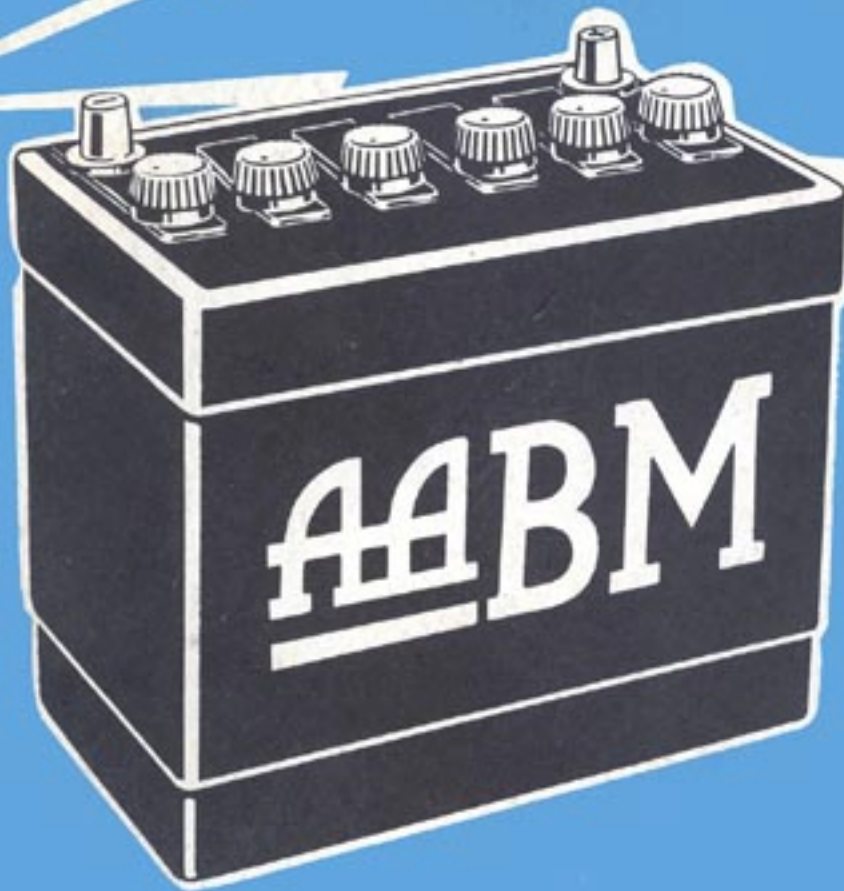


SIXTH EDITION

BATTERY SERVICE MANUAL

PRICE \$1.50



THE ASSOCIATION OF AMERICAN BATTERY MANUFACTURERS

The Association of American Battery Manufacturers had its beginning in 1924 and has served the automotive industry so constructively that today it includes in its active membership the most important battery manufacturers in the United States, as well as many others in countries throughout the world.

The public interest is admirably served by the Association through the sound policies established by its members. These policies have encouraged high standards of battery quality, have established fair and lawful practices in sales and service and have fostered improved safeguards for the health and economic welfare of those engaged in the manufacture of storage batteries.

In addition to the Active Membership of battery manufacturers, the Association includes as Associate Members a large group of companies engaged in the distribution, sale and servicing of batteries as well as a group who supply the materials related to storage battery manufacture. The Association can therefore be said to be truly representative of the entire Storage Battery industry.



S T O R A G E
B A T T E R Y
Technical
S E R V I C E
M A N U A L



SIXTH EDITION

PUBLISHED BY

**THE ASSOCIATION OF
AMERICAN BATTERY MANUFACTURERS**

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THE ASSOCIATION OF AMERICAN BATTERY MANUFACTURERS, INC.

F O R E W O R D

The Association of American Battery Manufacturers presents this Revised Sixth Edition of the Battery Service Manual with considerable pride and the hope that it will be useful in solving many of your problems. It represents the best thinking of the most capable engineers in the battery industry. It is authoritative—it is simple—it is understandable.

We are deeply indebted to the Technical Committee of our Association, and particularly those who have undertaken the responsibility for preparing and revising this Manual to keep it abreast of the many battery improvements and refinements as they develop. They have performed a tedious, time-consuming task in an outstanding manner.

Our sincere appreciation is extended to each and every one of these extremely capable Battery Engineers.

THE ASSOCIATION OF
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BATTERY CONSTRUCTION

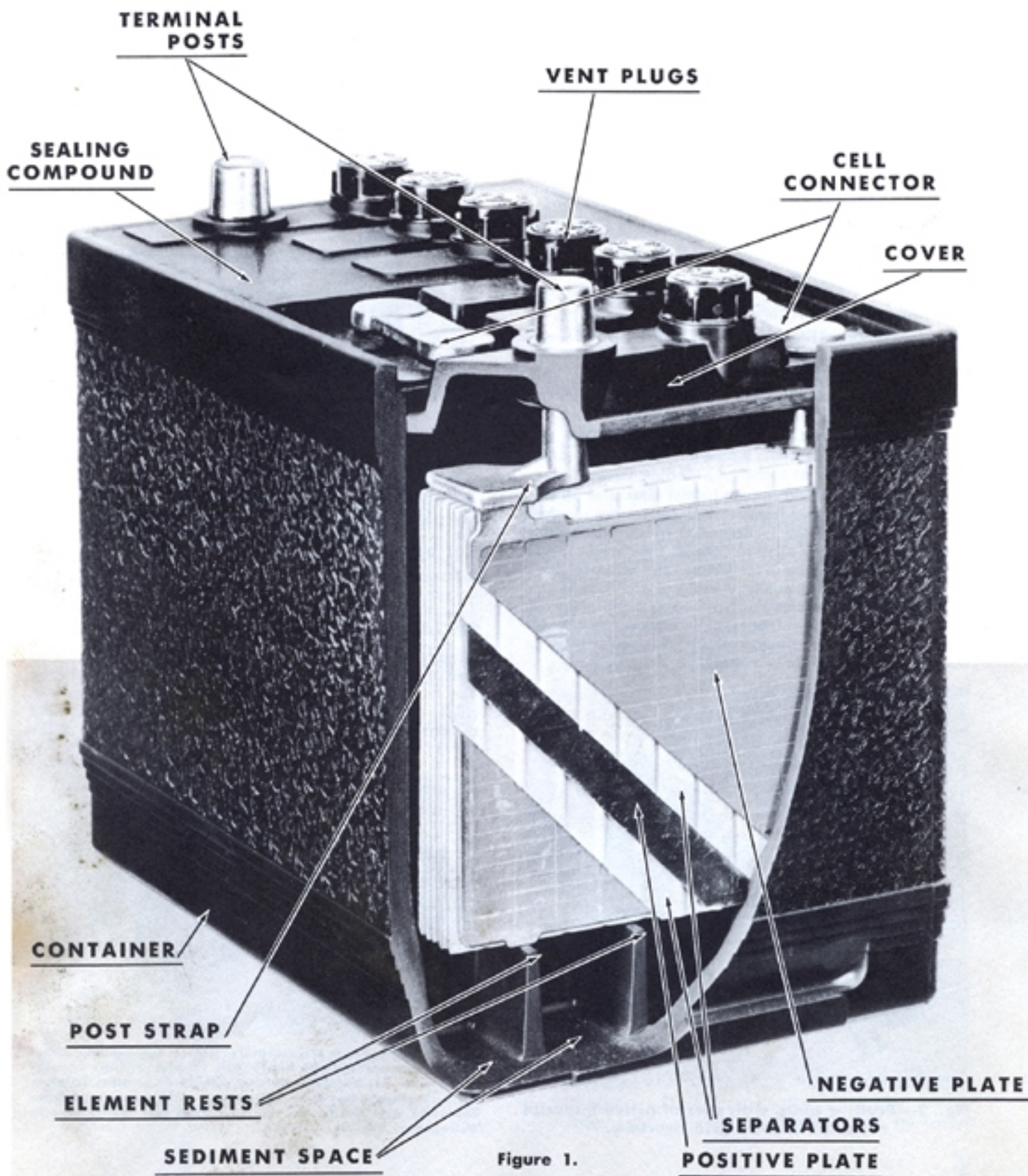


Figure 1.

BATTERY CONSTRUCTION

LEAD-ACID BATTERY DEFINED

The lead-acid storage battery is an electro-chemical device for storing energy in chemical form so that it can be released as electricity.

PARTS OF A BATTERY

The parts of a 6-cell, 12-volt battery are illustrated in Fig. 1 and are labeled for identification and reference. The sulfuric acid electrolyte is not shown.

CHEMICALS USED

There are four essential chemicals in a battery.

ESSENTIAL CHEMICALS	WHERE FOUND IN CELLS
Lead Peroxide	Positive Plates
Sulfuric Acid	Electrolyte
Water	Electrolyte
Lead	Negative Plates

GRIDS

The plates of a lead-acid storage battery consist of an electrically conducting grid framework in the meshes of which the active materials are incorporated by electro-chemical processes. These grids serve to conduct the current to and from the active materials of the positive and negative plates. An alloy consisting essentially of lead and antimony is used for the grids. The antimony stiffens and strengthens the soft lead. The presence of antimony also facilitates casting the fine detail of the wire structure of the grids and enables the battery weight to be kept to a minimum. See Fig. 2.

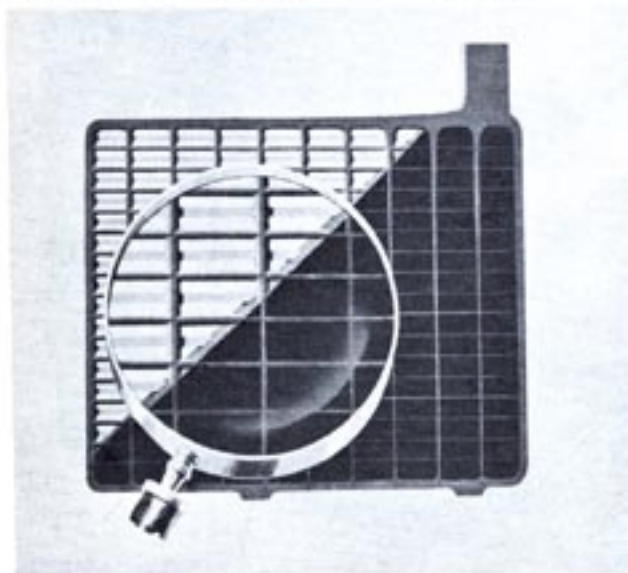


Fig. 2—Positive plate with part of active material removed to show grid structure.

POSITIVE PLATES

Positive plates are filled with lead peroxide active material. This is a dark brown crystalline material which consists of very small grains or particles, disposed so as to provide a high degree of porosity in order to allow the electrolyte to penetrate the plate freely. See Fig. 2.



Fig. 3—Negative Plate.

NEGATIVE PLATES

Negative plates, Fig. 3, are filled with a porous mass of lead, in spongy form, which electrolyte can penetrate freely. The active material also contains so called "expanders" included to prevent the sponge lead from contracting and reverting to the dense inactive state during the life of the battery.

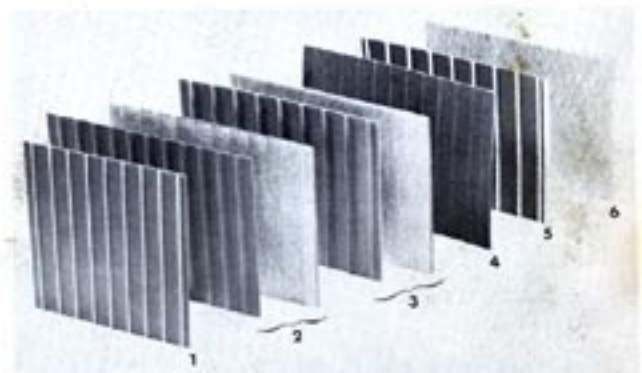


Fig. 4—Various Types of Separators (1) Resin Impregnated Cellulose Fiber Separator with Plastic Ribs. (2) and (3) Resin Impregnated Fiber Separators, with and without Fiber-Glass Retainer Mats. (4) Microporous Rubber Separator. (5) Microporous Rubber Separator with Plastic Ribs. (6) Fiber-Glass Mat Separator with Microporous Backing Attached.

SEPARATORS

No positive plate may touch a negative plate or else all the plates in the cell will lose their stored energy. Thin sheets of non-conducting porous material called separators, Fig. 4, must therefore be inserted between the plates. These include resin impregnated cellulose fiber types, also microporous rubber and other plastics, used both alone, and in combination with glass fiber mats, as well as flat glass fiber sheets with a microporous backing.

Separators have ribs on the side facing the positive plates to provide greater acid volume next to the positives, for reasons of improved efficiency, and to facilitate acid circulation within the cell. The ribs also minimize the area of contact with the positive plate which has a highly oxidizing effect on most separators. Glass fiber retainer mats, are sometimes placed between the positive plate and the separator to retard the loss of active material from the plate and to protect the separator from oxidation.

ELEMENT CONSTRUCTION

In one method of construction, the lugs of the positive plates are welded together, Fig. 5, forming a positive group, and the negative plates are similarly welded, forming a negative group. The two groups are put together as indicated in Fig. 5. Separators are then inserted between the plates with the grooved faces of the separators next to the positive plates.

In a second method of construction, a stack of alternate positive and negative plates, with a separator between each plate is built up, with the grooved faces of the separators again in contact with the positive plates. The lugs of each set of plates are then welded together as shown in Fig. 6. Each group of plates is provided with a post for connecting the elements in series in the battery.

The groups of plates assembled with separators, prepared by either method, are called an "element," Fig. 6. One element is used per cell.

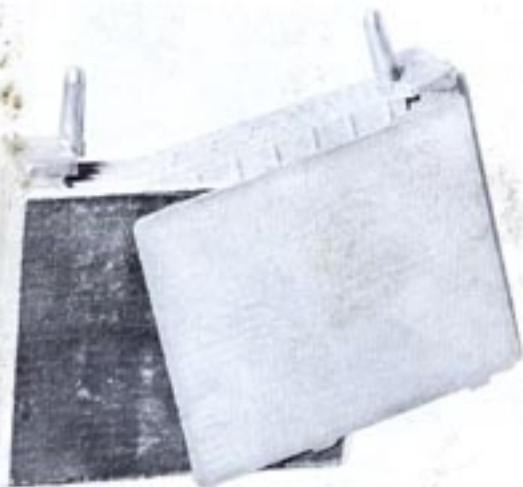


Fig. 5—Negative and Positive Groups (Groups of 11-Plate Element).



Fig. 6—Assembled Element (Assembled 11-Plate Element).

There may be any desired number or size of plates used in an element, depending upon how much energy is to be stored but there is always one more negative plate than there are positives for reasons of improved performance. The greater the plate surface area used per element the higher will be the voltage during discharge at high rates and low temperatures.

However, the open circuit voltage of a fully charged cell, no matter what the size of the cell or the number of plates in the element, is only a little over 2-volts. The battery voltage is the sum of the voltage of its cells.

ELECTROLYTE

The sponge lead and lead peroxide which fill the respective plates are referred to as the "active" materials of the battery. But these materials cannot become active until they are covered by a water solution of sulfuric acid called the "electrolyte." The sulfuric acid of the electrolyte supplies the sulfation which takes place within each of the plate materials and releases the electrical energy.

The sulfuric acid electrolyte is also the carrier for the electric current inside the battery between the positive and negative plates through the separators. The antimonial lead alloy of the grid framework of the plates carries the electric current to and from the active materials to the outside terminals.

The electrolyte of a fully-charged battery usually contains about 36% sulfuric acid by weight or about 25% by volume. This corresponds to a specific gravity of 1.270 at 80°F.

CONTAINER

The containers for automotive batteries are of the one piece molded type, Fig. 7, and are usually made of hard rubber, plastic or bituminous composition. These must withstand extremes of heat and cold as well as mechanical shock and must be resistant to the absorption of acid. In the bottom

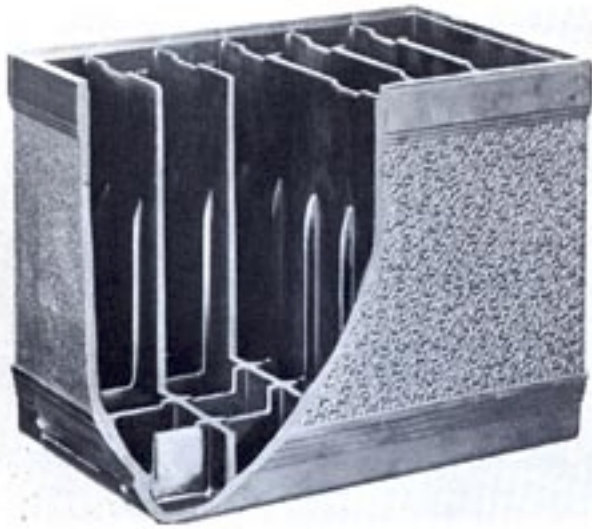


Fig. 7—Container cut away to show partitions and element rests.

of each cell compartment four narrow element rests or "bridges" are molded on which the element sets. When plates are provided with stub feet on their bottom edges, the feet of the positives sit on bridges 1 and 3 and the feet of the negative plates sit on bridges 2 and 4. This minimizes the danger of short circuits due to sediment which falls from the plates onto the bridges where the plates rest.

The repeated discharging and charging of a battery will gradually wear it out so that after a time the active material of the positive plates, which consists of extremely fine grains of lead peroxide, gradually disintegrates and loses physical contact with the plate on which it has been held. This loosened material, unless held in place, is free to fall off the plate and deposit in sediment spaces between the bridges at the bottom of each cell. By the time the sediment spaces fill up to the bottom of the element, the life of the cell is usually spent, since the shedded material will gradually form an electrical path or a short circuit between the positive and negative plates and will interfere with the charging and retention of charge of the battery. The battery may, of course, fail before this condition occurs for reasons which will be discussed later. Gasoline and oils should be kept away from bituminous composition containers as they will soften the bituminous binders.

