium content and improved structures.

■1-2 Principles of Lithium-ion Battery

●1-2-1 Mechanism of charge / discharge

Lithium-ion batteries do not use metallic lithium, so battery life is not reduced by internal short circuit caused by Lithium dendrites, which was the main weakness of other lithium secondary batteries. Furthermore the chemical stability of carbon anode, even fully charged is higher than metallic lithium. Therefore Lithium-ion batteries are safer systems.

Lithium-ion battery consists of lithium cobaltate cathode, graphite anode, organic solvent electrolyte including lithium salt and separator.

Fig.1-1 shows schematic for chemical reactions of Lithium-ion batteries. Both electrodes have layered structure, and when charging, lithium ions come out from the cathode and move through electrolyte to be deposited in between the layers of the graphite anode. When discharging the reaction is revised.
Reactions of charge and discharge are follows.

Reactions of Lithium-ion Battery

(Positive Electrode)

$$LiCoO_2 \underset{Discharge}{\overset{Charge}{\rightleftarrows}} Li_{1-x}CoO_2 + xLi^+ + xe^-$$

(Negative Electrode)

$$C_y + xLi^+ + xe^- \underset{Discharge}{\overset{Charge}{\rightleftarrows}} C_yLi_x$$

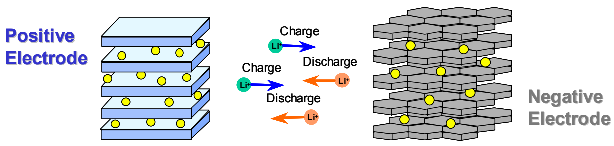
(Overall)

$$LiCoO_2 + C_y \underset{Discharge}{\overset{Charge}{\rightleftarrows}} Li_{1-x}CoO_2 + C_yLi_x$$

Lithium ions are the medium by which electrons are carried and are included in positive electrode materials. There is no need to treat metallic lithium in assembling Li-ion cells. During the charging process, lithium ions in the positive electrode transfer into the negative electrode and are placed between the layers of graphite, which makes electrical potential difference.

Since cells are partially charged during the production process for shipping purposes, the formula shown above can more accurately represented by 1-xCo_2/CyLix.

Fig.1-1: Diagram showing reaction of Lithium-ion battery when charging/discharging.



●1-2-2 Differences from Nickel Cadmium and Nickel Metal Hydride batteries

Ni-Cd and Ni-MH batteries are using alkaline aqueous electrolyte and hydro oxide ions carry the electrical charges. During charging water is created and oxygen gas is generated, so the charge/discharge process loses efficiency to below 100%. However, this sub-reaction can prevent overcharging enabling the manufacture of sealed batteries.

Conversely Lithium-ion batteries charge/discharge process is practically 100% efficient except the first charge/discharge cycle, but this is a disadvantage in overcharge and over-discharge.

Lithium-ion batteries use an organic solvent for the electrolyte which is different from alkaline rechargeable batteries and the conductivity being lower makes high rate discharge difficult. This is overcome by using larger area electrodes.

●1-2-3 Method of manufacturing

In order to ensure high performance and safety, there are many complicated manufacturing processes, and batteries are made in a carefully controlled environment using strictly controlled and maintained equipment.

The electrodes are manufactured using active materials, conductive agents and binder which are mixed with liquid. These mixtures are then uniformly coated onto the thin metal foil, then after drying, the electrodes are cut down to the designated sizes.

The cathode and anode electrodes are then wound together with a separator and inserted into a can and the electrolyte is filled. The sealing completes the battery assembly.

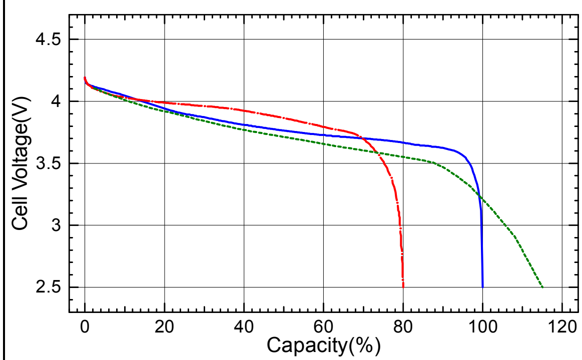
Prior to shipping the batteries to customers, the batteries will undergo an aging process, thorough inspections, initial charge/discharge cycle, etc., ensuring the highest quality of product is maintained.

●1-2-4 Cathodes

Materials containing lithium ions and which can be used the cathode active material must be capable of deintercalation of lithium ions during charge and intercalation of lithium ions during discharge. Lithium cobaltate ($LiCoO_2$) is used mainly in the marketplace and it is known that lithium nickelate ($LiNiO_2$) or lithium manganate ($LiMn_2O_4$) are also used for the cathode. Fig.1-2 shows comparisons of discharge characteristics for various cathode materials.

SANYO is using lithium cobaltate as the cathode because of its good reversibility, capacity, efficiency, voltage and flat discharge characteristics.

Fig.1-2: Discharge characteristics of different positive materials

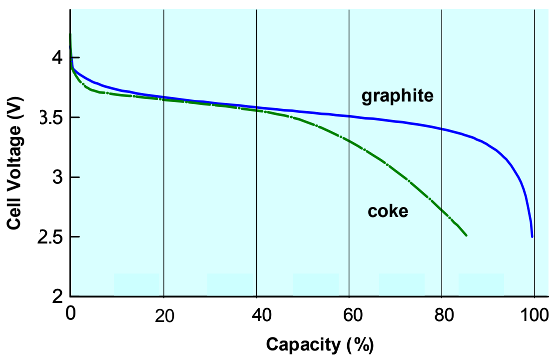


●1–2–5　Anodes

In order to create Lithium-ion batteries with higher energy density using carbon anodes, it must use a carbon material having large lithium storage capability.

Presently, two types of carbon materials are used. One is highly crystallized carbon like graphite and the other is amorphous carbon like coke. C_6Li is equivalent to a lithium ion doped in a hexagonal ring of carbon atoms, and its theoretical capacity is 372mAh/g. Highly crystallized carbon can obtain large capacity and graphite can obtain the capacity close to the theoretical value. The biggest difference between coke and graphite is discharge characteristics, and these characteristics are compared in Fig.1-3.

Fig.1–3: Discharge characteristics of different negative materials



Using the coke system, remaining capacity can easily be measured using the discharge curve, however graphite system is superior in terms of its fundamental purpose of supplying more energy.

SANYO is using graphite as the anode for the above mentioned reasons.

●1–2–6　Separators

Major functions of battery separators are to insulate positive and negative electrodes, retain the electrolyte and transmit lithium ions. To ensure functionality the separator needs to have the following characteristics;

(1) Electrical insulation
(2) Chemical and thermal stability against electrolyte
(3) Capability of holding electrolyte
(4) Porous for transmission of lithium ions
(5) Thinness and mechanical strength

Polyethylene and polypropylene porous thin films are generally used as suitable materials for above-mentioned requirements. The pores of these films melt and prevent the lithium ions from passing through the separator at certain temperature, which makes a major contribution to safety of Lithium-ion batteries as instructed in section 4-2.

●1–2–7　Electrolyte

Electrolyte carries out the essential role of carrying lithium ions (which means current flow).
In case of lead acid for Ni-Cd and Ni-MH battery, aqueous solution is used as electrolyte. However, because Lithium-ion battery is used at high voltages over 4V, which causes electrolysis of water, lithium salt in nonaqueous organic solvent is appropriate for electrolyte.

The organic solvent is required to satisfy the following characteristics.

(1) High conductivity of lithium ion
(2) Electric chemical stability (at over 4V)
(3) Chemical and thermal stability
(4) Wide temperature rage

Due to voltages over 4V, only limited types of solvent are suitable for Lithium-ion batteries. As for electrolyte salt, it is necessary to increase the conductivity of electrolyte and LiPF6 in mixed solvent mainly including ethylene carbonate is generally used.

●1–2–8　Materials for Can

Material for can of positive side have to withstand Lithium-ion's high voltage of over 4V. Stainless can be used for 3V, but Lithium-ion battery (cylindrical type) adopts nickel-plated iron for over 4V. On the other hand, Sanyo pioneered and has been leading the lightening competition by using aluminum alloy for outer can (negative) of prismatic types.

2

Cylindrical Type

■2−1 Features of Battery

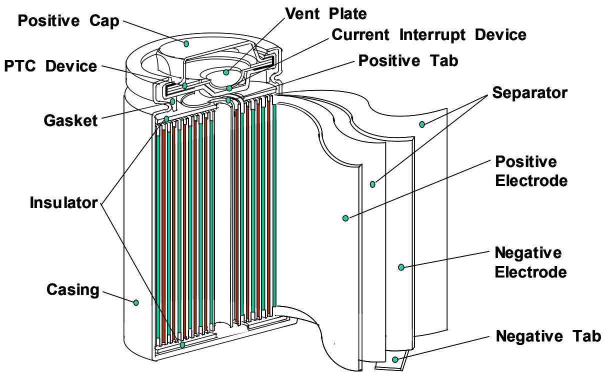
Standard cylindrical type was the first produced type in Lithium-ion history. Cylindrical types are used mainly in multi-series and parallel configurations for personal computers, camcorders, etc.

In general, cylindrical types have shorter width (diameter) and more capacity than prismatic types. This is why cylindrical types are very prefered when high capacity is needed for long tube-shaped space, such as a hinge of notebook PC.

■2−2 Structure of Battery

Fig.2-1 shows the structure of Sanyo's cylindrical type Lithium-ion cell.

Fig.2−1: Internal structure of Battery



As already mentioned, electrodes are a spirally wound roll consisting of very thin sheets of positive and negative electrode and high polymer separators.

Therefore cylindrical cells have an efficient structure which allows for a good performance for energy density, charge/discharge characteristics, and temperature characteristics.

The electrolyte is an organic solvent with high voltage stability mixed with lithium salt.

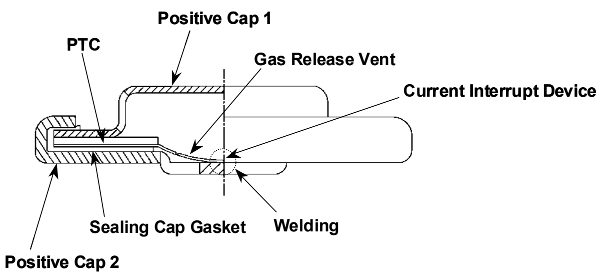
In order to keep safety in case of abnormal use, the cell has some protective parts in it such as PTC device, gas release vent, or special separator.

PTC has a combined function of current fuse and thermal fuse. When over-current flows through the PTC, self-heating increases its resistance. In a case like that, the resistance will go up to some 10k ohm, which controls abnormally large current. Cylindrical cells have a ring-shaped PTC in its sealing cap, which prevents excess current(e.g. by short-circuit) from causing abnormal heating of the cell.

