

THEORY AND DEFINITIONS

LEAD-ACID TYPE STORAGE BATTERIES

1. GENERAL

1.01 This section describes the theory, discusses the methods of operation, and includes definitions of general terms for lead-acid type storage batteries used in telephone offices.

1.02 The section is reissued to bring it up to date, to add information previously shown in Section A801.006, and to change the title of this section accordingly.

1.03 A storage cell is an electrolytic cell for supplying electrical energy, which cell, after being discharged, may be re-stored 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 a connected group of two or more storage cells. 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 which the process, in general, is not reversible.

1.04 The fundamentals of battery maintenance are covered by the five rules listed below. All the detailed recommendations and informational data in this and other sections of the practices are to assist in meeting these rules.

- (a) Maintain battery in healthy state of charge with as little excess charge as possible.
- (b) Maintain electrolyte level between maximum and minimum by the addition of approved water.
- (c) Keep the battery clean.
- (d) Keep temperature of electrolyte within limits.
- (e) Avoid explosions.

1.05 Information in this section is arranged under the following headings:

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2. THEORY OF OPERATION

Chemical Action

2.01 In a fully charged cell, the active materials consist of 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 lead sulfate on both plates, and water. 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 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 reversal is a charge of approximately 150 per cent of 8-hour capacity. Chemical conditions for theoretical full

charge and full discharge are shown below, but in practice these conditions, particularly the discharged condition, are only approached.

<u>CHARGED</u>		
<u>Positive Plate</u>	<u>Electrolyte</u>	<u>Negative Plate</u>
PbO ₂	2H ₂ SO ₄	Pb
(Lead Dioxide)	(Sulfuric Acid)	(Lead)
<u>DISCHARGED</u>		
<u>Positive Plate</u>	<u>Electrolyte</u>	<u>Negative Plate</u>
PbSO ₄	2H ₂ O	PbSO ₄
(Lead Sulfate)	(Water)	(Lead Sulfate)

2.02 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 liberated in this reaction combines with hydrogen from the water to form sulfuric acid at both plates. The consumption of water and the liberation of sulfuric acid, sometimes described as "getting the acid out of the plates" caused by the conversion of lead sulfate on both plates, produces 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 plates and oxygen at the positive plates and the cell starts to gas.

Charge and Discharge Rates

→ 2.03 The finishing rate (formerly called nominal charging rate) is a current value which can be absorbed by the cell throughout the charge without overheating or harmful gassing. It should not be exceeded toward the end of the charge, when the cell is gassing actively. There is no harmful effect in charging at a rate less than the finishing rate. To save time, a high starting rate may be used. → The rule, in such case, is that rates higher than the finishing rate should never be greater in amperes than the charge in ampere-hours yet to be returned to the battery. A rule that gives about the same results and is usually easier to apply is that charge rate may start as high as 150 per cent of the 8-hour discharge rate and taper to end at the finishing rate or lower, provided voltage does not exceed 2.30 volts per cell at any time prior to reaching the finishing rate and provided temperature limits are not exceeded. On a → constant voltage charge, after a deep

→ discharge making currents beyond the capacity of the charger permissible, the charge would start at charger maximum output current and remain at this constant current value until voltage was up to regulated value. The charge would then continue at constant voltage with the current falling off until full charge was reached. At this time, voltage, current, and specific gravity would be constant but electrolyte stability would not be apparent on samples which could be → reached by the hydrometer.

2.04 A trickle rate is the current necessary to replace local action (see 2.47) and keep a battery in a fully charged condition when the battery is delivering no load. This rate for batteries of nominal 1.210 specific gravity may be expected to range between → 1/4 of 1 per cent and 1 per cent of the 8-hour discharge rate of the battery for new lead-antimony cells and between 1/50 and 1/15 of 1 per cent for lead-calcium cells, depending on such factors as temperature and specific gravity. The trickle rate remains about the same for life on lead-calcium cells but may increase enormously for lead-antimony cells as they age. A cell floated → continuously at the proper voltage will automatically take the trickle rate it needs. In some emergency cell charge circuits, changes in the control may be required to obtain the reduced trickle currents taken by lead-calcium cells.

2.05 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 per cent 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.

2.06 Because of the large surface of active material and the low internal resistance, a battery can usually be discharged at any rate without injury. 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 considerable time, such as several days, since the diffusion of acid through the active material is more complete and a greater percentage of the active material is available to sustain the charge.

2.07 For purposes of comparison, telephone batteries are usually rated to discharge to 1.75 volts per cell in 8 hours. → The 3-hour capacity is roughly half of the → 8-hour capacity. Batteries designed for different purposes are usually rated at different discharge rates. Automotive batteries may have a 20-minute or a 90-second

rate, while radio batteries may be rated for discharge during 20, 40, 100, or 200 hours, this rating being intended to correspond approximately to a typical cycle of use for which they are designed.

