A Guide to the Safe Use of Lithium-Ion Secondary Cells in Notebook-type Personal Computers and Tablet Terminals

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Japan Electronics and Information Technology Industries Association

Introduction

In 2007, the Japan Electronics and Information Technology Industries Association (JEITA), in collaboration with the Battery Association of Japan (BAJ), published *A Guide to the Safe Use of Secondary Lithium-Ion Batteries in Notebook-type Personal Computers*, a guide which was later succeeded by the Electrical Appliance and Material Safety Act.

However, the number of incidents involving lithium-ion batteries has increased in recent years, prompting the Ministry of Economy, Trade, and Industry (METI) to commission a study by the Japan Quality Assurance Organization (JQA) in 2019. Titled *Study on safety standards for electrical products with lithium-ion secondary cells*, that publication identified new points that need to be considered, such as changes in the types of lithium-ion secondary cells being used, changes in how those batteries are installed in devices, and an increase in battery life span brought about by advancements in technology.

In response to the results of this study, JEITA decided to work with the BAJ to revise and republish *A Guide to the Safe Use of Secondary Lithium-Ion Batteries in Notebook-type Personal Computers* with safety measures that reflect the results of the study, under the direction of the Industry Safety Group's Manufacturing Safety Department within METI's Commerce and Information Policy Bureau.

The primary changes made to *A Guide to the Safe Use of Secondary Lithium-Ion Batteries in Notebook-type Personal Computers* are as follows.

- Since lithium-ion secondary cells became subject to the Electrical Appliance and Material Safety Act following the publication of the guide, chapters were rearranged and their contents, wordings, etc., were revised.
- Specific examples of production-control principles for manufacturing cells were added.
- The scope of application was defined as lithium-ion secondary cells used in notebook PCs and tablet terminals.
- Due to the increasing capacity of installed secondary cells, information about the flammability of devices when heat is being generated was revised.
- Because of the increase in devices equipped with polymer batteries that are not enclosed in a solid case, information about drops, vibrations, and physical shock was revised.
- As the increase in devices with internal secondary cells has made it easier for temperature to affect the interiors of devices, information about managing temperature was revised.
- Since most accidents occur after batteries have been used for long periods of time, points of caution that consider this fact—including controlling foreign contamination and managing battery charging—were added.

Scope of Application

This guide applies to lithium-ion secondary cells used in notebook PCs and tablets. It supplements the provisions of the Electrical Appliance and Material Safety Act by providing additional information that should be followed to ensure high levels of safety.

Cited Standards

[1] JIS C 62133-2: *Safety requirements for secondary cells in portable applications - Part 2: Lithium systems*; 2020

[2] JIS C 62368-1: *Audio, video, information, and communication technology - Part 1: Safety requirements*; 2018

Caution

Some of the information in this guide may conflict with technical patent rights, publicized patent applications, utility-model rights, or publicized utility-model applications. JEITA is not responsible for verification related to such technical patent rights, publicized patent applications, utility-model rights, or publicized utility-model applications.

Definition of Terms

The definitions of the main terms used in this guide are as follows.

cell:

a basic unit consisting of electrodes, a separator, electrolyte, terminals, and a housing, that supplies electricity by using charge current to convert chemical energy to electrical energy

battery:

a unit consisting of one or more cells that can be used as a source of electrical power, and is characterized by their voltage, dimensions, terminal locations, housing, and discharge performance

battery block:

a collection of one or more cells wired in parallel within a battery

maximum charge voltage:

the upper limit on voltage when charging cells, as specified by the battery manufacturer for safety reasons

cut-off voltage:

the lowest permissible voltage for a cell, as specified for safety reasons; this is different than the minimum battery voltage required to operate the PC or Tablet terminal minimum discharge voltage:

the lowest permissible voltage for a cell, as specified for safety reasons

maximum charge current:

the upper limit on electrical current when charging cells, as specified by the battery manufacturer for safety reasons

maximum discharge current:

the upper limit on discharge current for a cell, as specified for safety reasons; this can be defined in terms of the allowable continuous current or the allowable instantaneous current

standard temperature range (T2–T3):

the temperature range within which a cell can be charged at the maximum charge voltage and maximum charge current, as specified by the battery manufacturer for safety reasons

lower temperature range (T1–T2):

the temperature range within which a cell can be charged if the maximum charge voltage and/or the maximum charge current are modified, as specified for safety reasons; the upper limit of the range borders the standard temperature range, while the lower limit of the range is defined by the minimum charge temperature