In addition, the cell is equipped with a current interrupt device(CID) combined with a gas release vent. This will stop charging when pressure increases in the cell and the cell will vent in case of further increase in pressure. Fig.2-2 shows the structure of it. The top of the vent is welded to positive cap No.2.

When the vent is raised up by pressure in the cell, it will be removed from positive cap No.2 and current will never flow.

Fig.2–2: Structure Diagram of Sealing Parts



For separator, micro-porous polymer film is adopted based on the know-how of Lithium primary battery for cameras. The separator has current-interrupting function. If abnormal use (such as short-circuit) causes excess heat of the cell, meltdown will shut down the pores and restrain the flow of lithium ions.

Cylindrical cell is assembled and sealed using these kinds of functional parts.

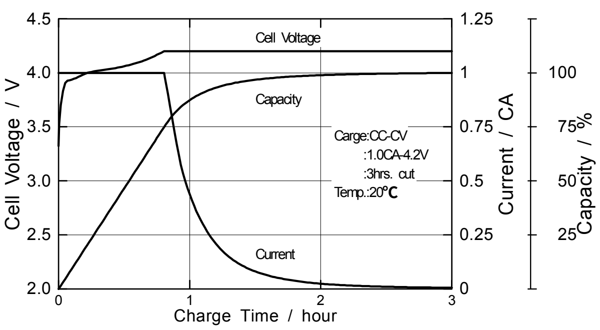
■2–3 Charge Characteristics

●2–3–1 Outline

Charge is the operation that makes the discharged battery reusable. Normally Lithium-ion battery is charged by constant current-constant voltage (CC-CV) method. For CC-CV charging, chargers need to control Max charge voltage, which is 4.2 +/- 0.03V(4.2 +/- 0.05V in special cases) for Sanyo's Lithium-ion batteries.

Fig.2-3 shows typical charge characteristics of Lithium-ion battery.

Fig.2–3 Charge Characteristics

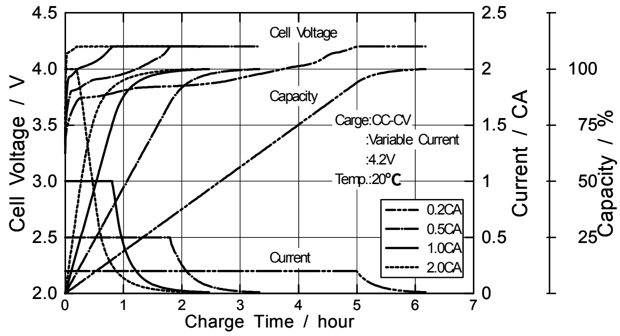


When a battery is charged with CC-CV (1C-4.2V), it is charged with constant current of 1C and the cell voltage gradually goes up to the controlled voltage(4.2V) in about 50 minutes. At this point, state of charge is about 80%. After that, CV charging starts and charge current decreases. Charging is completed in about 2.5 hours.

●2–3–2 Charge Conditions and Charge Time

Fig.2-4 shows charge characteristics depending on charge current.

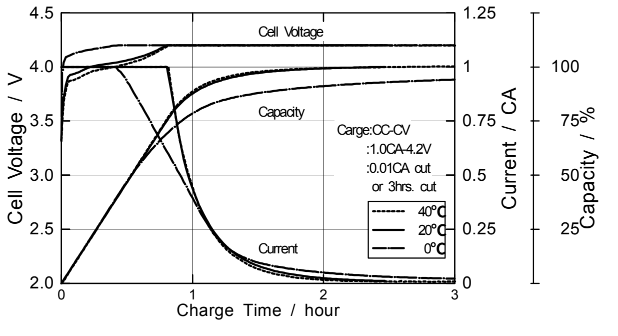
Fig.2–4: Charge current and Charge capacity



When charging at higher currents, the cell voltage rises more quickly. This is because of the rise of over-voltage in electrode reactions, and the rise of voltage caused by the internal resistance of the cell. Therefore, larger charge current will decrease the time of CC area. However, if the constant current is over 1C, current value makes no big differences on total time for 100% charge because percentage of CV area becomes much longer. Normal charge current for this battery is between 0.2C and 1C.

Fig.2-5 shows ambient temperature- charge amount characteristics.

Fig.2–5: Ambient temperature and Charge amount



The cell voltage depends on ambient temperature. The lower the ambient temperature, the higher the cell voltage because of the increase of over-voltage in electrodes reactions. The point is that charging at under 0deg.C is not practical because it takes long time to reach 100% charged state. The normal charge temperature is between 0 and 40deg.C.

Also charge capacity depends on the charge end current. Fully charged state can be defined as charging terminated by current under 0.02C – 0.05C. Larger terminating current means more room for charge.

●2−3−3 Precautions for Charging

Do not continuously charge, otherwise battery performance will deteriorate. Also, the charger needs to be designed on the same basis. (Refer to section5 "Charging method" for more details.)

■2−4 Discharge Characteristics

●2−4−1 Outline

Discharging voltage of Lithium-ion batteries changes depending on discharge current, ambient temperature and other conditions, but it is 3.7V on average, which is about 3times that of Ni-Cd and Ni-MH. This higher discharging voltage is one of the major advantages of lithium-ion. For example, appliances driven by 3-4V need 3series of Ni-Cd or Ni-MH whereas only 1 series of Lithium-ion is needed.

●2−4−2 Discharge Rate

Fig.2-6 and 2-7 show the relationship between discharge rate, voltage and capacity.

Fig.2−6: Discharge Rate (Rate)

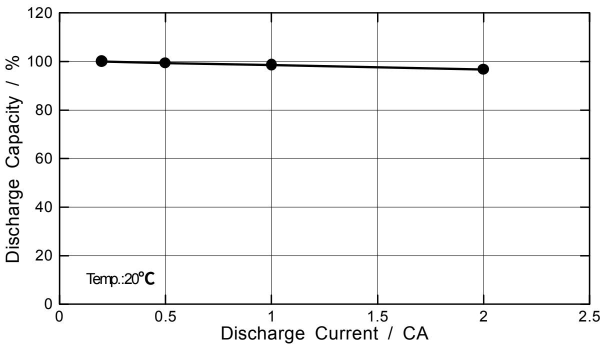
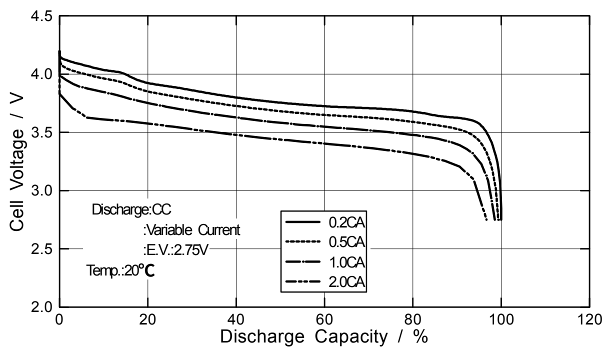


Fig.2−7: Discharge Characteristics (Rate)



Increasing discharge current means decreasing discharge capacity. This is because of decline of the reactivity of active materials. Also, larger discharge current causes lower discharge voltage because polarization voltage in electrode reactions increases. Standard discharge current is below 1C for continuous discharge and below 2C for pulse discharge because discharging with over 2C leads to large voltage drop.

●2−4−3 Ambient Temperature

Fig.2-8,9 illustrates the relationship between ambient temperature and cell voltage during discharge.

Fig.2−8: Discharge Rate (Temperature)

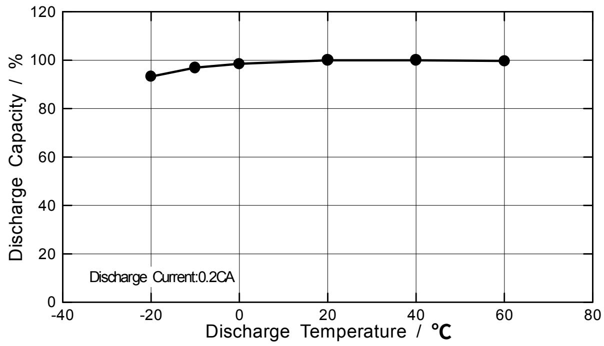
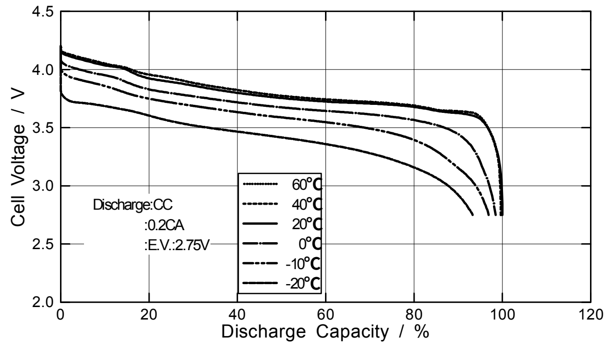


Fig.2−9: Discharge Characteristics (Temperature)



Discharge capacity at high temperature is equal to or larger than at room temperature, but the capacity at low temperatures decreases because low ambient temperature lowers reactivity of the electrode and cell voltage. This capacity deterioration is just temporary. The performance will recover at room temperature.

Cylindrical type has a PTC built in. PTC working conditions (ambient temperature and discharge current) need to be confirmed for each specific case because the conditions depend on configuration of assembled battery.

●2−4−4 Over−discharge

Over-discharge leads to deterioration of performance. Use Lithium-ion batteries over the recommended voltage limits.

In extreme cases that an assembled battery is deeply discharged, polarity of the cell with the lowest capacity will be reversed because the cells which compose the assembled battery have small differences of capacities. Repeated deep discharge could cause rapid deterioration of performance. Do not over-discharge batteries to avoid polarity reversal. For this reason, recommended discharge end voltages are listed below.

For 1 series(3.7V) connection: 2.75V or higher
For 2 series(7.4V) connection: 6.0V or higher
For 3 series(11.1V) connection: 9.0V or higher
For 4 series(14.8V) connection: 12.0V or higher

In addition, each assembled battery is equipped with over-discharge protection circuit, which sets up the over-discharge limit voltage (2.0-2.4V). (Refer to section4 "Safety " for more details.)

■2–5 Storage Characteristics

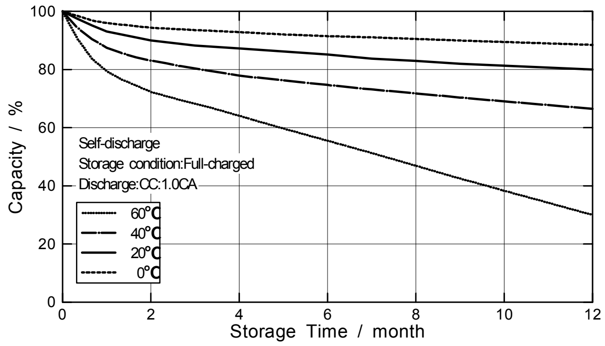
●2–5–1 Outline

Even when disconnected from a load after being charged, batteries lose their energy through self-discharge, which leads to capacity loss and lower voltage. The self-discharge of Lithium-ion battery is about 3%/month for 100%-charged state at room temperature, which is less than Ni-Cd and Ni-MH. Self-discharge rate depends on state of charge of battery and ambient temperature during storage. Practical self-discharge rate includes consumption current of protection circuit that is built in assembled batteries.