2.08 Due to less gassing towards the end of charge, lead-calcium cells can be completely recharged, while values of specific gravity which would indicate a discharged condition are still being read. To illustrate that the charging process is complete even though the specific gravity reading does not so indicate, the following tests were made. A lead-calcium battery was fully charged at 2.20 volts per cell, and the specific gravity of the electrolyte available to the hydrometer was 1.137 at the end of the charge. About 18 per cent of the 8-hour rate was then passed through the cell for 4 hours to promote mixing by gassing. As shown in Fig. 1, 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 some 4.5 per cent of the 8-hour capacity. If all of this current went to charge instead of gassing, this amount of charge would account for only a 6-point rise in the specific gravity. Most of the 51-point rise was due to the mixing caused by gassing. An additional test was made on a small cell to demonstrate the same point. A fully charged small cell showing low specific gravity was turned upside down to promote mixing. After this, the gravity was measured and showed values denoting full charge.

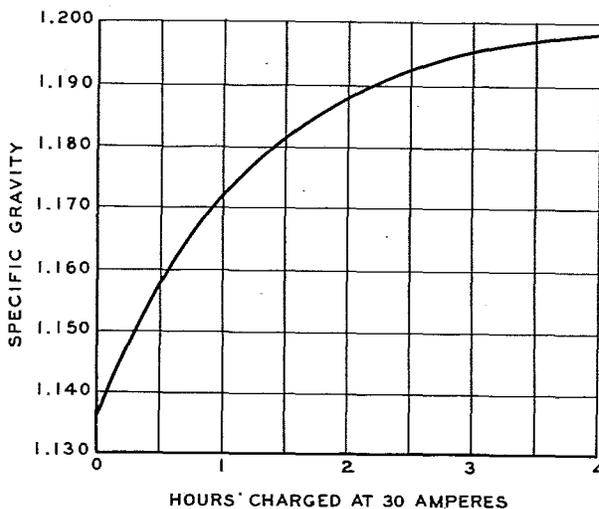


Fig. 1 - Effect of Gassing at 18 Per Cent of 8-hour Rate on Lead-Calcium Cell Charged Previously at 2.20 Volts

2.09 Typical charge curves of Fig. 2 for a fully discharged lead-calcium battery show that for both 2.20 and 2.15 volts per cell, 65 per cent of capacity is restored in the same time if the full 8-hour discharge rate is available from the charger and 80 per cent of capacity is restored in the same time for either voltage if charger output is limited to a third of the 8-hour discharge rate. In the latter case it is noteworthy that even at 2.15 volts per cell, full capacity is restored in 72 hours.

2.10 For partial discharges of less than 1 per cent 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. 3, it took 6-1/2 hours to replace a 32 per cent partial discharge and 9-1/2 hours to replace the last 32 per cent of a full discharge.

Specific Gravity of Electrolyte

2.11 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 becomes lower as the battery is discharged and rises as the battery is charged. The specific gravity readings of a cell may therefore be used 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. Due to the tendency of diffusion to cause hydrometer readings to rise for a time after charge or the addition of water; a drop in hydrometer readings during this period is a definite sign of discharge.

2.12 The specific gravity varies with changes in temperature of the electrolyte, dropping one point (0.001) for each 3-degree rise in temperature and rising one point (0.001) for each 3-degree drop in temperature. As it is essential that all readings be computed on a common temperature basis so 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. For many years, 70F was used as the reference temperature in telephone offices but 77F

