

## LEAD-ACID TYPE STORAGE BATTERIES

### THEORY AND DEFINITIONS

CONTENTS	PAGE	CONTENTS	PAGE
1. GENERAL . . . . .	1	2.23 Gas Explosion Hazard . . . . .	7
2. THEORY OF OPERATION . . . . .	2	2.24 Capacity . . . . .	8
2.01 Chemical Action During Discharge—Cell Polarity Reversal . . . . .	2	2.26 Capacity Variation With Temperature . . . . .	8
2.02 Chemical Action During Charge . . . . .	3	2.27 Efficiency . . . . .	9
2.03 Charge and Discharge Current Rates . . . . .	3	2.29 Voltage Generation . . . . .	9
2.08 Specific Gravity of Electrolyte . . . . .	3	2.30 Voltage During Discharge . . . . .	9
2.09 Electrolyte Mixing by Gassing and Diffusion . . . . .	4	2.31 End-voltage . . . . .	9
2.10 Reference Temperature for Specific Gravity . . . . .	4	2.32 Voltage Rise During Constant Current Charge . . . . .	9
2.11 Water Effect on Specific Gravity . . . . .	5	2.33 Excessive Voltage Variation Between Unlike Cells in a String . . . . .	9
2.12 Gravity Range . . . . .	6	2.34 Speed of Voltage Response to Current Changes . . . . .	10
2.13 Equalizing Charge and Full Charge Specific Gravities . . . . .	6	2.35 Behavior of Individually Overcharged Cell After Return to a Floating String . . . . .	10
2.14 Nominal Specific Gravity . . . . .	6	2.36 Cell Contamination by Contact Between Lead-antimony and Lead-calcium Parts . . . . .	10
2.15 Water . . . . .	6	2.37 Open Circuit Voltage . . . . .	10
2.16 Sulfation . . . . .	6	2.38 Temperature Effect on Voltage . . . . .	10
2.17 Mossing . . . . .	7	2.39 $\updownarrow$ Temperature of Electrolyte $\updownarrow$ . . . . .	11
2.18 Sediment . . . . .	7	2.40 Freezing of Electrolyte . . . . .	11
2.19 Stratification . . . . .	7	2.41 Local Action . . . . .	11
2.22 Gas Formation . . . . .	7		

**NOTICE**

Not for use or disclosure outside the  
Bell System except under written agreement

	CONTENTS	PAGE
3.	CHARGE . . . . .	11
3.01	Charge Equipment . . . . .	11
3.02	Manual or Automatic Charge Control . . . . .	11
3.03	Float Charge . . . . .	11
3.04	Constant Current Charge . . . . .	11
3.05	Variable Current Charge . . . . .	11
3.06	Charge by Load (Emergency Cells) . . . . .	11
3.07	Constant Voltage Charge . . . . .	11
4.	TYPES OF CHARGE . . . . .	12
4.01	Initial Charge . . . . .	12
4.02	Overcharge . . . . .	12
4.03	Equalizing Charge . . . . .	12
4.04	Boost Charge . . . . .	12
4.05	Mixing Charge . . . . .	12
4.06	Special Charge . . . . .	12

**ILLUSTRATIONS**

Fig. 1—Typical Charge Curves for a Fully Discharged Lead-calcium Battery . . . . .	4
Fig. 2—Comparison of Charge Rate at 2.20 Volts After Full and Partial Discharge . . . . .	5
Fig. 3—Electrolyte Mixing During Charge—Comparison of Lead-antimony and Lead-calcium Cells . . . . .	5
Fig. 4—Effect of Gassing at 18 Percent of 8-hour Rate on Lead-calcium Cell Charged Previously at 2.20 Volts . . . . .	6

	CONTENTS	PAGE
Fig. 5—Typical Voltage Curve During Discharge at 5-hour Rate . . . . .		9
Fig. 6—Typical Voltage Curve for Recharge at One-half the 5-hour Rate . . . . .		10

**1. GENERAL**

1.01 This section describes the theory of operation and includes definitions of general terms for lead-acid type storage batteries.

1.02 This section is reissued to modify and expand paragraph 2.23, Gas Explosion Hazard; also, paragraphs 2.39 and 2.40 have been revised and the titles changed. This reissue does not affect the Equipment Test List.

1.03 A **storage cell** is an electrolytic cell which supplies electrical energy. After being discharged, the cell may be restored to a charged condition by an electric current flowing in a direction opposite to the flow of current when the cell discharges. A **storage battery** is two or more storage cells connected in series. Common usage also permits this term to be applied to a single cell used independently. Storage batteries are sometimes called secondary batteries or accumulators in contrast with primary batteries which generate current but, in general, are not rechargeable.

**2. THEORY OF OPERATION**

2.01 **Chemical Action During Discharge—Cell Polarity Reversal:** In a fully charged cell, the active materials are lead dioxide on the positive plate and lead on the negative plate in a solution of sulfuric acid and water called electrolyte. **During discharge** the sulfuric acid of the electrolyte combines with the lead in the negative plate and with the lead dioxide in the positive plate, forming water and lead sulfate on both plates. This form of lead sulfate is in a finely divided state and is essential to the operation of the cell. The loss of sulfuric acid from the electrolyte in the formation of the lead sulfate causes the lowering of the specific gravity during discharge while the chemical reaction producing water further dilutes the electrolyte. If the discharge continues long enough, the available active material in both plates

becomes converted into sulfate and the voltage drops to zero. If one or more cells in series become fully discharged while the remainder of the cells are still discharging, there will be a **reversal**, that is, change of polarity on the discharged cells with adverse effect on the plates if repeated several times. Usual correction for reversed cells is a charge of approximately 150 percent of 8-hour capacity at a slow charge rate (see Section 157-601-701). Chemical conditions for theoretical full charge and full discharge are shown in the following table, but in practice these conditions, particularly the discharged condition, are only approached.