CELL COVERS AND VENT PLUGS

Cell covers, Fig. 8, are usually of molded hard rubber and provide an acid tight seal, by means of molded bushings, for the two terminal posts and the intermediate connections which protrude through the cover. The covers are also provided with vent openings of various constructions.

There are three types of one-piece cover battery construction: (1) Connectors molded in covers with openings to burn connector buttons, (2) recessed for cell connectors, (3) one-piece covers grooved to fit over intercell connections with the cover sealed on after all intercell connections are complete. (2) and (3) are shown in Fig. 9.

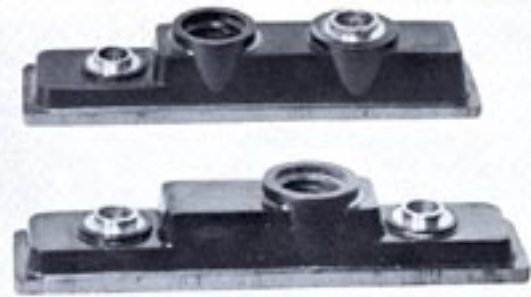


Fig. 8—Cell Covers.

Vent plugs of various designs cooperate with the cover vent openings to baffle the gases and electrolyte splashed and sprayed against the underside of the cover, to prevent loss of acid from the cells.

CELL CONNECTORS

In order to connect the cells of a battery in series, the elements are placed in each cell so that the negative terminal of one cell will be adjacent to the positive terminal of the next cell and so on throughout the battery. Cell connectors, Fig. 10, are placed over the protruding cell terminal posts and welded to them to connect the cells in series. Connectors must be heavy enough to carry the high current required for starting, without overheating.



Fig. 9—One-Piece Battery Covers.

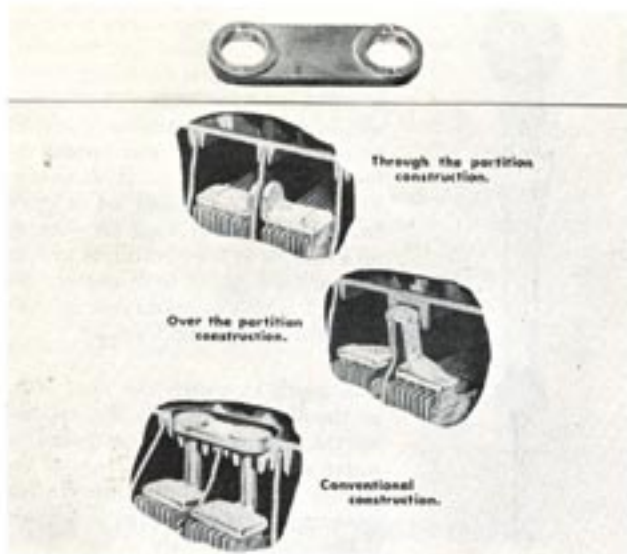


Fig. 10—Various Cell Connectors.

New construction techniques have been developed whereby cells are connected in series through the partitions or over

the top of the partitions prior to placing the cover on the battery. This type of construction provides an acid-tight seal between cells and is a shorter connection which assures minimum voltage loss.

TAPERED TERMINALS

Automotive battery terminals are of special design, being tapered to specified dimensions in accordance with standards agreed upon by the industry so that all positive and negative cable-clamp terminals will fit any corresponding battery terminal interchangeably. The positive terminal is slightly larger ($1\frac{1}{16}$ " diameter) at the top than the negative terminal ($\frac{9}{16}$ " diameter) at the top so as to minimize the danger of installing a battery in reverse. The minimum length of taper is specified as $\frac{5}{8}$ ".

SEALING COMPOUND

Sealing compounds are used to form an acid-tight joint between cell covers and containers. They are blends of specially processed bituminous substances having resistance to flow at high summer temperatures and resistance to cracking at low winter temperatures. In one-piece cover construction, rigid resin seals are used which are permanent and cannot be removed by heating.

PART II

HOW THE BATTERY WORKS

CHEMICAL ACTION OF DISCHARGE

When a cell is discharged by completing an external circuit, as in switching on the lights, the sulfuric acid acts on both positive and negative plate active materials to form a new chemical compound called lead sulfate. The sulfate is supplied by the acid solution (electrolyte) which becomes weaker in concentration as the discharge proceeds. The amount of acid consumed is in direct proportion to the amount of electricity removed from the cell. When the acid

in the electrolyte is partially used up by combining with the plates, the battery can no longer deliver electricity at a useful voltage and the battery is said to be discharged.

This gradual weakening of the electrolyte in proportion to the electricity delivered is a very useful action because it allows us to use a hydrometer to measure how much unused acid remains with the water in the electrolyte and this information enables us to judge about how much electrical energy is left in the cell.

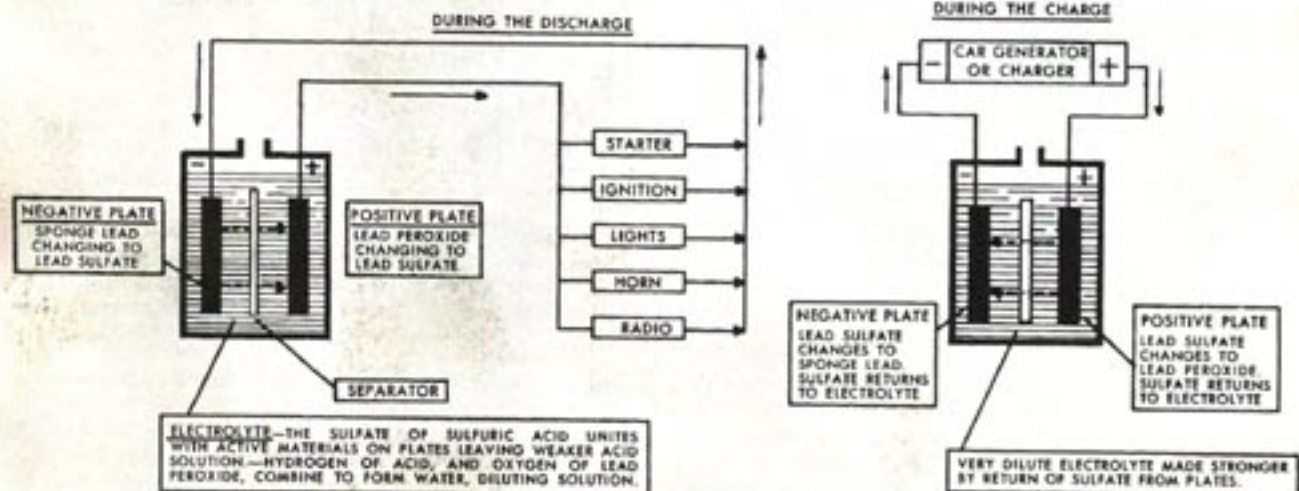


Fig. 11—Electro-Chemical action in a battery.

CHEMICAL ACTION OF CHARGE

By passing an electric current through the battery in a direction opposite to that of the discharge, the lead sulfate is decomposed. The sulfate is expelled from the plates and returns to the electrolyte, thereby gradually restoring it to its original strength. This action frees the plate active materials of sulfate and they are restored to their original chemical condition, ready to deliver electricity again. Hydrogen and oxygen gases are given off at the negative and positive plates respectively as the plates approach the full charged condition. This is the result of the decomposition of water by an excess of charging current not utilized by the plates. These gases are highly explosive and precautions must be taken to insure that no arc, spark, or flame comes into contact with the generated gases. The possibility of explosion is always present on exposure of the battery to sparks or flame, but is particularly hazardous at the end of the charging period.

CHEMICAL REVERSIBILITY

The most valuable characteristic of the lead-acid storage battery is its chemical reversibility. This means that, unlike a dry-cell battery which must be thrown away when it becomes discharged, the storage battery may have an electrical current passed through it in the direction opposite to the direction of discharge and the battery's active chemicals will be restored to the charged state. Fig. 11 indicates what happens when a battery is discharged, or when it is charged.

THE ABC'S OF SPECIFIC GRAVITY

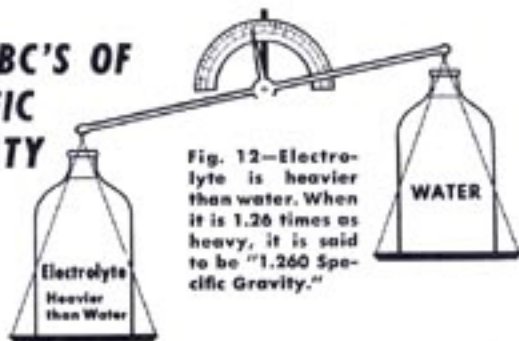


Fig. 12—Electrolyte is heavier than water. When it is 1.26 times as heavy, it is said to be "1.260 Specific Gravity."

Let us suppose we have a simple balance scale, Fig. 12. On one side we put exactly one pint of water. On the other we put exactly one pint of battery electrolyte (solution of sulfuric acid in water). The scale would go down on the electrolyte side indicating that the electrolyte is heavier than the pure water.

When the electrolyte in a fully-charged battery is 1.26 times as heavy as an equal volume of pure water, with both liquids at the same temperature, the battery electrolyte would be described as having a "Specific Gravity" of 1.260; meaning that its weight is 1.260 times the weight of pure water. When the battery discharges, the sulfuric acid in the electrolyte combines chemically with the plates and the remaining electrolyte becomes lighter in weight. By determining



Fig. 13—Service Station Hydrometer.

the relative weight of the electrolyte we can tell how much acid has combined with the plates and therefore estimate how much electrical energy is still left in the battery. But actual weighing of the electrolyte would be inconvenient, so we use instead an instrument called a Hydrometer, Fig. 13. This consists of a glass barrel and bulb syringe for sucking up a sample of the electrolyte to float an enclosed glass hydrometer, the stem of which is calibrated to read in terms of Specific Gravity.

The depth to which the float sinks in the liquid indicates the relative weight of the liquid compared to water and gives us a measure of the specific gravity of the liquid. The hydrometer floats low in the liquid if the specific gravity is low and it floats high in the liquid if the specific gravity is high. See Fig. 14.

The hydrometer float is made of glass and is equipped with a paper scale built inside the hydrometer with marks on it which must be read on a level even with the liquid surface, and this reading indicates the specific gravity of the liquid, subject to a correction for temperature which will be described later.

Fig. 15 illustrates the correct method for reading a hydrometer. The eye should be on a level with the surface of the liquid in the hydrometer barrel. Disregard the curvature of the liquid where the surface rises against the float stem and the barrel, due to surface tension. Keep float vertical.

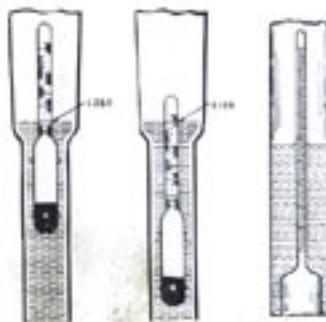


Fig. 14—
High float (left) means high specific gravity.
Low float means low specific gravity.

Fig. 15—
Correct method of reading hydrometer. Eye on level with liquid surface. Disregard curvature of liquid against glass parts. Do not tilt hydrometer while reading. Keep float vertical.

Fig. 16 graphically illustrates the relationship between specific gravity readings and the combination of the acid with the plates for various states of charge. Note the distribution of the acid indicated by the small black dots. Also note the corresponding height of the hydrometer float for each condition.

HYDROMETER MEASURES STATE OF CHARGE

A hydrometer of the syringe type, Fig. 13, used to measure the specific gravity of the electrolyte in a cell, gives an indication of how much unused sulfuric acid remains in the solution and is therefore a convenient indication of the approximate capacity still available in a normal cell. For accuracy, the liquid level of the cell should be at normal height when a hydrometer reading is taken and the electrolyte should be thoroughly mixed with any water which may have just been added. Hydrometer readings should, therefore, never be taken immediately after water has been added. The water should be thoroughly mixed with the underlying electrolyte, by charging, before hydrometer values are reliable.

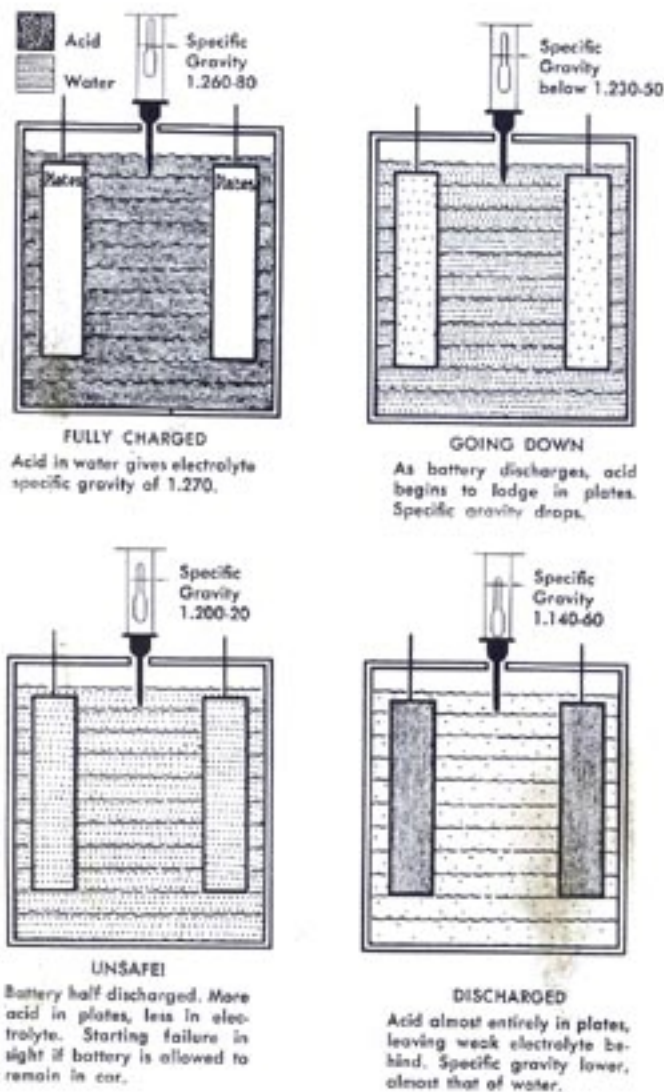


Fig. 16—During discharge, as acid combines with both Plate Materials, Hydrometer sinks lower. Note changing position of black dots in illustrations.

The following table illustrates typical ranges of specific gravity for a cell in various stages of charge with respect to its ability to crank the engine at 80° F., with initial Full-Charge Specific Gravity at either 1.260 or 1.280.

1.260 Sp. Gr.	1.280 Sp. Gr.	100% Charged
1.230 Sp. Gr.	1.250 Sp. Gr.	75% Charged
1.200 Sp. Gr.	1.220 Sp. Gr.	50% Charged
1.170 Sp. Gr.	1.190 Sp. Gr.	25% Charged
1.140 Sp. Gr.	1.160 Sp. Gr.	Very little useful capacity
1.110 Sp. Gr.	1.130 Sp. Gr.	Discharged

In reading a hydrometer, the barrel must be held vertically and just the right amount of acid be drawn up into the barrel with bulb fully expanded to lift the float freely so that it touches neither the side, nor the top, nor the bottom stoppers of the barrel.

The hydrometer barrel and float must be kept clean with soap and water so that the float will not stick to the sides. The float must be inspected occasionally for cracks which would allow acid to enter the airtight float and make any reading with it unreliable. If the paper scale inside the float is wet, it is an indication that the float leaks, and should not be used.

THERMOMETER CORRECTS HYDROMETER

No hydrometer reading is strictly correct until a temperature correction has been applied. At ordinary temperatures it is not usually necessary to correct a hydrometer reading for the temperature effect, but at extremes of temperature the correction may be important, so the method of correction will be described.

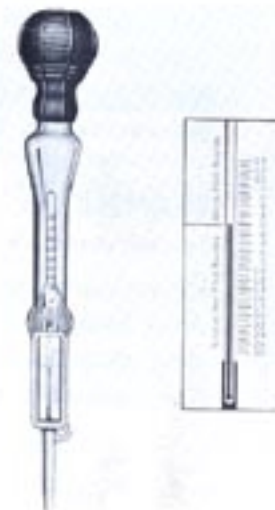


Fig. 17—Thermometer built into Hydrometer.

Hydrometer floats are calibrated to indicate correctly only at one fixed temperature. If used in acid at any other temperature, a correction must be applied. The reason for this lies in the fact that the acid volume expands when it is heated and shrinks when it is cooled. When expanded, due to heat, it will not be as dense and will not raise the hydrometer float as high in the acid, and this will cause the reading to be low. When the acid is cooled, the acid shrinks in volume and becomes denser which causes the hydrometer to rise higher and read too high.

The error due to temperature is well known and we can easily correct it if we know the temperature of the acid which surrounds the float in the hydrometer.

A battery Thermometer should be of the mercury-in-glass type, have a scale reading as high as 125°F. and be designed for not over a 1-inch bulb immersion. A suitable dairy type thermometer may prove satisfactory for the purpose.

In order to obtain consistent specific gravity readings, draw electrolyte in and out of the hydrometer barrel several times to bring the temperature of the hydrometer float to that of

the acid in the cell and then measure the electrolyte temperature in the cell. Some hydrometers, Fig. 17, have a small thermometer and a correction scale built into them so that the temperature correction can readily be made.

The temperature correction amounts to about .004 Specific Gravity, sometimes referred to as 4 "points" of "gravity" for each 10°F. change in temperature.

Battery manufacturers adjust the acid in their batteries so that the specific gravity readings are accurate only when the acid temperature is at 80°F. If the specific gravity reading is taken at any temperature other than 80°F. the correction for temperature must be made. The correction for temperature is .004 Sp. Gr. per 10°F. deviation from the standard base temperature of 80°F.

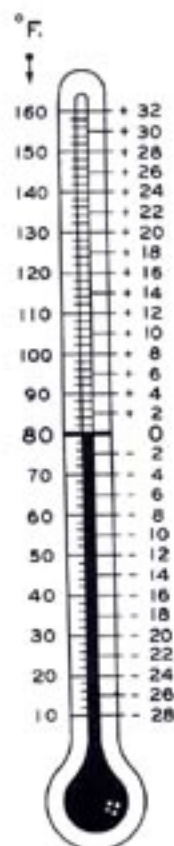
Fig. 18 illustrates the correction for hydrometer readings when the acid temperature (not the air temperature) is above or below 80°F.