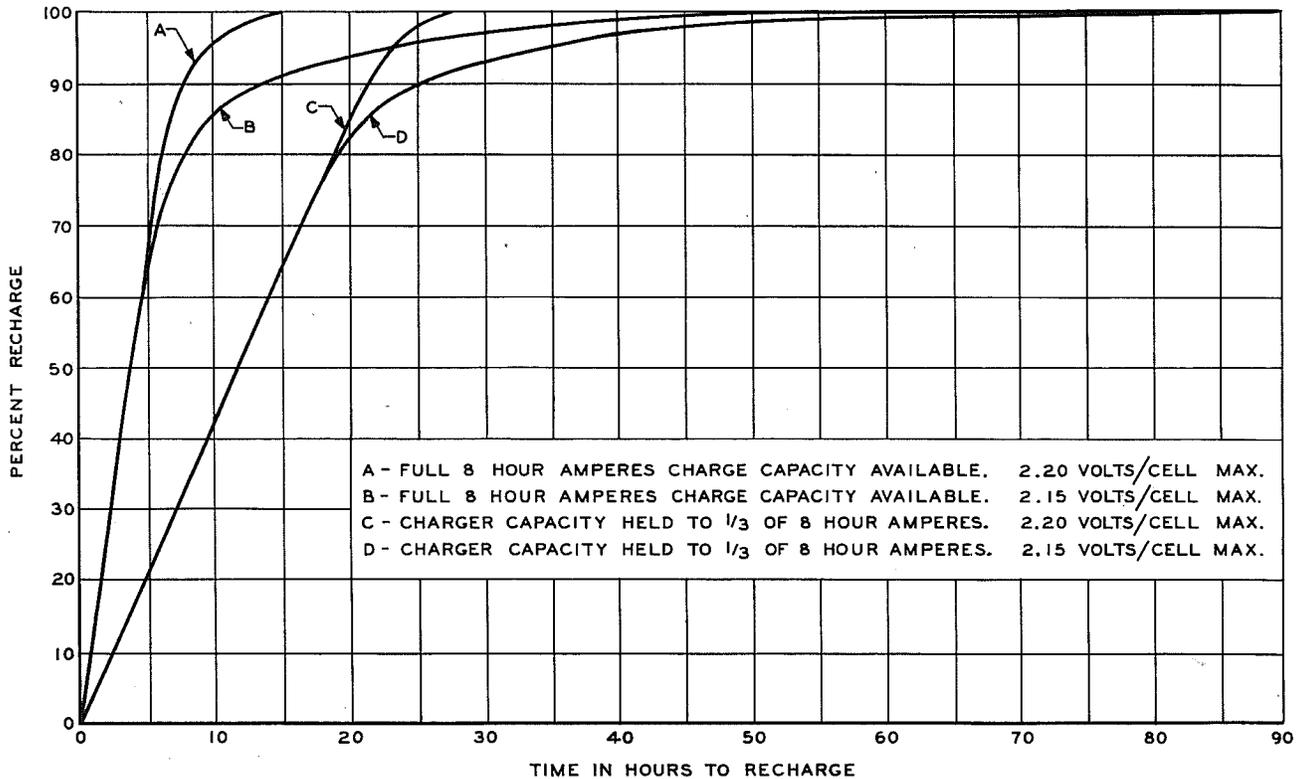


Fig. 2 - Typical Charge Curves for a Fully Discharged Lead-Calcium Battery

(25C) is the present standard as discussed in Section A401.001. 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, and a plus correction is applied to 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.

2.13 Change in surface level of the electrolyte due to loss of 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 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.

2.14 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 action. All instructions in these practices, however, calling for maintenance based on percentages of the gravity range assume the use of the full listed gravity range at the 8-hour rate.

2.15 The equalizing charge specific gravity is the gravity after an equalizing charge and in most cases after a boost charge. It, as well as the full charge specific gravity, which is the gravity after a regular charge, is reduced gradually due

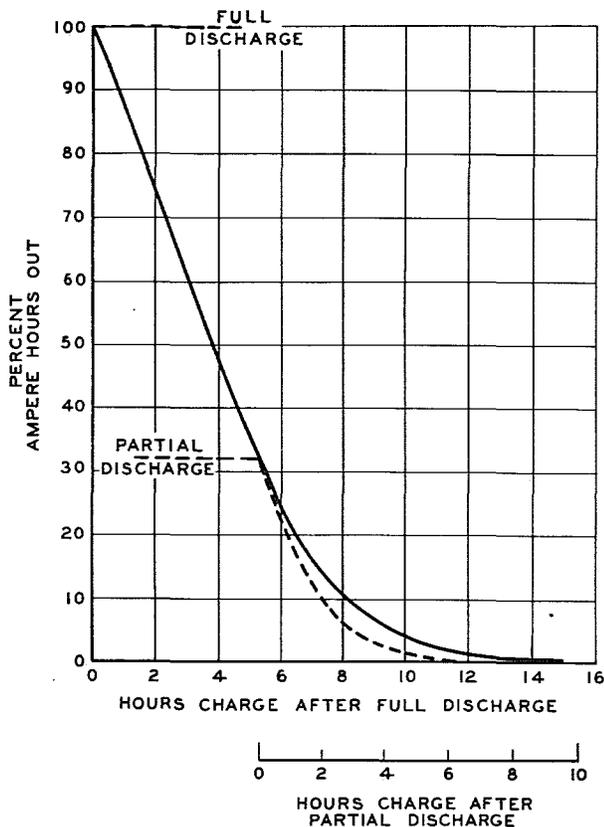


Fig. 3 - Comparison of Charge Rate at 2.20 Volts After Full and Partial Discharge

to sediment, sulfate, loss of acid as spray, and the general aging of the cell. After the specific gravity becomes stabilized, this drop may be about one point a year on float or from three to five points a year on cycle charge. It varies with the size of the battery, the normal working range, and particularly with the operating method employed.

2.16 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 at 77F. The majority of the batteries now used in telephone power plants have a nominal specific gravity of 1.210 (1.195 to 1.225).