CHARGED		
POSITIVE PLATE	ELECTROLYTE	NEGATIVE PLATE
PbO <sub>2</sub>	2H <sub>2</sub> SO <sub>4</sub>	Pb
(Lead Dioxide)	(Sulfuric Acid)	(Lead)
DISCHARGED		
POSITIVE PLATE	ELECTROLYTE	NEGATIVE PLATE
PbSO <sub>4</sub>	2H <sub>2</sub> O	PbSO <sub>4</sub>
(Lead Sulfate)	(Water)	(Lead Sulfate)

### 2.02 *Chemical Action During Charge:*

**During charge**, the electric current passes through the cell in the opposite direction to that of discharge and lead sulfate is converted to lead on the negative plate and to lead dioxide on the positive plate. The sulfate ions liberated in this reaction combine with hydrogen ions from the water to form sulfuric acid at both plates. The consumption of water and the formation of sulfuric acid, caused by the conversion of lead sulfate on both plates, produce the increase in specific gravity of the electrolyte observed during charge. When lead sulfate is not readily available for this reaction, the current decomposes the water to form hydrogen at the negative plate and oxygen at the positive plate and the cell starts to gas.

### 2.03 *Charge and Discharge Current Rates:*

During **battery charge**, the charger output equals the office load, if any, plus the charging current. When a lead-calcium cell is fully charged, the current at 2.20 volts per cell is less than 1

percent of the 8-hour rate. Therefore, the battery may be assumed to be practically charged when the difference between charger output and the office load is no longer distinguishable on office ammeters. During **discharge**, the battery current equals the office load minus the charger output, if any.

**2.04** Because of the large surface of active material and low internal resistance, a battery can usually be discharged at any rate. In general, the greatest output in both ampere-hours and watt-hours is obtained when the battery is discharged at a low rate over a long period of time, such as several days, since the diffusion of acid through the active material is available to sustain the discharge.

**2.05** For purposes of comparison, telephone batteries are usually rated to discharge to 1.75 volts per cell in 5 or 8 hours. A table comparing the 5-hour and 8-hour rates is included in Section 157-601-701.

**2.06** Typical charge curves of Fig. 1 for a fully discharged lead-calcium battery show that for both 2.20 and 2.17 volts per cell, 65 percent of capacity is restored to cells in approximately 5 hours if the full 8-hour rate is available from the charger. Also 80 percent of capacity is restored to both cells in approximately 19-1/2 hours when charging at 1/3 of the 8-hour discharge rate. In the latter case, it is noteworthy that even at 2.17 volts per cell, full capacity is restored in 70 hours.

**2.07** For partial discharges of less than 1 percent of battery capacity which last for only a few minutes, the time for complete recharge at 2.17 volts per cell is about three or four times the discharge period. It takes less time to recharge for a partial discharge than for the same ampere-hours coming at the end of a recharge from full discharge. As shown in Fig. 2, it took 6-1/2 hours to replace a 32 percent partial discharge and 9-1/2 hours to replace the last 32 percent of a full discharge.

**2.08 *Specific Gravity of Electrolyte:*** Specific gravity, as used in these practices, is the ratio between the density of the electrolyte and the density of water, taken as 1.000. The specific gravity of the electrolyte decreases as the battery is discharged and increases as the battery is charged. The specific gravity readings of a cell may therefore be used, with reservations (see 2.09 through 2.11),

during or after a discharge to indicate the proportion of rated ampere-hours discharged. During charge, however, and before recently added water has had time to mix thoroughly, the gravity readings seldom show the actual state of charge. With the low charge voltages used today, there is little gassing, and mixing is considerably curtailed. This slow mixing is more pronounced with lead-calcium than with lead-antimony.

**2.09 Electrolyte Mixing by Gassing and Diffusion:** The difference between the specific gravity, measured at the top of the cell on recharge, of parallel strings of lead-antimony and lead-calcium cells is shown in Fig. 3. A sharper rise in specific gravity commences on the lead-antimony string as soon as 2.2 volts is reached. This is because the gassing rate at 2.2 volts is approximately ten times greater for lead-antimony than for lead-calcium. Gassing promotes mixing of the electrolyte (see Stratification, 2.19 through 2.21, and Gas Formation, 2.22) so that the electrolyte available to the hydrometer provides a more accurate indication of state of charge. Because of their low gassing rate, lead-calcium cells regain their full charge specific gravity reading almost entirely by the diffusion process. Different separator designs, as well as electrolyte temperature, may affect the rate of electrolyte diffusion (see 2.38). Lead-calcium cells are much more likely than lead-antimony cells

to reach full charge while the specific gravity reading still indicates a partially charged condition. In a test (for purposes of illustration), a lead-calcium battery was fully charged at the slow charge rate of 2.2 volts per cell and the specific gravity of the electrolyte *available to the hydrometer* was 1.137 at the end of charge. About 18 percent of the 8-hour rate was then passed through the cell to promote mixing by gassing. As shown in Fig. 4, the specific gravity after 2 hours at this rate read 1.188, representing a 51-point rise. The charge applied for 2 hours was only 4.5 percent of the 8-hour capacity. If all this current had gone to charging instead of gassing, this amount of charge would account for only a 6-point rise in specific gravity. Most of the 51-point rise was, therefore, due to the mixing caused by gassing. In another test, after a small cell was fully charged, a low specific gravity was read, but after being turned upside down to promote mixing the specific gravity showed full charge.

