(C) Overcharge or abnormal charge: However, when a battery is overcharged or when charging is conducted at less than the specific temperature, the amount of oxygen gas generated by reaction (1) cannot be fully-absobed by reaction (2). So the internal pressure increases and the safety valves activate. The gas including hydrogen generated (along with oxygen) at the negative plate during exccesive overcharge will be released..

Reaction(3)

NEGATIVE PLATE

$$\underset{\text{(Hydrogen ions)}}{2H^{+}} \quad \underset{\text{(Electrons)}}{2e^{-}} \longrightarrow \underset{\text{(Hydrogen)}}{H_2}$$

It should be noted that when the safety valves functiin, electrolyte is consumed and its performance deteriorates. To prevent or reduce this, it is important that charging should be conducted under recommended conditions without overcharging.

4. CHARGING CHARACTERISTICS

4.1 Charging methods

Choose the appropriate charging method according to the applications and conditions of VRLA battery to get full performance from the battery. Methods available are: *semi-constant current charging method*, *constant current charging method*, *constant voltage charging method*, and *two-step constant voltage method*. The semi-constant current method and constant voltage method are generally used for batteries with cycle servicing. The constant voltage charging method is generally used for standby servicing (trickle or float). Also, the semi-constant current charging method is used for supplementary charging of the battery with extended storage period. Recently the two-step constant voltage charging method is being used for rapid charging of VRLA battery. Please refer to **Table 1** for an explanation of the charging methods and their features.

Table 1

Charging method	Cycle service	Standby (triclde or float)	Supplementary charge
Semi-constant current charging (simplified charging)	• Charging is possible within a relatively short period • Overcharge is easy because it is difficult to control the charging current • Low cost	Not applicable	• Charging possible within a relatively short period • Suitable for charging batteries connected in series. Control of the time is necessary to prevent overcharging • See **Fig 15**
Constant current charging	• Charging is possible within a relatively short period • Protective circuit required to prevent overcharge • High cost	Not applicable	• Charging to meet discharge quantity is possible by controlling the time • See **Fig 16**
Constant voltage charging (constant-current constant-voltage)	• Proper charge method • In general, charging requires a lot of time • Rapid charging is possible by changing set voltage and current. • Overcharge countermeasure necessary for the final stage of charge. • Normal cost	• Proper charge method • Inaccurate charge voltage may cause overcharge or undercharge • Relatively long time necessary for recovery after deep discharge • Normal cost	• Charging of batteries connected in series is possible for batteries discharged under a given condition • Normal cost • See **Fig 17**
Two-step constant voltage charge	• Reasonable rapid charging • High cost	• Charging for recovery is possible within arelatively short period even after deep discharge • High cost	

(1) Semi-constant current charging method (simplified method)

This method, referred to as a simplified method, is easy to perform and is widely used ***for cycle service batteries***. The charger consists of a transformer, diode and resistor. Impedance from these elements ensures charging without excessive changes in the charging current. With this method, the battery voltage increases while the charging current decreases, as the charging proceeds. The problem with this method is that the charging current flows in a large quantity at the final stage and causes overcharge. Care should be taken to avoid charging for more than the specified charge period. Therefore, it must be disconnected, usually within 12-24 hours, or after 100-120% of the preceding discharge has been returned. It is also sensitive to line voltage variations which can cause over- or under-charging. Consequently, this charging method can only be used in ***cyclic*** applications. Please refer to **Fig 2** and **Fig 3**.

Fig 2: Semi-constant current charging circuit

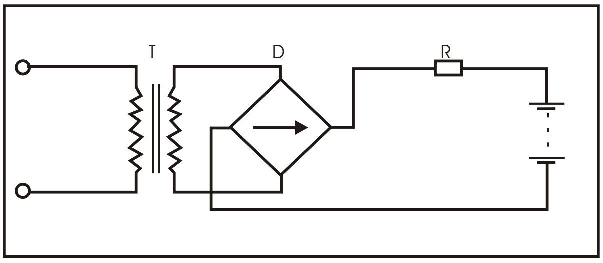
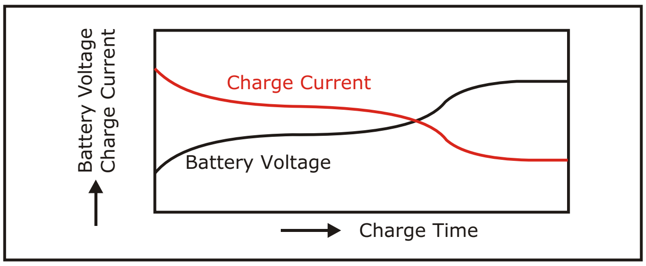