2.17 As discussed in 2.11, specific gravity at the end of a charge, particularly on lead-calcium cells, does not indicate the true state of charge, unless heavy gassing has occurred. However, during discharge the falling specific gravity will still be a measure of the capacity remaining, if to begin with, the electrolyte was completely mixed. See Figs. 4 and 5.

2.18 The difference in the specific gravity on recharge between two parallel strings is shown in Fig. 4. It can be seen that there is a sharper rise in specific gravity on the lead-antimony string which commences as soon as a voltage of 2.2 is reached, while very little rise occurs in the lead-calcium string. This is because the gassing rate at 2.2 volts is estimated to be ten times greater for lead-antimony than for lead-calcium. Hence, the lead-calcium cells regain their full charge specific gravity almost entirely by the diffusion process practically unaided by gassing. Approximately 95 per cent of the gravity range is restored in 2 weeks of further floating of the lead-antimony cells at 2.15 volts per cell, while it takes approximately 6 weeks for the lead-calcium cells. Different combinations of plate retainers may also affect the rate of diffusion.

Water

2.19 The use of distilled water for leveling electrolyte is theoretically ideal but the cost of the distilled water is not justified unless other reasonably satisfactory water is not 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. For this reason, water from artesian wells is less likely to be acceptable than is surface water. Fluorides in the quantities 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 receives too much charge, increasing the loss of water. Distilled water is sometimes impure, for example, water obtained by the distillation of steam from boilers in which water softeners were used. Tap water when used should be allowed to run for a while before filling cells or taking samples to avoid the presence of iron rust or sediment from the local piping. With acid of high specific gravity, it is dangerous to pour the water into the acid. With electrolyte or acid of 1.300 or lower specific gravity, it makes no difference whether the water is poured into the electrolyte or the electrolyte is poured into the water.

2.20 Cells shipped from the factory are not expected to overflow during the initial charge if no water or electrolyte is added on the job. Where water or electrolyte is added by the installer before the initial charge (possibly to replace the spillage) overflow during the initial charge is not expected, provided additions are made at temperatures above 50F and provided cells are not filled above the low level line. After turnover, overflow