**2.10 Reference Temperature for Specific Gravity:** The specific gravity varies inversely *with changes in temperature* of the electrolyte (see Section 157-601-701), dropping one point (0.001) for each 3°F rise in temperature and rising one point (0.001) for each 3°F drop in temperature. Since it is essential that all readings be computed on a common temperature basis so

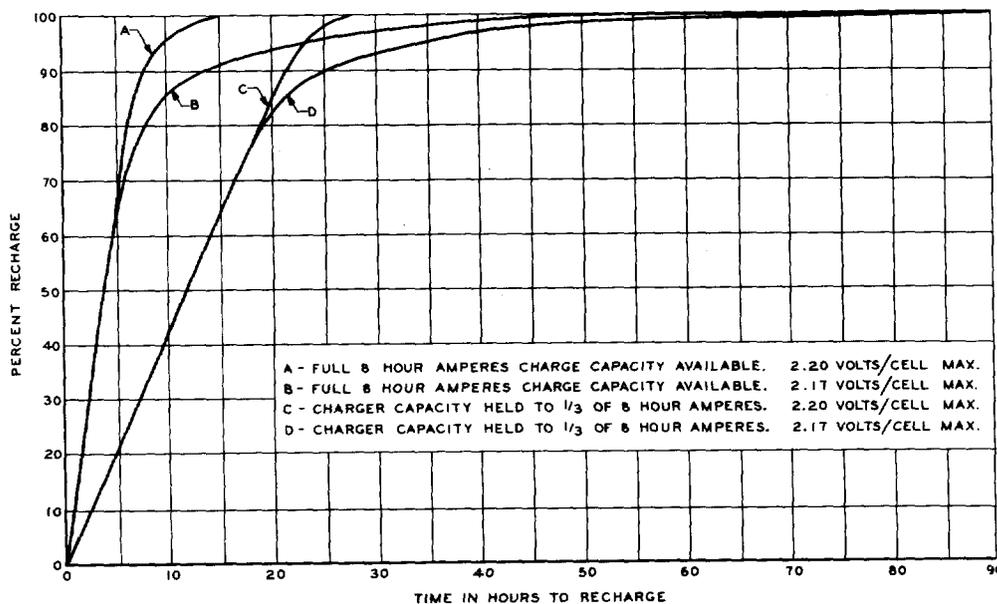


Fig. 1—Typical Charge Curves for a Fully Discharged Lead-Calcium Battery

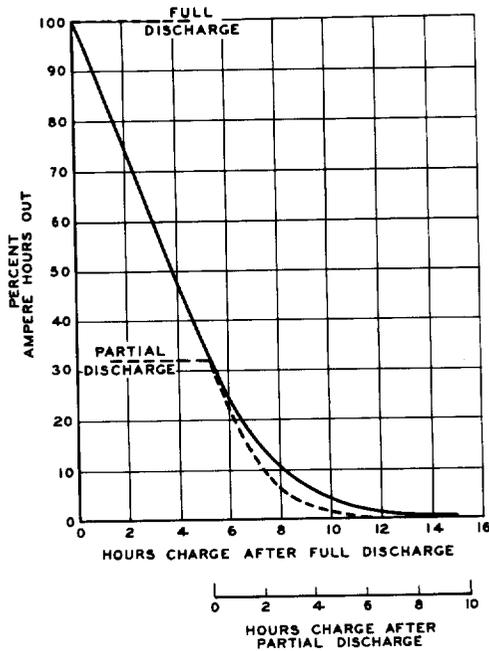


Fig. 2—Comparison of Charge Rate at 2.20 Volts After Full and Partial Discharge

that readings taken at different temperatures may be compared, a reference temperature is adopted and all readings are corrected to what they would be if the cell were at that reference temperature. The present reference temperature is 77°F. The direction in which the correction should be applied becomes evident if it is noted that cold electrolyte will expand when heated. As the electrolyte expands, it has, of course, a lower specific gravity. Therefore, a plus correction is applied to the readings taken at any temperatures above the reference temperature to make them correspond to readings at the reference temperature. Conversely, readings taken below the reference temperature require a minus correction.