The reader should note how misleading a hydrometer reading can be at extremes of temperature unless the temperature correction is taken into account.

In example No. 1, in cold weather, a dealer might install a partially-discharged battery at 20°F. in a car if he relied on the hydrometer reading alone, since it read 1.250, indicating nearly full charged if at 80°F., but when the temperature correction is applied, the true value is only 1.226 which corresponds to a substantially discharged battery. The installation of a battery in such a true low state of charge in a car in severe winter weather would probably result in starting difficulties due to further undercharging in service, with early return of the battery for recharge and customer dissatisfaction.

Example No. 2 might be encountered during very hot weather when a new battery is delivered to a dealer. 1.235 Sp. Gr. might indicate too low a state of charge, but corrected to 1.243 Sp. Gr. it is not unreasonably low if it has been enroute several days at high temperatures, under which conditions it will have lost several points of gravity per day by normal self-discharge. See "Self-Discharge," page 16.

Sometimes a low gravity reading of a hot battery while charging will be misinterpreted as a failure of the battery to take a full charge, but application of the temperature correction may show the battery to be fully charged. Attention is called to the fact that gravity readings may be misleading if taken just after a battery has been discharged at a high rate, such as prolonged cranking. This type of discharge weakens the acid in and adjacent to the plates and until this weak acid has had time to diffuse outwardly and mix with the remaining stronger acid in the cell, the gravity readings of acid taken at the top of the cell will be too high and indicate a higher state of charge than really exists. The acid will mix slowly if the battery stands idle for several hours, or the mixing will be more rapid if the battery is charged and the acid mixed by gassing.



EXAMPLE No. 1 —
Temperature below 80°F.
Hydrometer Reading 1.250
Acid Temperature 20°F.
Subtract .024 Sp. Gr.
Corrected Sp. Gr. is 1.226

EXAMPLE No. 2 —
Temperature above 80°F.
Hydrometer Reading 1.235
Acid Temperature 100°F.
Add .008 Sp. Gr.
Corrected Sp. Gr. is 1.243

Fig. 18

BATTERY CAPACITY

BATTERY SPECIFICATIONS

Complete battery performance and capacity specifications, together with detailed test procedures, are outlined in a separate publication entitled "Battery Specifications," as well as in the current edition of the "Year Book of the Storage Battery Manufacturing Industry."

Both of these publications are available at the office of the Association of American Battery Manufacturers, Inc., 19 North Harrison Street, East Orange, New Jersey.

VOLTAGE DETERMINED BY NUMBER OF CELLS

The "open circuit" voltage of a fully charged cell is 2.10 volts for acid of 1.260 Sp. Gr. This is true no matter what the size of the cell, since it is a fixed characteristic of the chemicals used in a battery and the strength of the electrolyte employed. A 12-volt battery is therefore made up of six "2-volt" cells, and a 6-volt battery is made up three "2-volt" cells.

The voltage of a cell "on discharge," however, is influenced very strongly by the size of the cell as well as by the state of charge at the beginning of the discharge, the rate of discharge, the electrolyte temperature, the design and condition of the battery. The average voltage of a cell on discharge while cranking, at 80°F. may be about 1.95-volts, whereas at 0°F. the voltage may be about 1.4-volts per cell. Generally speaking, the larger the cell the higher will be the cranking voltage under any given set of conditions of discharge rate and temperature, but it will never be as high as the open circuit voltage of the cell.

Battery voltage on discharge is affected by the concentration of the acid maintained in the pores of the plates. As soon as the acid in the pores is used up, by chemically combining with the active material of the plate, the voltage drops unless fresh acid outside the plate can diffuse into the pores. As the discharge proceeds, the acid outside the plates becomes weaker and the plate materials become saturated with sulfate so that it is increasingly difficult for acid and unused plate materials to be brought together for further chemical action. The voltage then drops to a value no longer effective in delivering useful current to the electrical system.

In cold weather the viscosity of the electrolyte increases and slows down the diffusion of the acid into the plate pores and through the separators. Although changes in open-circuit voltage are insignificant, the voltage on discharge decreases because there are changes in the nature of the electrochemical reactions as well as lowering of the voltage because of increased resistance losses in the electrolyte and separators.

The voltage of a battery on charge will be discussed under "Charging Storage Batteries" on Page 27, and under "Alternator and Generator Regulator" on Page 34.

CAPACITY DETERMINED BY PLATES AND ACID

The capacity of a battery depends upon the number and size of plates used per cell as well as upon the weight of plate materials and volume of acid present. Most automotive batteries are limited in capacity at low rates of discharge (20-Hour Rate) by the amount of acid contained in the cells or by the weight of positive plate material.

The starting capability is roughly proportional to the plate area. Automotive starting batteries are therefore built with thin plates to provide large plate areas per cell in order that acid may have quick access to as much active material as possible.

STANDARD CAPACITY RATINGS

The battery industry has arrived at several standards of battery performance which have been incorporated in the standards of the Association of American Battery Manufacturers, the Society of Automotive Engineers and the U. S. Government. A complete description of the test methods is presented in the publication of the Association of American Battery Manufacturers, Inc., entitled "Battery Specifications." A summary of the procedures of the rating tests are included here for informational purposes. All tests are based on filling gravities of 1.270 and full charged gravities of 1.280.

FILLED-DISCHARGE (ACTIVATION) TEST FOR DRY-CHARGED BATTERIES

In order to test for the charge retained in the plates, effectiveness of processing, and wetting characteristics of plates and separators, and the behaviour of the battery when activated under possible cold weather conditions, the Association of American Battery Manufacturers specifies the following test procedure.

1. Place battery and electrolyte in cold box at 30°F. $\pm 2^\circ\text{F}$. for 18 hours prior to test.
2. Remove from cold box and immediately fill the battery with the cold electrolyte.
3. Allow to stand 20 minutes after completing the filling of the last cell, then record specific gravity and temperature of the electrolyte.
4. Discharge 12-volt batteries of less than 90 ampere-hour capacity at 150 amperes (6-volt batteries and 12-volt batteries of 90 ampere-hour capacity or more at 300 amperes) to an end point equivalent to 1-volt per cell.
5. The performance of dry-charged batteries tested under these conditions within sixty days of manufacture should be 90% of the specified value for 5 or 10-second voltage when high-rate tested at 0°F., and 50% of the specified capacity in minutes when tested at 0°F.

6. A dry-charged battery, after having been tested as above should then be fully charged at a rate in amperes equal to the 20-hour discharge rate. Twenty-hour and Cold Tests may then be made.

The processing and construction of dry-charged batteries result in a decrease in initial 20-hour capacities. Therefore, 5% of the minimum 20-hour ratings should be deducted when testing dry-charged batteries immediately following the initial activation test.

The Society of Automotive Engineers specifies an Activation Test with the battery and electrolyte at 80°F. Other procedural details are similar to those outlined above. The performance requirements under the SAE Specification state that the time and voltage attained under the test conditions shall be the same as specified for the high rate discharge at 0°F.

CURRENT ACCEPTANCE TESTS

This test is designed to determine the ability of a new, previously untested battery to accept a charge under a regulated voltage system with the battery in a partially-discharged condition at 30°F.

All wet-charged batteries and all dry-charged batteries after filling are brought to a fully-charged state by charging at a rate corresponding to 1/20 of the ampere-hour rating.

The fully-charged battery is discharged at a rate of 15 amperes for the period of time necessary to remove 50 per cent of the rated 20-hour capacity.

The battery is then cooled to an electrolyte temperature of $30^{\circ} \pm 2^{\circ}\text{F}$. by placing in a suitable ambient temperature for a period of 16-24 hours.

When the electrolyte temperature has reached $30^{\circ} \pm 2^{\circ}\text{F}$., the battery shall be charged by impressing 14.4-volts across the terminals of 12-volt batteries or 7.2-volts across the terminals of 6-volt batteries with the battery still in the 30°F. ambient temperature.

This impressed voltage is to be held constant for a period of 10 minutes at which time the charging rate is to be noted. The charging rate at the 10 minute period is considered to be the current acceptance.

The basic requirement is 150 per cent of the 20-hour discharge rate with no value below 4 amperes.

20-HOUR RATING IN AMPERE-HOURS

This rating indicates the electrical size or reserve capacity of the battery. The fully-charged battery is brought to a temperature of 80°F. and is discharged at a rate equal to 1/20 of the published 20-hour capacity in ampere-hours. For example, a 12-volt battery rated by the manufacturer at 50 A.H. capacity would be discharged at 1/20 of 50, or at 2.5 amperes, until the terminal voltage falls to 10.50 volts. The number of hours required for the discharge, multiplied by the ampere rate of discharge, is the ampere-hour capacity of the battery and its 20-hour capacity. See Fig. 19. The same formula is used for the 6-volt batteries, with a 5.25 end voltage.

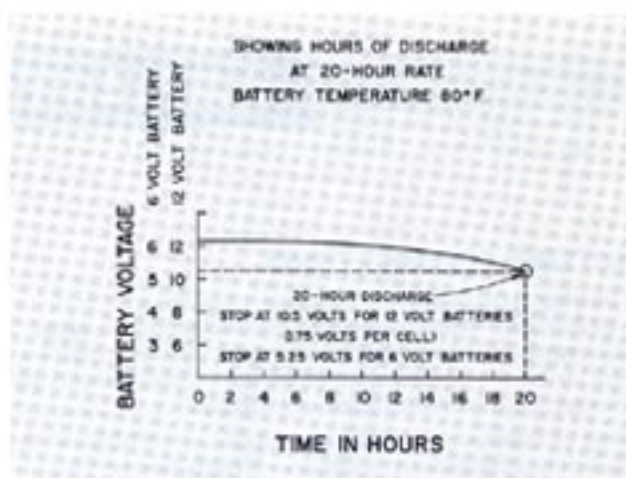


Fig. 19—20-Hour rating discharges.

COLD RATINGS AT 0°F.

All 12-volt batteries of less than 90 ampere-hour capacity are discharged at 150 amperes while 12-volt batteries of 90 ampere-hours capacity or more and 6-volt batteries are discharged at 300 amperes, at a temperature of 0°F.

These ratings indicate the cranking ability of a fully-charged battery at low temperatures and are expressed in the following two ways:—

1. By the terminal voltage of a fully-charged battery taken at 5 or 10 seconds after the start of discharge at the rate indicated above with an initial electrolyte temperature of 0°F.
2. By the number of minutes required for the battery to reach a terminal voltage equivalent to 1.0 volt per cell when discharged at the rate indicated above with an electrolyte temperature of 0°F. at the start. See Fig. 20 for a characteristic curve.

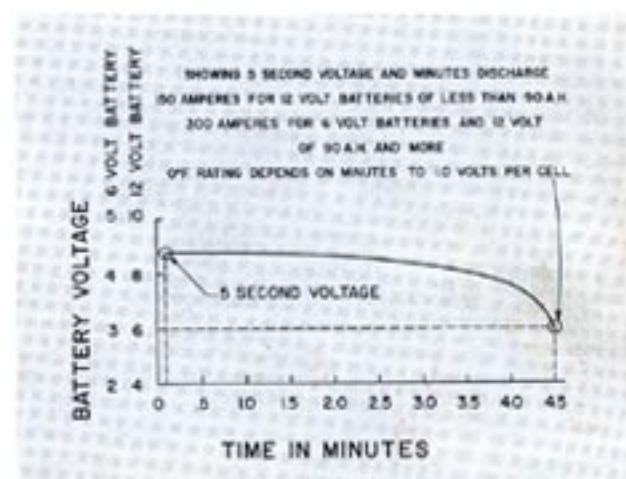


Fig. 20—Typical Cold Rating Discharges at 0°F.

THE 20-MINUTE RATING IN AMPERES

This rating once used widely in the industry, but abandoned as a standard, is a rating which at one time approximated the cranking ability of a battery at warm temperatures.

A fully charged battery at 80°F. is discharged at the manufacturer's published 20-minute rate until the voltage drops to the equivalent of 1.5-volts per cell. The battery should discharge for a minimum of 20 minutes.

There is no real justification for using this rating since it has no realistic connection with engine operation and serves only to confuse the buying public. This Association no longer recognizes the 20-minute rating, and has stated that as a matter of integrity in terminology, battery capacity should always be stated in terms of ampere-hours.

DIESEL ENGINE BATTERY RATINGS

Batteries for cranking diesel engines are required to deliver high sustained amperage. Several methods of rating such batteries are employed by various manufacturers. In addition to the ampere-hour capacity rating at the 20-hour rate at 80°F. and the minutes capacity rating at 300 amperes at 0°F., with a minimum 30-second voltage specified, such batteries are usually rated according to the number of amperes they will deliver for 1.5 minutes at 0°F. to an end voltage equivalent to 1.0-volt per cell.

LIFE TESTS (S.A.E.)

A battery usually wears out in service as the result of overcharging, undercharging or cycling; but temperature, age, vibration, or operator neglect all contribute to ultimate battery failure. It is not possible to duplicate car service conditions in the laboratory, but various tests have been developed which emphasize the wear on one or more of the components of the battery, so that when the battery fails, its worn-out parts may resemble those which have failed in car service.

OVERCHARGE LIFE TEST

One such test is the Overcharge Life Test which was designed when batteries were placed underhood and subjected to high engine-heat conditions. It is primarily a test of the positive-plate grid alloy and grid design, as this component of the battery is the most adversely affected. Neither the separators nor the negative plates undergo any substantial physical change. The positive active material usually remains in place with little or no shedding. The battery usually fails on this test by corrosion and disintegration of the positive grid structure.

All 12-volt batteries of less than 90 ampere hours capacity, are subjected to a continuous charge of 4.5 amperes for 110 hours, or 495 ampere-hours of overcharge, followed by a 48-hour standing period. A discharge capacity check at 150 amperes is then made to an end voltage equivalent to 1.2-volts per cell or a minimum discharge time of thirty seconds, whichever occurs first. During the entire test, the batteries are immersed to a depth of six inches in a water bath maintained at 100° + 5°F. This constitutes one Over-

charge Life unit and requires one week. The number of life units (weeks) is determined by counting the number of weeks during which the battery was capable of accepting the overcharge of 495 ampere-hours and the effect of the 48-hour stand and then delivering the 150 amperes discharge for 30 seconds before the battery voltage dropped to the equivalent of 1.2 volts per cell.

Water is added daily during charge to restore the electrolyte level to normal.

Twelve-volt batteries of 90 A.H. and above and six-volt batteries are charged at 9 amperes for 110 hours, or 990 ampere-hours of overcharge followed by 48-hour standing period, and discharged at 300 amperes to an end voltage equivalent to 1.2-volts per cell, or a minimum discharge time of 30 seconds, whichever occurs first.

LIFE CYCLE TEST

The Life Cycle is a test principally to evaluate battery internal components and it is therefore used as a development tool. It does not attempt to simulate car service conditions, which are extremely variable.

All 12-volt batteries of less than 90 A.H. capacity shall be discharged for one hour at approximately 20 amperes for a total of 20 ampere-hours and recharged at the rate of approximately 5 amperes for a total of 25 ampere-hours. For 12-volt batteries of 90 ampere-hours capacity or more and for 6-volt batteries, use double the ampere rates and double the ampere-hour values listed.

The total time for one complete cycle is six hours which permits 4 cycles per day or approximately 27 cycles a week. The temperature of the water bath in which the batteries are immersed during testing shall be maintained at 110° ± 5°F. In order to determine the condition of the battery throughout the duration of this life test, one complete discharge test is made each week at 20 amperes. The length of time in hours required for the battery voltage to drop to a final terminal voltage equivalent to 1.70-volts per cell while discharging at 20 amperes, multiplied by 20, gives the ampere-hour capacity of the battery at this rate.

When the capacity of the battery on a complete discharge cycle, at the above stated rates, drops below the ampere-hours equivalent to 40 per cent of the ampere-hours rated by the manufacturer at the 20 hour rate, the life test of the battery shall be considered completed. The point of failure shall be determined by plotting the ampere-hour discharge capacities. If a check is desired on the ability of the battery to maintain its cranking capability at low temperature during the cycle-life testing, discharges shall be at 150 amperes and 0°F. for 12-volt batteries of less than 90 ampere-hour capacity; all other batteries are to be discharged at 300 amperes and 0°F. at the second, fifth, and eighth weeks and each three weeks thereafter until the end of cycle life testing. The complete capacity discharge test is omitted in the week of the cold cycle test and each cold test is counted as a life cycle. Recharge after the cold discharge shall be at a rate of 3.8 amperes for a period equal to 1 hour for each minute discharge at 150 amperes, or 7.5 amperes for similar time periods on 300 ampere discharges.

EFFECT OF TEMPERATURE AND OIL VISCOSITY ON BATTERY PERFORMANCE

Battery capacity is greatly reduced by cold as it has a decided numbing effect on the electrochemical action. The following comparison, Fig. 21, graphically indicates the extent of the reduction in cranking power when the temperature drops from 80°F. to 32°F. or to 0°F.

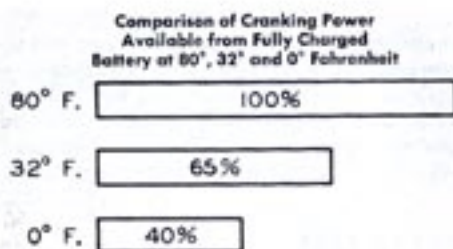


Fig. 21

Note from the length of the bars that only about 2/5 of the cranking power available at 80°F. is available at 0°F. even for a battery in good working condition and fully charged.

Stiff engine oil adds to the load of starting. The following Fig. 22 shows the relation of cranking power at temperatures corresponding to "summer", "freezing" and "zero" temperatures for an engine using S.A.E. 10W-30 multi-viscosity crankcase oil.

