GUIDE TO RECHARGEABLE LITHIUM-ION BATTERIES

1. Rechargeable Lithium-Ion Batteries

A rechargeable lithium-ion battery is an electrochemical system that can be used and reused to power electronics. There are many years of knowledge that have gone into the development of the lithium-ion battery. A great resource to get started understanding batteries better is www.batteryuniversity.com which has many articles describing lithium-ion batteries as well as batteries in general.

Batteries are energy storage devices, as such, they can be thought of them as you would an automobile's fuel (gas) tank. To simplify the fuel tank analogy further let's use a glass of water. That is not to imply that the chemical operation of a lithium-ion battery and its aging go through the same scenarios as a glass of water. It is only meant to help you understand fundamentally what is happening.

Figure 1.1 shows how a battery's capacity is measured along with the glass of water.

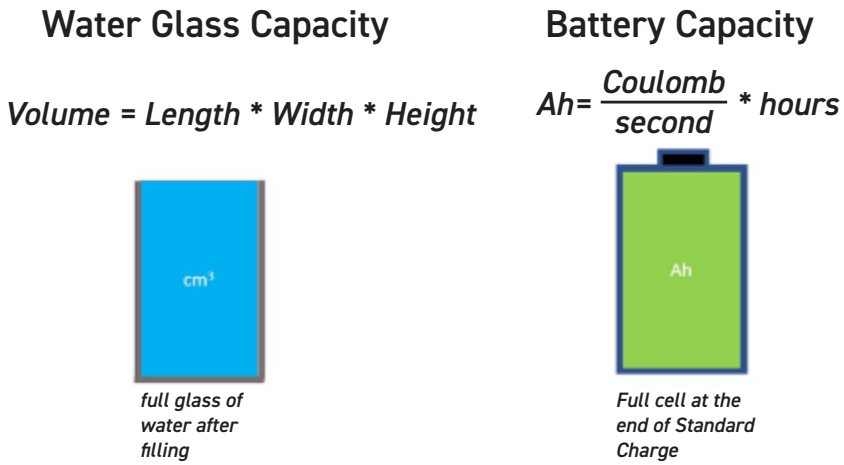

Figure 1.1: *Comparing Battery Charge to a Glass of Water*

While the glass's capacity is typically described using volume, a battery uses a unit called the Ampere-Hour (or Ah). This method was chosen to make it easier to understand quickly how long a battery would last, if you know the how much current a device consumes. For instance, if a device requires 1 Ampere to operate and it is attached to a 1 Ah battery, we know that the device will operate for 1 hour.

2. Battery Aging

From the moment a lithium-ion battery exits the production line it starts to age. While it may seem non-intuitive, the electrochemical reactions will continue even when the battery is idle, and no load is present between the terminals. Once a cell is built into a battery pack there is also a small load that is created from the protection device. With this being known, external conditions can and will also influence aging.

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2.1. Calendar Life

This type of aging is the loss in capacity a battery can store and deliver just from the length of time that has passed. It can also be thought of as Storage Aging since storage implies a fixed amount of idle time. While Cycling and Thermal Influence can play a part in altering the path a battery takes to expiration, even an idle battery will eventually reach old age. Materials break down over time and this is especially true from something as chemically active as a battery.

2.1.1. Remaining Capacity

This is the measure of the charge remaining after some event or condition has occurred. Calendar aging as we know it will lead to the loss of some amount but state of charge (explained in more detail below) and temperature will also alter the rate of loss. The loss from storage is also sometimes called Shelf Life which uses Remaining Capacity or Capacity Retention to quantify the change. Shure runs various storage tests on all its batteries before release. Remaining Capacity is tested and measured to ensure the battery is in line with the datasheets given from battery cell manufacturers. Battery cells that perform poorly are never selected for creation or replacement of a Shure Rechargeable Lithium-Ion Battery.

2.1.2. Recovery Capacity

While Remaining Capacity is a measure of the loss of charge over time. Recovery Capacity is a way to measure the change in the amount of charge a battery can hold. *Figure 1.1* showed how to measure battery capacity. Aging effects will diminish this capacity over time.

2.2. Cycle Life

This type of aging occurs from normal charge and discharging of the lithium-ion battery. As the battery cycles, the electrodes lose some of the ability to hold ions and electrons like they once did. In a lithium-ion battery, cycling can alter the ability to hold charge or it could also lead to chemical layers being created that impede the motion of ions from one electrode to the other.

Most lithium-ion batteries are rated to a certain number of cycles before reaching a Recovery Capacity of 80%. It is at this 80% point that replacement is recommended by the battery cell manufacturers. Shure Rechargeable Lithium-Ion Batteries keep track of a calculated version of Recovery Capacity called Battery Health. Battery Health is reported by the battery back to most Shure devices. Reference your Shure device's user guide for more information on checking Battery Health on your specific device.