**2.11 Water Effect on Specific Gravity:**

Change in *surface level* of the electrolyte due to loss of or addition of water also affects specific gravity. This must be taken into consideration when comparing specific gravity readings taken at appreciably different surface levels. Lowering of electrolyte level is caused by evaporation and electrolysis of the water. Sulfuric acid is not

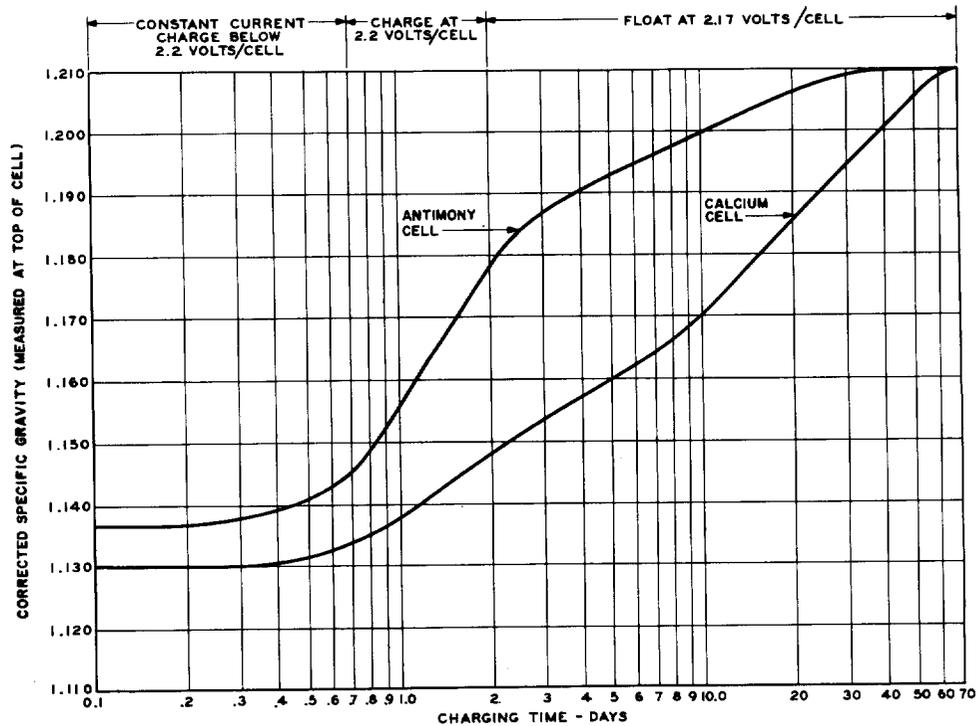


Fig. 3—Electrolyte Mixing During Charge—Comparison of Lead-Antimony and Lead-Calcium Cells

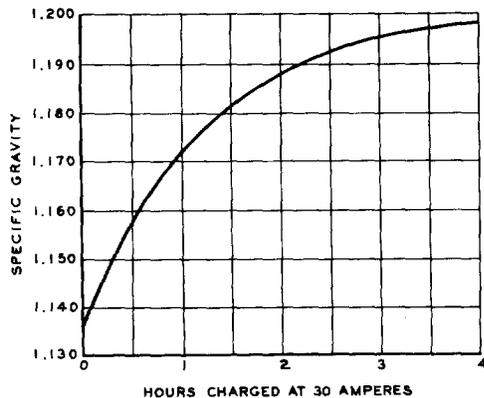


Fig. 4—Effect of Gassing at 18 Percent of 8-Hour Rate on Lead-Calcium Cell Charged Previously at 2.20 Volts

affected by these two processes and the acid lost by spraying may be disregarded. In restoring level, therefore, water only should be added, not acid or electrolyte. After adding water, specific gravity readings are seldom accurate until the water has had time to thoroughly mix (see 2.19 through 2.21).

**2.12 Gravity range** is the difference in specific gravity of the electrolyte of a fully charged cell and of the same cell discharged to the point where, for practical purposes, it is considered as fully discharged. The actual amount of this difference depends upon the quantity of electrolyte in the cell as compared with the quantity of available active material in the plates. If the plates are badly sulfated or a portion of the active material has been dissipated so that the full capacity is not available, the range in specific gravity to complete discharge is reduced approximately in proportion to the reduction in capacity. The range also varies with the rate of discharge. Ampere-hour capacity and, therefore, the gravity range, increases as the discharge rate is decreased, because more time is available for diffusion of the electrolyte in the pores of the plates and a larger part of the total active material is able to take part in the chemical reaction. All instructions in these practices, however, calling for maintenance based on the percentages of the gravity range assume the use of the full listed gravity range at the 5-hour rate.

**2.13 Equalizing Charge and Full Charge Specific Gravities:** The *equalizing charge specific gravity* is the gravity after

an equalizing charge (see 4.03) and in most cases after a boost charge. It, as well as the *full charge specific gravity*, is reduced gradually due to sedimentation, sulfate formation, and the general aging of the cell. After the specific gravity becomes stabilized, this drop may be about one point a year on float. It varies with the size of the battery, the normal working range, and particularly with the operating method employed.

**2.14 The nominal specific gravity** of a cell is an assumed value which the cell will approximate when new, fully charged, with the electrolyte near the maximum level and temperature of 77°F. The majority of the batteries now used in telephone power plants have a nominal specific gravity of 1.210. High gravity cells (nominal specific gravity 1.300) are used in colder locations such as some unattended repeater stations because of the very low freezing point of high gravity electrolyte.