●2–5–2 Storage Temperature

The relationship between storage temperature and residual capacity is shown in Fig.2-10.
High temperature increases the self-discharge rate.

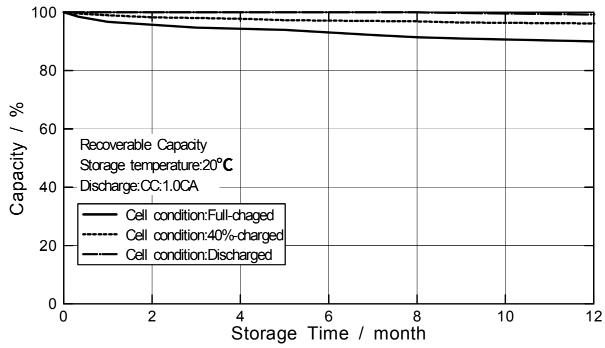
Fig.2–10: Storage Characteristics (Residual capacity rate)



●2–5–3 Recoverable Capacity after Storage

Following long-term storage, Lithium-ion battery cannot recover 100% capacity by recharging. The rate of recovery depends on state of charge and storage temperature. In these cases, the lost capacity never recovers completely even after several cycles of charge and discharge. Fig.2-11 shows recoverable capacity rate after long-term storage from 100%, 40% charged state and discharged state.

Fig.2–11: Storage Characteristics (recoverable capacity rate)



The higher the state of charge, the lower the amount of capacity becomes recoverable. Higher storage temperature increases the differences. In other words, recoverable capacity depends on the state of charge. The lower the state of charge, the more capacity can be recoverable. If stored at discharged state, except for over-discharged state, Lithium-ion battery can recover 100% capacity even at storage temperature of 60deg.C.

A decline of recoverable capacity rate is also caused by long-term storage at over-discharged state of below 1V. This phenomenon appears earlier at higher storage temperature. The reason is that higher temperature accelerates self-discharge and will reduce the time taken for the cell voltage to reach 1V. This is why Sanyo recommends that Lithium-ion battery is stored at low temperature and at discharged state unless it becomes over discharged state.

●2–5–4 Precautions for Storage

In order to optimize Lithium ion battery's performance, compliance with following conditions is recommended.

(1)Storage Temperature, Humidity

Ensure that the batteries are stored in non-condensing atmosphere with no corrosive gas. (Humidity 65+/-20%)

Less than 30days: -20 to 50deg.C
30 – 90days : -20 to 40deg.C
More than 90days: -20 to 30deg.C

Do not store out of above listed temperature range and/or at extremely high humidity, or leakage and rust could happen.

(2) Long-term Storage

Even though over-discharge protection is built into each battery pack, if it is stored connected to a load, the recoverable capacity rate tends to reduce because it takes shorter to fall down to over-discharge protection working voltage. For this reason, disconnect battery from load in a case of long-term storage, or battery could not be fully charged and the recoverable capacity rate could be deteriorated.

Charge about 10% every 6months if the battery is not used for long periods.

Please consult Sanyo on details because it depends on battery pack design (e.g. cell configuration, protection circuit).

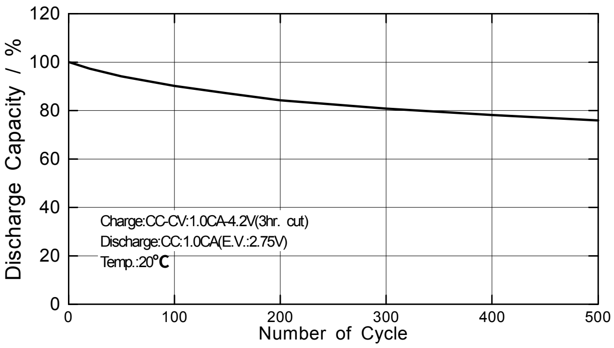
■2−6 Cycle Life

●2−6−1 Outline

In general, end of cycle life of secondary batteries is defined when capacity falls below 60% of the nominal capacity and no longer recovers by subsequent cycles. Cycle life largely depends on the cycle conditions such as charge, depth of discharge, current and ambient temperature.

Fig.2-12 gives an example of cycle characteristics.

Fig.2−12: Cycle Characteristics



Conditions that will reduce cycle life.

- -Over-charging with excessive voltage
- -Continuous charging
- -Charging and discharging with excessive current
- -Over-discharging to protection working voltage
- -Ambient temperature out of the recommended range.

Unlike other kind of secondary, Lithium-ion batteries do not suffer from memory effect.

●2−6−2 Factors affecting Cycle Life

(1) Reasons for Battery Cycle Life Reduction

Cycle life is determined mainly by the degradation of electrolyte causing a rise in internal resistance and decline of reversibility of electrode active materials.

These kinds of phenomena are accelerated when charge-discharge conditions recommended by Sanyo are not maintained.

(2) Battery Temperature

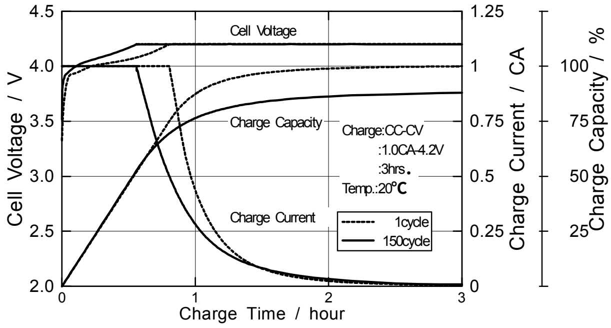
Cell temperature is one of the factors that make a difference on cycle life of Lithium-ion battery. Sanyo's recommendation is 0-40deg.C for charge and 0-60deg.C for discharge.

Long-term storage of charged cells at high temperature also shortens the cycle life.

(3) Condition of Charge

Fig.2-13 shows the relationship between cycle number and charging voltage curve. After cycling, the CC area reduces and the CV area becomes extended. This transition occurs due to increase of internal resistance caused by charge-discharge cycles.

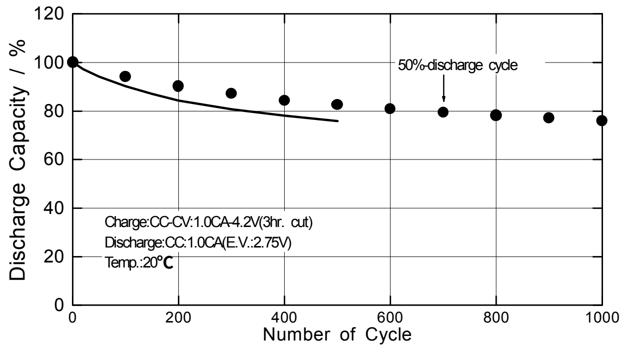
Fig.2−13: Cycle Characteristics (Charge)



Above mentioned is referring to full charge-discharge. However, in practical use, shallow charge-discharge is used in most cases. Lithium-ion batteries have no memory effect like Ni-Cd and Ni-MH.

Then, let us explain about shallow charge-discharge cycle characteristics. In a case of, for example, an experimental regular cycle of full charge - 50% discharge cycle, the cycle life is about twice as long as normal full cycle. This is shown in fig.2-14.

Fig.2−14: Cycle Characteristics (Depth of Discharge)



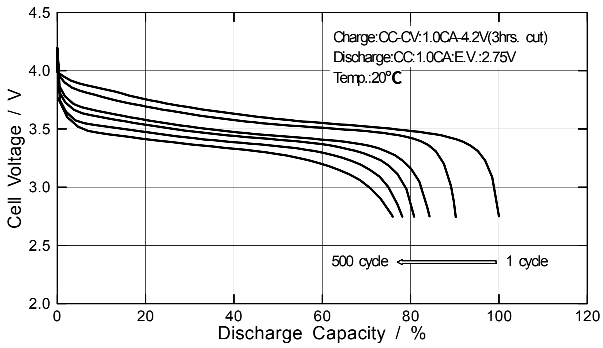
Lithium-ion batteries have the regulated controlled charge voltage. Charging by voltage beyond the controlled voltage (over-charge) can deteriorate cycle life. And that also could cause heat, explosion and fire because of abnormal reactions inside the cell.

Continuously charging without time control also reduces cycle life. Charging should be stopped at a given time limit or when a specific current is reached.

(4) Condition of Discharge

After several hundreds cycles, discharge voltage of Lithium-ion batteries reduces. Fig.2-15 shows relationship between number of cycles and discharge characteristics. The reason for this voltage change is due to the increase of internal resistance brought about by cycling.

Fig.2–15: Cycle Characteristics (Discharge Characteristics)



3

Prismatic Type

■3−1 Features of Battery

In connection with small and light weight-sizing of applications, the battery used as the power supply has also been asked for less-space, light weight and a high performance. Following this trend, prismatic type has been developed, keeping the good features of cylindrical type.

Based on Sanyo's cylindrical technology and adding new innovative technologies, the prismatic type achieved the goal of giving light weight and high capacity.

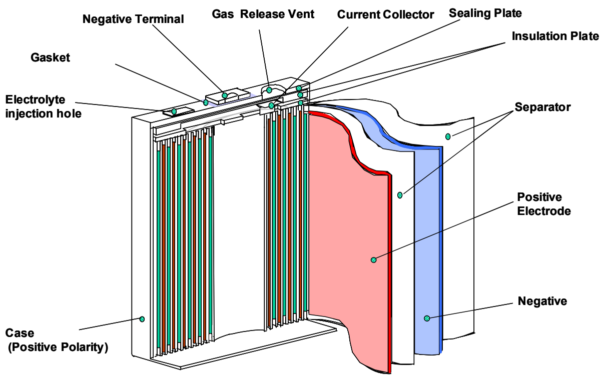
Light weight was achieved by using aluminum alloy for the case increasing the energy density by 30% in comparison to batteries using a steel case. Using the aluminum can for prismatics compensates for any weight increase which would have occurred when changing battery form from cylindrical.

The aluminum can and laser welding technologies are very complex. But Sanyo developed and pioneered these technologies and brought light weight products to market ahead of our competitors. Sanyo continues to improve the technology by bringing products that are lighter with even increasing capacity.

■3−2 Structure of Battery

Fig.3-1 shows the structure of Sanyo's prismatic type Lithium-ion cell.

Fig.3−1: Internal structure of Battery



The electrodes are manufactured as mentioned in section 1-4-2.

Prismatic cells are essentially made the same as cylindrical cells. The wound electrodes, with a separator in between is compressed and inserted into the case which is then closed with a sealing plate.