upper temperature range (T3–T4):

the temperature range within which a cell can be charged if the maximum charge voltage and/or the maximum charge current are modified, as specified for safety reasons; the lower limit of the range borders the standard temperature range, while the upper limit of the range is defined by the maximum charge temperature

minimum charge temperature:

the lowest permissible temperature for a cell when charging, as specified by the battery manufacturer for safety reasons [Note: corresponds to T1]

maximum charge temperature:

the highest permissible temperature for a cell when charging, as specified by the battery manufacturer for safety reasons [Note: corresponds to T4]

maximum discharge temperature:

the highest permissible temperature for a cell, as specified for safety reasons

upper limit discharge-start temperature:

the highest temperature that the surface of a cell can be when it begins to discharge, as specified for safety reasons

temperature limit:

the temperature that a cell must not exceed when being stored or used, as specified by the battery manufacturer for safety reasons

Chapter 1 — Points to consider when designing lithium-ion secondary cells

1-1 Overview

Lithium-ion secondary cells use metallic oxides containing lithium (metals such as Co, Mn, or Ni) as cathodes, carbon material as anodes (graphite, hard carbon, etc.), and organic solvents as electrolyte. They are charged and recharged as lithium ions travel back and forth through the electrolyte between the cathode and anode. Since the lithium is always maintained in an ionized state, these batteries maintain a high degree of safety in theory.

During the creation of this guide, a detailed analysis was performed on the causes and mechanisms of hazardous incidents involving explosions or fires with lithium-ion secondary cells on the market. This resulted in the identification of the following causes for thermal runaway in cells, which is one of the primary factors in hazardous incidents.

1 **Internal short circuit (including those caused by external pressure on the battery)**

2 **Overcharging**

3 **External short circuit**

4 **External heating**

5 **Usage that exceeds the anticipated time period or environment**

Internal short circuits in particular are presumably the result of a combination of factors, including foreign contamination within cells, voltage or other imbalances between the cells in a battery, and the application of high charging voltage to certain cells. This suggests that safety measures are needed for each element within the lithium-ion battery systems used in cells, batter ies, PCs, and tablet terminals.

In addition to stating principles for the design and production control of cells that can help achieve higher levels of safety, this chapter also discusses important points related to the safe usage of cells (Approach to Operating Region (Range of Safe Usage)).

1-2 Production-control principles for manufacturing cells

Ideally, manufacturers of cells will implement the production control needed to ensure product safety. Some examples of principles for manufacturing safe cells are listed below.

1 **Striving to minimize the amount of foreign contamination included in procured raw materials**

2 **Controlling and eliminating magnetic material**

3 **Controlling humidity**

4 **Controlling the voltage etc. of completed cells**

5 **Identifying defective products through the voltage management of completed cells after they have aged**

6 **Controlling deviations in electrode location (misalignment during winding etc.)**

7 **Performing regular inspections of extracted samples (every few hours)**

8 **Controlling the amount of electrolyte inserted**

9 **Ensuring the traceability of component (or material) lots, workers, etc.**

Manufacturers of cells have been implementing the following two measures to prevent foreign contaminants from entering their batteries. Improving these production-control methods is fundamental to delivering quality cells to the market. Moving forward, manufacturers must continually work to improve quality and achieve high levels of production control.

1 Building manufacturing environments in which foreign material does not contaminate electrodes

2 Verifying that foreign contaminants are not present

The following are some examples of measures for preventing foreign contaminants from entering cells.

1 Removing foreign material from shoe soles via an air shower or sticky tape at the entrance

2 Controlling the metal shavings generated by the sliding surfaces of machinery

3 Removing foreign material by using air or blocking it with a cover

4 Preventing foreign material from adhering by controlling static electricity

5 Automating manufacturing processes

6 Using magnets, filters, etc. in pipes to remove foreign matter from liquid materials

7 Managing methods to prevent foreign contamination when recovering after a problem or defect

8 Avoiding the accumulation of foreign material

However, it is difficult to prevent contamination from microscopic particles that are undetectable with current technology. Therefore, methods for controlling foreign material must be implemented in the design of batteries to reduce the risk of the dangerous internal short circuits that can occur when they are used continuously under their prescribed operating conditions. Metrics for the control of foreign material include size, conductivity (iron, nickel, stainless steel, copper, etc.), and burr height. However, the management of foreign material described above does not consider factors such as the use of devices outside their prescribed operating conditions.