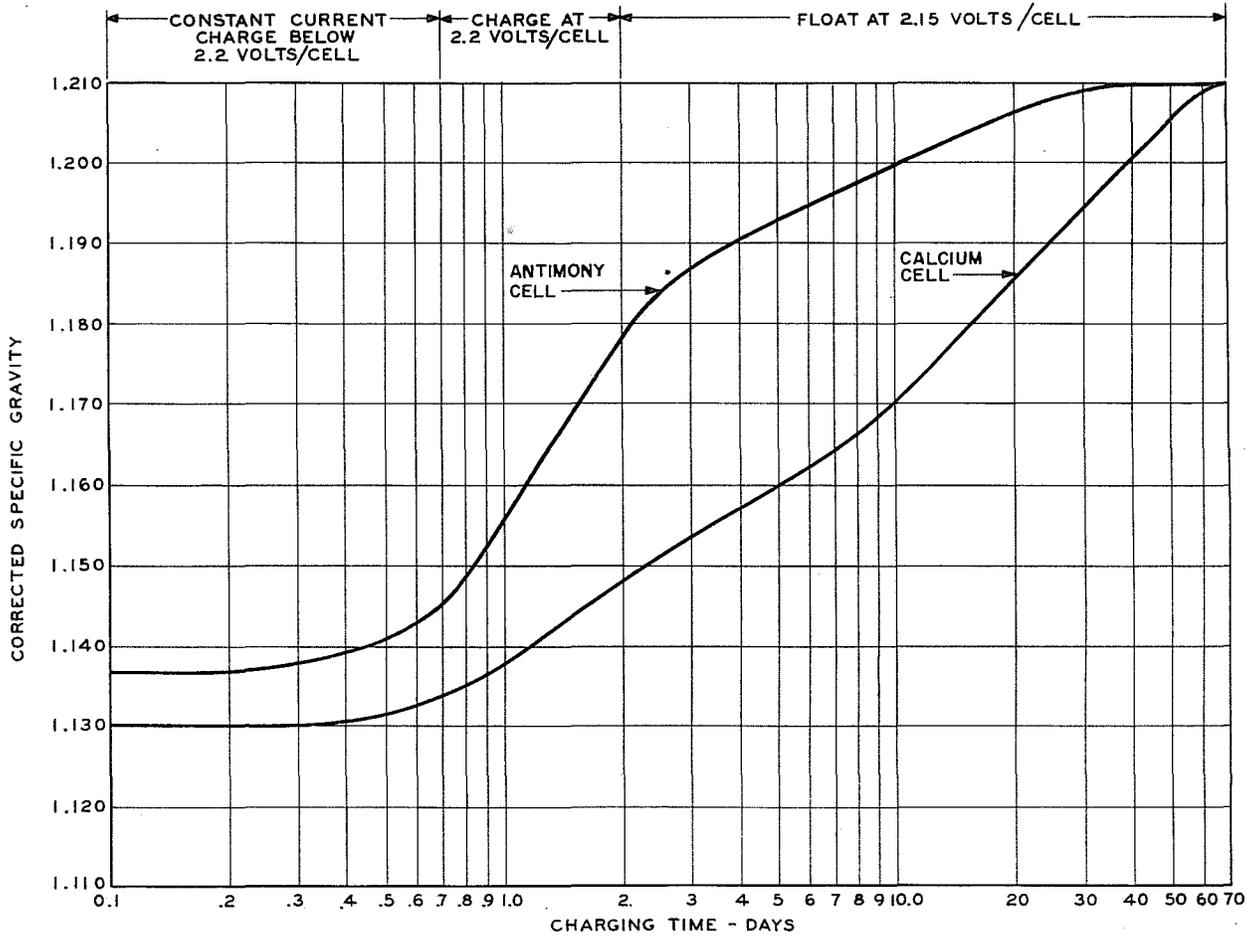


Fig. 4 - Specific Gravity Measured at Top of Cell

is not expected, provided additions are made at temperatures above 50F and provided cells are not filled above the high level line, but it is recommended that filling be toward the end of, rather than before, a charge. Even though overflow is considered improbable, its results are so objectionable that the possibility of overflow should be kept in mind during gassing charges at voltages above 2.30 volts per cell. Where imminent overflow is discovered, it can be avoided by reducing the charging rate.

Sulfation

2.21 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

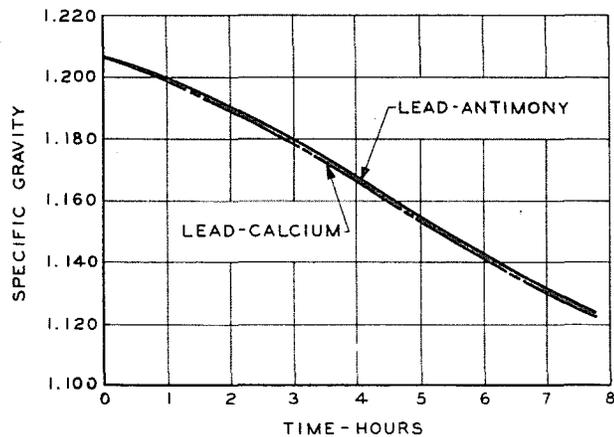


Fig. 5 - Discharge Curves - Antimony and Calcium Cells in Parallel

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 in the same manner as the finely divided useful substance by considerable extra charging. Details on indications of sulfation and corrective action are available in Section A401.001. Dropping the full charge specific gravity from 1.210 to 1.170 to correct for sulfation gives a theoretical loss of about 15 per cent in capacity but there will be more capacity actually available than with badly sulfated plates in electrolyte at 1.210. Due to the lower self-discharge rate of lead-calcium cells, they are much less likely to become "sulfated" than are lead-antimony cells.

Mossing

2.22 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. Moss which is observed on the active parts of a negative plate merely indicates that there is an abundance of active material which is being kept charged.

Sediment

2.23 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.

Stratification

2.24 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 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 without the diffusion which occurs at lower rates. 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 long periods 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.

2.25 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.

2.26 Stratification at the top of a cell after charge or after adding water may persist on float for 2 weeks with lead-antimony and 6 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 difference is not harmful.

Formation of Gas

2.27 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 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.

2.28 The mixture of gasses given off during charge, principally due to electrolysis of the water, is explosive if in sufficient

concentration. Battery rooms and enclosures should be ventilated. Flames, arcs, sparks, etc., in the vicinity of the battery should be avoided. At no time should electrolyte level be allowed to drop below the minimum and the supervisor should see that all antiexplosion precautions of the practices and of local instructions are followed faithfully.

Capacity

2.29 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 77F, when discharged to an average voltage of 1.75 volts per cell. When discharged at higher than the 8-hour rate, the expected output in ampere-hours is less than the rated capacity, and at lower rates or on intermittent loads it is more. The initial capacity is slightly less than the rated value. Capacity of 100 per cent or higher is reached after several months of service. This results in somewhat longer battery life than if full capacity were available at installation.

2.30 The capacities of older batteries, particularly on charge-discharge routines, may be considerably reduced due to the loss of active material and to impurities in the water used for leveling. In the past this has been recognized by engineering most plants on the assumption that the capacity near end of life would be less than 100 per cent, possibly 75 per cent, of rated value. Experience indicates that it is no longer necessary to make the assumption for full-floated batteries. It is now recommended that new full-floated batteries be calculated on the basis that they will have 100 per cent capacity at the end of their anticipated life. Where feasible and approved by the supervisor, full capacity discharge tests of entire strings at the 8-hour rate or at office-busy hour rate are the most conclusive check of the actual capacity of any battery where doubts exist as to its true condition. Less conclusive checks based on high rates and usually applied as spot checks on a few cells of the string are also available. See Section A401.001.