To reduce weight, an aluminum can is used as the case. The sealing plate is laser welded to the can ensuring high reliability against leakage.

Same as cylindrical cells, prismatic cells are equipped with a gas release vent to release the internal gas in case pressure increases in the cell.

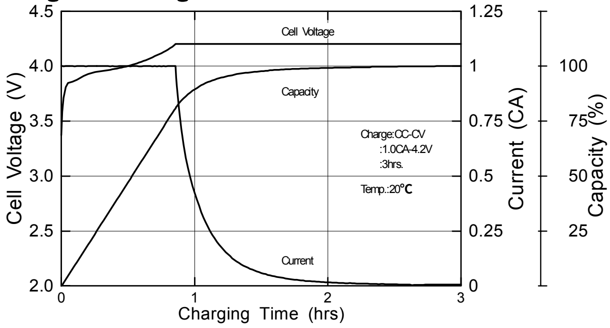
■3–3 Charge Characteristics

●3–3–1 Outline

Charge is the operation that makes the discharged battery reusable. Normally Lithium-ion battery is charged by constant current-constant voltage (CC-CV) method. For CC-CV charging, chargers need to control Max. charge voltage, which is 4.2 +/- 0.03V(4.2 +/- 0.05V in special cases) for Sanyo's Lithium-ion batteries.

Fig.3-2 shows typical charge characteristics of Lithium-ion battery.

Fig.3–2 Charge Characteristics

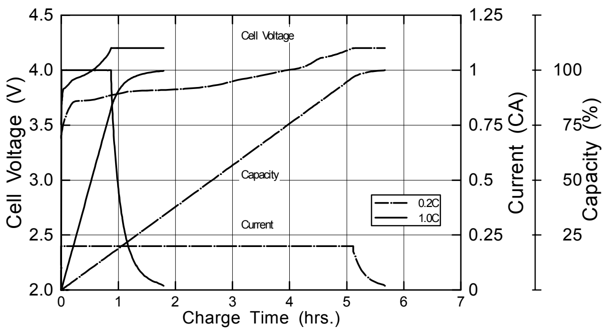


When a battery is charged with CC-CV (1C-4.2V), it is charged with constant current of 1C and the cell voltage gradually goes up to the controlled voltage(4.2V) in about 50 minutes. At this point, state of charge is about 80%. After that, CV charging starts and charge current decreases. Charging is completed in about 2.5 hours.

●3–3–2 Charge Conditions and Charge Time

Fig.3-3 shows charge characteristics depending on charge current.

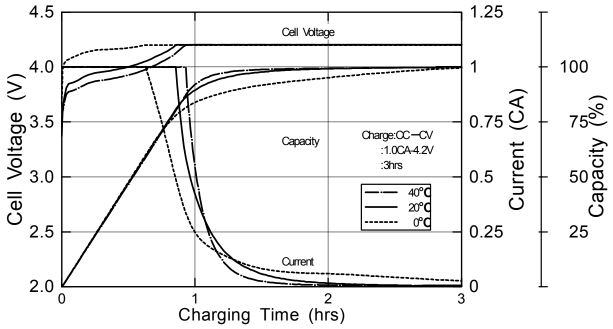
Fig.3–3: Charge current and Charge capacity



When charging at higher currents, the cell voltage rises more quickly. This is because of the rise of over-voltage in electrode reactions, and the rise of voltage caused by the internal resistance of the cell. Therefore, larger charge current will decrease the time of CC area. However, if the constant current is over 1C, current value makes no big differences on total time for 100% charge because percentage of CV area becomes much longer. Normal charge current for this battery is between 0.2C and 1C.

Fig.3-4 shows ambient temperature- charge amount characteristics.

Fig.3–4: Ambient temperature and Charge amount



The cell voltage depends on ambient temperature. The lower the ambient temperature, the higher the cell voltage because of the increase of over-voltage in electrodes reactions. The point is that charging at under 0deg.C is not practical because it takes long time to reach 100% charged state. The normal charge temperature is between 0 and 40deg.C.

Also charge capacity depends on the charge end current. Fully charged state can be defined as charging terminated by current under 0.02C – 0.05C. Larger terminating current means more room for charge.

●3–3–3 Precautions for Charging

Do not continuously charge, otherwise battery performance will deteriorate. Also, the charger needs to be designed on the same basis. (Refer to section5 "Charging method" for more details.)

■3–4 Discharge Characteristics

●3–4–1 Outline

Discharging voltage of Lithium-ion batteries changes depending on discharge current, ambient temperature and other conditions, but it is 3.7V on average, which is about 3times that of Ni-Cd and Ni-MH. This higher discharging voltage is one of the major advantages of lithium-ion. For example, appliances driven by 3-4V need 3series of Ni-Cd or Ni-MH whereas only 1 series of Lithium-ion is needed.

●3-4-2 Discharge Rate

Fig.3-5 and 3-6 show the relation between discharge rate, voltage and capacity.

Fig.3-5: Discharge Rate (Rate)

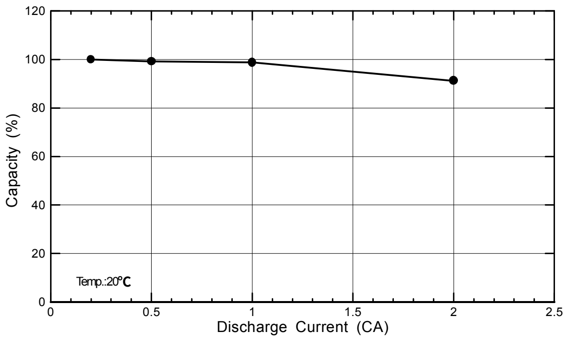
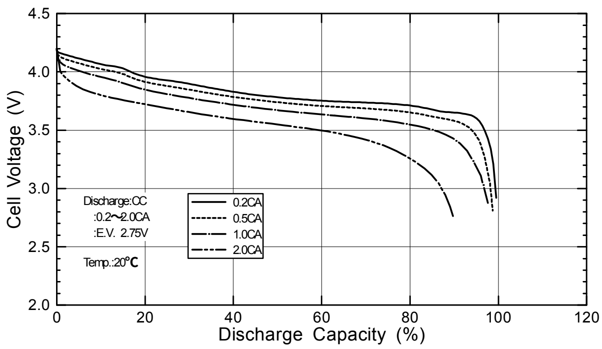


Fig.3-6: Discharge Characteristics (Rate)



Increase of discharge current means decrease of discharge capacity. This is because of decline of the reactivity of active materials.

Also, larger discharge current causes lower discharge voltage because polarization voltage in electrode reactions increases.

Standard discharge current is below 1C for continuous discharge and below 2C for pulse discharge because discharging with over 2C leads to a large voltage drop.

●3-4-3 Ambient Temperature

Fig.3-7,8 illustrates the relationship between ambient temperature and cell voltage during discharge.

Fig.3-7: Discharge Rate (Temperature)

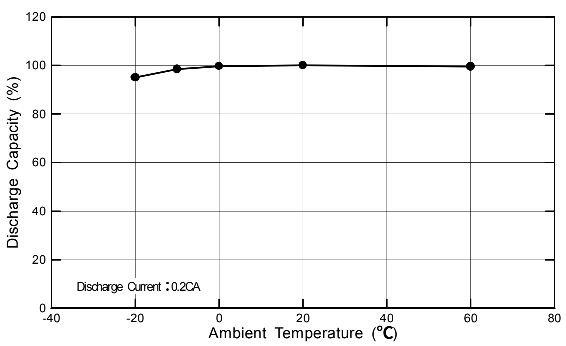
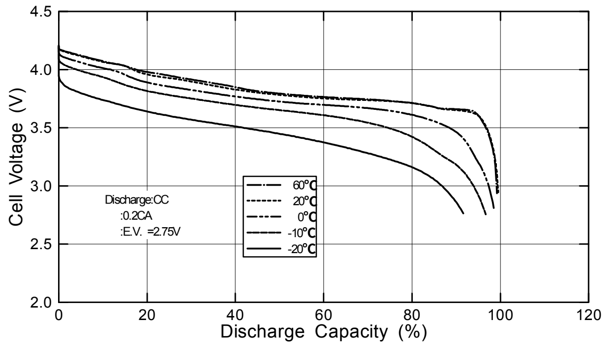


Fig.3-8: Discharge Characteristics (Temperature)



Discharge capacity at high temperature is equal to or larger than at room temperature, but the capacity at low temperatures decreases because low ambient temperature lowers reactivity of the electrode and cell voltage. This capacity deterioration is just temporary. The performance will recover at room temperature.

The ambient temperature and the condition of discharge current vary by configuration of assembled battery same as cylindrical type, the actual battery pack to be checked.

●3-4-4 Over-discharge

Over-discharge leads to deterioration of performance. Use Lithium-ion batteries over the recommended voltage limits.

In extreme cases that an assembled battery is deeply discharged, polarity of the cell with the lowest capacity will be reversed because the cells which compose the assembled battery have small differences of capacities. Repeated deep discharge could cause rapid deterioration of performance. Do not over-discharge batteries to avoid polarity reversal. For this reason, recommended discharge end voltages are listed below.

For 1 series(3.7V) connection: 2.75V or higher
For 2 series(7.4V) connection: 6.0V or higher
For 3 series(11.1V) connection: 9.0V or higher
For 4 series(14.8V) connection: 12.0V or higher

In addition, each assembled battery is equipped with over-discharge protection circuit, which sets up the over-discharge limit voltage (2.0-2.4V). (Refer to section4 "Safety " for more details.)

■3-5 Storage Characteristics

●3-5-1 Outline

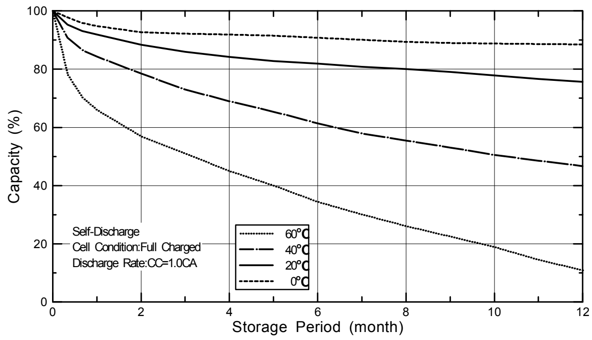
Even when disconnected from a load after being charged, batteries lose their energy through self-discharge, which leads to capacity loss and lower voltage. The self-discharge of Lithium-ion battery is about 3%/month for 100%-charged state at room temperature, which is less than Ni-Cd and Ni-MH. Self-discharge rate depends on state of charge of battery and ambient temperature during storage. Practical self-discharge rate includes consumption current of protection circuit that is built in assembled batteries.

●3-5-2 Storage Temperature

The relationship between storage temperature and residual capacity is shown in Fig.3-9.

High temperature increases the self-discharge rate.