In addition to the above production-control principles, manufacturers of cells must continually strive to further improve product quality. For example, it is important to undergo a conceptual shift toward designing batteries that do not experience thermal runaway even if foreign material is present and to develop new evaluation standards and technologies for testing batteries under more stringent conditions, in addition to those stipulated in existing IEC and JIS evaluation standards.

1-3 Principles for designing cells

The following points should be kept in mind when designing batteries that do not explode or ignite when contaminated with foreign material (which has the potential to cause internal short circuits).

1 Design a cell structure that reduces the probability of internal short circuits even if foreign material is present

2 Use materials, designs, and manufacturing methods (including inspections, disposal, etc.) that prevent explosions and ignition even if internal short circuits occur

Capable of generating large amounts of heat, internal short circuits have a theoretically high chance of occurring due to foreign material creating a conductive path between the metal of the current collector and the opposing electrode. Therefore, making design decisions that prevent internal short circuits in these locations is an effective way to achieve the structure indicated in ①.

Point ② goes a step further than the approach in ①, aiming to have battery manufacturers use materials, designs, and manufacturing methods (including inspections, disposal, etc.) that prevent explosions and ignition even if unpredictable internal short circuits occur, as long as the usage conditions specified by those manufacturers are followed.

JIS C 62133-2 provides testing methods for verifying the effectiveness of such newly implemented safety features in the design of cells.

1-4 Approach to Operating Region (Range of Safe Usage)

1-4-1 Overview

To ensure the safe usage of lithium-ion secondary cells, companies that design and manufacture them must strictly follow the information listed here. To achieve higher levels of safety, this section discusses how to approach a safe operating region—an important element in the safe usage of cells—according to some newly defined terms.

1-4-2 Approach to voltage

Charge voltage must be applied to propel the chemical reactions that charge a battery. But too much charge voltage will produce an excess of chemical reactions or else side reactions that lead to thermal instability (creating the possibility of thermal runaway). For this reason, it is extremely important that the charge voltage does not exceed the value specified by the battery manufacturer, regardless of the circumstances. At the same time, battery manufacturers must verify the safety of their cells when charged at the specified voltage.

1 Maximum charge voltage

Definition: the highest permissible voltage when charging a cell, as specified for safety reasons

When a battery is charged at a voltage that exceeds the maximum charge voltage, excess lithium ions are desorbed from the active cathode material, which degrades the crystalline structure and makes it easier for oxygen to be released. It can also cause lithium to be deposited on the carbon anode material. In this state, there is a greater chance for thermal runaway if an internal short circuit or other problem occurs compared to when charging is done under the specified conditions. Therefore, charging at a voltage that exceeds the maximum charge voltage must be avoided. Also, there is a need for a protection system that anticipates malfunctions in the way the battery charger manages charging.

The secondary protection voltage should be a value close to the maximum charge voltage for each temperature range whenever possible, since charging is taking place in an excessive charge range that should not be entered in the first place. Also, using a battery that has activated this secondary protection in the past is prohibited. However, discharging it is allowed.

The above does not include voltage fluctuations that are not followed by the migration of lithium ions within the battery, such as AC components that are 50 kHz or higher and presumed to be ripples or noise.

2 Minimum discharge voltage

Definition: the lowest permissible voltage for a cell, as specified for safety reasons

Ideally, a cell will not discharge at voltages below the cut-off voltage specified by its manufacturer. Discharging below the cut-off voltage can cause the metal of the anode's current collector to dissolve and form localized deposits during charging. These deposits then grow in the direction of the cathode, creating the potential for internal short circuits or leaks. A cell will preferably not be charged if its voltage is below the cut-off voltage.

Note: In JIS C 62133-2, the "cut-off voltage" in section 3.26 and the "minimum discharge voltage" in the figure (Operating regions of Typical Lithium-Ion Secondary Cells) have the same definition.

1-4-3 Approach to temperature and current

Battery charging is a chemical reaction that is greatly affected by temperature. Things like the ease with which side reactions occur and the state of charge products differ significantly according to temperature, even if the maximum charge current and maximum charge voltage are the same. Therefore, maximum charge current and maximum charge voltage must be defined for each temperature range, and charging conditions must be applied to each range as well—for example, by reducing the maximum charge current, the maximum charge voltage, or both for low and high temperature ranges which conceivably have stricter requirements for safe usage. However, if they are within the scope of the charge conditions specified by the battery manufacturer for the standard temperature range, lower temperature range, and upper temperature range, they can be set as the charge conditions for actual usage.

Also, temperature and current may exceed the minimum and maximum values for a short period of time to detect temperature and current and initiate a response.