Fig 3: Semi-constant current charging Characteristics



(2) Constant current charging method

This method consists of charging the battery with constant current. With this method the charging time and charging quantity can easily be calculated. To do so, an expensive circuit is necessary to obtain a highly accurate constant current. Consequently, this charging method is rarely used ***for general purposes***. While this charging method is very effective for recovering the capacity of a battery stored for an extended period of time, or for occasional overcharging to equalize cell capacities, it lacks specific properties required in today's electronic environment. Please refer to **Fig 4** and **Fig 5**.

Fig 4: Constant current charging circuit

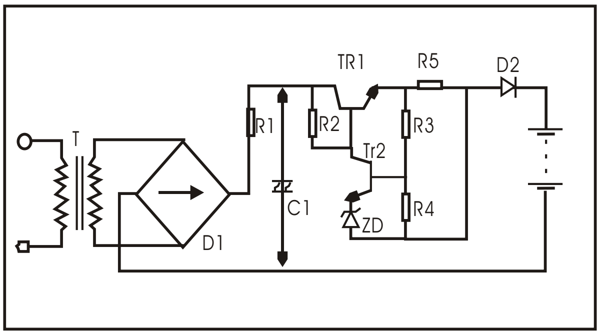
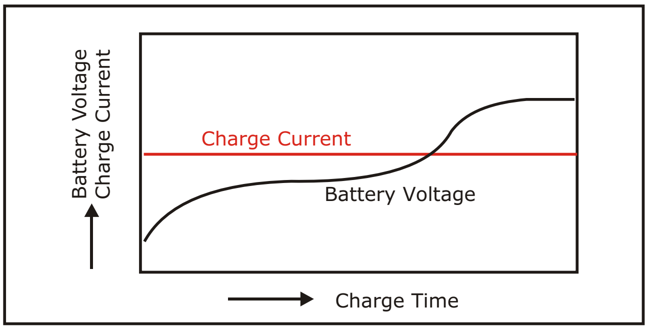


Fig 5: Constant current charging characteristics



(3) Constant voltage charging method (constant-current /constant-voltage charging method)

This method is the best method to charge VRLA batteries, consisting of applying constant voltage to the battery with a constant voltage unit. This charging method utilizes a different voltage between its voltage and battery voltage. The charging current is initially large and decreases towards the end of charging. It is necessary to set the charging voltage according to battery charging and temperature characteristics. Inaccurate voltage causes an overcharge or an undercharge. Since there is a large current flow at the start, this method requires a large capacity charging unit which will be more expensive. Consequently the constant-current, constant-voltage charging method with limited initial current is widely used ***for cycle and standby batteries***. Please refer to **Fig 6** and **Fig 7**.

Fig 6: Constant current / voltage charge circuit

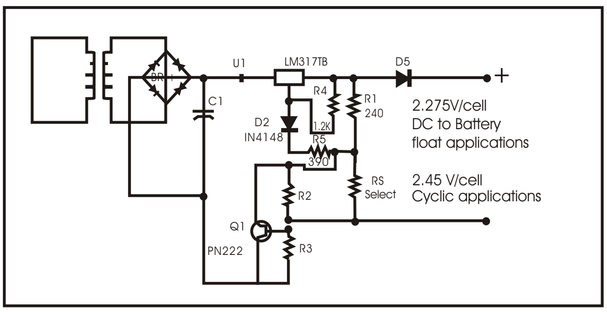
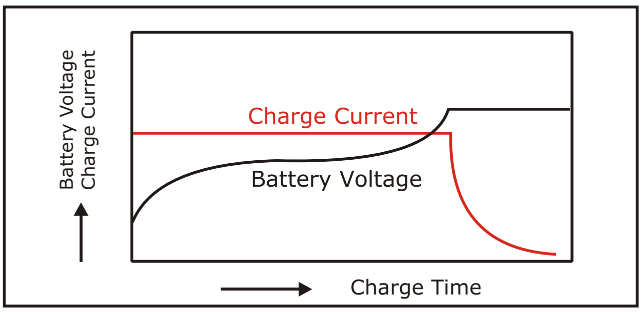


Fig 7: Constant current / voltage charge characteristics



The constant voltage charge method is recommended to charge our battery. When charging, the lead sulfate of the positive plate becomes lead dioxide. As charging continues, the positive plate begins to generate O_2 causing a sudden rise in battery voltage. A constant voltage charge, therefore, gives rise to detection of this voltage increase and control of the charge amount. This type of charging generally employs a constant-voltage constant-current method with current limitation to prevent the initial current (at low battery voltage) from increasing.