**2.15 Water:** The use of distilled water for leveling electrolyte is theoretically ideal, but the cost of the distilled water is not justified where other reasonably satisfactory water is available. Even where the local tap water is not satisfactory, it may be more economical to transport satisfactory water from some other nearby source than to use distilled water. Chlorine or iron present in any quantities make water unsatisfactory for battery use and excesses of any solids are objectionable (see 157-601-701 for table of allowable impurities). For this reason, water from artesian wells is less likely to be acceptable than is surface water. Fluorides in amounts usually added to drinking water for health reasons will not adversely affect the water for battery use. The ill effects of water impurities are cumulative and are therefore more pronounced where a battery repeatedly receives too much charge, increasing the loss of water. Deionized water which meets the requirements specified in Section 157-601-701 is satisfactory for battery use.

**2.16 Sulfation:** During the normal discharge of a cell, lead sulfate is being formed. If a cell is permitted to stand completely discharged, is habitually undercharged, or is otherwise neglected, the sulfate reaches a condition where the pores become filled, making the active material dense and hard. This form of sulfate makes the portions of the plates on which it is deposited inactive, thus reducing the capacity to that which is given by the remaining good material. A plate or cell in

this condition is ordinarily referred to as "sulfated." The harmful sulfate when not in too large masses can usually be converted into lead dioxide and lead by considerable extra charging. Details on indications of sulfation and corrective action are available in Section 157-601-703. Due to the lower self-discharge rate of lead-calcium cells, they are much less likely to become sulfated than are lead-antimony cells.

**2.17 Mossing:** Moss is an accumulation of spongy lead material on the working faces and top edges of the negative plates. It consists of active material thrown off from the plates. It is circulated by excessive gassing to the extent that it lodges upon the negative grid. When it collects in a considerable amount on the top of the plates, it generally indicates that the cell is habitually receiving excessive overcharge causing excessive gassing.

**2.18 Sediment:** In the normal use of a cell which is regularly discharged and charged, the active material, mostly from the positive plates, is gradually worked loose from the plates and settles to the bottom of the cell in the form of sediment. Unnecessary overcharging, resulting in excessive gassing, accelerates the wear on the plates and consequently the accumulation of sediment. If sediment piles up, either on the bottom of the container or on the plate supports, so that it comes into contact with the bottom of the plates, it will produce a partial short circuit which will shunt part of the current during charging and will also cause the affected cell to discharge continuously when not being charged. With present operating methods, particularly continuous float, there is very little sediment deposited.

**2.19 Stratification:** Variation in the specific gravity with depth is known as stratification. Since by volume the weight of sulfuric acid is greater than water, it tends to settle to the bottom of the cell as it comes out of the plates during a charge. This is more pronounced on constant voltage charge where a charge is started at a high rate, since in such batteries the acid is released from the plates rapidly by the high initial charging current and it runs down the surface of the plates. In addition, when the battery approaches the charged stage, the current rate is so low that there is little active gassing. Such stratification existing over a long period of time may be harmful. On constant current charge where gassing is more active during the latter part of the charge, the

gassing tends to keep the electrolyte stirred up, consequently causing a more even distribution of acid throughout the cell. Specific gravity readings have a tendency to rise after shutdown of a gassing charge. This is due to the gas bubbles passing out of the electrolyte, making it heavier, and also due to the denser electrolyte in the pores of the plates diffusing through the rest of the solution.

**2.20** Serious stratification is not likely to occur in batteries operated by the continuous float method since with this method there is no heavy charge and acid is emitted slowly from the plates. Temporary stratification may be caused by water added to the top of the cells.

**2.21** Stratification at the top of a cell after charge or after adding water may persist on float for 2 weeks with lead-antimony and 10 weeks with lead-calcium. During the period of temporary stratification, a fully-charged battery will still give its full capacity on discharge. Natural diffusion on a floated battery will reduce stratification to five to ten points between the top and the bottom of the plates. Such a difference is not harmful.

**2.22 Gas Formation:** As the cell approaches the charged condition, most of the active material has become converted and the remainder cannot absorb current as rapidly as during the earlier part of charge. If energy is supplied at a rate greater than that at which lead sulfate can be converted, the excess current decomposes water, and gas is liberated. This is generally known as gassing of a cell. A small amount of gassing may be useful at intervals since it not only mixes the electrolyte (see 2.09) but also may assist in loosening and converting hard sulfate which may have formed on the plates. Too frequent gassing should be avoided, however, as it tends to loosen useful active material which is then lost as sediment.

**2.23 Gas Explosion Hazard:** The mixture of hydrogen and oxygen gasses given off during charge, due to electrolysis of the water, is **explosive** if in sufficient concentration. **A mixture of hydrogen and air is explosive if the hydrogen concentration exceeds 4 percent by volume.** The maximum volume of hydrogen evolved per hour can be approximated from the following formula:

$$\text{Volume of H}_2 \text{ (cubic feet/hour)} = 0.0148 \text{ X float current in amps.}$$

If float current cannot be measured, the following values can be used as estimates of float currents at 2.17 volts per cell at 77°F:

<u>KS-5562</u>	<u>ampal</u>	<u>KS-15544</u>	<u>I(ampal)</u>	<u>KS-5553</u>	<u>ampal</u>
L-07	7.0	L-508	0.085	L-508	1.60
		L-501	0.040	L-501	0.80
		L-409	0.033	L-409	0.65
		L-407	0.027	L-407	0.53
		L-405	0.022	L-405	0.43
		L-403	0.015	L-403	0.30

**Note:** The above float current for KS-5562 and KS-5553 lead-antimony cells are for end of life. Float currents for new cells are one-third the above.♦

Battery rooms and enclosures should be ventilated. Flames, arcs, sparks, etc, should be avoided in the vicinity of the battery. At no time should electrolyte level be allowed to drop below the minimum and the supervisor should see that all anti-explosion precautions of the practices (see Section 157-601-701) and of local instructions are followed faithfully.