2.31 Capacity Variation With Temperature: The greater chemical activity present at higher temperatures, although it increases the losses and shortens the life of the battery, results during the period of higher temperature in greater capacity per discharge cycle. 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 at the 8-hour rate.

	<u>Temperature</u> (Degrees F)	<u>Capacity</u> (Per Cent)
→	110	114
→	90	106
	77	100
	70	97
	60	92
→	40	80
	20	65
	0	45

Efficiency

2.32 The efficiency of a storage battery on cycle operation 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. Efficiency is dependent on the resistance of the cell, the rate of electrolysis of water, and short circuits due to punctured separators.

2.33 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 per cent of the discharge, although 105 per cent is theoretically sufficient for lead-calcium. In addition to the discharge-charge inefficiency, there are long term losses due to local action. See 2.47.

Voltage

2.34 The voltage of a storage battery is due primarily to the fact that a difference of potential exists between two conducting substances immersed in the same electrolyte. For open circuit voltage, see 2.42.

2.35 On discharge, a circuit is completed across the battery terminals, the current flows, and the voltage available at the terminals is reduced immediately to the initial voltage by the resistance drop, and later to a continuing and increasing degree by the weakening of the electrolyte density, particularly in the pores of the active material as the discharge progresses. The greater the discharge current, compared with

the amount of active material available, the more rapidly is the electrolyte immediately adjacent to the plates diluted by the water being formed and the lower the cell voltage becomes. At the same time, the surface active material is being converted into lead sulfate on both plates and when all immediately accessible material is converted, the cell has both electrodes of the same material and the voltage approaches zero. If the current is interrupted or reduced to a very small value, the diffusion of electrolyte increasing the strength in the pores of the plate and the penetration to other active material below the sulfated surface may restore the voltage till it reaches almost full value again, as measured by a voltmeter without other load.

2.36 For this reason, voltage readings provide an unreliable means of determining the condition of charge and can be used for this purpose only when current of a fixed value is flowing continuously. After the initial rapid drop, a more or less uniform decrease in voltage occurs during the discharge up to the point where the available active material is substantially converted. The voltage at this point is the final voltage and depends on the rate. It is taken as the end of discharge, since very little capacity can be obtained after it is passed. Plant design usually assumes a final voltage of 1.75 volts per cell.

2.37 As charge with constant current is started, there is a small immediate increase in voltage across the terminals due to resistance drop, and very rapidly thereafter, a large increase due to the countervoltage set up at the surfaces of the plates. The voltage then rises gradually and more or less uniformly until the charge approaches completion, at which time it becomes constant at a value which depends upon the charging rate, the electrolyte density, the design and the age of the battery elements, the temperature, etc. See Fig. 6. The specific gravity of the electrolyte would also be constant at this point, but as mentioned before, stability of electrolyte might not show on samples which can be reached by the hydrometer.

2.38 Voltage variations between cells may be excessive where unlike cells are in the same string. This would complicate maintenance and tend toward excess charge on high-voltage cells and undercharge on low-voltage cells. See Fig. 7. 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, must be of the same capacity rating, and must have plates of the same material, either all lead-antimony.

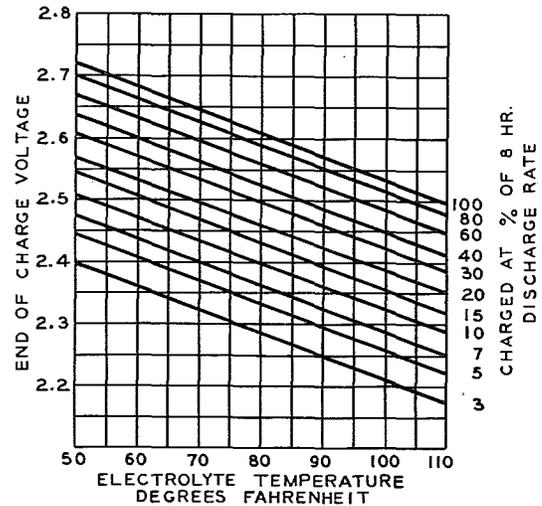


Fig. 6 - Initial Charge Minimum Final Voltage

Note: Maximum final voltages at initial charge may run 10 per cent higher for lead-antimony and 15 per cent higher for lead-calcium.

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 wood, 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, if of the same age as the main string, and use the new cells in the emergency group. Where this is not feasible, the name of the manufacturer and the serial number of the replaced cell or if it is not available, the manufacture date stamped on the cell, should be given in the order.

2.39 The speed of response of voltage to changes in current is somewhat faster with lead-calcium than with lead-antimony.

2.40 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.

2.41 Lead-antimony alloy should never be allowed in contact with the electrolyte of lead-calcium cells, as it will contaminate them with resulting voltage irregularities.