1 Standard temperature range (T2–T3):

Definition: the surface temperature range within which a cell can be charged at the maximum charge voltage and maximum charge current, as specified for safety reasons; a range of 10 °C to 45 °C is typical (refer to JIS C 62133-2 A.4.2.1)

Note: Standard temperature range is indicated by T2–T3 in the figure (Operating regions of Typical Lithium-Ion Secondary Cells). If recommending a temperature range other than 10 °C to 45 °C, JIS C 62133-2 A.4.2.2 must be applied.

The standard temperature range defines the conditions within which a cell can be charged at the maximum charge voltage and maximum charge current, which are specified for safety reasons. If the surface of a cell exceeds T3 during charging, the charge conditions for the upper temperature range must be applied. If the surface of a cell falls below T2 during charging, the charge conditions for the lower temperature range must be applied.

2 Upper temperature range (T3–T4)

Definition: higher than the standard temperature range, this is the surface temperature range within which a cell can be charged if the maximum charge voltage and/or the maximum standard temperature range are modified, as specified for safety reasons

Note: Upper temperature range is indicated by T3–T4 in the figure (Operating regions of Typical Lithium-Ion Secondary Cells).

When charging in the upper temperature range, a higher quantity of lithium migrates from the active cathode material. Because this increase in migrating lithium lowers the stability of the cathode's crystalline structure, it decreases the battery's safety.

At the same time, it decreases the relative temperature difference between the upper temperature range and the range in which thermal runaway occurs. This makes it easier for the battery to experience thermal runaway if something like an internal short circuit happens. Consequently, the maximum charge voltage and/or the upper temperature range must be modified when charging within the upper temperature range (refer to JIS C 62133-2 A.4.3.1 and A.4.3.2).

When designating the charge conditions for the upper temperature range or specifying a new upper limit for the upper temperature range, JIS C 62133-2 A.4.3.3 and A.4.3.4 must be applied. If the surface of a cell exceeds T4 prior to or during charging, the battery must not be charged with any sort of current.

3 Lower temperature range (T1–T2):

Definition: lower than the standard temperature range, this is the surface temperature range within which a cell can be charged if the maximum charge voltage and/or the maximum standard temperature range are modified, as specified for safety reasons

Note: Lower temperature range is indicated by T1–T2 in the figure (Operating regions of Typical Lithium-Ion Secondary Cells).

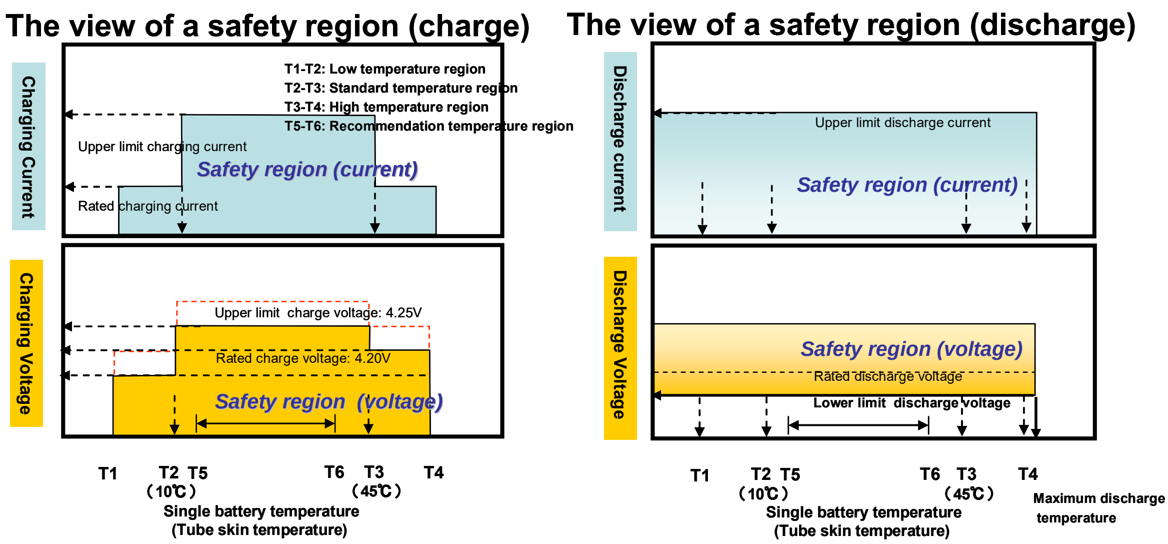
In the lower temperature range, the rate of material migration decreases and the lithium-ion receptivity of the active anode material (carbon) worsens. This makes it easier for metallic lithium to form on the surface of the carbon. Under these conditions, the thermal stability of the battery decreases and there is a chance for overheating and thermal runaway to occur. Also, lithium-ion receptivity is heavily dependent on temperature in the lower temperature range. Lithium-ion receptivity within batteries composed of multiple cells connected in series varies according to temperature. This can potentially prohibit sufficient safety.