2.3. Thermal Influence

A lithium-ion battery that is stored, charged, or discharged while in an extreme temperature environment can develop permanent performance loss. If exposed for long periods of time or many iterations of exposure, the lithium-ion battery could also become inoperable. A general rule for lithium-ion batteries is that they are like people. If a person would be uncomfortable in the temperature, then it is probably not the best condition for the battery. There is a slight exception to this rule, and that is lower temperature. While a person may not be comfortable in an environment that is under room temperature, batteries store well several degrees below that. Optimal storage temperature is a steady and consistent level between 5-25 °C.

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2.4. State of Charge (SOC) Influence

Lithium-ion batteries that have been stored with high SOC can age faster and have permanent performance loss much like the thermal influence from the previous section. On the other side of the spectrum, storage of a lithium-ion battery at too low an SOC can lead to the lithium-ion battery permanently being unrecoverable in a safe manner.

3.0 V as the empty point is what is considered operationally empty. However, there are still small amounts of charge contained in the lithium-ion battery below 3.0 V. Shure Rechargeable Lithium-Ion Batteries have been designed to normally operate down to 3.0 V. Then, depending on the battery cell being used, it will disconnect the outside world from the battery cell when the voltage reaches an even lower undervoltage point. After this threshold is reached, the battery will no longer be allowed to be recovered. The reason for this is because the battery cell begins to break down further.

It is never recommended to store lithium-ion battery after it hits 3.0 V or device shutdown as there is not much time before Remaining Capacity will deplete to the under-voltage threshold. Charging to full can lead to other aging mechanisms, so it not always best, but without a Storage mode it is probably the best course of action. Storage mode is the best option when available as described in Section 3.

3. Shure Storage Mode

Some Shure chargers have advanced features for customers that what some more control over Shure Rechargeable Lithium-Ion Batteries. One such feature is the Storage mode option (see section 4 for more details). As SOC can affect the loss of Recovery Capacity, Shure added the Storage mode feature to limit the maximum Charge Voltage. This allows a user to charge the batteries up to a point that is low enough to prevent side reactions from occurring when stored in a room temperature environment.

You may notice that there is a voltage printed on the label or packaging of a device (typically between 3.6–3.8 V). This is not to be confused with the Storage mode Charge Voltage. The label voltage is the nominal battery voltage as given from the manufacturer. That means it is the voltage most likely to be seen given an average of the voltage curve of a particular battery.

The Storage mode Charge Voltage is chosen based on what is roughly a mid-point SOC across all Shure batteries. Currently that Storage mode Charge Voltage is set to 3.8 V in Shure chargers that support it. When a Shure Rechargeable Lithium-Ion Battery is attached to a charger in Storage mode it will charge that battery to 3.8V before signaling completion. Shure chargers also contain discharge functionality for Storage mode so if the Shure Rechargeable Lithium-Ion Battery is above 3.8 V when attached it will discharge until it has a steady 3.8 V.

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It should also be noted that Storage mode is only meant to get the Shure Rechargeable Lithium-Ion Battery to the appropriate level to be stored. Both Normal and Storage mode have recharge features built in so, as Remaining Capacity is lost over time, they will be topped off back to the Charge Voltage for the respective mode. That recharging adds to cycle life and diminished Recovery Capacity. When the recharge cycle is not expected to happen quickly it would be best if the batteries were stored independent of the chargers for long term storage. This is especially true if Normal mode is used, as leaving the lithium-ion battery close to 100% SOC for extended period increases aging.

4. Handling Instructions

Here are the best practices for handling Shure Rechargeable Lithium-Ion Batteries:

1. Use of Storage Mode

When Shure rechargeable batteries will not be used for extended periods of time, we highly recommend using your Shure charger in Storage mode, which will leave the Shure Rechargeable Lithium-Ion Battery in a slightly depleted state that is optimal for long-term storage. If your charger does not support Storage mode, then charge the batteries to full as you normally would. Under no circumstance would you want to store batteries that have been fully discharged.

2. Store Batteries Separate from Device

Removable batteries should be taken out of any charger or device when storing for extended periods. If the battery is built into the device, then make sure any switches or power are set to off.

3. Store at Room Temperature

Batteries should be stored in a controlled, room temperature environment, so the temperature remains relatively steady. Normal infrastructure systems using heat/air conditioning with a thermostat is perfectly adequate. Large temperature fluctuations, or extreme hot or cold storage, will speed up and increase the aging of a lithium-ion battery.

4. Long-term Storage

All batteries are subject to self-discharge over time and can degrade to the point of no-recovery if not refreshed. If possible, we highly recommend that batteries be recharged using Shure charger's Storage mode feature, if available, every six months. When Storage Mode is not available, recharging to full is an acceptable solution. When possible, remove batteries from charger when fully charged.

Again, as a general rule: please remove lithium-ion-powered devices and batteries when fully charged and store outside the charger for best lithium-ion battery healt. While these techniques can help maintain battery life, lithium-ion batteries do age and degrade over time.

Disclaimer: These guidelines are intended as a general explanation of how to handle Shure lithium-ion batteries. Always reference Shure product user guide and supporting documentation, and any applicable health and safety regulations for any specific handling instructions.

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