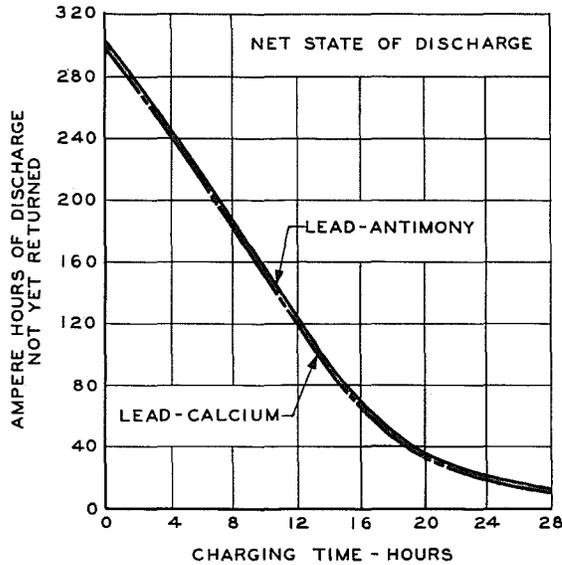


Fig. 7 - Recharge of Antimony and Calcium Cells in Parallel at 2.2 Volts per Cell

For this reason, lead alloy filling funnels on lead-calcium cells have a green or blue distinguishing color to indicate they are of lead-calcium composition. Funnels made of plastic will not contaminate nor will the indiscriminate use of hydrometers or thermometers.

2.42 Open Circuit: Upon discontinuing a charge, the voltage immediately drops a small amount, equivalent to the resistance times the current, 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. 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 +77F 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.

2.43 Increased temperature facilitates the chemical action, promotes diffusion by making the electrolyte less viscous, and decreases 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, there being some 0.0038 volt increase in voltage for each degree F drop in temperature during charge at the 8-hour discharge rate.

Temperature

2.44 The best average cell temperature, considering both cell life and battery capacity, is from 65F to 75F. Temperature from 65F down to freezing are objectionable only because of the lowered battery capacity. See 2.29 to 2.31. Temperatures above this range reduce the life of the cell and increase local action in the plates. See 2.47. Except on initial charge, 110F should not be exceeded. It is hoped that this maximum will be approached only during infrequent charges, such as boost or equalizing charges. While there is a definite increase in temperature on charge there is little, if any, increase on discharge at the current values usually experienced in telephone offices. For effect of temperature on specific gravity, see 2.12. For its effect on voltage, see 2.43.

2.45 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. The following table gives the temperatures to which electrolyte at different specific gravities at 77F can be cooled before ice crystals start to form.

<u>Specific Gravity at 77F</u>	<u>Freezing Temperature (Degrees F)</u>
1.030	+30
1.060	+26
1.090	+20
1.120	+12
1.150	+ 3
1.180	- 9
1.210	-28
1.240	-55
1.270	-85
1.283	-99 (lowest)
1.300	-92
1.330	-72

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 even approaching the above freezing temperatures are dangerous because water or low specific gravity electrolyte formed in the pores of the plates and separators will freeze.

2.46 With a fully charged cell having fixed voltage applied to its terminals, the current roughly doubles for each 15 degrees F rise in temperature. This to some extent explains the reduced life at high temperatures.

Local Action

2.47 Local action is defined as the loss of otherwise usable chemical energy by spontaneous currents within the cell or battery regardless of its connection to an external circuit. It is primarily due to current flowing between different parts of the plate due to such parts being at slightly different 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

Charge Equipment

3.01 Batteries are usually charged from generators, rectifiers, or other batteries. The term charger has sometimes been used to mean a rectifier, as distinguished from a generator, but is now used interchangeably with charge equipment whenever information as to the type of charging source is not pertinent.

3.02 Depending on plant design, the control of starting and stopping the charge may be either manual or automatic and the control of charge voltage and current may be either manual or automatic.

Charge Methods

3.03 With float, the battery terminals are held at a specified voltage (see 5.01) so that proper trickle current (see 2.04) 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 float voltage. No discharge is required for the benefit of the battery.

3.04 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 2.37. Typical final voltages are shown in Fig. 6.

3.05 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. Continuous variable current charge is described in 5.10.

3.06 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 by the charger 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. See 2.03.

3.07 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. See 2.03.

4. TYPES OF CHARGE

4.01 A regular charge is the normal day-by-day charge received by a cycled battery. It usually brings the battery up to full charge or slightly under, avoiding any overcharge.

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 causes shorter cell life due to wearing away of active material and may also cause buckling and cracking of plate grids.

4.03 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 serious loss where excessive sulfate has had time to form. In the past, the term freshening charge was used for the initial charge of cells shipped filled and charged.

4.04 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.