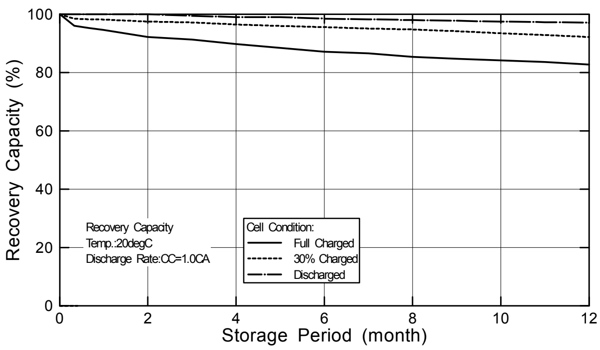
Fig.3-9: Storage Characteristics (Residual capacity rate)



●3-5-3 Recoverable Capacity after Storage

Following long-term storage, Lithium-ion battery cannot recover 100% capacity by recharging. The rate of recovery depends on state of charge and storage temperature. In these cases, the lost capacity never recovers completely even after several cycles of charge and discharge. Fig.3-10 shows recoverable capacity rate after long-term storage from 100%, 40% charged state and discharged state.

Fig.3-10: Storage Characteristics (recoverable capacity rate)



The higher the state of charge, the lower the amount of capacity becomes recoverable. Higher storage temperature increases the differences. In other words, recoverable capacity depends on the state of charge. The lower the state of charge, the more capacity can be recoverable. If stored at discharged state, except for over-discharged state, Lithium-ion battery can recover 100% capacity even at storage temperature of 60deg.C.

A decline of recoverable capacity rate is also caused by long-term storage at over-discharged state of below 1V. This phenomenon appears earlier at higher storage temperature. The reason is that higher temperature accelerates self-discharge and will reduce the time taken for the cell voltage to reach 1V. This is why Sanyo recommends that Lithium-ion battery is stored at low temperature and at discharged state unless it becomes over discharged state.

●3-5-4 Precautions for Storage

In order to optimize Lithium ion battery's performance, compliance with following conditions is recommended.

(1)Storage Temperature, Humidity

Ensure that the batteries are stored in non-condensing atmosphere with no corrosive gas. (Humidity 65+/-20%)

Less than 30days: -20 to 50deg.C
30 – 90days : -20 to 40deg.C
More than 90days: -20 to 30deg.C

Do not store out of above listed temperature range and/or at extremely high humidity, or leakage and rust could happen.

(2) Long-term Storage

Even though over-discharge protection is built into each battery pack, if it is stored connected to a load, the recoverable capacity rate tends to reduce because it takes shorter to fall down to over-discharge protection working voltage. For this reason, disconnect battery from load in a case of long-term storage, or battery could not be fully charged and the recoverable capacity rate could be deteriorated.

Charge about 10% every 6months if the battery is not used for long periods.

Please consult Sanyo on details because it depends on battery pack design (e.g. cell configuration, protection circuit).

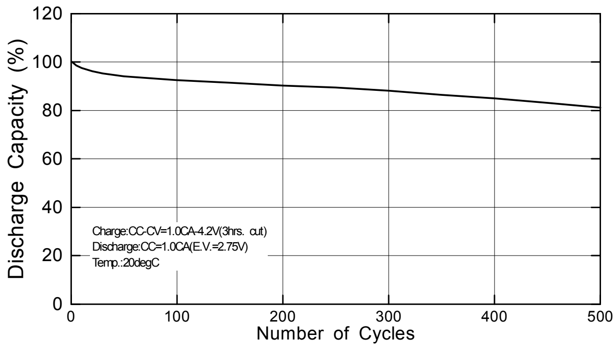
■3-6 Cycle Life

●3-6-1 Outline

In general, end of cycle life of secondary batteries is defined when capacity falls below 60% of the nominal capacity and no longer recovers by subsequent cycles. Cycle life largely depends on the cycle conditions such as charge, depth of discharge, current and ambient temperature.

Fig.3-11 gives an example of cycle characteristics.

Fig.3-11: Cycle Characteristics



Conditions that will reduce cycle life.

- -Over-charging with excessive voltage
- -Continuous charging
- -Charging and discharging with excessive current
- -Over-discharging to protection working voltage
- -Ambient temperature out of the recommended range.

Unlike other kind of secondary, Lithium-ion batteries do not suffer from memory effect.

●3-6-2 Factors affecting for Cycle Life

(1) Reasons for Battery Cycle Life Reduction

Cycle life is determined mainly by the degradation of electrolyte causing a rise in internal resistance and decline of reversibility of electrode active materials.

These kinds of phenomena are accelerated when charge-discharge conditions recommended by Sanyo are not maintained.

(2) Battery Temperature

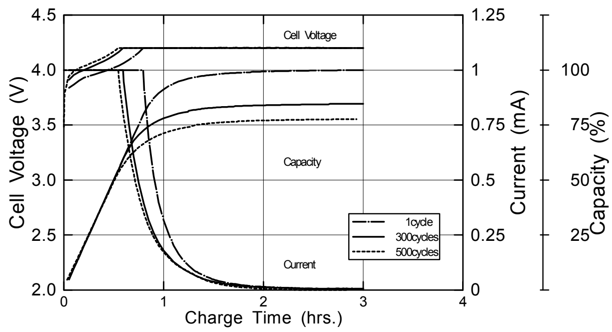
Cell temperature is one of the factors that make a difference on cycle life of Lithium-ion battery. Sanyo's recommendation is 0-40deg.C for charge and 0-60deg.C for discharge.

Long-term storage of charged cells at high temperature also shortens the cycle life.

(3) Condition of Charge

Fig.2-13 shows the relationship between cycle number and charging voltage curve. After cycling, the CC area reduces and the CV area becomes extended. This transition occurs due to increase of internal resistance caused by charge-discharge cycles.

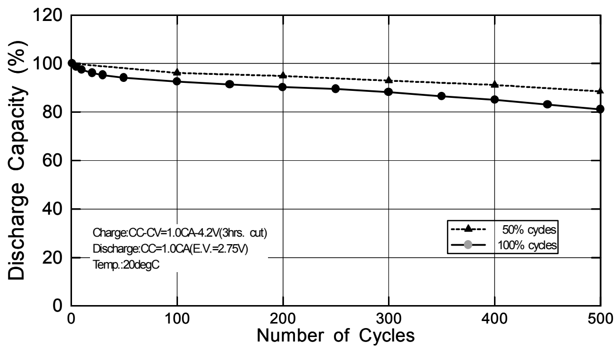
Fig.3-12: Cycle Characteristics (Charge)



Above mentioned is referring to full charge-discharge. However, in practical use, most case is shallow charge-discharge. Lithium-ion battery has no memory effect like Ni-Cd and Ni-MH.

Then, let us explain about shallow charge-discharge cycle characteristics. In a case of, for example, a experimental regular cycle of full charge - 50% discharge cycle, the cycle life is about twice as long as normal full cycle. This is shown in fig.3-13.

Fig.3-13: Cycle Characteristics (Depth of Discharge)



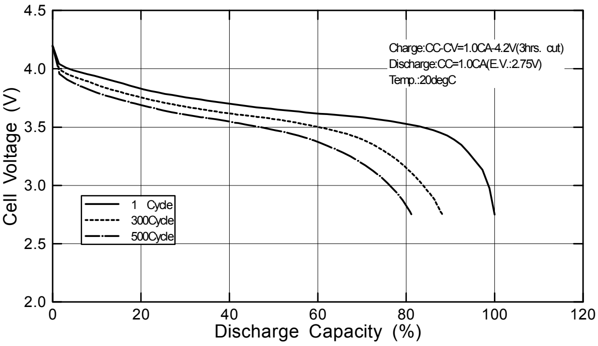
Lithium-ion batteries have the regulated controlled charge voltage. Charging by voltage beyond the controlled voltage (over-charge) can deteriorate cycle life. And that also could cause heat, explosion and fire because of abnormal reactions inside the cell.

Continuously charging without time control also reduces cycle life. Charging should be stopped at a given time limit or when a specific current is reached.

(4) Discharge Conditions

After several hundreds cycles, discharge voltage of Lithium-ion batteries reduces. Fig.3-14 shows relationship between number of cycles and discharge characteristics. The reason for this voltage change is due to the increase of internal resistance brought about by cycling.

Fig.3-14: Cycle Characteristics (Discharge Characteristics)



4

Safety

■4‒1 General Safety

While a Lithium-ion battery exhibits the advantages of high energy density and high voltage, unlike the conventional metal lithium battery, it ensures high safety. As the name Lithium ion implies, no lithium metal or alloy is present and lithium exists only in state of ions.

However, Lithium-ion batteries contain combustible materials so to ensure maximum safety, strict tests and examinations are performed in case of application failure or misuse.

Moreover, the battery is protected from over charge, over discharge, and over-current by incorporating a protection circuit when it is assembled to the complete pack.

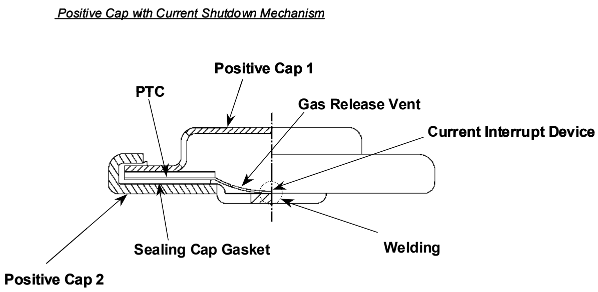
Batteries supplied by Sanyo satisfy the guideline of safety for lithium rechargeable batteries and are approved by UL standards which is the organization evaluating body for 3rd party products.

■4‒2 Safety Mechanism

The cylindrical type of Lithium-ion battery is equipped with safety mechanisms, such as a current interrupt device, a gas release vent, and protection device like a PTC, in the battery.

(1) Gas release vent with current interrupt device
Fig4-1 shows the current interception for cylindrical type of lithium ion battery.

Fig.4‒1: Current Interrupt Device



The gas release vent works when the internal pressure rises with abnormal heat generation or over charge by failure of all of charger, protection circuit and protective device.

Top part of gas release vent is welded on positive cap 2, and the safety is secured with no conductivity lifting and detaching the vent from the welding. This function is for disconnecting the load by force when it is charged abnormally.

If the battery is exposed to extreme high temp and the internal pressure increases rapidly, the gas release vent works and the gas inside is released safely.

(2) PTC

PTC has 2 functions. It serves as a current fuse and a thermal fuse. Internal resistance increases with heat generation with high current flow. The value of internal resistance depends on the size of the element. Normally it is several 10mΩ and if value increases to several 10kΩ it trips to limit the current.

Cylindrical type have round PTC inside of the sealing plate and it prevents abnormal heat generation when the current flows at a high rate caused by external short circuit or other reason.

(3) Separator

A separator is a micro porous film of high polymer that is based on technologies for lithium batteries used in cameras. When abnormal heat is generated by external short circuit or other condition, the pores in the separator seal-up due to the separator melting. This cuts off the current.