**2.24 Capacity:** The *rated capacity* or ampere-hour capacity is the number of ampere-hours which can be delivered under specified conditions as to rate of discharge, final voltage, and temperature. For example, the rated capacity in ampere-hours of batteries classified under the 8-hour rate is the product of eight times the 8-hour discharge rate in amperes at a temperature of 77°F when discharged to an average voltage of 1.75 volts per cell. The rated capacity in ampere-hours of batteries classified under the 5-hour rate is the product of five times the 5-hour discharge rate in amperes at a temperature of 77°F when discharged to an average voltage of 1.75 volts per cell. ♦As the discharge rate (current) is increased, battery efficiency decreases (Paragraph 2.12).♦ The *initial capacity* may be slightly less than the rated capacity and will normally reach 100 percent in service.

**2.25** The *capacities of older batteries*, particularly on charge-discharge routines,

may be reduced due to loss of active material and positive plate growth. This has been recognized by engineering most plants on the assumption that the capacity near end of life would be less than 100 percent. It is now recommended that new full-floated batteries be calculated on the basis that they will have 75 percent capacity at the end of their anticipated life. If the capacity of a battery is doubtful, see Section 157-601-701 for discharge capacity test and for anticipated life of full-floated batteries.

**2.26 Capacity Variation With Temperature:**

Battery capacity increases with an increase in discharge temperature but the life of the battery is reduced (see 2.39). This change in capacity varies with the design of the cell and increases with higher discharge rates. The following values give some idea as to the extent of this change in terms of the capacity.

<u>DISCHARGE TEMPERATURE (DEGREES F)</u>	<u>CAPACITY (AT 8-HOUR RATE IN PERCENT)</u>
110	114
90	106
77	100
70	97
60	92
40	80
20	65
0	45

**2.27 Efficiency:** The efficiency of a storage battery is the ratio of the output of the cell to the input required to restore the initial state of charge under specified conditions of temperature, current rate, and final voltage.

**2.28** In power plant operation, the efficiency of general interest is the **ampere-hour efficiency**. This represents the electro-chemical effectiveness of the cell. It is the current output times hours of discharge, divided by the current input times hours of charge to restore the cell to full charge. It is lower for lead-antimony cells than for lead-calcium cells. For either type, the required recharge is usually specified at 110 percent of the amount of discharge although 105 percent is generally sufficient for lead-calcium.

**2.29 Voltage:** The voltage of a storage battery is due to the potential difference between the positive and negative plates. This potential difference is a result of the chemical action occurring at the individual plates. For open circuit voltage, see 2.37.

**2.30 Voltage During Discharge:** On discharge, a load is placed across the battery terminals which causes current to flow to the external circuit. The voltage at the terminals is immediately reduced to an **initial voltage** due primarily to the battery internal resistance and also supersaturation of the electrolyte with lead sulfate. This is usually followed by an abrupt rise in voltage to a so-called **plateau** voltage due to precipitation of lead sulfate from the supersaturated solution. During the remaining greater part of discharge, the voltage falls slowly from the plateau voltage to approximately 1.8 volts. The gradual decrease in voltage is due to the increasing internal resistance of the cell resulting from the depletion of the sulfuric acid electrolyte and the conversion of the conducting active materials at both positive and negative plates to nonconducting lead sulfate. After approximately 1.8 volts, the cell voltage drops more rapidly. This point is known as the **knee** of the discharge curve, and it signifies that the acid in the porous interiors of the plates is being rapidly depleted. The plateau voltage and the voltage at the knee of the discharge curve are dependent on the discharge current. These voltages generally increase as the discharge current decreases. A typical 5-hour rate discharge curve is shown in Fig. 5. See also Section 157-601-504 or 157-601-505 for a typical voltage curve during

discharge and recharge when using KS-20142 L1 type discharger-rechargers.

**2.31 End-voltage:** The minimum discharge voltage at which a plant can still operate is called the end-voltage. Power plants, in general, vary in design to operate at end-voltages varying between 1.90 to 1.75 volts per cell.

**2.32 Voltage Rise During Constant Current Charge:** As constant current charge is started, there is an immediate increase in voltage mainly due to the internal resistance of the discharged cell. The voltage then rises gradually due to formation of lead dioxide at the positive plates and lead at the negative plates. At the completion of charge, the voltage rises abruptly to a relatively constant final charge voltage. This sharp rise in voltage is due to depletion of the lead sulfate discharge product and the concurrent evolution of gases—oxygen at the positive plate and hydrogen at the negative plate. The final charge voltage depends on the charging current and also on the electrolyte specific gravity, temperature, grid alloy, and age of the cell. Fig. 6 shows a typical recharge curve at one half the 5-hour discharge rate for a discharged lead-acid cell.