We see that at 0°F. the engine requires approximately twice the power to crank that it required at 80°F. With the use of single-viscosity winter-grade S.A.E. 20W oil the cranking power requirement rises about 2½ times on the drop in temperature from 80° to 0°F.

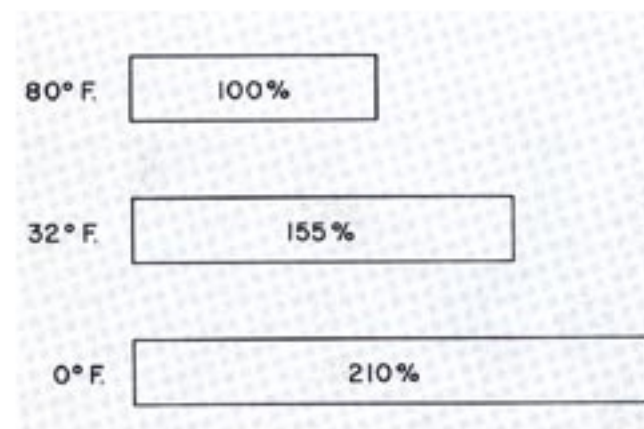


Fig. 22—Comparison of power required to crank engine with S.A.E. 10W-30 oil at 80°, 32° and 0° Fahrenheit.

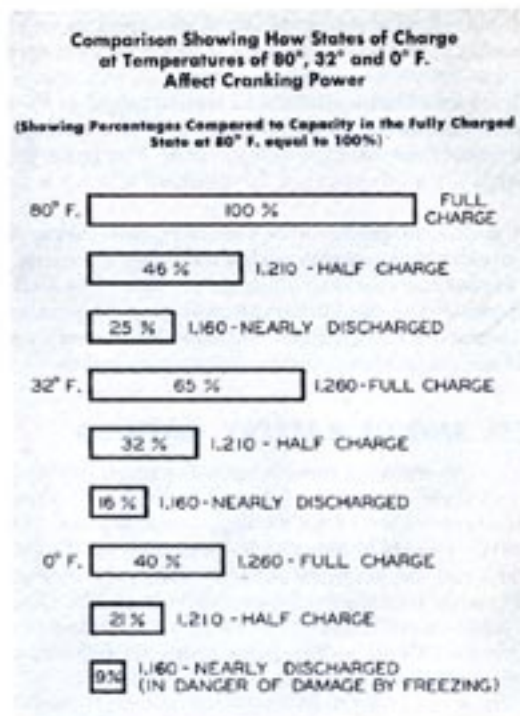


Fig. 23

The combined effect of 0°F. cold, in reducing battery capacity to 2/5 of its normal power and the increase in cranking load due to stiff oil to 2 times the warm weather load, gives us a better appreciation of the job a battery has to do in cold weather and emphasizes the need for keeping a battery in the nearly fully-charged condition during cold weather. The importance of keeping a battery fully charged is shown in Fig. 23. Here for temperatures of 80°, 32° and 0°F. we have compared the cranking power available in a good battery at the fully-charged (1.260 Sp. Gr.), half-charged (1.210 Sp. Gr.) and discharged (1.160 Sp. Gr.) condition.

Note that a nearly-discharged battery at 0°F. has less than 1/10 the available cranking power of a fully-charged battery at 80°F. This emphasizes why it is a wise precaution to keep batteries fully charged and to recommend recharges when the gravity falls to 1.225 or below. A battery discharged to 1.100 Sp. Gr. or less cannot be expected to crank an engine at any temperature.

The above gravities labeled "half-charge" and "nearly-discharged" are related to the ability of the battery to crank an engine at 80°F. and are not based on the 20-hour discharge at 80°F.

A battery discharged at a slow rate, corresponding to a load such as the 20-hour rate, would be considered "half-discharged" at about 1.180 Sp. Gr. and "discharged" at about 1.080 Sp. Gr. at 80°F. See Page 23.

PART IV

INSPECT SHIPMENTS BEFORE ACCEPTANCE

There are two conditions in which automotive batteries may be shipped, as follows:

Description of Condition for Shipping	Plates Charged or Uncharged	Condition of Plates and Separators When Shipped	Cells Filled or Unfilled
Wet-Charged	Charged	Wet	Filled
Dry-Charged	Charged	Very Dry	Unfilled

INSPECT SHIPMENTS FOR DAMAGE

Immediately upon receipt, check electrolyte levels to detect possible liquid loss during shipment. In the case of dry-charged batteries, only visible damage can be considered because there is no electrolyte present. Inspect incoming batteries for mechanical damage, either visible or concealed, which may have been incurred in shipment. A "concealed damage" is understood to mean a damage to the contents of a package which is not in evidence at the time of delivery by the carrier but which is later discovered.

The carrier or carriers are responsible for batteries lost or damaged in transit. The title to goods rests with consignee when batteries are shipped F.O.B. factory, and only the consignee can legally file claims. When loss or damage is noted at time of delivery, require the person making delivery to note loss or damage on freight bill or affix his signature under consignee's memo of the loss or damage. Submit claim by presenting to carrier who made delivery the following information:

1. Standard Form for Presentation of Loss and Damage Claim.
2. Original Bill of Lading.

3. Original or Certified Copy of Invoice.

4. Original Paid Freight Bill with signed notation of loss or damage.

When loss or damage is discovered after delivery:

1. Segregate damaged batteries, cartons or crates.
2. Immediately request carrier to make inspection and confirm request with a letter. If inspection is waived, obtain a written "waiver."
3. If inspection is not made by carrier within five days, make your own inspection report. If possible, use form "Inspection Report of Loss or Damage Discovered after Delivery of Freight."
4. Submit claim by presenting all the four items listed above under the section headed "When the loss or damage is noted at time of delivery" and in addition submit "Carrier's Inspection Report" or "Waiver" or your request for inspection and your report on your own inspection.

If no acknowledgement of claim is received within thirty days, request same by letter. If no settlement is made within sixty days, review claim for a decision regarding necessary action, legal or otherwise. Two years are allowed in which to file suit after a claim is disallowed in writing by the carrier.

PART V

WET BATTERY STOCK MAINTENANCE

PREPARATION OF STOCK

In the absence of level indicators, the proper electrolyte level is about $\frac{1}{4}$ " to $\frac{1}{2}$ " above the tops of the separators at 80°F. for batteries of standard construction. The electrolyte level in very cold batteries will be lower than normal, so let batteries warm to normal temperature before judging electrolyte levels. Remember to correct hydrometer readings for temperature if accurate values are desired and make due allowances for the time and temperature involved in transit. See examples Page 10.

ROTATION OF STOCKS

New batteries should be placed in stock, preferably in their cartons, in such a location that the oldest batteries can be sold first. Batteries will slowly discharge during storage and must be located so that they can be reached for recharging without moving newer batteries away from in front of them. All batteries should be fully charged at the rate mentioned under "Boosting Charge" before placing in stock.

The batteries should be segregated by types. The date a battery is received can be marked on the carton or battery with chalk. This date can be helpful in selecting the oldest battery of any type in stock for earliest sale.

RACKS FOR STORAGE

Batteries should never be piled on top of one another. Simple racks for temporary battery storage can be made from loose flat boards supported by the batteries themselves. No nails are required. All boards are cut from $\frac{3}{4}$ " stock. Uprights may be 10" high, with the grain, and of about 12" width. Shelf boards can be 4" wide and 38" long, the lumber to be free from unsound knots. 8 uprights and 10 shelf boards will permit stacking 25 batteries, 5 batteries per row and 5 tiers high, if desired. See Fig. 24.

The stack is built up as follows:

Lay parallel on a smooth flat floor two shelf boards spaced so that the bottom ends of the batteries are supported by them. Place 5 batteries side by side in a row and insert one upright between batteries Nos. 1 and 2 and one between Nos. 4 and 5, pushing the batteries up snugly together so as to support the upright pieces as shown in Fig. 24. When not in use, the rack boards can be compactly stored. The above rack is only for compact, temporary storage. A heavier, permanent rack with shelves 24" apart will provide working space over the batteries for hydrometer testing and charging the batteries.

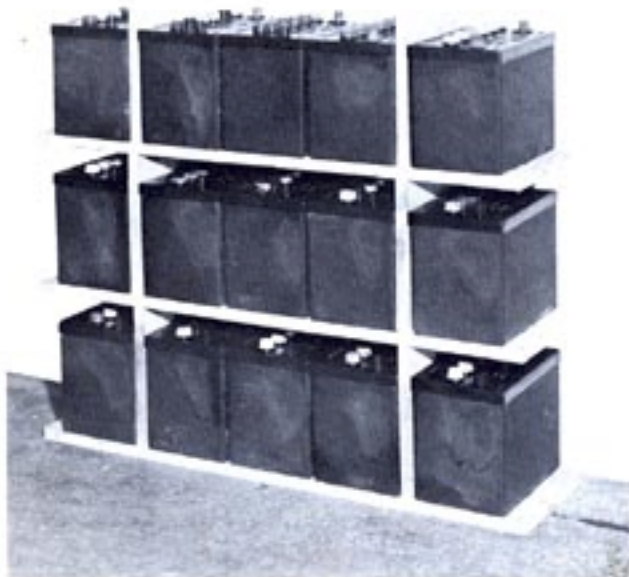


Fig. 24—Battery Storage Rack.

SELF-DISCHARGE — CAUSES AND EFFECTS

The grid framework of plates is cast from an alloy of antimony and lead containing from 4% to 9% antimony. During charging of a battery, some antimony dissolves

from the positive-plate grids and deposits on the sponge lead of the negative plates, where it sets up a local electrochemical action with the sponge lead. This slowly discharges the negative plates. The rate of this self-discharge increases with an increase in the antimony content of the positive grids and because of other factors. The presence of small quantities of other impurities may affect either the positive plates or the negative plates or both.

All automotive wet batteries will therefore slowly discharge on standing and will discharge much faster when warm than when cold. They may discharge faster when fully charged than when only partially charged. At normal temperatures of 80°F., loss of capacity by self-discharge, starting with a fully-charged battery, may amount to an average of about .001 Sp. Gr. per day over a 30-day period. At the start, it may amount to .002 Sp. Gr. loss per day and gradually taper off to less than .001 Sp. Gr. loss per day by the end of 30 days. The effect of temperature on self-discharge for the average fully charged new battery in good condition may be about as follows:

At 100°F.0025 Sp. Gr. per day
At 80°F.001 Sp. Gr. per day
At 50°F.0003 Sp. Gr. per day

The above values are approximate for about the first 10 days of standing after being fully charged. Some makes of batteries will have a higher and some a lower rate of self-discharge than the above, depending upon the methods of manufacture and the purity of materials used. To minimize the extent of self-discharge, store batteries in as cool a place as possible, away from hot air ducts or radiators in winter and shielded from direct sunlight in summer.

ALL BATTERIES SHOULD BE FULLY CHARGED BEFORE INSTALLATION

BOOSTING-CHARGE

To make up for the loss of charge while standing in stock, a boosting charge without excessive overcharge should be given batteries whenever they fall .040 in Sp. Gr., corrected to 80°F. for temperature, no matter whether they are to remain in stock or are to be made ready for sale. This will be about every thirty days at warm temperatures, and less often during cold weather. Observe level of electrolyte before putting on charge; and if necessary, add water to the cells to bring to proper level.

A charge rate of one ampere for each positive plate in one cell should be used to charge the battery. For example, a battery having eleven plates per cell, five of them being positives would be charged at a rate of five amperes. If a slow charger is not available see section on "Charging Storage Batteries," page 27.

Chalk can be used to date the carton or battery whenever it receives a recharge in stock. This will help to determine

which batteries are ready for delivery and which batteries need charging.

DISPLAY BATTERIES MUST BE CHARGED

Wet batteries used for display purposes or standing in cars

in storage must not be forgotten and neglected. They should be considered as batteries "in stock" and boosted whenever the gravity falls .010 or to a Sp. Gr. of 1.220 where fully charged gravity is 1.260. Many dealers prefer to use "dummy" batteries, with no elements in them, for display purposes.

PART VI

DRY-CHARGED BATTERIES

The dry-charged battery is just what the name indicates. It is a battery containing charged plates in a dry condition. When filled with sulfuric acid electrolyte and boost charged, it is essentially the same as the conventional wet battery.

The manufacture of the dry-charged battery calls for special processing in the handling and drying of the plates and separators.

The plates are manufactured by passing a direct current through them while immersed in an electrolyte of dilute sulfuric acid. The fully-charged plates are then removed from the electrolyte, washed in water, and completely dried without appreciable exposure of the negative plates to air or oxygen. This is necessary because the active material of the fully-charged negatives is finely divided sponge lead which oxidizes, that is, loses its charge when exposed to oxygen in the air in the presence of minute quantities of moisture.

In order to obtain dry-charged negatives, the plates must either be dried in an inert atmosphere such as superheated steam, oxygen-free products of combustion or a vacuum dryer, or dried so rapidly that excessive oxidation cannot take place.

Thorough drying of positive plates and separators is necessary in order to produce a battery free of moisture, a condition which is essential for a satisfactory dry-charged battery.

Positive and negative plates and separators may either be dried separately or as elements with the separators in place.

When water-washed, charged plates and separators are dried together, the addition of a separator wetting agent at the end of the washing period is ordinarily required for satisfactory battery activation from the dry-charged to the wet-charged state.

After assembly of dry-charged batteries, proper precautions must be taken to prevent moisture from entering the battery during the period it remains in a dry, unfilled state.

Dry-charged batteries should be stored in a cool, dry place

with humidity as low as possible; also with ambient temperature between 60° and 90°F., as uniform as possible and not subject to frequent changes.

IMPORTANT INFORMATION ON ACTIVATION OF DRY-CHARGED BATTERIES

Battery grade sulfuric acid electrolyte of the correct specific gravity must be added to the dry-charged battery in the field either at the warehouse or by the dealer.

In order to make certain that the proper electrolyte is used and the battery is properly activated, it is the practice of many manufacturers to furnish packaged electrolyte for their dry-charged batteries along with instructions for placing the battery into service. These instructions must be carefully followed.

Present-day manufacturing techniques assure satisfactory dry-charged batteries as they leave the factories, but the unknown factor in transportation, storage conditions, temperature, battery age, stock rotation, and activation determine whether the customer will receive satisfaction.

One must realize that a battery "breathes" with the fluctuation of ambient temperature and, since its active materials are sensitive to both moisture and oxygen, it is adversely affected by the atmosphere.

Merchandisers know they cannot control humidity conditions nor follow the stringent requirements of storing dry-charged batteries in a cool, dry place in ambient temperatures between 60° or 90°F.; therefore, the activating instructions must contain sufficient boosting instructions to protect their customers.

Each year, as the first cold weather arrives and is sustained for several days, battery sales are brisk and troubles multiply because most merchandisers are required to activate and install batteries beyond the charging facilities they have available. The American Automobile Association has reported that in recent years "Battery and Electrical" failures are the predominant cause of service calls. Although we might argue with the A.A.A. figures, and counter with the fact that any hard starting condition which would run

down the cold battery, would be classified as "Battery Failure," we must admit that some of the failures are due to improper dry-charged battery activation.

One way the industry can reduce the number of service calls is through sufficient boost charging of the dry-charged battery prior to installation in the customer's car.

These are the conditions when cold batteries are filled with cold electrolyte:

1. Cold electrolyte has a much higher viscosity than warm; thereby impairing its circulation through the separators and the pores of the plates.
2. The ability of the plates to accept a charge at low temperatures is reduced because of changes in the nature of the chemical reactions taking place.

Here is the accepted method for activating dry-charged batteries to overcome the problem of unknown conditions.

1. Fill each cell of the battery to the top of the separators with the correct battery-grade electrolyte as specified by the manufacturer's instructions. Using higher or lower specific gravity electrolyte than recommended can impair the battery performance. Originally filling each cell to top of separators, permits expansion of electrolyte as battery is boost charged.
2. When manufacturer recommends filling gravities of 1.250 or higher, boost charge 12-volt batteries at 30-40 amps. (6-volt batteries at 60-70 amps.) until the specific gravity of the electrolyte is 1.240 or higher and electrolyte temperature is at least 80°F. BOTH CONDITIONS MUST BE MET. If electrolyte bubbles violently while charging, reduce charging rate until excessive bubbling action subsides, then continue charging until 1.240 and 80°F. are reached. (In tropical climates, lower filling specific gravities are recommended. See Part XI, Page 23.)
3. Check volume of electrolyte in all cells and adjust to prescribed level with additional electrolyte as required.
4. Install battery in car. Turn lights on and be sure ammeter shows discharge. For cars not having ammeters, check manufacturer's manual for proper polarity. Request customer to return in one week for battery check. After battery has been in service, add only approved water. DO NOT ADD ACID.

Following these instructions will assure proper activation and satisfied customers, regardless of temperature and conditions of storage.

When cold weather warnings are forecast, it is recommended practice to anticipate demand by activating and boosting popular size batteries in advance; thus, batteries will be ready for installation at time of need and not overtax the charging equipment available.

DRY-CHARGED BATTERIES IN STORAGE

The question as to the length of time dry-charged batteries can be stored is frequently asked and is difficult to answer because of numerous factors involved. These include the original processing of the plates and separators, the exposure to temperature variations, and humidity conditions during storage. Under adverse conditions, the dry-charged battery may lose its charge in a matter of several weeks; under the best conditions, it may have good charge retention after several years.

The benefit of a dry-charged battery is that it does not experience any appreciable deterioration such as harmful sulfation or corrosion which may occur with a wet battery. The dry-charged battery can lose its charge during long standing periods in stock in a dry condition due to moisture breathed into the battery. This, however, is not harmful; and by merely filling the battery with proper electrolyte and bringing it to a state of full-charge, it becomes essentially a new battery.

Under good storage conditions, the electrolyte specific gravity on activating a dry-charged battery will drop approximately .010 points and temperature will rise 7° to 10°F. within twenty minutes of filling the battery. A battery under these conditions requires little boost charging. However, should the specific gravity drop .020 points or more with corresponding increase in temperature, the negative plates have been oxidized and the battery requires boost charging for one hour or longer at prescribed ampere rates to reach the 1.240 specific gravity and 80°F. to assure proper starting.