(4) Thermal Fuse

Certain models of prismatic Lithium-ion batteries are equipped with current interruption devices such as thermal fuses.

For assembled battery packs, the protection circuit is incorporated to prevent over-charge, over-discharge and over-current. A thermal fuse or PTC can be added when necessary.

■4-3 Criteria of Safety

Batteries supplied by Sanyo satisfy the guideline of safety for lithium rechargeable batteries and are approved by UL standards which is the organization evaluating body for 3rd party products.
The test requirements of Battery Association of Japan are as follows.

Test Items of Battery Association of Japan
4.3.(1) Electrical Test

External Short Circuit Test: No explosion or fire after having 6hours short circuit made with less than 50mΩ lead between terminals.

Forced Discharge Test: No explosion or fire after 250% forced discharge of rated capacity. The test may be stopped when the current flow is prevented by operation of protection parts which are in the battery.

Continuous Charge Test: No safety vent operation, deformation, explosion or fire after being continuously charged for 1 month in conditions recommended by Sanyo.

Over Charge Test: No explosion or fire after 250% charge with Sanyo recommended current. The test may be stopped when the current flow is prevented by operation of protection parts which are in the battery.

Over Current Test: No explosion or fire after having 100% charge of rated capacity with 3 times as much as Sanyo recommended charge current. The test may be stopped when the current flow is prevented by operation of protection parts which are in the battery.

4.3.(2) – I Mechanical Test

Vibration Test: No deformation, explosion or fire with vibration for 90 - 100 minutes in the XYZ direction with the amplitude of 0.8mm, frequency 10 to 55Hz sweeping speed 1Hz/in.

Impact Test: No deformation, explosion or fire with a impact on XYZ direction, which the minimum acceleration for initial 3ms is 75g and the peak acceleration is between 125g and 175g.

Drop Test: No explosion or fire when dropped at random 10 times onto the concrete floor from 1.9m height.

4.3.(2) – II Mechanical Test = Abnormal Abuse

Nail Test: No explosion or fire for 6hours after penetrated by 2.5 to 5mm diameter nail at center of / perpendicular to the cell .

Crush Test: No explosion or fire with 13kN pressure having battery in between 2 flat iron plates.

Impact Test: No explosion or fire when the impact of 9.1kg weight drops from 61cm height onto the battery which has 7.9mm diameter bar placed on it vertically to top terminal direction.

Drop Test: No explosion or fire when dropped at random onto the concrete floor from 10m height.

4.3.(3) – I Environmental Test

High Temp. Storage: (a) No explosion or fire with 5hours storage in 100 ℃ followed by 24 hours in 20℃.
(b) No explosion or fire with 30days storage in 60 ℃ followed by 24 hours in 20℃.

Temp. Cycle Test: No explosion or fire with 10 cycles of 2hours storage in -20℃ and 2 hours storage in 60℃.

Low Pressure Test: No explosion or fire when left in 11.6kPa atmosphere absolute for 6hours .

4.3.(3) – II Environmental Test = Abnormal Abuse

Heating Test: No explosion or fire with 60min. heating in an oven at 130℃ which raised at a rate of 5±2℃/min.

Immersion Test: No explosion or fire with 24 hours immersion in water at room temperature.

■4-4 Protection Circuit

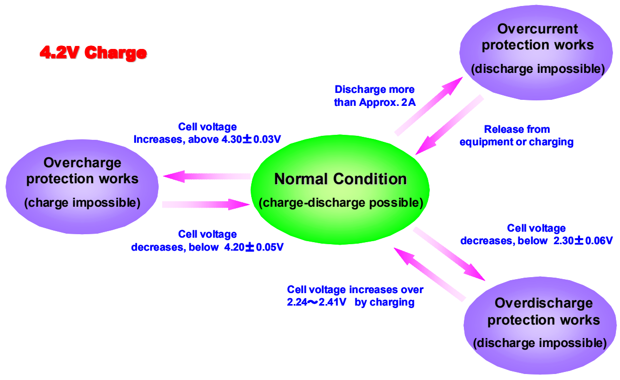
The protection circuit to control charge and discharge is built into Sanyo Lithium-ion battery pack. By incorporating the protection circuit, the battery is protected from over-charge, over-discharge and over-current.

Although there is a basic specification of the protection circuit, a detailed specification may be customized to suit the application.

Also the protection circuit is customized if the pack configuration (e.g. terminal position, shape) is different from other packs considering the productivity, but the function and the circuit remain the same.

Fig 4-2 shows one example of the basic operation of protection circuit.

Fig.4-2: Lithium-ion Battery for PCB Work Flow Chart



(Over-Charge Protection)

It protects the battery from over-charge by misuse or charger failure. The over-charge is generally detected and the charging is stopped at Typ. 4.28-4.35V/cell.

The over-charge protection is released and reset when the voltage is dropped to Typ. 4.20V/cell.

(Over-Discharge Protection)

If a Lithium-ion battery discharges to about 0V or is left for a long period in the discharged state less than 1.0V, it will cause performance degradation. Therefore the over-discharge protection is equipped in the assembled battery pack. The voltage which detects over-discharge is usually set at Typ. 2.30V/cell.

The over-discharge protection is released and reset when the voltage rises more than Typ. 2.3V/cell.

(Over-Current Protection)

In order to protect the protection circuit and the battery from over-current discharge, the over-current protection is equipped. It is set up so that it operates around 2A current flows usually.

The over-current protection is released and reset when the battery is charged again.

5

Charging Method

■5-1 Charging Outline

Generally, charging of Lithium-ion batteries is performed by constant current constant voltage charging method. Although amount of charge depends on charging voltage, exceeding each regulated value for current or voltage is forbidden. When charging starts with constant current and battery voltage reaches its designated value, it will change to constant voltage charging. The charging current begins attenuation and battery voltage approaches to fully charged state for regulated voltage. Charging by constant current need not to be precise and semi-CC is allowed. However, charging by constant voltage should be regulated precisely not to affect charging capacity or overcharge.

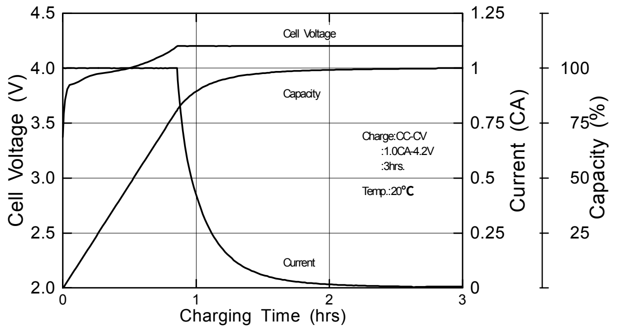
Generally, higher current value for constant current area is thought to reduce total charging time. Despite charging at higher rate only means reaching voltage limit earlier, the overall charging time to reach full charge will remain almost the same. It is preferable that charging current is set to 0.5 -1C. Lower charging current value is also advantageous to cycle life. Battery charging is also affected by temperature and when charging at low temperatures the charging time will be extended. Charging at low temperature is not forbidden but best avoided.

■5-2 Charging Method

Generally, charging of Lithium-ion batteries is by constant current - constant voltage charging method. Since constant current-constant voltage charge is a charging method which controls charging voltage, charging voltage is usually set 4.2V.

Fig. 5-1 shows the general charging characteristics for prismatic type Lithium- ion battery.

Fig.5-1: Charge Characteristics

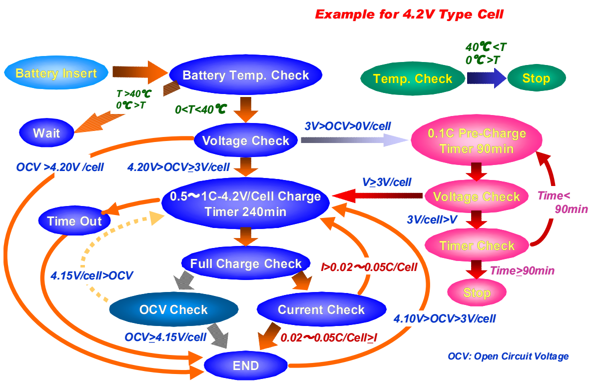


Constant current charge is continued for 50 minutes, and when battery voltage reaches 4.2V, it changes to constant voltage charge. Full-charged state is judged from two methods. One is defined by charging time, and the other is by charging current value (reduced current value in constant voltage area). For example, in Fig. 5-1, when charging time passes over 150 minutes, charging current approaches zero, it can be judged to be fully charged in 180 minutes since commencing charging. Moreover, method with judging from current value has merit which can shorten charging time.

■5−3 Charging method of assembled battery

When charging assembled batteries which consist of two or more batteries, it is necessary to monitor battery temperature, voltage for each block and charging time. Fig. 5-2 shows general charging flow for Lithium-ion batteries.

Fig.5-2: Charging Flow Chart



Initially, battery temperature is monitored with a thermistor inside battery pack, and if it is within allowable temperature range for charging, voltage of battery pack is checked. This check is required for confirming whether preliminary charge is needed, and when battery voltage is less than 3V, preliminary charge is necessary. Since charging current for this procedure needs to be under the condition that FET inside the protection circuit does not generate heat, it is necessary to carry it out at approximately 0.1C. If battery voltage becomes more than 3V, rapid charge at 1C is possible. It is necessary to terminate charging when current attenuates to 0.02-0.05C or less, or when OCV exceeds set voltage. In other words, charge current has to be complete zero.

Re-charging should start from low state of charge which is caused by self-discharge and discharge drawn by both the protection circuit and FG system. This is because if batteries have been stored in a high state of charge at high temperature, cell performance will deteriorate.

A re-charging point could be decided by application so that low level charged state does not inconvenience the customer.

6

Important Cautions for Handing Batteries

■6-1 Outline

Various safety features have been included in the design of the Lithium-ion, however, misusing or mishandling batteries can lead to fluid leakage, heat generation, fire, or explosion. To prevent these situations from occurring and to ensure safe use of Lithium-ion batteries, please strictly observe the following precautions.

■6-2 Restriction on Usage

●6-2-1 Restriction on Usage Environment

●The recommendation temperature range for use of the Lithium-ion is as follows,

Charge : 0~40℃
Discharge : -20~60℃
Storage : -20~50℃

Above-listed temperature range is confined depending on the kind of protection circuits or protection devices that compose the pack. And also if using current is over 1C, temperature range is confined.

●Do not use or store a battery at high temperature, such as in strong direst sunlight, in cars under hot weather, or directly in front of heaters. This may cause battery fluid leakage, impaired performance, and shortening of battery service life.

●Do not charge a battery when it is cold (below 0℃), or outdoors at cold temperature (below 0℃). This may cause impaired performance and shortening of battery service life

●Do not splash fresh or saltwater on a battery, or allow the terminals to become damp. This may cause heat generation and formation of rust on the battery and its terminals.