Charging for Cycle Operation:

Cyclic applications generally require that recharging be done in a relatively short time. The initial charge current, however, must not exceed 0.3C amp (30% of rated capacity). Just as battery voltage drops during discharge, it slowly rises during charge.Full charge is determined by voltage and inflowing current. When, at a charge voltage of 2.45±0.05 volts / cell, the current accepted by the battery drops to less than 0.01C amps (1% of rated capacity), the battery is fully charged and the charger should be disconnected or switched to a float voltage of 2.25 to 2.30 volts / cell. The voltage should not be allowed to rise above 2.45±0.05 volts / cell.

Charging for Standby Operation:

Standby applications generally do not require that the battery be charged as fast or as frequently as in cycle operation. However, the battery must be kept constantly charged to replace the energy that is expended due to internal loss and deterioration of the battery itself. Although these losses are very low in VRLA batteries, they must be replaced at the rate of the battery self-discharges; at the same time the battery must not be given more than these losses or it will be overcharged. To accomplish this, a constant voltage method of charging called float charging is used.

(4) Two-step constant voltage charging method

This method uses two constant voltage devices. In the initial charge phase the high voltage setting is used. When charging is nearly complete and the charge voltage has risen to a specified value (with the charge current decreased), the charger switches the voltage to the lower setting. This method allows ***rapid charging in cycle or float service*** without the possibility of overcharging even after extended charging periods. The diagram in **Fig 8** is an example of a charging circuit forthis type of charger, and the graph in **Fig 9** shows charging characteristics,

Fig 8: Two-step constant voltage charging circuit

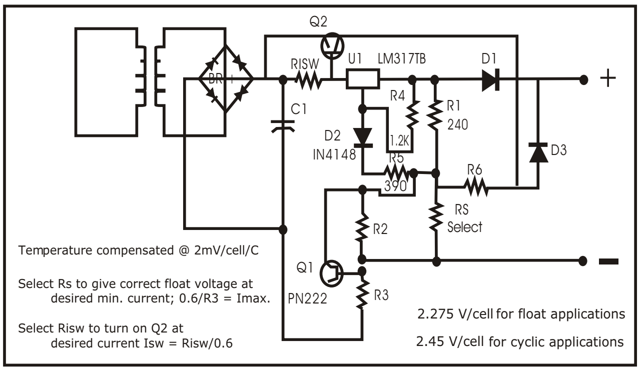
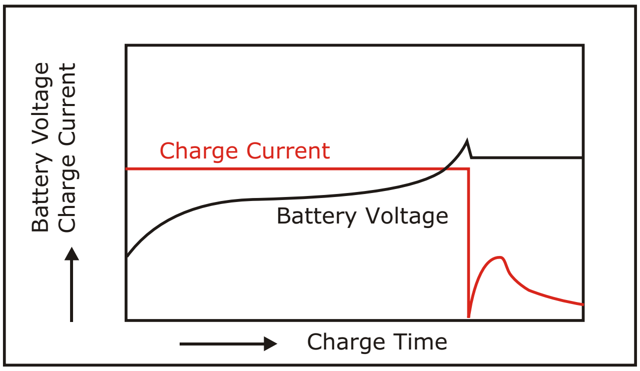


Fig 9: Two-step constant voltage charging characteristics



4.2 Charging characteristics

During constant voltage or taper charging, the battery's current acceptance decreases as the charging voltage increases. The battery is fully charged once the current stabilizes at a low level for a few hours.

Caution: Never charge or discharge a battery in a hermetically,or sealed enclosure. Batteries generate a mixture of gases internally. Given the right set of circumstances, such as extreme overcharging or shorting of the battery, these gases might vent into the enclosure and create the potential for an explosion when ignited by a spark. If in doubt, or concepts of proper use and care are unclear, please contact our local sole agent or distributor or our engineering department.

Please note that there are two criteria for determining when a battery is fully charged:

(1) the final current level

(2) the peak charging voltage while this current flows.