Here are the steps to follow to determine if a dry-charged battery has oxidized negative plates. In all instances, be sure to correct hydrometer readings to 80°F.

1. Check the specific gravity and temperature of the electrolyte in the package before filling the dry-charged battery.
2. Fill battery and let stand for 20 minutes.
3. Recheck electrolyte in battery for specific gravity and temperature.
4. The difference between 1 and 3 will indicate the degree of oxidation of the negative plates. The greater the difference, the longer charging time required. When differences are extremely high, indicating negatives badly oxidized, the battery should preferably be brought to full charge at a low ampere rate.

After the dry-charged battery has been activated it must be serviced, handled and kept charged just like any other wet battery. (See New Batteries Returned for Charging, Page 22.)

The chief advantage of the dry-charged battery is the fact that it can be stored for long periods of time in a dry condition without permanent deterioration. It may gradually

lose its charge over a period in storage, but after filling and bringing to a full charge, it is very much like a new wet battery.

The chief objections to the dry-charged battery are the necessity of handling acid and the inability to give the battery a thorough quality check before shipment.

PART VII

NEW BATTERY INSTALLATION

SELECTING THE SIZE

Batteries sold for replacement should be of an electrical size at least equal to the battery placed in the car by the manufacturer. Frequently, additional current-consuming devices have been added to the car by the owner which may make a larger capacity battery desirable.

The drain on the battery of a modern car may be very high when the engine is not running. High capacity alternators or generators carry the electrical load when the engine is running, but too small a battery may be discharged so much by lights and radio when the car is parked that cold weather starting is seriously impaired before the driving time allows the alternator or generator to restore the charge to the battery. An electrically oversized battery is therefore highly desirable to provide a factor of convenience and safety. A larger battery will also have longer life and therefore be a worthwhile investment. Cars equipped with air conditioning definitely require larger batteries.

TYPICAL CURRENT LOAD OF MODERN CARS (in Amperes)		
	Accessory Switch Load	Max. Vehicle Operating Load
Switch		
Parking	4 to 8	—
Low-Beam Headlamp	8 to 14	—
High-Beam (4) Headlamp	12 to 18	18
Heater	6 to 7	—
Windshield Wiper	2 to 3	3
Air Conditioner	10 to 15	15
Radio	0.4 to 1.8	1.8
Ignition—Standard	3	—
Ignition—Transistorized	8 to 12	12
Alternator Field	3 to 5	5
Total	—	54.8
Summer Starting	100 - 400 Amperes*	
Winter Starting	225 - 500 Amperes*	

*Values vary with engine size, engine temperature and oil viscosity.

Fig. 25

The position of the battery in some cars, with very little clearance between the hood and battery terminals, necessitates the installation of a replacement battery with the same

overall height as the original battery. This factor should be carefully checked.

REMOVING OLD BATTERY

When removing the old battery, note carefully the location of the positive battery terminal so that the new battery can be installed in the same manner in order to avoid the danger of installing reversed. Remove "ground" terminal first.

In removing or tightening the hex nut on the bolt of clamp terminals use only a $\frac{3}{16}$ " box end wrench, Fig. 26. On spring loaded terminals, only the proper pliers should be used.



Fig. 26—Box end wrench.

Inspect the cradle for possible damage caused by loss of acid from the old battery. Be sure it and its hold-downs are mechanically strong and free from corrosion before installing the new battery. Corroded parts and cable terminals may be cleaned with water, to which some household ammonia or sodium bicarbonate (baking soda) has been added, by scrubbing with a stiff brush. Do not scrape lead coating off brass clamp terminals when cleaning. Dry and paint corroded steel parts with acid-proof paint. Do not paint battery terminals.



Fig. 27—Terminal Puller

Examine cables and terminals to be sure that cables are of correct size. (See "Effect of Cable Size on Cranking," page 21). See that insulation is intact and that the clamp terminal or its bolt are not eaten away, exposing brass or iron to provide future terminal corrosion. Urge replacement of such unserviceable parts. Clean and tighten ground connection to the frame as well as tighten switch and starter connections.



Fig. 28—Terminal Cleaner — Combination of Brushes for Brightly Cleaning Clamp Terminals and Tapered Posts each time they are reconnected. Very important in Voltage-regulated systems.

CABLE TERMINALS AFFECT CRANKING AND CHARGING

As the acid eats away terminals, and exposed cable, the deposit of corrosion builds up resistance and restricts proper current flow to the starter and other electrical units.

On cars equipped with voltage regulators, where the alternator or generator voltage is held within a narrow range, the resistance due to corrosion keeps the battery from re-

ceiving the proper charging current and gradually starves it, causing an undercharged, sulfated battery.

Corroded contact surfaces of all clamp terminals and battery terminal posts should always be cleaned bright with a wire brush in order to make a perfect contact each time they are replaced. Fig. 28 shows a convenient tool for this purpose.

It is good practice when replacing terminals to grease them with a heavy-bodied mineral grease or petrolatum. Do not apply an excessive quantity as it may flow onto the sealing compound and soften it.

Do not hammer clamp terminals onto battery posts. To do so may result in severe damage to the brittle hard-rubber cell covers and sealing compound.

INSTALL NEW BATTERY FULLY CHARGED

When a customer buys a new battery he is paying for and is entitled to receive one which is fully charged. Only a fully-charged battery can deliver the published and guaranteed performance, which is the basis of the sale. Anyone who wishes to protect himself against trouble and costly service should make sure that the batteries sold to his customers are fully charged when installed. In the case of Dry-Charged Batteries the adherence to the suggestions outlined in the section on "Activation of Dry-Charged Batteries" on Page 17, should result in trouble-free operation.

Replacement cables should be of sufficient length to reach the terminal posts without causing undue strain on the posts and covers. Cables that are too taut will cause damage to posts and cause sealing compound to crack and acid to leak.

The battery should rest level in the cradle and be fastened securely in place by a suitable hold-down, using care to tighten hold-downs evenly from each end, a little at a time, so as not to distort or break the container. Do not draw hold-downs too tight. Where a hold-down is fixed at one end, care must be exercised to insure proper seating of the battery prior to applying pressure to the moveable portion.

Before connecting the cables, check the polarity of the terminals of the battery to be sure it is not reversed. Note that the tapered positive terminal of the battery is $\frac{1}{16}$ " larger at the top than the negative and that the opening of the positive cable clamp terminal is correspondingly larger to fit. Do not drop terminal corrosion in cells. Connect the "grounded" terminal last. Tighten terminal bolts, being careful to place clamp terminals and cables in such a position that they do not interfere with removal of vent plugs, or rub on hold-downs or other parts.

On cars equipped with alternator systems it is imperative that the polarity connection of the battery is correct, since if the engine is started with the battery reversed, the rectifier diodes and wiring harness will be irreparably damaged. In the case of cars with transistorized radios, damage would occur if the radio were turned on with the battery reversed.

As a matter of policy, the radio should always be turned off when working on the battery.

In any case, as an added safety measure a final check of the cable connections should be made with particular attention paid to matching the larger cable clamp to the larger terminal post.

On cars equipped with ammeters, the procedure of turning on the lights and noting that the ammeter deflects to the minus or discharge side of the scale indicates definitely

that the battery is properly installed with regard to polarity. On cars without ammeters this procedure is impossible and reliance must be placed in the cable checking as described in the previous paragraph, or in the instructions in the car manufacturer's manual.

CHECK CHARGING CIRCUIT

Suitable equipment is available for checking the charging circuit. Follow the manufacturer's procedure in the use of the instruments. Checking of charging circuits without such equipment is not recommended.

PART VIII

EFFECT OF CABLE SIZE ON CRANKING

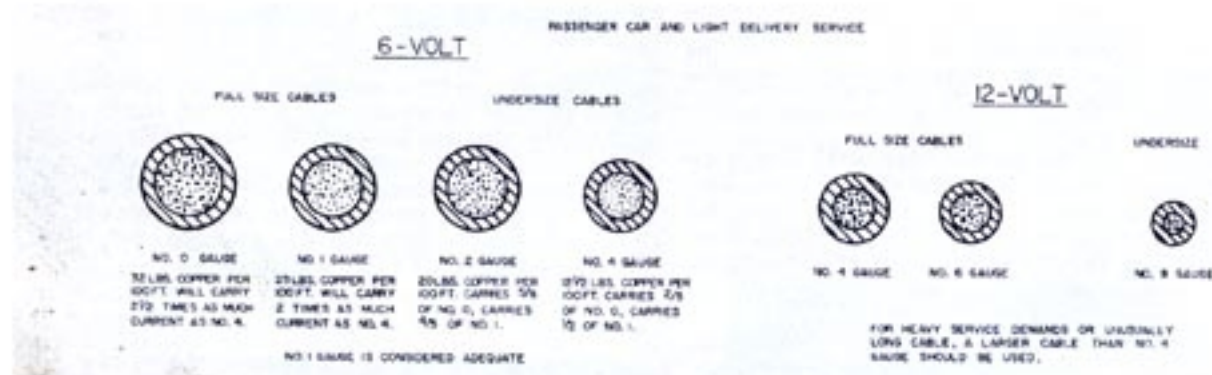


Fig. 29—Cable Sizes.

Battery cables must carry the extremely heavy starting current with a minimum loss of voltage, since the speed of cranking is dependent on the voltage made available at the starting motor.

Cables for passenger cars having 12-volt systems are usually of the standard Number 4 or Number 6 gauge except for special applications where heavier cables may be used.

Cables for passenger cars having 6-volt systems are usually of the standard Number 0 or Number 1 gauge, the Number 0 being the larger.

In the preceding chart, Fig. 29, a comparison of full size versus undersize cables is given.

Voltage can be lost by the use of cables which are undersize and also by clamp terminals which are corroded.

NEW BATTERIES RETURNED FOR CHARGING

EARLY DISCHARGE NOT UNCOMMON

It is quite common to receive a complaint, especially during very cold weather, about new batteries returned for charging within a few days or weeks after sale, which leads to the belief that there must be something wrong with them. This type of complaint began when the automotive battery industry first came into existence and will continue just as long as automotive batteries are sold. Actually very few batteries so returned have anything wrong with them, but because they are new, the inexperienced person, and sometimes even the one who should know better, believes them to be defective because he cannot find the reason for their becoming discharged.

A very important point to check in every case where this trouble is encountered is the policy followed in regard to the installation of new batteries.

Was the battery fully charged when installed? This is extremely important because the installation of a partially-discharged battery may not only lead to its return for charging but may also result in short life and an adjustment. The gravity and temperature of the battery should therefore be recorded at the time of sale for future reference.

Were tapered terminals and clamp terminals brushed clean and greased when installation was made? If not, high-resistance connections may exist and the battery cannot be kept charged. This is very, very important on voltage-regulated systems.

It is a fact that many new batteries will come back for charging when they become discharged and, provided they were fully charged and properly installed, they may be considered legitimate recharge jobs for which full price should be collected. Too often they are recharged gratis because of a desire to keep a good customer satisfied and because of a lack of knowledge of the true circumstances and how to deal with them, but they are legitimate recharge jobs just the same. The battery is usually involved in any starting failure, but the fact that it is discharged does not necessarily point to a defective or faulty battery. Insufficient hours of driving, worn cables, trouble in the electrical system, such as voltage regulator out of adjustment, corroded connections or alternator or generator in need of repair, slipping drive belt, etc., can cause a battery to become discharged and the condition cannot be blamed on the battery. See "Car Alternator or Generator System," page 34.

BATTERY TESTS FOR DEFECTS

A properly equipped dealer has three ways of testing a battery to determine its condition:

First—He can put it on charge to see whether it takes a charge satisfactorily. If it does, it has passed one test successfully and is probably in good condition.

See "Charging Storage Batteries," Part XV, page 27.

Second—If a discharge tester is available he may test the battery for capacity after charge, and if this test shows full capacity the battery is in good condition.

Third—Only in rare cases should this test be needed, but it can be made by anyone who doubts the results obtained from the first two. Let the fully-charged battery stand on the shelf for three to seven days to see whether the standing loss due to self discharge is excessive in any cell. If it is not, then the battery has successfully passed every test and is without question in serviceable condition. See "Self-Discharge—Causes and Effects," page 16.

TESTS MUST BE BELIEVED

If the foregoing tests show the battery to be in good condition, the results must be believed. This seems obvious, but is emphasized because many who are inexperienced in handling batteries and who fail to learn the reason for the discharged condition are liable to end by blaming the battery because they feel that since they cannot find any other cause, it must be the battery.

It may help to remember that a new battery will slowly discharge standing idle in stock, but it will not become fully discharged in a week or two. If it comes back discharged within a week or two, there must be some reason for this condition other than the battery itself. It may also help to remember that for every new battery returned for charging, many more old batteries come back for the same reason. Nobody complains about the old batteries.

Never forget that there are ways to prove whether a battery is or is not at fault, and when these show it to be in good condition, the battery is completely absolved as a cause of trouble.

PART X

WATER

Water for use in automotive batteries may be a good grade of drinking water, excluding mineral waters.

Adding water to a cell will lower the specific gravity of the electrolyte, but this does not mean that the cell has lost any of its charge.

Watch for batteries that require excessive water. The need for excessive water may be an indication of a charging system which is out of adjustment and indicates that the battery is being subjected to the damaging effects of overcharging.

The larger proportion of present-day batteries are provided with liquid-level indicators in the vent openings of the covers. Where such provisions are not present the normal electrolyte level should be $\frac{1}{4}$ to $\frac{1}{2}$ inches above the top of the separators.

The electrolyte level, correctly adjusted at a warm temperature when fully charged and gassing, may drop as much as $\frac{3}{16}$ " when cooled to 0°F. This is due to the contraction of the electrolyte and to the shrinkage of the gas bubbles trapped in and beneath the element.

PART XI

ACID GRAVITY FOR TROPICAL CLIMATES AND SPECIAL CONSTRUCTIONS

TROPICAL CLIMATES

Batteries operated at high temperatures in tropical climates are usually provided with electrolyte of about 1.225 Sp. Gr. when fully-charged. This milder strength of acid is less deteriorating to separators and plates, which results in longer battery life. A tropical climate is considered one in which water never freezes.

Attention is called to the fact that batteries can be fully charged and yet have different values of specific gravity. The following table gives the specific gravity values for typical batteries in various states of charge, these batteries having indicated gravities in the fully-charged state. Values are shown for batteries with a fully-charged gravity of 1.280 and 1.260 as used for cold and temperate climates, and in the last column values are shown for a battery with a fully-charged gravity of 1.225, as might be used in tropical climates.

State of Charge *	Specific Gravities as Used in		Specific Gravity as Used in Tropical Climates
	Cold and Temperate Climates		
Fully Charged	1.280	1.260	1.225
75% Charged	1.230	1.215	1.180
50% Charged	1.180	1.170	1.135
25% Charged	1.130	1.120	1.090
Discharged	1.080	1.070	1.045

*State of charge as indicated by specific gravity when discharged at 20 hour rate.

The above are more or less typical specific gravity ranges. Gravity ranges will vary somewhat, depending on battery construction and ratio of electrolyte volume to active material.

SPECIAL CONSTRUCTIONS

Some types of batteries are constructed with an extra-large space for water above the elements where over three times the usual water reserve is provided above the separators. As a result of the extra water used, the specific gravity of the electrolyte at full level and with cells fully-charged is 1.250 Sp. Gr., which is sometimes stated on the vent plugs of these special batteries. The same quantity of sulfuric acid is used in these batteries as is used in batteries with equivalent size elements having a fully-charged specific gravity of 1.270. The extra water volume results in the milder acid strength and requires that the battery be re-watered one-third as often as the conventional battery.

EFFECT OF REDUCING FULL-CHARGE ACID GRAVITY

Most manufacturers have reduced the gravity of their batteries of standard construction from 1.280, containing 38% H_2SO_4 by weight, to 1.260, containing 35.6% H_2SO_4 by weight, in order to obtain the benefits of the somewhat milder acid strength during the life of the battery. This may have the effect of reducing the initial capacity of the battery, since the capacity of a battery depends upon the amount of acid in the electrolyte.

The amount of electrolyte in a battery will strongly affect its capacity since battery capacity is determined by three components — (1) weight of positive active material, (2) weight of negative active material and (3) weight of sulfuric acid in the electrolyte. This required weight of sul-

furic acid to yield a specified electrical capacity can be provided either — (a) in smaller volume of high specific gravity or (b) larger volume of lower specific gravity. Either combination will enable a battery to meet its published ratings.

However, if the specific gravity of the acid of a battery as originally designed is reduced, but the acid volume remains the same, the battery's capacity will be reduced. Take, for example, a 100 A.H. capacity battery of standard construction with normal electrolyte volume and having a fully-charged gravity of 1.280. If the gravity is reduced to 1.260, the 20-hour capacity may fall off 4 per cent to perhaps 96 A.H. and the cold capacity may drop as much as 15 per cent. It is obvious, therefore, that the acid gravity of such a battery cannot be lowered without reducing its capacity. In general, however, lower gravity favors life — higher gravity favors 20-hour capacity and cold capacity. The volume and gravity of electrolyte used in automotive batteries is, therefore, carefully calculated to deliver guaranteed rated electrical performance and usually represents a good compromise between capacity and battery life.

If acid is either lost or is added to a battery after it leaves the factory, one can be misled in referring to the above table of values to determine state of charge from hydrometer readings. It may be necessary to fully-charge a battery to determine accurately what its fully-charge gravity is unless the "fully-charged" gravity is marked on the battery or on the accompanying instruction tag.

MIXING BATTERY ELECTROLYTE

Diluting concentrated acid of 1.835 is not recommended because of the dangers involved. When undertaken as a result of circumstances, extreme care must be taken in preparing electrolyte by diluting 1.835 Sp. Gr. Battery Grade sulfuric acid with water.

In mixing, always pour the acid into the water — do this slowly — never pour water into acid, for it will virtually explode. Stir continually with a clean, new,

wood stick while acid is being added, after which throw the stick away. Because considerable heat is generated when strong acid is mixed with water, take specific gravity readings and make final adjustment of gravity after electrolyte has cooled to room temperature. Never fill batteries with electrolyte much hotter than room temperature.