Therefore, the maximum charge voltage and/or the maximum charge current specified for the standard temperature range must be modified when charging within the lower temperature range (refer to JIS C 62133-2 A.4.4.1 and A.4.4.2).

When designating the charge conditions for the lower temperature range or specifying a new lower limit for the lower temperature range, JIS C 62133-2 A.4.4.3 and A.4.4.4 must be applied. If the surface of a cell falls below T1 prior to or during charging, the battery must not be charged with any sort of current.

4 Current and temperature ranges during discharge

If the upper limit discharge-start temperature is exceeded, discharge must not begin. The temperature while discharging must not exceed the maximum discharge temperature. The maximum discharge current must not be exceeded while discharging. Minute amounts of current discharged when devices are powered down or in standby mode as well as current discharged to detect the upper limit discharge-start temperature are considered to be in a paused state. The maximum discharge current does not apply to AC components that are 50 kHz or greater and do not cause lithium ions within the cell to react (ripples etc.).



Temperature domain	- T1	T1-T2	T2-T5	T5-T6	T6-T3	T3-T4	T4-
Capacity	Small			Design center value		Almost similar	
Characteristic	×	△	○	◎	○	△	×
Safety	×	○	○	○	○	○	×

Figure: Approach to Operating region

The values specified for each range in the figure are determined after verifying the results of the IEC JIS C 62133-2 safety tests conducted by each cell manufacturer. The temperature limit must not be exceeded, even during the brief time prior to the sensor detecting the temperature. (However, this may be deemed acceptable through discussions with the cell manufacturer.)

1-4-4 Approach to battery lifespan

Generally, a cell's capacity will decrease as it goes through repeated cycles of charging and discharging or if it is maintained in a high-temperature state. But even batteries with reduced capacity can still be used as long as they do not experience abnormal phenomena such as leaking. However, such batteries can also have a higher chance of producing leaks because the decomposition of electrolyte inside them generates a gas that increases their internal pressure. Therefore, usage conditions for lithium-ion secondary cells must be determined by considering the usage duration and environment and consulting with the battery manufacturer.

Chapter 2 — Points to consider when designing lithium-ion batter ies

2-1 Overview

Notebook PCs and tablet terminals do not use lithium-ion secondary cells in their single-cell form, but rather batteries composed of multiple cells.

Therefore, when considering how to achieve higher levels of safety for the usage of lithium-ion secondary cells, it is necessary to promote further improvements of batteries—namely, the logical arrangement of the cells and circuit boards that make them up and the design of their electrical management and protection systems.

In addition, because selecting the best battery for a device and using that battery properly when it is installed in the device are both essential for improving safety, the prescribed operating conditions (including predictable cases of misuse) must be discussed and refined through discussions between the battery and device manufacturer, starting in the device's design phase.

This chapter discusses points to consider when designing lithium-ion batteries, with a focus on the following areas.

1 Arrangement of cells and circuit boards

2 Drops, vibrations, and physical shock

3 Temperature control

4 Overcharge protection

5 Overdischarge protection

6 Long-term usage

2-2 Arrangement of cells and circuit boards

2-2-1

Adhere to the following rules to prevent damage occurring in one cell from spreading to other cells. Also, designs should take JIS C 62368-1: 2018 M.3.3 into account.

1 To prevent damage (high temperatures) in one cell from influencing other cells, the below internal arrangement is preferable for batteries consisting of multiple cells.

● Avoid arrangements in which the top covers of cells face each other.

● Prevent explosions by using an arrangement that minimizes the impact that damage to one cell has on other cells.

2 Ideally, the following will be taken in account to prevent high-temperature electrolyte vapor vented by a safety valve from collecting within the battery and igniting.

● Provide an exhaust port for electrolyte vapor and face it away from the user.

3 Implement the following so that electrolyte vented by a safety valve does not cause secondary damage (short circuits etc.) to the circuit boards inside the battery.

● Provide short-circuit prevention by coating critical components or arranging them so that leaks from cells do not contact the circuit board (for instance, by installing partitions).