●6-2-2 Restrictions on Condition of Use

●Use our specified charger to charge Lithium-ion batteries, or observe the specified charging conditions. Failure to follow proper charging procedures may cause excessive voltage, excessive current flow, loss of control during charging, leakage of battery fluid, heat generation, bursting, or fire.

● Do not connect different assembled batteries together. This may cause electrical shocks, fluid leakage, heat generation, bursting, or fire. And also do not connect same assembled batteries in series. This may also cause electrical shocks, fluid leakage, heat generation, bursting, or fire.

■6–3 Preparation before Use

● 6–3–1 Requests of Reading the Operation Manual

- ● Please emphasize in operation manual the description of "Before using Lithium-ion batteries, please be sure to read the operation manual and precaution. After reading the manual, keep it on hand and refer to it as necessary."
- ●As to how to charge the lithium ion battery, please read carefully the operation manual of charger.
- ●As to how to install battery into a device and how to remove battery from a device, please read carefully the operation manual of the device.

6–3–2 Do not Connect Batteries to a Power Source

- ● The Lithium-ion battery has +(positive) and –(negative) terminals. If a battery does not work when connected to a charger or device, do not attempt to force the connection. Verify the accuracy of + and – terminals. Charging the battery with the terminals reversed may drain rather than charge the battery, or cause abnormal chemical reaction inside the battery, abnormal current flow during discharge, fluid leakage, heat generation, bursting or fire
- ● Do not connect a Lithium-ion battery directly to a power outlet or insert it into a cigarette lighter socket in a car. High voltage may cause fluid leakage, heat generation, bursting or fire.

6–3–3 Inspection of Batteries before Use

- ● If a newly purchased battery has rust, generates heat, or is abnormal in any other way, do not use it. Take it back to the store where you purchased it.
- ● If a battery is to be used for the first time or it has not been used for a long time, be sure to charge it.

■6–4 Non-specified Use

● 6–4–1 Do Not Use for Other Than Specified Use

- ● Do not use the Lithium-ion battery in any device other than those specified by Sanyo. Depending on the device being used, doing so may cause abnormal current flow, leakage of battery fluid, heat generation, bursting or fire.
- ● There are some devices for which the Lithium-ion is not suitable. Read carefully the instruction manual and precautions for the device in which you want to use the Lithium-ion battery.

■6–5 Methods of Use

● 6–5–1 Precautions for Users with Small Children

- ●Keep Lithium-ion battery out of reach of infants babies and small children. When charging or using a battery, do not let infants babies or small children remove the battery from the charger or the device being used.
- ●If a small child is to use a Lithium-ion battery, be sure to carefully instruct the child on the contents of the instruction manual before use. During the time that the child is using the battery, be sure to monitor this and make sure that the battery is being used according to the directions in the manual.
- ● To avoid accidental swallowing, keep the batteries and the device out of the reach of babies and small children. If by any chance a battery is swallowed, contact a physician (doctor) immediately.

●6–5–2 Operation

Do not use the Lithium-ion batteries together with other batteries of different type, brand name or capacity. That may cause leakage of battery fluid, heat generation, bursting or fire.

●6–5–3 Do Not Misuse Batteries

When using Lithium-ion batteries, be sure to observe the following precautions:

- ● Do not dispose Lithium-ion batteries in fire or heat. Doing so may melt the insulation, damage the sealing parts or protective devices, cause leakage of battery fluid (electrolyte) from the batteries, bursting or fire.
- ● Do not connect the +(positive) and –(negative) terminals of Lithium-ion batteries with a wire or electrically conductive materials. Do not carry or store Li-ion batteries together with metal necklaces, hairpins, or other electrically conductive materials. Doing so may short circuit the battery, which could result in excessive current flow and possibly cause leakage of battery fluid, heat generation, bursting or fire. When carrying or storing batteries, use an electrically nonconductive (insulated) case.
- ● Use Sanyo's specified charger to charge Lithium-ion batteries, or observe the specified charging conditions. Failure to follow proper charging procedures may cause excessive voltage, loss of control during charging, leakage of battery fluid, heat generation, bursting or fire.
- ● Do not solder a lead wire or plate directly to Lithium-ion batteries. The heat generated by the soldering may melt the insulation, damage the sealing parts or protective devices, cause leakage of battery fluid, heat generation, bursting or fire.

- Do not charge or use Lithium-ion batteries with the +(positive) and –(negative) terminals reversed. Charging the battery with the terminals reversed may drain rather than charge the batteries, or cause abnormal chemical reaction inside, abnormal current flow during discharge, leakage of battery fluid, heat generation, bursting or fire.
- Do not connect a Li-ion battery directly to a power outlet or insert it into a car cigarette lighter socket. High voltage may cause excessive current flow, leakage of battery fluid, heat generation, bursting or fire.
- Do not break open the casing of a battery or damage it. Doing so will expose the battery to the risk of a short circuit, and may cause leakage of battery fluid, heat generation, bursting or fire.
- Do not strike or drop Lithium-ion batteries. A sharp impact can cause leakage of battery fluid, heat generation, bursting or fire.
- Do not connect two Lithium-ion batteries in series as this may cause leakage of battery fluid, heat generation, bursting or fire.
- Do not transport Lithium-ion batteries by holding onto the connectors or lead wires, as this may damage the batteries.

●6–5–4 Do Not Alter or Remove Protective Mechanisms or Other Parts

Do not disassemble Lithium-ion assembled batteries. Doing so may damage the protection circuit or protective devices, cause an internal or external short circuit. It may also cause leakage of battery fluid, heat generation, bursting or fire.

Do not disassemble Li-ion bare cells. There is the danger of flammable fluid being spilt. It may also cause an internal or external short circuit, leakage of battery fluid, heat generation, bursting or fire.

Do not alter or reconstruct Lithium-ion batteries. Protective mechanisms (devices) for preventing danger are built into the assembled batteries. If they are damaged, this could result in excessive charging voltage, control loss during charging or discharging, leakage of battery fluid, heat generation, bursting or fire.

● 6–5–5 Do Nor Use in Ways Which Reduce Battery Safety

In case of pack assembly, the gas release vent that releases internal gas is located at the sealing part (+) of the Lithium-ion battery (cylindrical type). Do not deform or cover this part or obstruct the release of gas. If the gas release vent cannot work properly, this could result in leakage of battery fluid, heat generation, bursting or fire.

The gas release vent that releases internal gas is located at the sealing part (-) of some model of the Lithium-ion battery (prismatic type). Do not deform or cover the vent or obstruct the release of gas. If the gas release vent cannot work properly, this could result in leakage of battery fluid, heat generation, bursting or fire.

● 6–5–6 Do Not Use Continuously for Periods Longer than The Rated Time or with Loads Exceeding the Rated Load.

Do not overcharge Lithium-ion batteries exceeding the predetermined charging period specified in the charger's instruction manuals. Also, do not recharge a battery fully charged. This may cause leakage of battery fluid, heat generation, bursting or fire.

It could also deteriorate the performance or cycle life.

●6–5–7 When Batteries Are Not in Use

Be sure to turn off the equipment or the device after using Lithium-ion batteries. Failure to do so may cause leakage of battery fluid.

During non-use, do not leave the Lithium-ion battery connected to the equipment or the device for a long time. To prevent leakage of battery fluid and corrosion (rust) during the period when the Li-ion is not being used, remove the battery from the equipment or the device and store it in a place at low humidity and temperature of −20 to +30℃. Batteries that have not been used for a long time may not be fully charged.

■6–6 Maintenance and Inspection

● 6–6–1 Sanyo Recommends Periodic Inspections

Lithium-ion batteries have a predetermined operating life. If the operating time shortens excessively, this means that the battery life has expired. If it comes to that point, stop use immediately and replace with new batteries.

● 6–6–2 Inspection and Cleaning (including label on unit)

If the Lithium-ion battery terminals are dirty, clean them with a soft, dry cloth prior to use. These terminal dirt causes loose contact with the equipment or the device, loss of power, or inability to charge.

■6–7 Countermeasures

● 6–7–1 Do Not Use Defective or Abnormal Battery

If Lithium-ion batteries are not fully charged after the battery charger's predetermined charging period has elapsed, stop the charging process. Prolonged charging may cause leakage of battery fluid, heat generation, or bursting.

If Lithium-ion batteries leak electrolyte, change color, change shape, or change in any other way, do not use them. Usage may cause heat generation, bursting or fire.

●6-7-2 Emergency Measures

If leaked electrolyte comes in contact with the eyes, flush the eyes immediately, washing them thoroughly with clean water from a tap or other source, and consult a doctor. Leaked electrolyte can damage the eyes and lead to permanent loss of eyesight.

If skin or clothing comes in contact with leaked electrolyte, wash this area immediately with clean water from a tap or other source. Leaked electrolyte can cause skin damage.

■6-8 Precautions for the Design and Installation into Equipment Incorporated Lithium-ion Batteries

● Do not install Lithium-ion batteries near the transformers or other heat sources. This may cause leakage of battery electrolyte, impair performance or shorten the operating life of Lithium-ion batteries.

●Design the equipment or the device so that battery current will not leak into the equipment or the device when it is switched off or in a non-operating status. Failure to observe this may cause leakage of battery electrolyte, impair performance or shorten the operating life of Lithium-ion batteries.

●Use a material that has durability against the electrolyte around the batteries.

●Batteries should be fixed to prevent from shaking and damage to batteries when it is dropped or vibrated.

■6-9 Regarding to recycle

Lithium-ion battery is a designated product of "Recycle Law"(in Japan). The battery after using is valuable resource, so don't throw away. When a battery is no longer usable, after discharge, attach tape to the terminals or connection cord to insulate the battery, and then cooperate recycle. Please contact Sanyo's office in your region for detail of other countries than Japan.

■6-10 Others

●When batteries or products with battery built-in are exported, Sanyo should be contacted regarding battery import/export regulations of the countries of destination.

●When batteries or products with battery built-in are transported, Sanyo should be contacted regarding battery transport regulations.

● Please understand that improvements, external appearances, types and specifications are subject to change without notice.

●For safety reasons, please contact Sanyo regarding use conditions and equipment structure before marketing products with built-in battery.

■6-11 Cautions to be Indicated on Lithium-ion battery

The Lithium-ion battery includes flammable objects such as organic solvent. If the handling is missed, there will be possibility that the battery ruptures, flames or generates, or it will cause the deterioration or damage of battery. Please observe the following prohibitive matters. And also, adding protection device to the equipment may cause trouble affecting the battery, by the abnormality of equipment. In addition, mention the following matters as "Prohibition Points on Handle" in the instruction manual of the equipment.

To ensure safe use of the Lithium-ion battery, clearly indicate the cautions shown below on the battery. To make the cautions easier to understand, add the following marks.

Use in cases where misuse of the battery creates a strong possibility of death or serious injury.

Use in cases where misuse of the battery creates a possibility of death or serious injury.

Use in cases where misuse of the battery creates a possibility of mild or serious injury to the user, or damage to equipment. Also use in cases where misuse may adversely affect product quality and reliability.