Use nothing but glass, glazed earthenware, hard rubber, or lead containers to mix or store electrolyte. Use care or the heat of mixing may crack glass containers. To prepare electrolyte of any specific gravity between 1.100 and 1.400, add one part by volume of concentrated 1.835 Sp. Gr. battery-grade sulfuric acid to the approximate number of parts of water shown in the following table.

Desired Specific Gravity	Approximate Number of Parts of Water to Which Must Be Added One Part of 1.835 Specific Gravity Sulfuric Acid, by Volume
1.100	9.8 parts water by volume
1.200	4.3 parts water by volume
1.250	3.3 parts water by volume
1.300	2.5 parts water by volume
1.400	1.6 parts water by volume

WARNING: Concentrated acid of 1.835 Sp. Gr. must be handled with great care as it will blister the skin and damage the clothing. It is advisable to wear goggles, rubber gloves, and a protective apron when working with it.

Neutralize acid electrolyte spilled on clothing with dilute ammonia water or a water solution of baking soda. If 1.835 Sp. Gr. acid gets on clothes, dilute it with clean water first, then neutralize.

If acid is splattered into the eyes wash it out at once with plenty of clean water only. Next, seek medical aid if the acid was concentrated or if discomfort continues.

PART XII

ACCIDENTAL IMPURITIES

Colorless liquids like gasoline, kerosene, turpentine, anti-freeze, or carbon tetrachloride (fire extinguisher fluid) are sometimes mistaken for water and added to a battery. Gasoline, kerosene, turpentine and some other liquids lighter than water, and which will not readily mix with water, will float and can be removed by flooding each cell carefully with water to flow off the impurities. After this, the gravity

of the electrolyte must be adjusted. Such fluids in time often soften the sealing compound and the resulting mixture is difficult to remove unless cleaned off promptly. Soluble liquids like sea or salt water, vinegar, alcohol or harmful acids such as nitric, hydrochloric or acetic acids will ruin the battery.

SERVICING BATTERY IN CAR

Good battery servicing should include the following seven points:

- ① Provide protective fender cover for car finish.
- ② Clean battery top with a stiff brush, being careful not to scatter corrosion products. Wipe off with a cloth wetted with ammonia or baking soda in water. Finally wipe with a cloth with clear water.
- ③ Inspect cables — urge replacement if unserviceable. Inspect the terminal posts to see that they are not deformed or broken.
- ④ Clean the battery terminal posts and the inside surfaces of the terminal clamps to a bright metal surface, whenever they are removed. Coat the contact surfaces

with mineral grease or vaseline before the terminals are reconnected.

- ⑤ Inspect cradle and adjust hold-downs. Urge replacement if unserviceable.
- ⑥ Make hydrometer or Voltage Tests.

If only a hydrometer is available, and if the electrolyte level is too low for the test, fill the cells to proper level with water and charge the battery sufficiently to mix the electrolyte, or request the owner to return the following day for rechecking.

- ⑦ Add water to bring the electrolyte level to the proper point, but avoid overfilling. See section on Water, page 23.

TESTING BATTERY FOR SERVICEABILITY

INSTRUMENTS

Testing a battery for serviceability requires the use of instruments of unquestioned accuracy.

A Hydrometer should be graduated to read from 1.160 to 1.320 in graduations of .005 specific gravity. The graduated markings should be not less than $\frac{1}{16}$ inch apart and accurate to within .002 Sp. Gr. The graduated portion of the stem should be about 2 inches long. Clearance between float and barrel, at smallest diameter, should be a minimum of $\frac{1}{8}$ inch around all sides.

A battery Thermometer should be of the mercury-in-glass type, have a scale reading as high as 125°F. and be designed for not over a 1-inch bulb immersion. A suitable dairy-type thermometer may prove satisfactory for the purpose.

Shop electrical meters for battery testing should be accurate within 2 percent over the entire scale range. Laboratory meters should be accurate within $\frac{1}{2}$ of 1 percent over the entire scale range and should be of the permanent magnet moving coil type, the voltmeter preferably being shielded from external magnetic fields.

A good Voltmeter should have a 3-volt scale in .02-volt divisions and be accurate to within 1% over full scale for measuring cell voltage and/or a scale covering 15 volts in .1-volt divisions for testing overall battery voltage. The

resistance of a good voltmeter is at least 100 ohms per volt. A portable type D.C. voltmeter of at least 100 ohms per volt sensitivity, accurate to at least 1% and having a range of 150/15/3 volts would be satisfactory for accurate test work.

A portable type D.C. Ammeter accurate to at least 1 percent, with scale range of 50/25/10 amperes and used with an external 500 ampere shunt to obtain a 500 ampere range, would be satisfactory for accurate test work.

OPEN-CIRCUIT VOLTAGE BATTERY TESTERS

The open-circuit voltage of a battery will vary slightly with the specific gravity of the electrolyte in the individual cell. A sensitive voltmeter can therefore be provided with a scale which indicates equivalent specific gravity or state of charge and can be used as a sort of "electrical hydrometer" under certain conditions. Such instruments must have a separate scale calibrated for each separate fully-charged gravity, or a correction factor must be used if the cells are adjusted to any other fully-charged gravity. For example, such O.C.V. meters, in order to be reliable, must either be used only on batteries and/or cells whose fully-charged gravity is that for which the instrument is calibrated, or be used with a correction factor of .01 volt equals .010 specific gravity.

Example: 1.260 Sp. Gr. = 2.10 Volts/Cell = 6.3 Volts/6-Volt Battery
= 12.6 Volts/12-Volt Battery

BATTERY TESTING CHART — Fig. 30

HYDROMETER TEST (80°F.) (See Note "A" Below)	STATE OF CHARGE OR BATTERY CONDITION	CORRECTION OR REMEDY
(1) 1.215 Sp. Gr.	(1) Probably Good.	(1) No correction required if variation among cells not over .050 Sp. Gr. Give high rate discharge capacity test. If test O.K., check operation and setting of voltage regulator. Make a thorough check of the electrical system for short circuits, loose connections, corroded terminals, etc.
(2) Less than 1.215 Sp. Gr.	(2) Questionable.	(2) Battery should be recharged. After recharge repeat step No. 1 (See note "B").
(3) Cells showing more than 50 Points (.050 Sp. Gr.) variation in gravity.	(3) A. Short circuit in low cell. B. Loss of electrolyte by leakage or excessive overcharge. C. Improper addition of acid or contaminants. D. Natural or premature failure. E. Cracked box partition.	(3) Try to recharge battery (See note "B"). If .050 Sp. Gr. variation persists battery should be replaced. If battery accepts recharge and variation does not persist repeat step No. 1.

OPEN CIRCUIT VOLTAGE TEST	STATE OF CHARGE OR BATTERY CONDITION	CORRECTION OR REMEDY
(4) Battery or cells showing more than 1/2 charge.	(4) Probably good.	(4) Apply remedy given for No. 1 above.
(5) Battery showing less than 1/2 charge or cells showing less than 1/2 charge but not more than .05 volts variation.	(5) Questionable.	(5) Apply remedy given for No. 2 above.
(6) If cell connectors are accessible, cells showing more than .05 variation.	(6) See No. 3 above.	(6) Apply remedy given for No. 3 above.

NOTE: A — For batteries having normal fully-charged specific gravity of 1.260 or above at 80°F. the electrolyte level should be 1/4" to 1/2" above separators. Do not take readings soon after adding water, but charge until solution is mixed. Hydrometer readings should be corrected for temperature if temperatures are very far from 80°F.

NOTE: B — For batteries with special fully-charged gravity and/or extra electrolyte space — consult manufacturer's recommendations.

For proper charging procedures refer to "Charging Storage Batteries", Page 27, and consult charging equipment manufacturer's specifications.

HIGH RATE DISCHARGE TEST		
(7) Use high rate discharge tester in accordance with manufacturer's recommendations. (See common electrical difficulties below.)		

COMMON ELECTRICAL DIFFICULTIES

SHORT CIRCUITS

The presence of short circuits in the wiring can be determined by switching off all electrical equipment and, with the ground strap connected, tapping the other cable terminal against its battery post. Sparking will be produced if there is a substantial short circuit in the wiring. Be sure that fuses have not been burned out before making this test. One should check the possibility of a stuck stop light or other switch before accepting the evidence of sparks as a certain indication of a short circuit. To detect a very slight short circuit, place a low-reading ammeter in the circuit.

HIGH RESISTANCE

A voltage drop (while cranking) of more than .2 volts (2/10) between the starting motor cable and the car frame can cause hard starting regardless of battery condition. This can be caused by poor contact between cable terminal and car frame, or between clamp terminal and battery post or starter-switch contacts, frayed, corroded or broken cable. Locate the high resistance by cranking the warm engine with the ignition off. Where the starter and ignition are interconnected on the same switch, the high tension wire from the center of the distributor cap will have to be disconnected temporarily and grounded to prevent damage to the ignition coil. This procedure will prevent the engine from starting during the cranking test. Repair or replace component causing the high resistance or loss in voltage.

No temperature correction factor has to be applied to the gravities indicated by O.C.V. meters. However, the instruments cannot be used on batteries and/or cells which have just come off charge, as the gases held on the plates cause the instrument to give a falsely high reading. The instruments are useful for testing batteries in stock, but must be used with caution on batteries coming into a station in cars. Cranking the engine briefly with ignition off or turning on headlights for two minutes before testing will remove the gas effect (surface charge) from the readings. Letting batteries stand on open circuit for several hours after charging will dissipate the gases from the plates and enable correct readings to be obtained.

HIGH-RATE DISCHARGE EQUIPMENT

High-rate discharge equipment is available in a variety of forms. Most of these work on the principle of discharging the battery through a fixed resistance, for about 15 seconds, and measuring the battery and/or cell voltages while dis-

charging at a high rate to determine the cranking ability of the battery.

The tester meter must have 2% accuracy over the entire scale range(s). The tester should be capable of discharging the battery as a unit and measuring voltage as the criterion for passing or failing the battery.

BATTERY TESTING CHART

A step-by-step procedure based on hydrometer and voltmeter readings is shown in the "Battery Testing Chart" Fig. 30. This chart will be helpful in rendering correct battery service.

Recent developments in the design of automotive batteries have led to intercell connectors which are no longer accessible for voltage test prods. Therefore, individual cell test voltages can no longer be used and a procedure based on specific gravity and over-all terminal voltage (open circuit and under load) must be followed.

PART XV

CHARGING STORAGE BATTERIES

PREPARING BATTERY FOR CHARGING

Wash all dirt from a battery and clean its terminals before placing it on charge but do not allow dirt to get into cells. Bring the liquid level in the cells to the correct level. If the battery is extremely cold, let it warm up before adding water as the level will rise as it warms. When a high-rate fast charger is used for charging it may be necessary to remove electrolyte to $\frac{1}{8}$ to $\frac{1}{4}$ inch above the separators to prevent overflowing. This electrolyte should be retained in a clean jar and returned to the cells after charging has been completed. The electrolyte should finally be adjusted to the proper level with water.

CHARGING CURRENT

Use only Direct Current from a charging source controlled so that the rate to the battery will not be excessive.

Several methods for converting Alternating Current to Direct Current are commercially available for service station use.

HIGH-RATE FAST CHARGING

A battery may be charged at any rate which does not cause the electrolyte temperature of any cell to exceed 125°F. and does not cause excessive loss of the electrolyte. This rule does not apply to badly-sulfated batteries. Such batteries should be charged at specified low rates.

High-rate fast chargers are usually constant potential machines of very high current capacity so that initial charge

rates of 50 to 60 Amperes are common for 12-volt batteries, while for 6-volt batteries these rates will be doubled.

High-rate fast chargers built for handling both 12 and 6-volt batteries require care to insure that the proper setting is used for the particular battery involved in order to avoid damage to the charger and the battery being charged. Where means are provided and are used to control the temperature and violence of gassing, it is practical to boost normal batteries in this way. Some of these chargers are equipped with a time-limiting or temperature limiting device to protect the battery from exceeding temperature of 125°F.

High-rate chargers cannot be expected to fully charge batteries within an hour, but they do charge the battery sufficiently well so that it can continue to give service commensurate with its condition and state of charge.

More than one battery, either all 12-Volt or all 6-Volt, can be charged on high-rate fast chargers. When this is done connect the batteries in parallel; that is connect positive to positive, and negative to negative. Refer to the charger manual for detailed instructions.

The high-rate chargers can inflict irreparable damage on a battery if the safeguards provided by the manufacturer are ignored or circumvented by the operator. Operating instructions on high-rate chargers, as issued by each manufacturer, should be carefully followed.

CONSTANT-POTENTIAL CHARGING

Constant-potential chargers start the charge off at a high rate, and as the battery voltage builds up, the charge rate tapers off to a lower value depending on the design of the charger and on the condition, age, and temperature of the battery. A battery in good condition is not harmed by this type of charging. A badly-sulfated battery, however, may not come up to full-charge in a normal way on this type of charger. Temperature must be watched carefully with this method of charging as it may rise very rapidly.

CONSTANT-CURRENT SLOW CHARGING

The constant-current method of charging is the old and well-established method for charging batteries where the internal cell condition is not known and where a diagnosis of trouble is being made.

Connect the positive lead from the charger to the positive terminal of the battery and connect the negative lead to the negative terminal. If several batteries are being charged in series, they should be connected from the positive terminal of one to the negative terminal of another so that when the row of batteries is connected, there will be a positive and a negative battery terminal free for connecting the positive and negative charger leads respectively.

The positive terminal of a battery is usually marked with a "+" or "P" or "POS" and it has a slightly larger top diameter ($\frac{11}{16}$ "") than the negative ($\frac{7}{8}$ ""). A safe rate for bench charging is 1 ampere per positive plate per cell. For example, in a battery having 11 plates per cell, 5 of them would be positives, so the charge rate would be 5 amperes for the battery. If several batteries of different sizes are being charged in series, the rate for the line must be determined by the smallest battery in the circuit. If necessary, it is considered safe to leave batteries on charge overnight at one-half the day-time rate of charge.

Watch temperature of batteries carefully and if the temperature of any one of them reaches 125°F., lower the rate. Electrolyte will expand and the liquid level rise due to heat and displacement of liquid by gas bubbles forming at the plates while the battery is on charge.

Hydrometer readings should be recorded hourly for each cell of each battery as soon as it approaches the fully charged state. A battery is fully charged when the cells are all gassing freely and the gravity ceases to rise for three successive readings taken at hourly intervals. Excessive gassing of the electrolyte may cause the liquid to exhibit a falsely-low gravity due to the small gas bubbles displacing the liquid, so allow the gas bubbles to rise to the surface of the liquid in the hydrometer barrel before reading the hydrometer float scale.

At this time, the charge voltage, while on charge at the 1 ampere-per-positive rate, will depend upon the temperature and the age and condition of the cells. A uniform charge voltage for all of the cells in any particular battery is a condition to be desired — a subnormal voltage of one of

the cells may indicate a defect such as a broken separator or an internal short. Stop charging any battery when all cells are gassing freely and gravity will not rise further when tested at three hourly intervals. Most batteries can be recharged at normal rates in from 12 to 16 hours. Excess charging is wasteful of current, decomposes water, and is harmful to the positive plates. Do not stop short of the fully charged state, however, as outlined above, even if it takes 24 hours or longer. A badly sulfated battery will require longer than a normal battery.

Unless electrolyte has been lost through spilling or leaking, it should not be necessary to add acid to a battery during its life. Remember to make the temperature correction for hydrometer readings, as warm electrolyte will read low and this might be mistaken for failure of the battery to rise normally in gravity. It might also be mistakenly concluded that the battery would not take a full charge.

TRICKLE CHARGERS

Trickle chargers are effectively used for keeping display batteries freshly charged and ready for sale. Avoid continuous overcharge for long periods of time. Whenever such chargers which have an output of less than one ampere are used, it is very important that they be used in strict accordance with directions, since continuous overcharging for an indefinite time, even though at a very low rate, can be very destructive to the grids of the positive plates, causing them to disintegrate. Many who operate such chargers turn them off at night to avoid overcharging.

BATTERY GASES EXPLOSIVE

The gases issuing from a charging battery are a mixture of hydrogen and oxygen gases and will explode with great violence and spraying of acid if a spark or flame is brought too near them. A room or compartment in which charging batteries are confined should be ventilated. Do not bring a flame or sparks near vent openings.

In all automotive battery cells small quantities of hydrogen gas are given off at the negative plates even when the cells are not being charged. It must therefore be assumed that explosive mixtures of hydrogen gas are present within the cells at all times. A torch, match flame, lighted cigarette, or sparks from metal tools accidentally contacting the terminals could cause ignition of the gases.

To avoid sparks, do not disturb connections between batteries while charging; first throw switch "Off" at charger. The possibility of ignition of hydrogen gas by static electricity accumulated on the car, or on one's person, and discharging near the vent openings can be minimized if, immediately before working on the battery, a metal rod or wire is touched to the car bumper and to the ground.

The improper use of a "Booster" battery to start a car when the normal battery is inadequate presents definite explosion hazard. To minimize this hazard the following procedure is suggested.

1. When possible, use equipment with a switch in the line connecting the booster battery to the installed battery.
2. Always "rock" the connector clips to insure secure grip contact.
3. If only jumper cables are available, always securely connect the installed battery first; and when connection is made with the "booster" battery, exercise extreme care in the handling of the cable clips. In disconnecting, always break the connection at the "Booster" battery first.

Another source of explosion lies in the reverse connection of charging equipment. This hazard is present with all types of chargers, but particularly in the case of the High Rate equipment. It can only be eliminated by careful checking of the connections before throwing the operating switch.

If for any reason acid electrolyte should be spattered in the eyes, wash it out immediately with copious quantities of clean, cold water cupped in the hands. Seek medical aid if discomfort continues.