4.05 A boost charge is an overcharge of arbitrary length, the over-all time for each voltage being specified. On floated

batteries it is given after an emergency discharge, on the first evidence of irregularity or undercharge, and periodically.

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

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

5. OPERATING METHODS

Continuous Float (See Section A301.005)

5.01 Float voltage is now specified as 2.17 volts per cell for cells with specific gravity from 1.180 to 1.225. Higher float voltages are necessary for higher specific gravities, for example, 2.24 volts per cell for 1.285 specific gravity. Theoretically, lower float voltage should be used with lower specific gravities except where the specific gravity has been lowered because of a sulfated condition of the cell, in which case, no reduction in float voltage is recommended. With low float voltage, the current is insufficient to maintain the negative plates and serious sulfation may appear even in the first few years of operation. With high float voltage, the current is excessive for the positive plates and will cause a reduction in their life. The actual loss of life due to high float has never been determined accurately but for estimating purposes may be taken as 3 to 5 per cent for each 0.01 volt above 2.17 volts per cell when temperatures do not exceed 90F. Specified float voltages are compromises based on the conflicting technical and economic factors involved and careful adherence to them is strongly recommended. No cell should float for long periods below 2.13 volts.

5.02 Loss of expected life on float depends largely on the degree of inaccuracy of the float voltage, how frequently the batteries are discharged, and the depth of such discharges. Too much emphasis can hardly be placed on the repeated checking and accurate calibration of voltmeters. Faulty methods of calibration have been observed, such as when a 15-volt scale voltmeter was compared with a 50-volt portable voltmeter. The 50-volt portable voltmeter besides being read on the most inaccurate part of its scale did not have fine enough scale divisions to insure a good calibration. It is also possible that where power board voltmeters were removed to a instrument test shop that, by the time they had been reinstalled, errors had been introduced due to handling.

5.03 The low trickle rate of lead-calcium cells, see 2.04, is an advantage in saving power costs and reducing water additions. It has the disadvantage of making it harder to bring a nonuniform cell into line during normal float. Because of this, it is felt that where one cell has to be given extra charge, it will be better to use a single cell charger. Such chargers can be placed across one cell or two adjacent cells in a working battery with no service reaction except that rates above the finishing rate may introduce noise on talking circuits.

5.04 With continuous float - automatic, a voltage regulator holds the voltage at all times very close to the float value. The battery does a minimum amount of work which results in maximum battery life. Maximum reserve capacity is always available and very close voltage regulation is obtained for the connected circuits.

5.05 Continuous float - manual attempts to obtain the same results by manual control but this is quite difficult except at no load and at constant loads. Some emergency cells and engine starting batteries are examples of continuous float - manual at no load.

Cycle Operation - Manual (See Section A301.007)

5.06 With charge-discharge, the battery has a definite period of charge, followed by a period of discharge. Where there is only one battery, the charger also carries the load during the charging period. Where there are duplicate batteries and the necessary switching equipment, each battery, in turn, is disconnected from the load for charging.

5.07 Charge-float-discharge is the same as charge-discharge except for the improvement made by adding a floating period between the end of the charge and the start of the discharge.

Cycle Operation - Automatic

5.08 In ampere-hour meter controlled plants (see Section A301.018), charge is started automatically when the meter reads 10 per cent discharged, and stopped when the meter reaches zero discharged. An adjustable resistor allows more ampere-hours to be put back into the battery during charge than taken out during discharge. With about one cycle a day this can usually be adjusted sufficiently high to compensate for the internal losses of the battery. The length of charge can be controlled somewhat by changing the charging rate but the length of discharge is fixed by the load and the

size of the meter. Where the meter and battery are large to care for future growth or nontelephone emergency equipment, the length of cycle is often too long to allow sufficient feedback and frequent overcharges must be given or auxiliary charging equipment furnished.

5.09 Voltage relay controlled plants (see Sections A301.016 and A301.017) are of two types. Where the relay has both high and low voltage contacts, the charge is switched between high- and low-charging rates or charge is stopped and started as the battery reaches the high and low settings of the relay contacts. With single-contact voltage relays, the charge is started or switched to a high rate by a time clock or when a call comes in, and is stopped or switched to a low rate when the voltage rises to the setting of the relay contacts.

Continuous Variable Current Charge (see Section A301.015)

5.10 With continuous variable current charge, the charger output remains on continuously with a fixed setting, and the rate is not changed periodically to meet varying conditions but is based on a long cycle, such as a week. The battery will partially discharge during heavy-load periods and recharge during light- or no-load periods, usually getting a slight overcharge at the end of the long (weekly) cycle. This overcharge should not be excessive, but on the other hand, the maximum discharge at any point in the cycle cannot be too great. A suitable setting is not always possible, particularly where the 24-hour discharge in per cent of battery rating is high and there is a long idle period, as over a 2-day weekend. In such cases, some form of 2-rate charge may be necessary.