4.2.1 Fig10 depicts an example of typical charge characteristics for ***cycle*** service where charging is non-continuous and peak voltage can, therefore, be higher.

4.2.2 Fig 11 illustrates typical characteristics for ***standby*** service type charge. Here, charging is continuous and the peak charge voltage must, therefore, be lower.

Fig.10: Constant voltage charging characteristics (Cycle service)

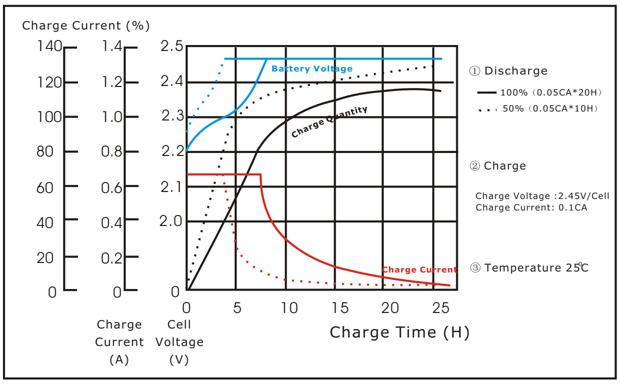
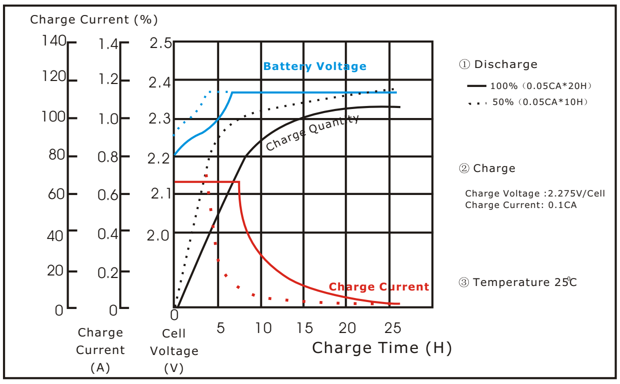


Fig.11: Constant voltage charging characteristics (Standby service)

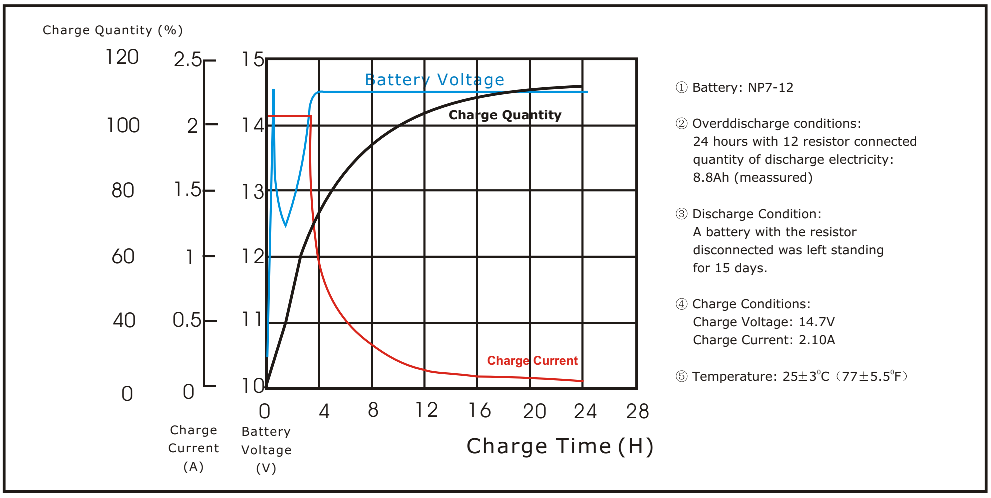


Overdischarge means a battery is discharged below our specified cut-off voltage. Compared to the alkaline battery, VRLA battery is very sensitive to overdischarge. Overdischarge results in failure to recover normal capacity, reduced capacity, or shortened service life, overdischarge also occurs by leaving the battery in a discharged state. The VRLA battery can overcome this problem. If the battery is overdischarged and left standing in a discharged state for several days, it can recover its original capacity when charged. However it is necessary to avoid overdischarge situations as much as possible. **Fig 12** shows an example of the charge characteristics after overdischarge and leaving the battery in a discharged state.

4.3.1 The original capacity can be recovered after two or three consecutive overdischarges or leaving the battery in a discharged state. Beyond this limit, the battery may not recover to its original capacity.