PART XVI

FACTORS AFFECTING BATTERY LIFE

OVERCHARGING

Charging a battery greatly in excess of what is required is harmful in several ways, as follows:

- 1 Severely corrodes the positive plate grids with consequent mechanical weakening and loss of electrical conduction.
- 2 Decomposes water of electrolyte into hydrogen and oxygen gas. Gas bubbles tend to wash active material from the plates and carry moisture and acid from the cells as a fine mist.
- 3 Decomposition of water leaves acid more concentrated. Concentrated acid is harmful to cell components, particularly at high temperatures over a prolonged period of time.
- 4 High internal heat is created, which accelerates the above mentioned corrosion of positive plate grids and damages separators and negatives. Also, containers may be softened and distorted and sealing compound displaced.
- 5 Overcharging alone or in combination with a previous condition of undercharging may cause severe buckling and warping of positive plates with accompanying perforation of separators.
- 6 May cause damage by corrosion to cradle, cables and other vital electrical and engine parts by forcing liquid from the cells if charge rates are excessive.

UNDERCHARGING

- 1 A battery operated with insufficient charge over a long period of time may develop a type of sulfate in the plates which is dense, hard and coarsely crystalline and which cannot be readily electrochemically converted to normal active material again. Such lead sulfate, being less dense than the active material from which it was formed, will set up strains in the positive plates so that distortion or bowing of the plates, called buckling, may result. Buckling will be produced, especially if the sulfated battery is

subjected to sudden prolonged overcharging, as might be experienced on a long trip or by an alternator or generator-regulator system which has gotten out of adjustment. Severely buckled plates will pinch the separators at the plate corners or chafe the center of the separators. This may result in perforations of the separators and develop a short circuit in the cell.

- 2 A battery operated in an undercharged condition is not only unable to deliver full power, but is liable to freeze during severe winter weather. See section on "Freezing of Electrolyte", page 30.

- 3 Lead sulfate formed on the plates during discharge is relatively insoluble as long as the specific gravity of the electrolyte indicates a substantially charged condition, but if allowed to drop much below this state the lead sulfate becomes increasingly soluble and, aided by temperature fluctuations of the electrolyte, may migrate over a considerable period of time into the pores of the separators and deposit as a white crystalline mass. Subsequent charging may convert these crystalline deposits to metallic lead which may "short" the positive and negative plates through the areas of the separators affected. These small shorts may cause a condition of low cell voltage when the battery is charged. For this reason automotive battery cells should not be allowed to stand idle in a discharged condition.

LACK OF WATER

Water is one of the essential chemicals of a lead-acid storage battery and under normal conditions of operation is the only component of the battery which is lost as the result of charging. It should be replaced as soon as the liquid level falls to the top of the separators. If water is not replaced, and the plates are exposed, the acid will reach a dangerously high concentration that may char and disintegrate the separators and may permanently sulfate and impair the performance of the plates. Plates cannot take full part in the battery action unless they are completely covered by the electrolyte.

Sulfuric acid must never be added to a cell unless it is known to have been lost.

LOOSE HOLD-DOWNS

Hold-downs, if not properly adjusted, may allow the battery to bounce around in the cradle. This may cause the bridges on which the elements rest to notch the bottom of the separators and may cause the plates to notch the bridge tops, causing a severe disarrangement of the elements. The bouncing of the battery may also crack or wear the container badly and cause sealing compound to open and leak acid. Leaking acid corrodes terminals and cables and results in high-resistance battery connections, thereby weakening the battery's power and shortening its life. Hold-downs, on the other hand, can be too tight, distort or crack the container, allowing loss of acid from the cells, and this will cause loss of battery capacity.

BATTERY ELECTROLYTE SUBSTITUTES

No satisfactory substitute electrolyte has been found for the simple mixture of sulfuric acid in water. Use no substitutes.

EXCESSIVE LOADS

A battery should never be used to propel the car by the use of the starting motor with clutch engaged except in a great

emergency. This may produce extremely high internal battery temperature and damage the starting motor.

FREEZING OF ELECTROLYTE

The electrolyte of a battery in various states of charge will start to freeze at temperatures indicated below. The given temperatures indicate the approximate points at which the first ice crystals begin to appear in the solution. The solution does not freeze solid until a lower temperature is reached. Solid freezing of the electrolyte may crack the container and damage the positive plates.

A $\frac{3}{4}$ charged automotive battery is in no danger of damage from freezing. Therefore, keep batteries at $\frac{3}{4}$ charge or more, especially during winter weather.

Specific Gravity (Corrected to 80°F.)	Freezing Temperature Degrees Fahrenheit
1.280	-90°F.
1.250	-62°F.
1.200	-16°F.
1.150	+ 5°F.
1.100	+19°F.

PART XVII

INTERNAL EXAMINATION OF CELLS

The repair of defective batteries is not justified. The high cost of parts and labor as compared to the cost of replacement with a new battery make any projected repairs uneconomical. Batteries having one-piece covers sealed to the containers with permanent cements cannot in any case be opened for repair.

The following discussion is presented for its informational value, and is illustrative of some of the points covered in Part XVI, "Factors Affecting Battery Life."

INSPECTION FOR SHORT CIRCUITS

This condition may result from material falling from the plates and being deposited in sufficient quantity to short-circuit the plates at the bottom or edges. Or it may be the result of lead growing ("treeing") from plate to plate through a hole or split in a separator, or a rough edge on a plate may have cut through the separator. Lead may have run down during the lead burning of either the plates to the post straps or the connectors to the posts. Such a "run-down" may not short-circuit the element until later when considerable wear has occurred. One plate or several plates in the element may have "buckled", causing excessive wear and failure of separators resulting in a short circuit of the element.

EXAMINATION OF POSITIVE PLATES

FINELY DIVIDED SHEDDING

Finely divided, even shedding over the entire surface of the positive plates, Fig. 31, is characteristic of a battery after long service.



Fig. 31—Positive Plate exhibiting shedding after long service.

GRID OXIDATION

Long continued over-charging is always accompanied by oxidation of the positive grids, which reduces the metallic cross-section of the grid wires and weakens the plate, Fig. 32, so that it is easily broken under slight pressure or vibration. Over-charging can be corrected only by lower adjustment of the voltage regulator to meet driving conditions.

CHUNKY SHEDDING

This may be caused by too high a charging rate on a sulfated positive plate. It also might be caused by the battery freezing while discharged. Too high a charging rate would probably be accompanied by oxidation of the plate frame. Chunky shedding may also be induced by vibration due to loose mounting of the battery in the carrier.



Fig. 32—Positive Plate, showing severe disintegration due to collapse of grid mesh, corroded by overcharging.

CRACKED OUTSIDE GRID FRAMES

This indicates severe expansion due to the positive plates having been in a partly-discharged condition and having been permitted to stand until considerable hardening action has taken place. This condition is aggravated by overcharging after plates have become sulfated.

HARD PLATES

When the material in the plate is hard when scratched, like the surface of an unglazed tile, it is indicative of heavy sulfation. It may be corrected by a long, slow charge, from 60 to 100 hours at half the normal rate, unless the sulfate has become too extensive and coarsely crystalline.

BUCKLED PLATES

Buckling of positive plates may be caused by plates standing in an undercharged state for a considerable period of time, or may be the result of excessive charging, especially after plates have previously become densely sulfated by standing in an under-charged state. See Fig. 33.

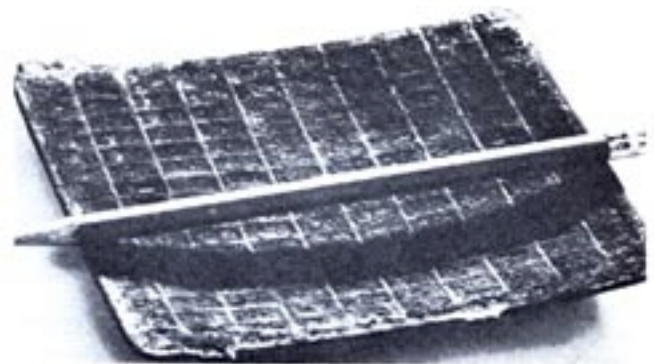


Fig. 33—Severely buckled Positive Plate.

DISCOLORATION

Low electrolyte level will sometimes result in the formation of a distinct area or zone of whitish sulfate near the tops of the positive plates which were exposed to the air, while the area covered by electrolyte will remain brown in color. See Fig. 34. The activity of such a sulfated area is permanently impaired even though electrolyte level is restored.

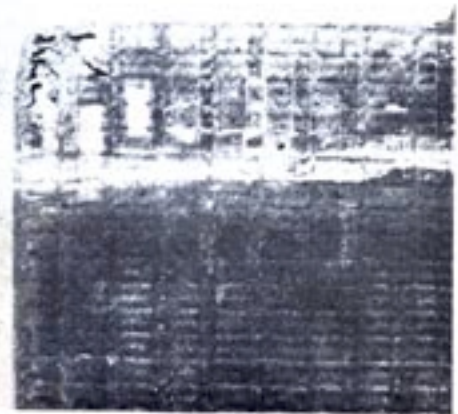


Fig. 34—Badly sulfated positive plate resulting from low electrolyte level.

Discoloration of plates with white lead sulfate may also appear in elements which have stood for considerable time in a discharged condition in electrolyte of very low specific gravity.

EXAMINATION OF NEGATIVE PLATES

GLOSSY NEGATIVE MATERIAL

Fully-charged sponge lead negative material normally has a slate gray color and glosses to a metallic sheen when rubbed smooth with the back of the thumbnail.

SANDY NEGATIVE MATERIAL

This may result from operation of the battery when the element is shorted, or may be caused by high-gravity acid aggravated by high temperatures. If these conditions of high gravity and high temperature prevail for some time, the negative sponge lead may become soft and mushy.

If the material appears to be sandy when rubbed with the back of the thumbnail, it may be due only to a discharged condition. This is due to the fact that very often when a negative plate is only partially charged, the material may have an appearance similar to a sandy negative. If, after charging for at least 24 hours and until the gravity stops rising (it may take two or three days), the sandy feeling of the material is not removed, the negative plates may be considered worthless.

LOSS OF ACTIVE MATERIAL

Loss of negative active material from the grids may be the result of high-specific-gravity acid, of charging when the element is short-circuited, or of excessive temperature due to continuous charging at an excessive rate.

DISCOLORATION

A white discoloration may be due to the accumulation of white lead sulfate, resulting from low electrolyte level, or standing in a semi-charged condition. Dark discolorations may be due to small deposits of metallic impurities such as antimony or copper, or may be due to the battery having been accidentally charged in reverse for a prolonged period.

EXAMINATION OF SEPARATORS

NORMAL CONDITION

Separators which are firm but flexible, not black in color and without splits or holes, are considered normal.

SOFT OR EXTREMELY BRITTLE

This condition is caused by prolonged exposure to high temperature (above 110°F.), high-specific-gravity acid (above 1.300) resulting from water loss, or a combination of both of these conditions. These conditions usually turn the separator very dark, almost black in color. Microporous rubber or plastic separators are usually not so affected.

WORN SEPARATORS

Worn separators with ribs almost destroyed and the back web perhaps perforated, Fig. 35, are characteristic of separators subjected to excessive pressure caused by buckled plates or excessively-expanded negative material or excessive vibration. Separator deterioration resulting from excessive temperatures or high-specific-gravity acid, will make the separator much darker in color than when the cause is pressure from plates.

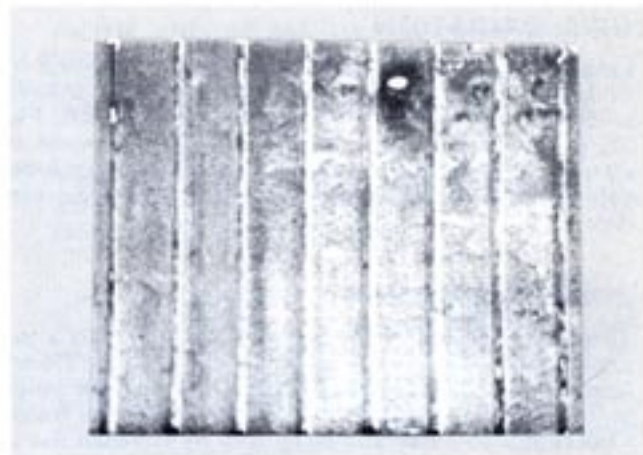


Fig. 35—Separator severely-oxidized, ribs worn and perforated near corner, due to buckled positive plate.

PITTED SEPARATORS

Pitting of separators results from pressure due to contact with loosened active material from positive or negative plates. When caused by positive material, the pitting starts on the ribbed side of the separator and may show dark-colored, carbonized spots. When due to negative material, the pitting starts on the side of the separator in contact with the negative plates and is often characterized by a "worm-holed" appearance due to movement of loose particles of active material.

FRINGED AT BOTTOM

This may be caused by excessive wear due to buckling of positive plates, or may result from oxidation of the separators by the shedded positive active material.



Fig. 36—Severely-notched separator due to vibration of loose element, or battery loose in cradle.

NOTCHED AT BOTTOM

Notches at points where separators rest on the bridges indicate either loose installation of the battery or excessive looseness of the element in the cell compartment allowing separators to chafe on the bridges. See Fig. 36.

If the battery was loose in the car, the outside of the container may show abrasion where it came in contact with the battery-carrier supports. If the container does not show such abrasion, it is possible that the element was assembled too loosely in the cell without shims. Excessive and prolonged vibration can also cause this condition in correctly assembled and installed batteries.

EXAMINATION OF CONTAINERS

ABRASION

If container abrasion is noted, Fig. 37, it is a sure sign that the battery has not been securely held in position. It is then probable that the resulting severe vibration has seriously damaged the elements and possibly caused cracks in the container. This condition may also have caused plates to wear deep notches in the element rests, Fig. 37, or the rests to have worn deep notches in the bottom of the separators, Fig. 36.

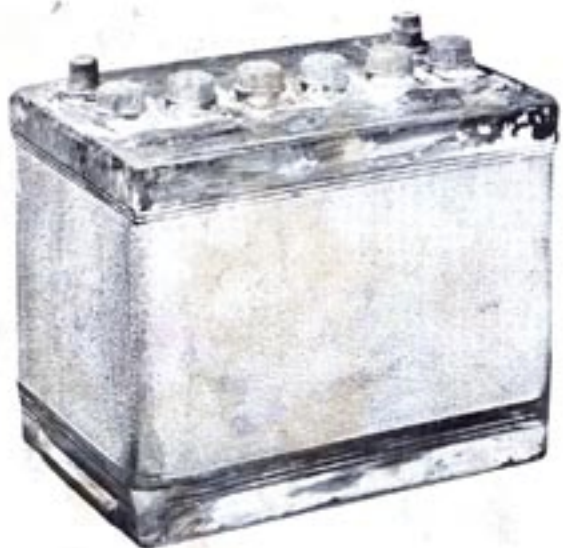


Fig. 37—Container worn by loose hold-downs.

PARTITION FAILURE TESTS

If the battery is giving trouble and requires repeated recharging, even after adjustment of the charging system, and the fully-charged voltage of cells while on charge is uniform, test for cracked or porous partitions.

If two adjacent cells have gravity readings considerably lower than the others, it is a fairly good indication that there is electrical leakage between the two cells. The positives of one cell, and the negatives of the next, discharge against each other.

CONTAINER LEAKS

External leaks or seepage can often be detected by inspection of the box walls. If in doubt about a leak on the bottom of the box, wash the battery all over, dry it and set it on a clean dry piece of paper on a clean, dry board, where a leak will produce a wet spot.

DISTORTION AND BULGING

Hold-downs which are too tight may pull containers out of shape and cause sealing compound to sag and crack. High temperatures experienced in under-the-hood locations will aggravate distortion and may permit bulging of any long, unsupported cell walls by the constant pressure of the weight of liquid in the cells. The materials of which containers are made become softer when heated to high temperatures, and may distort under a steady pressure, even though it be small.

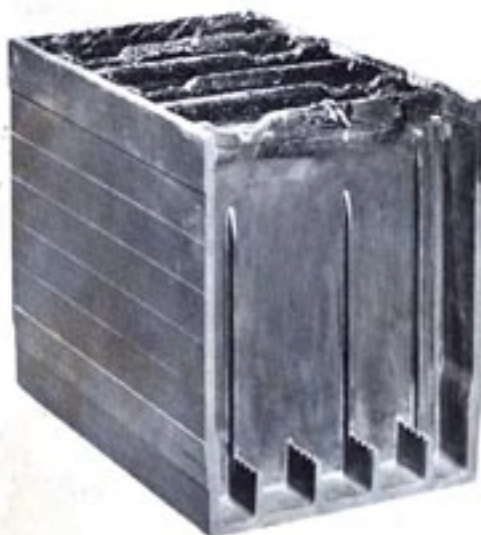


Fig. 38—Element rests severely-notched by vibration of loose element or battery loose in
hold-down

CAR GENERATOR SYSTEMS

The alternator or generator is the source of all electrical energy in a vehicle. It supplies power for the ignition, lights, heater blower, radio, air conditioner and other accessories. The battery stores some of the generated energy in chemical form to be used when the generating system is not running. The battery is not the source of electricity, but only a storage reservoir. In starting, for instance, the battery supplies the energy, but as soon as the engine starts, the generating system should start to replace the electrical energy removed from the battery. This is naturally dependent on the capacity of the alternator or generator and the connected load. The capacity of the alternator or generator must be sufficient to carry the complete connected load of the electrical system. Original equipment batteries are selected with sufficient capacity to crank the engine and supply enough electrical energy for the ignition system for starting the engine.

Over a period of years the uses of electricity for powering accessories have increased considerably. These developments have brought about changes in the generating systems. It has, for the most part, caused the D.C. generator to become obsolete in favor of the alternator. It became impossible to design a D.C. generator which would have any available output at idle in a machine size that was practicable from an economic point of view. Some of the main differences between alternators and D.C. generators are listed below:

1. Rectification on D.C. generators is accomplished by use of a commutator. On the alternator this is accomplished by use of silicon rectifiers.
2. Field and armature are transposed in the D.C. generator and alternator. The field rotates on the alternator while the field is stationary on the D.C. generator. Conversely, the armature rotates on the D.C. generator while it is stationary on the alternator.
3. Brushes carry full load current on the D.C. generator, but only field current on the alternator.
4. The alternator weighs considerably less than the D.C. generator. This is due mainly to the elimination of the heavy frame necessary on D.C. generators.
5. Alternators are multi-pole machines, while the standard automotive D.C. generators are two-pole machines.
6. Control systems for the alternator differ somewhat from those of the D.C. generators. This is explained in the

various service manuals supplied by the alternator manufacturers.