4 If the circuit board is equipped with a component that records the operational status of the battery, position it so that any heat generated by a damaged battery does not affect it.

● Position memory components away from cells.

2-2-2

Flame-resistant material should be used in the cases of batteries and PCs to keep any occurring damage localized.

● The grade of flame-resistance for a battery's case should follow the requirements of JIS C 62368-1: 2018 M.4.3 (Fire-Prevention Enclosures).

● If the secondary cells are integrated within the device, the entire device can also be enclosed in a fire-prevention enclosure.

2-3 Drops, vibrations, and physical shock

PCs and tablets should be designed to reduce the chance of an internal short circuit occurring within the cells of their batteries, even if they are dropped, vibrated, or subjected to physical shock or some other localized pressure exerted from the outside.

Suitability can be verified through the drop test described in the Electrical Appliance and Material Safety Act or section M.4.4 of JIS C 62368-1: 2018 (Drop Test for Devices with Lithium-Ion Secondary Cells).

In addition, a warning in the instruction manual of the PC, tablet, or battery or a label on the battery itself should alert users to stop using the battery if it is dropped, vibrated, or physically shocked.

2-4 Temperature management

Using a thermistor or other mechanism to effectively manage the temperature within a battery is essential to ensuring that it is charged and discharged safely and appropriately. Below are some points to keep in mind when designing systems for controlling the charging and discharging of batteries.

1 Monitoring temperature and controlling charging and discharging

● Measure the surface temperature of cells within the battery to monitor temperature. Also, if there is only one thermistor or similar component, determine where to position it by considering the temperature distribution within the battery when installed in the PC or tablet terminals.

● Charging and discharging should be controlled in accordance with sections 1-4-2 (Approach to voltage) and 1-4-3 (Approach to temperature and current).

● Suitability can be verified through section M.4.2 of JIS C 62368-1: 2018.

2 Temperature variation among cells
Because temperature variation among the cells in a battery causes variations in voltage, it has a significant impact on safety when charging as well as the decline of capacity. Therefore, the following points must be heeded.

● Sufficiently consider the arrangement of cells as well as their positioning inside the PC or tablet terminal to keep their temperature uniform within the battery.

● Designs that keep surface-temperature variation among cells within 5 °C are preferable.

3 Handling temperature abnormalities

● If the charge/discharge control element (a field-effect transistor etc.) inside the battery experiences abnormal temperatures, sever the charge/discharge path by using a circuit breaker such as a temperature fuse.

● Ideally, the circuit breaker (temperature fuse etc.) will sever the charge/discharge path if the monitored temperature within the battery exceeds the maximum temperature.

2-5 Overcharge protection

1 The following measures must be taken to control charging of the battery block within the battery.

● Manage the total battery voltage as well as the voltage of each battery block.

● The voltage of each battery block within the battery must not exceed the maximum charge voltage for a cell.

● If overcharging (primary protection) is detected, suspend the charging process. However, discharging is allowed.

2 Multilayered protection (overcharging)
Use methods such as failure mode and effects analysis (FMEA) on the entire charge/discharge system to determine the risk of anticipated failures, employing multilayered protection if necessary.

2-6 Overdischarge protection

Overdischarging a secondary lithium-ion battery can cause the metal of its anode’s current collector to dissolve and form localized deposits during charging. These deposits then grow in the direction of the cathode, creating the potential for internal short circuits or leaks. Ideally, charging will not take place if the voltage of a battery block falls below the minimum discharge voltage.

2-7 Long-term usage

Long-term use of a cell causes changes in its internal state (increased internal pressure etc.) compared to its initial usage, which can heighten the risk of hazardous events depending on how and where it is used.

Therefore, battery manufacturers (companies that manufacture cells and batteries) will ideally work with device manufacturers to determine the necessity and validity of comprehensive control methods for lithium-ion secondary cells in devices.

Such control methods can include regulating charge voltage, preventing charging if capacity has declined to a certain point, regulating charge current, and raising the cut-off voltage.

As some incidents have occurred after long-term usage, the following should also be implemented.

- Use the instruction manual of the PC, tablet, or battery to inform users that lithium-ion secondary cells are a consumable item.

- Provide a warning in the instruction manual of the PC, tablet, or battery or a label on the battery itself to alert users that they should stop using lithium-ion secondary cells if abnormal behavior is exhibited.

- Provide specific examples in the instruction manual of the PC, tablet, or battery of the abnormal states that require users to stop using a battery.

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