4.3.2 Always perform constant voltage charging with 2.45 V/cell with maximum current of 0.05CA. The charge voltage range between 2.250 to 2.275 V/cell may not be enough to recover to the capacity above. In this case, repeat charge and discharge two or three more times. **Fig 12** shows an example of the charge characteristics after overdischarge and leaving the battery in a discharged state. As this figure shows, the charge current remains unchanged during the initial period of charge, this is not considered abnormal.

Fig 12: charging characteristics after overdischarge and leaving a battery in a discharged state



4.4 Temperature compensation

The charge voltage of the battery decreases with increasing temperature and vice versa. Accordingly, charging with a given voltage requires an increased charge current when the temperature is high and decreased charge current at a lower temperature. Temperature compensation is not necessary when the battery is charged at an ambient temperature between 5℃(41℉) to 35℃(95℉), with average temperature below 25℃ (77℉). At temperatures below 5℃(41℉) or above 35℃(95℉), temperature compensation for charging voltage is necessary. **The temperature coefficient is:**

(1) For cycle service: -5m V/℃ cell

(2) For standby use (trickle charge or float charge): -3.3mV/℃ cell

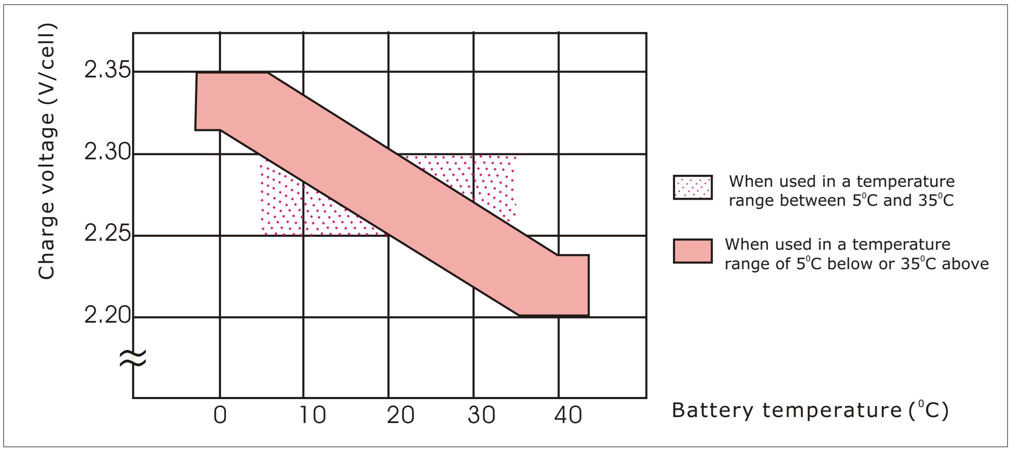
For the charging voltage of each VRLA battery, refer to **Table 2**.

Table 2 Charging voltage and maximum charging current

Applications	Charging voltage (V/cell)			Max.charging current (A)
	Temperature	Set point	Allowable range	
Cycle service	25°C(77°F)	2.45	2.40~2.50	0.3C
Standby	25°C(77°F)	2.275	2.25~2.30	0.3C

Refer to **Fig 13** in order to prevent a poor charge under low temperatures and overcharge under high temperatures, the charging voltage must be set at the appropriate value according to the battery temperature.

Fig 13: Relation between battery temperature and charging voltage for standby use



Notes:

(1) Even under high temperature, a charging voltage more than 2.2V/ cell of open circuit voltage is required.

(2) Even under low temperature, the charging voltage must be set less than 2.35V/cell so as to prevent gas generating from the battery.

(3) The battery life will be shortened as the service temperature rises.

(4) Using the battery for a long period at the temperature over 40°C may cause a thermal runaway.

5. DISCHARGING CHARACTERISTICS

5.1 Discharge characteristics at different discharge rate

The capacity of the battery depends on the discharge rate being used. VRLA battery is rated at 20 hours discharge rate which is defined as the nominal capacity or 100% capacity point, while some VRLA btateries are rated at 10 hour discharge rate which have rated capacity more than 24Ah. The final voltage is 1.75V per cell. **Fig. 14** shows the discharge performance at various discharge rates. When the loading on the battery is increased, the available capacity drops.

Fig.14 Discharge Characteristic Curves at various rates (at 20°C, 68°F)