ALTERNATOR AND GENERATOR REGULATORS

The development and refinement of the common three-unit regulator became a necessity for regulation of a charging system using the D.C. shunt generator. This regulator consists of a circuit breaker, voltage regulator and current regulator. When the generator is operating at charging speeds, the circuit breaker connects the generator to the battery and when the generator slows or stops, it opens the circuit to prevent the battery from discharging back through the generator. The current regulator unit protects the generator from excessive output by limiting the current to a value considered safe for the generator and for which the generator was designed. The voltage regulator unit operates in the same manner as the current regulator, but is sensitive or operates with respect to voltage rather than current and limits the voltage to a value which is safe for battery charging and safe for the other components in the electrical system.

Now that most automobiles are using the alternator in place of the D.C. generator, regulation has shown considerable change. Instead of one common type regulator there are a multitude of types. The design of the alternator is such that it does not require a current regulator. The alternator is self-limiting in its current output, also there is no actual requirement for a circuit breaker. The rectifier assembly is so connected to the output terminal that a properly connected battery cannot discharge back to the windings. The silicon rectifier is a device which allows current to flow in one direction, but blocks current flow in the opposite direction.

The only function of the regulator system used with alternators is to provide control of the output voltage for protection of the battery and electrical components.

BATTERY AND REGULATOR SYSTEM

The life and performance of the battery are so greatly influenced by the regulator that it is vitally necessary to understand how they depend on each other for satisfactory operation. What may appear to be a battery failure is often attributable to a regulator which has not been properly adjusted. Unless the regulator is known to be in a satisfactory operating condition, it may not free a car from battery trouble to install a new battery. The following facts concerning this close relationship between battery and regulator should be carefully studied.

Fact No. 1 — The Battery Is the Basis of Regulation

By "regulation" is meant the control of electrical pressure (voltage) and current flow (amperes) in the charging system.

The battery, generating unit and regulator must work as a team. The battery's ability to resist charge increases as the battery approaches full-charge and decreases when the battery becomes discharged. We call this battery characteristic "counter voltage" or "CEMF" (counter electromotive force). This behavior is vitally important and gives us a full statement of "Fact No. 1" = The Battery Regulates The Charging System By Its Change In Counter Voltage. Fig. 39 points out how the "CEMF" affects battery charging.

The chart is divided into two areas — a white area and a grey area. The dividing line is at 14.4 volts, representing a typical voltage regulator setting or "limit" for a 12-volt system. Thus the grey zone covers conditions which are prevented by the limiting action of the regulator, while the white zone is the working area of the battery. Battery terminal voltage is indicated on the left of the chart, while the numbers along the bottom represent the charging current from the alternator or D.C. generator. The heavy black lines marked with various states of charge are called "Charge Voltage Curves". These curves tell us what charge rate a healthy battery at 80°F. may be expected to accept at various voltages and at various states of charge. To use the chart, select a voltage and move straight across to the right until we intersect the charge voltage for the particular state of charge we are interested in. Moving straight down from the intersection, we can read the charge rate in amperes. If we like, we can reverse this procedure, starting with a charge rate and reading off the corresponding voltage. The curves show that a battery in the more discharged condition will accept higher charge rates at fairly low voltages. For instance, the $\frac{1}{2}$ charge curve shows that a battery in this condition will accept approximately 30 amperes at 14.4 volts for a 12-volt system and will take more at higher voltages. We can assume here, however, that even at higher voltages the current would be limited to the generator or alternator capacity. In the case of the D.C. generator this would be limited by the regulator, and in the case of the alternator, by the self-limiting feature of the alternator itself. We have assumed the limit to be 35 amperes in Fig. 39.

As the battery becomes more nearly charged, higher and higher voltages are required to maintain the same charge rate. The voltage regulator steps in to limit the voltage, so the charge rate is reduced. Thus we see that a $\frac{3}{4}$ charged battery at 14.4 volts can be charged at 15 amperes; at full charge a voltage of 14.4 gives only about 2 amperes.

We can state this principle of regulation in simple terms by saying — IF THE CHARGING VOLTAGE IS LIMITED, THE CHARGING RATE WILL BE REDUCED BY THE BATTERY AS IT COMES UP TO CHARGE. This is the reason that batteries must be considered in any discussion of regulation. It also brings up another important fact.

HOW BATTERY VOLTAGE VARIES WITH CHARGE RATE AND STATE OF CHARGE AT 80°F. AS INDICATED ON CURVES ON A 12-VOLT SYSTEM

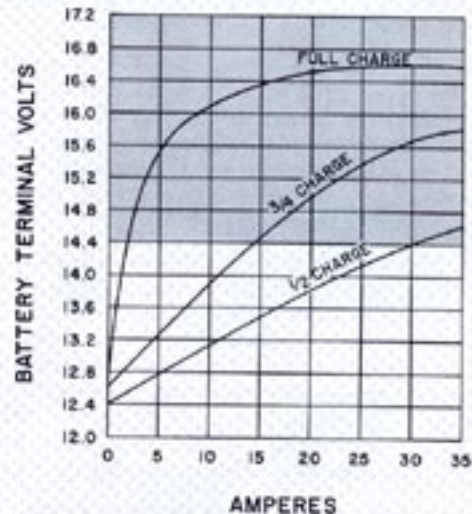


Fig. 39

HOW BATTERY VOLTAGE VARIES WITH CHARGE RATE. SHOWING EFFECT OF TEMPERATURE AND STATE OF CHARGE ON A 12-VOLT SYSTEM

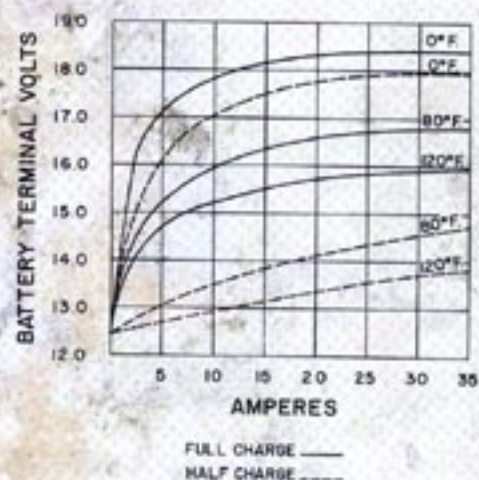


Fig. 40

Fact No. 2 — Anything that Affects the Battery or Regulator Affects Regulation

We have seen how much the STATE OF CHARGE of the battery affects charge voltages. There is another variable which has almost as much effect. That variable is TEMPERATURE. Fig. 40 shows graphically the effects of both states of charge and temperature on charge voltage. Again we concern ourselves with a 12-volt system.

Note that a half-charged battery at 0°F. will accept something in the order of 2 amperes at 14.4 volts. Under the same conditions the battery will accept about 27 amperes at 80°F. and full alternator or generator output at 120°F. This is a serious matter in actual automobile operation since various parts of our country are subject to wide variations in temperature.

The effect of temperature on regulation is further intensified by the fact that the regulator, too, is affected. To compensate for the changing temperatures under which the battery must perform, regulators have components and characteristics designed into them to change the system voltage. As the ambient temperature decreases, the charging voltage is increased to overcome the higher battery CEMF, and thus to permit recharging. As the temperature increases, the voltage is reduced to avoid overcharging the battery.

Because the limits actually held by the regulator are dependent on the temperature of this regulator, it is very important to control its temperature while checking and adjusting. For this reason, service instructions emphasize that all regulator checks and adjustments must be made at "operating temperature" and under carefully controlled conditions. Settings made without observing these conditions are erratic and difficult to reproduce. False settings thus obtained are responsible for many forms of electrical trouble resulting from too high or too low a voltage limit.

Since the battery is essentially a chemical product, its charging properties are often altered by chemical changes in the battery itself. Changes of this kind may be brought about deliberately by the manufacturer or they may result from long use, prolonged operation at high temperatures, and the addition of impurities. Any significant change made in the charge-voltage characteristics of a battery will definitely affect regulation and may be responsible for early failure if overlooked. Sulfation, while normal, may be troublesome if it is allowed to become excessive. Since sulfation is likely to occur whenever batteries are neglected for a long period of time, it can occur in new batteries in stock as well as in used ones. A battery which is sulfated often will not accept an adequate charge rate from the alternator or generator, and rapidly starves to death on the job. Battery men can find no better argument for systematic care of batteries in stock than the necessity for protecting the vital charge-voltage characteristics. A battery with abnormal charge characteristics simply cannot exist under the close voltage limits in a modern automobile.

This brings us to a third fundamental of regulation:

Fact No. 3 — Regulator Settings Must Be Correct for the Battery and Type of Service

We have seen how the battery actually controls its own charge rate when the voltage regulator limits the charge

voltage. We have also seen how much the battery charge voltage and the regulator are affected by changes in temperature. Putting the two ideas together, it is not difficult to see that the setting of the voltage regulator is extremely important. The proper adjustment of the voltage limit on any vehicle largely determines the success or failure of the electrical system on that vehicle. An incorrect voltage regulator setting can cause damage ranging from burned-out lights and damage to the ignition system, to complete destruction of the battery and/or generating unit. Failure to understand the importance of this matter results in unnecessary and costly service expense to owners of automotive equipment. Changes in setting, of course, must be made only by a qualified automotive electrician.

Granting that the voltage regulator setting is very important, the question then becomes, "what is the proper setting?" The ideal setting may be defined as, "that setting which will keep the battery at or near full charge with a minimum use of water when the vehicle is used in its customary way." Such a definition makes it easy to see what must be done. We simply set the regulator within the range and make frequent checks of the battery over a period of several days or a few hundred miles of service. If the battery loses water rapidly, the setting is too high and should be reduced. (A usage of 1 to 2 ounces of water per cell per 1,000 miles has been found to be acceptable.) If the battery falls below three-fourths state of charge, the setting is too low and should be raised.

When designing automotive equipment, the manufacturers select a voltage specification which will satisfactorily maintain the battery in a healthy state of charge. This selection is based on the type of equipment and the type of service. Because of this selection, it will seldom be necessary to adjust the voltage setting outside the "satisfactory" range published by the regulator and car manufacturers.

Since the voltage regulator is temperature-compensated, normal changes in temperature do not require that the regulator setting be modified. Also, the requirements of a constant-duty application are foreseen by the manufacturer so that a special voltage setting is specified. Occasionally, different battery characteristics or abnormal operating conditions do require a modification of the voltage setting to maintain the battery in a satisfactory state of charge. When a check of the battery, over a reasonable period of time, shows that it is being undercharged or overcharged, the regulator setting should be checked according to the manufacturers' recommendations. If it is found necessary to "tailor" the voltage setting for that particular application, set the unit to the upper or lower limit of the "satisfactory" range to correct the undercharging or overcharging. Only in extreme cases will it be found necessary to use a setting outside the "satisfactory" range.

On applications where extreme heat is encountered, the battery may show serious overcharging even at fairly low regulator settings. The reason is that the battery's counter-voltage or ability to resist charge is greatly reduced as it heats up. When in this condition, the battery is unable to reduce the charging rate to a safe value and thus continues to get even hotter. This condition normally indicates the need for a still lower setting of the voltage regulator, or better ventilation of the battery (or both). It is usually better to reduce the voltage setting first to correct overcharging

as this is often all that is required. If a minimum setting does not prevent overheating, then battery ventilation should be checked.

When reducing the voltage regulator setting to prevent overcharging of the battery, care must be taken that the setting is not reduced below a safe limit from a mechanical standpoint; manufacturer's instructions should be followed in all cases.

If a battery continues to overcharge seriously after adequate ventilation has been provided and the voltage setting has been reduced, it is likely that the battery already has been permanently damaged by continued overheating and/or overcharging, or has an internal "short." In such a case, of course, the only remedy may be a new battery.

Minimum voltage regulator settings may be required for vehicles driven continuously at high speeds with moderate electrical loads. This classification would include, for example, traveling salesman's cars, cross-country buses, and some trucks. Here the problem is one of holding the final or "taper" charge rate down to a value which will not seriously harm the battery. The number of miles driven is more than enough to keep the battery fully-charged, and overcharging is a constant threat.

At the opposite end of the scale are the vehicles which are driven too little, too slowly, or which encounter low battery temperatures regularly. When a battery is cooled, its counter voltage increases rapidly. In extreme cases the generator may be able to put little or no charging current into the battery at normal regulator settings. Batteries in these units suffer continuously from undercharging and are chronic sources of trouble. Mild cases of undercharging often can be cured by higher voltage regulator settings, but severe and persistent undercharging requires periodic recharging from an outside source. In very severe sub-zero climates it is a good idea to connect a low-rate charger to the battery at night to keep the battery warm enough to accept charge when driven in the daytime. Applications in which persistent undercharging most often occur are infrequently-used private cars, delivery trucks, and some types of buses. In addition, almost any vehicle not equipped with a special charge-at-idle generator will give trouble if driven slowly and continuously, as in very heavy traffic.

Summing up, we find that we can write Eight Rules for Good Regulation which cover the minimum essentials.

EIGHT RULES FOR GOOD REGULATION

1. Remember that the battery is the basis of regulation.
2. Remember that anything which affects the battery or regulator affects regulation.
3. Strive for low water-consumption as an indication of proper regulator setting.
4. Watch battery ventilation.
5. Keep all electrical connections clean, tight, and wires intact.
6. Remember that all regulator checks and adjustments must be made under specified conditions.
7. When unusual service conditions require it, adjust the regulator to the job.

8. Whenever possible, keep a follow-up record on the battery.

Remember that driving habits and the use of accessories are important factors in keeping the battery in a satisfactory state of charge.

PRECAUTIONS TO BE OBSERVED WHEN SERVICING SYSTEMS USING ALTERNATORS

1. REVERSED BATTERY CONNECTIONS MAY DAMAGE THE RECTIFIERS, VEHICLE WIRING, OR OTHER COMPONENTS OF THE CHARGING SYSTEM. — Battery polarity should be checked with a voltmeter to assure that it conforms to that required. Note which terminal post is connected to ground before reinstalling a battery.
2. IF BOOSTER BATTERIES ARE USED FOR STARTING THEY MUST BE CONNECTED PROPERLY TO PREVENT DAMAGE TO THE SYSTEM. — Always make certain that the (-) negative terminal of the booster battery is connected to the (-) negative terminal of the vehicle battery and that the (+) positive terminals are connected together.
3. CARE SHOULD BE TAKEN WHEN CONNECTING A "FAST CHARGER". — It is advisable to remove the battery ground strap before charging. It is not advisable under any condition to attempt to start the vehicle by using the "fast charger" as a booster.
4. DO NOT ATTEMPT TO POLARIZE THE ALTERNATOR. — No polarization is required. Any attempt to do so may result in damage to the alternator, regulator or circuits.
5. THE FIELD CIRCUIT MUST NOT BE GROUNDED AT ANY POINT. — Grounding of the field will damage the regulator. Extra care must be taken when working near this electrical system.
6. GROUNDING OF THE ALTERNATOR OUTPUT TERMINAL MAY DAMAGE THE ALTERNATOR AND/OR CIRCUIT COMPONENTS. — Unless the regulator is equipped with a circuit breaker, this terminal is "hot" even when the system is not in operation. Grounding this can cause considerable damage.
7. DO NOT GROUND THE ADJUSTING TOOL TO THE REGULATOR BASE WHEN ADJUSTING VOLTAGE UNIT OR OTHER REGULATOR COMPONENTS. — The adjusting tool should be insulated.
8. CARE SHOULD BE TAKEN IN THE USE OF BATTERIES OF HIGHER-THAN-SYSTEM VOLTAGE EITHER TO BOOST A BATTERY OF LOWER VOLTAGE, OR IN STARTING. — Never leave the higher-voltage battery in the system. When used for boosting, disconnect the vehicle battery ground. When used for starting, disconnect the higher-voltage battery as soon as vehicle is started.
9. ALTERNATORS MUST NOT BE OPERATED ON OPEN CIRCUIT WITH THE FIELD WINDING ENERGIZED. — High voltages will result, causing possible rectifier failure. Make sure all connections are secure.

ELECTRICAL TERMS DEFINED

DIRECT CURRENT (DC)

A continuous, unidirectional and non-pulsating current produced by storage batteries. If produced by a generator or rectifier, there may be some slight variation due to commutators of generators, or due to the rectification characteristics of rectifiers.

Volt—The unit of measure for electrical pressure or electromotive force, measured by a voltmeter.

Ampere—The unit of measure for current flow, measured by an ammeter.

Ampere-Hour—A unit of measure for battery capacity, obtained by multiplying the current flow in amperes by the time in hours during which the current flows. For example, a battery which delivers 3 amperes for 20 hours can be said to have delivered 3 x 20 or 60 ampere-hours.

Watt—The unit of electrical power obtained by multiplying the amperes flowing by the voltage which forces it to flow. Watts = amperes x volts.

Watt-Hour—The unit of electrical energy obtained by multiplying the ampere-hour output by the average voltage during the discharge. Watt-hours = volts x amperes x hours.

Ohm—The unit of electrical resistance opposing current flow and causing heat when current flows.

Ohm's Law—Expresses the relationship between volts, amperes and ohms in an electrical circuit. The law may be expressed in three ways:

$$\text{Ohms} = \frac{\text{Volts}}{\text{Amperes}}$$

$$\text{Volts} = \text{Amperes} \times \text{Ohms}$$

$$\text{Amperes} = \frac{\text{Volts}}{\text{Ohms}}$$

Knowing any two of the three values of voltage (Volts), Current (Amperes), or Resistance (Ohms), the third value can be calculated from one of the above three expressions of the law.

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