(Lithium-ion Batteries Handling Precautions)

Before using Lithium-ion battery, make sure to read this instruction manual and precautions. Keep the manual for future reference. For further information, contact Sanyo..

⚠ Danger!

- Do not disassemble or modify the battery pack. The battery pack is equipped with built-in safety/protect-ion features. Should these features be disabled, the battery pack can leak acid, overheat, emit smoke, burst and/or ignite.
- Do not connect the positive (+) and negative(−) terminals with a metals object. Do not transport or store the battery together with metal objects such as necklace, hairpins, etc. Otherwise, short-circuiting will occur, over-current will flow, causing the battery pack to leak acid, overheat, emit smoke, burst and/or ignite, or the metal object such as wire, necklace or hair pin can generate heat.
- Do not discard the battery pack into fire or heat it. Otherwise, its insulation can melt down, its gas release vent or safety features will be damaged and/or its electrolyte can ignite, possibly leading to acid leakage, overheating, smoke emission, bursting and/or ignition on it.
- Do not use or leave battery near a heat source such as fire or a heater (80℃ or higher). If the resin separator should be damaged owing to overheating, internal short-circuiting may occur to the battery pack, possibly leading to acid leakage, overheating, smoke emission, bursting and/or ignition or the battery pack.
- Do not immerse the battery pack in water or sea-water, and do not allow it to get wet. Otherwise, the protective features in it can be damaged, it can be charged with extremely high current and voltage, abnormal chemical reactions may occur in it, possibly leading to acid leakage, overheating, smoke emission, bursting and/or ignition.
- Do not recharge the battery pack near fire or in extremely hot weather. Otherwise, high temperature can trigger its built-in protective features, inhibiting recharging, or can damage the built-in protective features, causing it to be charged with an extremely high current and voltage, and, as a result, abnormal chemical reactions can occur in it, possibly leading to acid leakage, overheating, smoke emission, bursting and/or ignition.
- To recharge the battery pack, use the battery charger specifically designed for the purpose and observe the recharging conditions specified by SANYO. A recharging conditions (higher temperature and larger voltage/current than specified, modified battery charger, etc.) can cause the battery pace to be overcharged, or charged with extremely high current, abnormal chemical reaction can occur in it, possibly leading to acid leakage, overheating, smoke emission, bursting and/or ignition.
- Do not pierce the battery pack with a nail or other sharp objects, strike it with a hammer, or step on it. Otherwise, the battery pack will become damaged and deformed, internal short-circuiting can occur, possibly leading to acid leakage, overheating, smoke emission, bursting and/or ignition.
- Do not strike or throw the battery pack. The impact might cause leakage, overheating, smoke emission, bursting and/or ignition. Also, if the protective feature in it becomes damaged, it could become charged with an extremely high current and voltage, abnormal chemical reactions can occur, which can lead acid leakage, overheating, smoke emission, bursting and/or ignition.
- Do not use an apparently damaged or deformed battery pack. Otherwise, acid leakage, overheating, smoke emission, bursting and/or ignition of the battery pack may occur.

⚠ Warning!

- Do not use the battery pack in combination with primary battery pack (such as dry-cell battery pack) or battery packs of different capacities or brands. Otherwise, the battery pack can be over-discharged during use or overcharged during recharging, abnormal chemical reactions may occur, possibly leading to acid leakage, overheating, smoke emission, bursting and/or ignition.
- Keep the equipment or batteries out of the reach of small children, in order to avoid them to swallow batteries. In the event the batteries are swallowed, consult a doctor immediately.
- If recharging operation fails to complete even when a specified recharging time has elapsed, immediately stop further recharging. Otherwise, acid leakage, overheating, smoke emission, bursting and/or ignition can occur.
- Do not put the battery into a microwave oven or pressurized container. Rapid heating or disrupted sealing can lead to acid leakage, overheating, smoke emission, bursting and/or ignition.
- If the battery pack leads or gives off a bad odor, remove it from any exposed flame. Otherwise, the leaking electrolyte may catch fire, and the battery pack may emit smoke, burst or ignite.
- If the battery pack gives off an odor, generates heat, becomes discolored or deformed, or in any way appears abnormal during use, recharging or storage, immediately remove it from the equipment or battery pack charger and stop using it. Otherwise, the problematic battery pack can develop acid leakage, overheating, smoke emission, bursting and/or ignition.

⚠ Caution!

- Do not use or subject the battery pack to intense sunlight or hot temperatures such as in a car in hot weather. Otherwise, acid leakage, overheating, smoke emission can occur. Also, its guaranteed performance will be lost and/or its service life will be shortened.
- The battery pack incorporates built-in safety devices. Do not use it in a location where static electricity (greater than the manufacturer's guarantee) may be present. Otherwise, the safety devices can be damaged, possibly leading to acid leakage, overheating, smoke emission, bursting and/or ignition.
- The guaranteed recharging temperature range is 0 to 40℃. A recharging operation outside this temperature range can lead to acid leakage and/or overheating of the battery pack, and may cause damage to it.
- If acid leaking from the battery pack contacts your skin or clothing, immediately wash it away with running water. Otherwise, skin inflammation can occur.
- Children should not use the battery pack unless they have been carefully instructed on the contents of the Operation Manual and their parents or guardians have confirmed that the children understand and appreciate the proper usage and safety hazards presented by the battery pack.
- Store the battery pack in a location where children cannot reach it. Also, make sure that a child does not take out the battery pack from the battery pack charger or equipment.
- Before use, carefully study the Operation Manual and Precautions. Also, Safe-keep the manual for future reference.
- For recharging procedures, refer to the Operation Manual of your battery pack charger.
- If you find rust, a bad odor, overheating and/or other irregularities when using the battery pack for the first time, return it to your supplier or vendor.

Glossary

Active material	The chemically reactive material in an electrode which generates electricity in a battery.
Assembled battery	A battery composed of two or more cells.
Breaker	When the battery temperature or the current reaches a certain level, the breaker opens the circuit and stops the current. It recovers after operating, and is built into the battery.
C	C is a value which expresses the rated capacity of a battery. Charging and discharging current are generally expressed as a multiple of C. For example, if the rated capacity is 1200 mAh, a current of 0.1C is equal to 1200×0.1＝120 mA.
Cadnica	The brand name of Sanyo ' s nickel-cadmium batteries.
Cell	The minimum unit of a battery.
Charge efficiency	Charge efficiency indicates the ease with which a battery can be charged. It is obtained by dividing the discharge capacity by the product of the charging current and the time.
Charge retention	The amount of capacity remaining after a charged battery is stored for a period of time.
Depth of discharge	Capacity removed from a battery as compared to its actual capacity. It is expressed as a percentage.
Discharge capacity	The amount of charge taken from the battery when discharged at the rated current and ambient temperature until the discharge end voltage is reached. Generally expressed in units of mAh (milliampere-hours).
Discharge rate	Expresses the amount of current during discharging. If an amount of time "h" is required to reach the discharge end voltage when the battery is discharged at a current level "i" the discharge is called an "h"-hour discharge rate, and "i" is called the "h"-hour discharge rate current. In practice the rated capacity is used as a standard for the discharge rate.
Electrochemical polarization voltage	The voltage between the battery terminals and the potential between the electrodes differ when current is flowing and when it is not flowing. This is called polarization. The difference in potential and in voltage is called the electrochemical polarization voltage.
Electrolyte	The medium which transmits ions (charged particles) during the electrochemical reaction in a battery.
End voltage	This is a limit voltage which indicates the point at which discharging must end. It is roughly equivalent to the usage limit in actual use.
Energy density	The amount of energy stored in a battery. It is expressed as the amount of energy stored per unit volume or per unit weight (Wh/r or Wh/kg).
Gas release vent	A safety mechanism that is activated when the internal gas pressure rises above a normal level. There are two types: Automatically resealable, and unresealable.
High-rate discharge	Discharge at a current of 2 It or more.
IEC publication	The standard specified at the International Electrotechnical Commission.
Ion	An atom or group of atoms carrying a positive or negative charge.
IR-drop	A drop in battery voltage due to the internal impedance of a battery or a drop in voltage of a conductor which connects batteries.
It	{It} is a standard shall be expressed as; It(A)＝C5(Ah)/1(h) C5 is the rated capacity of the cell or battery, in ampere-hours.
Leakage	The leakage of electrolyte to the outer surface of the battery.
Negative electrode	The electrode which has a negative potential. During battery discharge, current flows from the external circuit into this electrode.
Nickel-Cadmium battery	This is a secondary battery which uses nickel hydroxide as the active material in the positive electrode, and a cadmium compound as the active material in the negative electrode.
Nominal capacity	The standard capacity designated by a battery manufacturer to identify a particular cell model.
Nominal voltage	Used to indicate the voltage of a battery. In the case of Lithium ion batteries,

	it is 3.7 V per cell.
Open circuit voltage	The voltage between the two terminals of a battery with no load.
Operating voltage	The voltage between the two terminals of a battery when a load is connected. Normally the voltage when 50% of capacity has been discharged is indicated.
Over-discharge	Discharging a battery to the point that the voltage is lower than the end voltage set for the battery.
Over-voltage	The difference between the actual potential at which an electrochemical reaction occurs, and its theoretical equilibrium potential.
Over-charge	Charging a battery when it is already fully charged.
Polarity reversal	Reversal of the polarity of a battery due to forced over-discharge
Positive electrode	The electrode which has a positive potential. During battery discharge, current flows from this electrode into the circuit.
Positive temperature coefficient	A resistor with a positive temperature coefficient. When a large current flows, its resistance increases and restricts the current.
Pulse current	A current which lasts only a short time.
Quantity of charge	The amount of charge used to charge a battery. In the case of constant current charging, it is obtained by multiplying the current by the charging time, and expressed in units of Ah (ampere-hours).
Quick charging	A method of charging at a large current in a short period of time.
Rated capacity	A basic value that indicates the capacity of the battery. Indicated on the battery case.
Residual capacity	Normally indicates the capacity remaining in a battery after partial discharge or prolonged storage.
Reversal charge	Reversing the "＋" and "－" polarity of the battery and forcing current to flow from the negative electrode to the positive electrode.
Secondary battery	A battery which can be recharged and used repeatedly.
Self discharge	A decrease in battery capacity which occurs without any current flow to an external circuit.
Separator	The component within a battery, which separates the electrodes, prevents short-circuiting, and holds the electrolyte.
Short circuit	Directly connecting the positive electrode (terminal) to the negative electrode (terminal) of the battery.
Thermal fuse	This is a fuse which melts when the temperature reaches a certain point and breaks the current. Once it melts, it can no longer be used. It is built into assembled batteries.
Thermistor	A circuit element with a negative temperature coefficient. It is built into batteries and used to detect ambient temperature or battery temperature.
Trickle charging	Charging a battery to compensate for loss of capacity due to self-discharge. Not necessary for Lithium ion battery because of its low self-discharge.