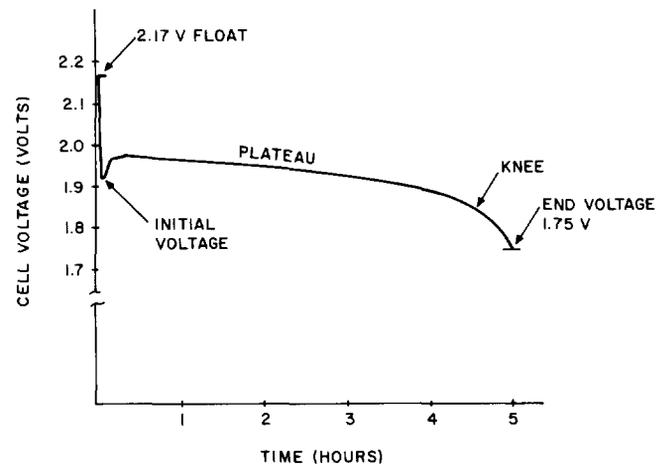


Fig. 5—Typical Voltage Curve During Discharge at 5-Hour Rate

**2.33 Excessive Voltage Variation Between Unlike Cells in a String:** Voltage variations between cells may be excessive where unlike cells are in the same string. This would complicate maintenance and tend toward excess

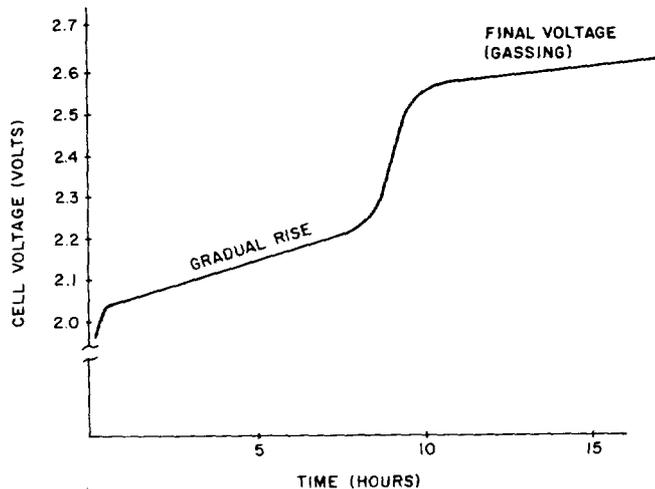


Fig. 6—Typical Voltage Curve for Recharge at One-half the 5-Hour Rate

charge on high-voltage cells and undercharge on low-voltage cells. Unlike strings of the same number of cells may be operated in parallel. For satisfactory operation, however, cells in the same string should be alike. They must be from the same manufacturer (see exception in following note), must be of the same capacity rating, and must have plates of the same material, either all lead-antimony or all lead-calcium. It is also very desirable, but not always possible, that all cells of the same string be of the same age (within a year or so); have separators of the same type, either all rubber or all plastic, and have plates of the same thickness. Cells of new strings may be assumed to be alike. For replacement of one or a few cells, it may sometimes be preferable to transfer cells from the emergency group. Where this is not feasible, the name of the manufacturer and the serial number of the replaced cell or, if the serial number is not available, the manufacture date stamped on the cell should be given in the order.

**Note:** In certain specified cases (see Section 157-601-701) where manufacture of a cell has been discontinued, substitution of like cells produced by another manufacturer is allowable up to a small percentage of the total number of cells in the string.

**2.34 Speed of Voltage Response to Current Changes:** The speed of response of voltage

to changes in current is somewhat faster with lead-calcium than with lead-antimony.

**2.35 Behavior of Individually Overcharged Cell After Return to Floating String:**

After an individual lead-calcium cell has been given a substantial overcharge and then returned to float operation in a string of cells which has had no similar overcharge, the charged cell will have **low voltage temporarily**. This irregularity will disappear in a few weeks of normal float operation.

**2.36 Cell Contamination by Contact Between Lead-antimony and Lead-calcium Parts:**

Lead-antimony alloy should never be allowed in contact with the electrolyte of lead-calcium cells and vice versa, as this will contaminate the cells with resulting **voltage irregularities** (see Cautions in Section 157-601-701 under "Specific Gravity Readings" and "Water and Level of Electrolyte").

**2.37 Open Circuit Voltage:** Upon discontinuing a charge, the voltage immediately drops a small amount, then falls rapidly to about 2.15 volts per cell. Thereafter, the drop is slow and the voltage may persist near this value for several minutes while the gas on the positive plates is being dissipated. If no discharge current is flowing, the voltage will stay higher than the open-circuit value for a long time, not arriving at open-circuit value for several hours or even several days. The nominal open-circuit voltage is 2.05 volts per cell for lead-antimony and 2.06 volts per cell for lead-calcium but the actual value varies with temperature and specific gravity. A simple rule for estimating open-circuit voltage at 77°F is specific gravity plus 0.84 for lead-antimony and 0.85 for lead-calcium. Examples, with 1.210 specific gravity, open-circuit voltage is  $1.21 + 0.84 = 2.05$  volts, while with 1.170 specific gravity it is  $1.17 + 0.84 = 2.01$  volts where cells are lead-antimony.

**2.38 Temperature Effect on Voltage:**

Decreasing the electrolyte temperature inhibits chemical action, slows down diffusion by making the electrolyte more viscous, and increases the internal resistance of the cell. The resulting change in voltage can usually be disregarded except possibly on discharge at substantial rates in low ambient temperatures. On open circuit, the voltage decrease per degree F drop in temperature is in the order of 0.00015 volt, while on discharge it is appreciably greater, sometimes reaching as much as 0.003 volt

at high rates. On charge, the effect is reversed, with 0.0038 volt increase in voltage for each degree F drop in temperature during charge at the 8-hour discharge rate.

**2.39 ♦Temperature of Electrolyte:♦** The best cell temperature, considering both life and capacity is from 65 to 80°F. Temperatures lower than 65°F are objectionable only because of lowered battery capacity. High temperatures are objectionable because of increased positive plate corrosion and the resulting decrease in battery life. ♦If operated at electrolyte temperature above 90°F for over 2 months per year, battery life expectancy must be reduced by 20 percent.♦ For lead-calcium cells, the life at 90°F is only half that at 77°F and at 100°F, the life is one quarter that at 77°F. The life of lead-antimony cells at 90°F is three-fifths that at 77°F, and at 100°F, the life is one-third that at 77°F. Therefore, operation at elevated temperatures is not advisable and, except on initial charge, 110°F should not be exceeded ♦(see Section 157-601-201).♦

**2.40 ♦Freezing of Electrolyte:♦** Freezing of electrolyte in the pores of the plates, particularly the positive, will cause considerable damage and loss of cell life not immediately apparent from battery voltage or appearance. See Section 157-601-701 for a table giving freezing temperatures at various specific gravity values. On float or very low discharge rates, ambient temperatures below the freezing temperature for short periods are seldom harmful. In emergencies, power can usually be taken from the battery for extended periods at ambient temperatures below the freezing temperature, but it is quite likely to cause permanent damage to the battery. High rate discharges in ambients approaching freezing temperatures are dangerous because water or low specific gravity electrolyte formed in the pores of the plates and separators will freeze.

**2.41 Local Action: ♦**Local action is defined as the loss of plate capacity due to self-discharge within the cell. It is primarily the result of discharge currents flowing between different parts of the plate due to small differences in voltage.♦ It varies with age of cell, temperature, specific gravity of electrolyte, state of charge, etc, and is greatly accelerated by any impurities which get into the electrolyte.

### 3. CHARGE

**3.01 Charge Equipment:** Batteries are usually charged from generators and rectifiers. The term **charger** has sometimes been used to mean a rectifier, as distinguished from a generator. However, the term **charge equipment** is now generally used whenever information as to the type of charging source is not pertinent.

**3.02 Manual or Automatic Charge Control:** Depending on plant design, the control of charge voltage and current or of starting and stopping the charge may be either manual or automatic.

**3.03 Float Charge:** On float, the battery terminals are maintained at a specified voltage (see Section 157-601-301) so that proper trickle current is furnished to the cells. Maximum life is to be expected with continuous float; loss of battery life varies directly with the size and frequency of variations from the specified float voltage. No discharge is required for the benefit of the battery.

**3.04 Constant Current Charge:** With constant current charge, the charging current is held as nearly constant as practicable. The voltage will increase as the charge progresses until final voltage is reached. See Fig. 6 for a typical constant current charge curve.

**3.05 Variable Current Charge:** With variable current charge, the charger setting remains fixed for the duration of the charge or is infrequently adjusted. The current tends to reduce as the battery voltage builds up and, in addition, the current to the battery varies as the office load changes.

**3.06 Charge by Load (Emergency Cells):** Charge by load is a type of variable current charge used on recharge of emergency cells. With this system the cells are in series with the charger so that all current furnished to the load or to the main battery passes as charging current through the cells being charged by load. Such charge should be watched to see that charging current is not excessive.

**3.07 Constant Voltage Charge:** With constant voltage charge, the voltage is brought up to a predetermined value and is then held at this

value for a fixed time. The current automatically tapers off to a small value toward the end of the charge so that heavy gassing is eliminated.

#### 4. TYPES OF CHARGE

**4.01** An *initial* charge is the first charge given the batteries after receipt from the manufacturer. It is quite important that this charge be given as soon as possible after shipment from the battery company, to avoid excessive sulfate formation (see Section 157-601-703).

**4.02** *Overcharge* is any charge where charging is continued after the cells are fully charged. It may or may not represent excessive charging. More charging than necessary can cause shorter cell life due to wearing away of active material. Overcharge at high currents may also cause buckling and cracking of plate grids.

**4.03** An *equalizing* charge is a charge that is continued to a measured end; that is, until current and voltage or specific gravity have been

stabilized for a specified time. It is a form of overcharge given periodically under some operating routines and in cases of sulfation or other evidence of chronic undercharge.

**4.04** A *boost* charge is an overcharge of arbitrary length, the overall time for each voltage being specified. On floated batteries it may be given after an emergency discharge and on the first evidence of irregularity or undercharge. (See Section 157-601-701).

*Note:* Some plants are not capable of boost charging and the cells are floated continuously.

**4.05** A *mixing* charge is given after adding an appreciable quantity of water or high specific gravity electrolyte, if reasonably prompt mixing is not expected under normal operating routines. It usually consists of the equivalent of one hour of overcharge at the 8-hour rate.

**4.06** A *special* charge is any charge ordered by local supervision to care for local conditions.